An overview of forest and harvested wood product carbon quantification and reporting for the California Board of Forestry and Fire Protection (BOF) AB 1504 and the California Air Resources Board Natural and Working Lands (CARB NWL) inventories

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Plain Language Summary

Staff at CARB and CAL FIRE have developed tools and/or methods to estimate and monitor change in carbon contained in California's forested lands. The two agencies launched their respective forest carbon inventory efforts in different years in response to different legislative mandates. The tools rely on open source data, ranging from data gathered from on-the-ground measurement plots to products developed from satellite remote sensing, and models. Both CARB and CAL FIRE use contemporary scientific methods with high-quality data sources, but even the best available data sources contain partial or limited information. Furthermore, quantification approaches are continually evolving, and different methods have their own strengths and limitations that depend on the use case. The two inventories represent different land types, different time periods, and different stages of the harvested wood product life cycle. As a result, different carbon estimates for the same area of interest are expected. Overall, the CAL FIRE Inventory reports slightly higher carbon stocks in live tree and standing dead tree pools than the CARB inventory and lower carbon stocks in fallen dead tree and litter pools. Overall, the total carbon stock for these pools is slightly higher in the CARB inventory. However, this report demonstrates that differences are less pronounced than the two efforts suggest at face value. In more recent analysis years, both inventories indicate that live trees are accumulating more carbon than they are losing.

Taken together, the two approaches aid assessment of current conditions and trends across California's forests. As new data and methods emerge, ongoing collaboration between CARB, CAL FIRE and academic researchers continues to inform forest carbon inventory efforts. Given the uncertainty inherent to any carbon inventory effort, it is useful to have multiple inventory estimates to compare to each other. This helps us understand how close we may be to the true value of the total amount of carbon stored in California's forests. Different approaches also complement each other and help identify ways to further refine future estimation.

Executive Summary

This document provides a comparison of forest carbon quantification approaches used for: 1) the California Board of Forestry and Fire Protection's (BOF) Assembly Bill (AB) 1504 Forest Ecosystem and Harvested Wood Product Carbon inventory for the forest sector (i.e., BOF Inventory), and 2) the Forest and Other Natural Lands (FONL) portion of California Air Resources Board's (CARB) Natural and Working Lands (NWL) Inventory (i.e., CARB NWL Inventory). Particular attention is paid to definitions, data sources, and how these aspects compare between the two carbon quantification approaches. The BOF Inventory is developed by staff at CAL FIRE and the U.S. Forest Service Pacific Northwest Research Station. This inventory relies on direct measurements on permanent forested plots throughout the state

as part of the U.S. Department of Agriculture, U.S. Forest Service Forest Inventory and Analysis (FIA) program. The CARB NWL Inventory integrates FIA data and satellite data from federal LANDFIRE datasets. Although both inventories use FIA data, their results differ because CARB combines it with satellite data, uses a different methodology, and has used older vintages of FIA data than the BOF Inventory.

Differences in the inventory results stem largely from differences in the definition of forest land, although both definitions are consistent with Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance[1]. The "forest" definition used for the CARB NWL Inventory includes shrub- and tree-dominated lands while the definition for the BOF Inventory includes tree-dominated lands and lands temporarily without trees (i.e., less than 30 years without trees). The latest NWL inventory published in December 2018[2] covering the 2012-2014 time period reports higher forest carbon stocks and lower amounts of net change compared to the BOF Inventory for the 2017 reporting period[3]. However, special analyses in this document comparing tree-dominated lands within these inventories reveals the sources of differences in the estimates, with some differences becoming less pronounced.

Carbon stocks.

- The BOF and CARB NWL statewide estimates for **area of tree-dominated forest land** are similar.
- Estimates for **above-ground live (AGL) tree-dominated forest carbon stocks** are comparable in the inventories, with CARB NWL estimates generally lower than estimates reported by the BOF. CARB NWL estimates for AGL tree carbon are approximately 16% lower than BOF estimates. This is an expected result given uncertainties in mapping land cover and forest structure, differing data vintages, definitions of forest, approaches to up-scaling estimates to statewide, and sensitivity to disturbance.
- The CARB NWL estimates of forest carbon contained in **standing dead tree pools** are lower than in the BOF Inventory, whereas NWL estimates for **down dead tree and litter pools** are higher than the BOF estimates. Some of these differences may be attributed to newer FIA protocols used in the BOF Inventory that were not in practice at the time of the CARB NWL Inventory.
- While CARB NWL estimates for AGL tree carbon are lower than BOF estimates, NWL estimates for **total forest carbon for tree-dominated lands** is approximately 33% higher due to the higher stocks reported in dead pools.
- CARB NWL soil organic carbon (SOC) estimates are approximately 21% greater than BOF SOC estimates, but the NWL SOC estimates include shrub-dominated as well as tree-dominated lands.

Carbon stock changes.

- The CARB NWL Inventory reports a lower amount of **net forest carbon accumulation** each year compared to the BOF Inventory, with some time periods demonstrating net forest carbon losses rather than gains.
- Comparing only changes in **aboveground live tree pools in tree-dominated lands**, these differences remain but are less pronounced. However, due to different analysis periods and

[1] IPCC (2003)
[2] CARB (2018a)
[3] Christensen et al. 2019

inventory components, comparing estimates between the two approaches must be interpreted carefully.

- A notable difference in results from these two methods can be seen in the different amounts of change for periods characterized by extensive wildfire activity. Generally, estimates of **carbon losses from fire** are much higher in the CARB NWL Inventory compared to the 2017 BOF Inventory. In the BOF Inventory, while some low-intensity disturbances may register more easily in the field than with remote sensing, some disturbances may occur outside of ground networks and may not be detected immediately.
- Compared to the BOF Inventory, the CARB NWL Inventory estimates greater losses of carbon in disturbed areas and fewer gains of carbon in undisturbed areas.
- Differences in how each inventory addresses forest land conversions results in the BOF Inventory reporting much lower amounts of **change in AGL pools due to forest land conversion** compared to the CARB NWL Inventory. In the BOF Inventory, land conversion is defined as land-use change, whereas the CARB NWL Inventory defines land conversion as land cover change. Additionally, since the NWL definition of forests includes shrub-dominated lands, changes in these lands contributes to the amount of carbon considered lost due to forest land conversions. For example, if there are great disturbances to shrub-dominated lands, such as from wildfire, higher stock loss for forests would be reported in the CARB NWL Inventory than in the BOF Inventory, which does not consider shrub-dominated lands at all (and also does not classify wildfire as land conversion in the near-term). When comparing changes in the AGL pool for tree-dominated lands only due to forest land conversions, the differences are less pronounced.
- Forest land carbon stock changes associated with **timber harvest activities** appear better captured in BOF reporting compared to the CARB NWL Inventory, which relies on remote sensing detection of pronounced changes in forest structure.
- Several differences exist in how the BOF and CARB NWL inventories address harvested carbon, from how biomass removals are determined, to how they are related to timber volumes, how they are allocated to harvested wood product carbon pools, and how those pools are treated within the inventories themselves. As a result, and due to differences in harvest detection described above, a greater **harvest volume** for the 2001-2010 period of analysis is reported in the BOF Inventory compared to the CARB NWL Inventory. Approximately 2.5 times more harvested carbon and 1.8 times the amount of carbon persisting in harvested wood product pools at the **end of the ten-year period of analysis** is reported by the BOF method compared to the CARB NWL Inventory. The BOF method also shows a 4.5 times greater amount of harvested carbon loss to the atmosphere compared to the CARB NWL Inventory. It is important to note that in this ten-year period approximately 93% of the harvested carbon that was transferred to the atmosphere in the BOF Inventory was burned with energy capture and may represent some level of fossil fuel substitution.

Some of the differences between the BOF and CARB NWL estimates are attributed to trade-offs associated with sources and methods and opportunities for alignment are summarized here:

- Different time periods of analysis for estimates of carbon stock change. The BOF Inventory is designed to capture large-scale, long-term trends. Carbon stocks are provided as a rolling average over the most recent 10-years of FIA measurements. Carbon stock-changes by pool are provided as an annual average of change on plots measured 10-years apart. Since the CARB inventory uses data from satellites that is refreshed annually or biannually, its carbon stock estimates represent a snapshot in time.

- Different land category definitions such as inclusion of shrub-dominated land in the CARB NWL Inventory but not in the BOF Inventory and associated differences in how shrub-to-tree transitions are represented.
- Slight differences in the assumption of carbon fraction of biomass used in the calculations for each estimate – CARB NWL uses 0.47 while the BOF Inventory uses 0.50When the same carbon fraction is used, the NWL carbon stock estimate approaches the BOF estimate.
- Tree foliage differences – foliage comprises approximately 3-5% of the BOF estimate, but is not explicitly accounted for in the CARB NWL estimate. Including tree foliage in future NWL inventories is a possible improvement.
- Differences in the amount of growth detected by remote sensing used in the CARB NWL method compared to direct re-measurement of ground-based field plots in the FIA-based method. Updating growth factors applied to undisturbed tree-dominated lands using the latest FIA data is a possible improvement to future NWL inventories.
- Differences in dead pool (standing and down dead, litter) estimates. The CARB NWL Inventory is based on older FIA protocols for these pools. Both the BOF and NWL inventories seek to improve those estimates.
- Differences in how changes in carbon from disturbances are attributed (i.e., forest land conversions, fire, harvest). Apportioning post-fire remnant carbon to dead pools, separating fires in tree-dominated versus shrub-dominated lands, and improving detection of harvests are possible improvements to future NWL inventories. Reducing the measurement cycle from 10 years to 5 years in the FIA program will improve the timeliness of disturbance detection in the BOF Inventory.
- Differences in how harvest volumes are related to carbon mass, and how harvest is allocated to carbon stored in wood products. Opportunities to incorporate data from the BOF HWP C inventory to the CARB NWL Inventory are being explored.

It is possible for these two approaches to support each other for inventory verification purposes, which is a cornerstone to IPCC-consistent GHG accounting. Through ongoing inter-agency collaboration, the BOF Inventory and CARB NWL Inventory serve as complementary efforts to statewide monitoring and reporting of forest land carbon. Additionally, each inventory method has different strengths, and as such can provide answers to different types of questions. For example, the BOF Inventory detects widespread forest changes such as growth, mortality, and removals, with particular success in detecting incremental growth and low-magnitude changes such as “light” disturbances like partial harvests. The CARB inventory can detect abrupt changes in forest cover from disturbances very well. Both inventories can attribute the cause for changes in carbon stocks, but the CARB inventory can show what individual events led to changes in carbon stocks.

Background

In 2006, Assembly Bill (AB) 1803 transferred responsibility for maintaining a statewide greenhouse gas (GHG) inventory from the California Energy Commission (CEC) to the California Air Resources Board (CARB), and the California Global Warming Solutions Act of 2006 (AB 32) assigned CARB as the lead agency to work with state agencies and stakeholders to reduce the state's impact on climate change. In implementing the requirements of AB 1803 and AB 32, and to ensure consistency and comparability with other jurisdictions as California engages in climate policy discussions with other nations and subnational jurisdictions, CARB has followed the GHG inventory framework defined by the United Nations Intergovernmental Panel on Climate Change (IPCC) since 2006. A jurisdiction-wide GHG inventory that meets the international inventory standard includes quantification of direct emissions from human activities as well as carbon stock change on land.

The first edition of CARB's GHG inventory was published in 2007 and included an estimate of carbon sequestration on forest and grassland based on limited information available at the time. CARB recognized that further technical development was needed to quantify carbon stock across California's landscapes. In 2011, CARB began to cooperate with University of California (UC)-Berkeley, the National Park Service (NPS), U.S. Department of Agriculture (USDA) Forest Service - Pacific Southwest Research Station (USDA-FS PSW), and a consultancy (Spatial Informatics Group) to develop methods to generate geospatially explicit estimates of carbon stocks and change on forests and other natural lands across the state.[4] CARB created a team to focus on the development of the ecosystem carbon portion of the GHG inventory. This portion of the inventory that focuses on ecosystem carbon stocks is called "Natural and Working Lands Inventory," and the other parts of the inventory that focus on direct emissions from human activities are included in CARB's annual statewide GHG inventory. In 2016, CARB published the first edition of the Forest and Other Natural Lands (FONL) portion of CARB's NWL Inventory, generated using the new methods developed from the collaboration with UC Berkley, NPS, and USDA-FS PSW.[5] A complete CARB NWL Inventory that includes all quantified land types, including FONL, wetland, cropland, urban forest, and soils, was published in December 2018.[6]

The initial AB 32 Scoping Plan[7] included a forest sector target with a goal of maintaining the forest carbon sink with a net annual sequestration rate of 5 million metric tons of carbon dioxide equivalent (MMT CO2e). In 2008, the Board of Forestry and Fire Protection (BOF) developed a strategy to address the AB 32 legislation. In 2010, Assembly Bill 1504[8] directed the BOF to ensure that its rules and regulations governing the harvesting of commercial forest tree species consider the capacity of forests to sequester carbon dioxide sufficient to meet or exceed the state's greenhouse gas reduction goals. To fulfill anticipated reporting requirements, in 2016 the California Department of Forestry and Fire Protection (CAL FIRE) initiated a collaboration with the U.S. Department of Agriculture (USDA) Forest Service (FS) Pacific Northwest Research Station (PNW) Forest Inventory and Analysis (FIA) program to generate and report estimates of California forest ecosystem and harvested wood products carbon

[4] CARB (2013)
[5] CARB (2016c)
[6] CARB (2018a, b)
[7] CARB (2008)
[8] AB 1504 Forest Resources: Carbon Sequestration

stocks and change. The first BOF Inventory with FIA data was released in late 2017 for the 2015 reporting period, with another release in 2018 for the 2016 reporting period, 2019 for the 2017 reporting period, 2020 for the 2018 reporting period and 2021 for the 2019 reporting period. In 2017, CAL FIRE initiated a collaboration with the University of Montana-Bureau of Business and Economic Research (BBER) to examine the harvested wood product portion of the forest carbon inventory. These results are included in the 2017 reporting period published in 2019[9]. Revisions to the HWP C model were then completed to remove lag times in when carbon was allocated to certain pools and decay was applied to improve the ability to complete quality control and quality assurance checks on the data. Revisions to the Monte Carlo Uncertainty analysis for HWP C stocks were also completed to correct narrower than expected confidence intervals. Initial corrections were included in the BOF 2018 data update with remaining corrections included in the 2019 data update.

Both the CARB NWL Inventory and the BOF Inventory report on forest carbon stocks and net forest carbon stock change. Net forest carbon stock change is the sum of the carbon gains and losses amongst the various forest carbon pools. Positive numbers represent a net gain (e.g., sequestration), while negative numbers represent a net loss (e.g., emission) of carbon.

The CARB NWL Inventory published in December 2018 provided estimates for 2001-2010, 2010-2012, and 2012-2014. Most of the comparisons in this document use the 2012-2014 time period, with earlier time periods provided as examples in some instances. The 2012-2014 inventory reported net forest carbon change of approximately 3.63 MMT C, or 1.82 MMT C/yr (live and dead pools not including soils or wood products) and approximately 4.5 billion metric tons for forest carbon stock. Losses include carbon exiting forests via timber harvests. For informational purposes, the CARB NWL Inventory contains separate estimates of stock-change associated with tree harvests, which include accounting for carbon persisting in solid form as wood products[10].

Although the BOF Inventory has been released through the 2019 reporting period, comparisons in this document use the 2017 reporting period as that was the latest report at the time this analysis started. The 2017 reporting period demonstrated that California's forests remain net sinks, sequestering 7.6 MMT C/yr. This value includes changes in forest ecosystem pools (8.0 MMT C/yr), harvested wood product pools (0.2 MMT C/yr), non-CO2 emissions from wildfires (-0.1 MMT C/yr), and forest land conversions (-0.5 MMT C/yr). Forest ecosystem and harvested wood product carbon stocks are approximately 3.4 billion metric tons. Forest ecosystem carbon stocks are approximately 3.3 billion metric tons, with approximately 0.1 billion metric tons C contributed by wood products generated since 1952.

The purpose of this paper is to take a deeper dive into the forest sector results of the CARB NWL Inventory and the BOF Inventory to determine where true differences and similarities lie. While it can be confusing for the State to have two different inventories for the forest sector, there are different strengths and weaknesses to each approach. It is possible for these two approaches to support each other for inventory verification purposes, which is a cornerstone to IPCC-compliant GHG accounting.

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[9] Christensen et al. (2019)
[10] e.g. Table 13, CARB (2018a)

Forest Ecosystem Carbon Inventory Approaches

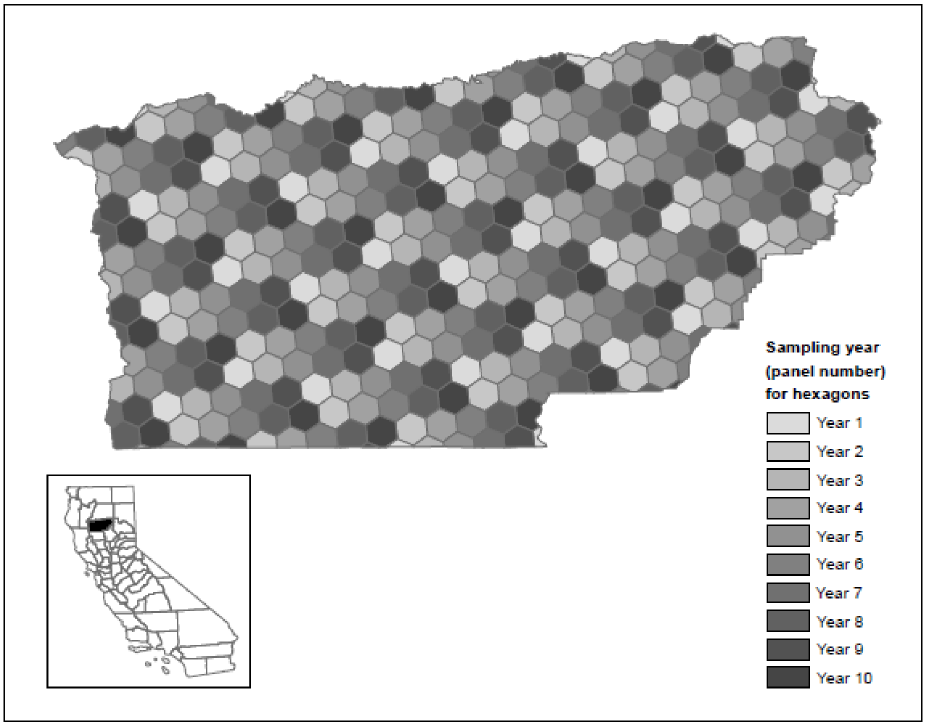
FIA Design

Both the BOF Inventory and the CARB NWL Inventory rely on FIA data products. The national FIA program was established in 1928 to inform economic and forest management planning. A current FIA network sampling and plot design was implemented beginning in 2001.[11,12] Permanent field plots cover approximately one acre and are distributed over a hexagonal grid, with each grid comprising an area of approximately 6,000 acres. The hexagons in California are assigned to ten evenly-dispersed panels (however, not all field plot locations sample forested areas). Each panel is measured in a specific year, providing a balanced annual sample of the state each year. Measurement of all panels occurs on a ten-year cycle, so in a given year, 10% of all field plots within the state (see "panel" in Figure 1) measure a suite of attributes. Attributes include tree species, live tree dimensions, forest and ownership type, and dead woody materials amongst others.[13] Plot re-measurement occurs in the tenth year (Figure 2). By 2020, all FIA plots in the state will have been measured at least twice. Re-measurements provide explicit information on individual tree change such as growth, removals and mortality (GRM). Early data from re-measured plots on forest tree growth, mortality and removals was first reported in 2016.[14]

Uncertainties associated with measurement, sampling, regression, and model selection influence regional-scale estimates of forest biomass and carbon stocks. FIA sampling errors (SE) included with estimates represent the uncertainty associated with sampling areas (plots) that are small relative to total forest area. Uncertainties are associated with regression models (allometric equations) that are the basis for estimating tree wood volume and biomass (bole, bark, stems, roots, foliage) from measurements of trunk diameter and tree height. Moreover, multiple regression models exist for some tree species, and model selection can contribute to uncertainties in carbon estimates ranging between ± 20 to 40 percent[15]. Uncertainty associated with regression models and model selection are not included in FIA estimates. However, national biomass allometric equations are currently being improved through on-going studies. Essential to FIA results are also statistical procedures used to scale plot level data to large geographic areas, using weighting factors based on grouping remotely-sensed and other statewide ancillary variables into strata.

[11] Appendix 1: Inventory Design and Methods. In: Christensen et al. (2008)
[12] Bechtold and Patterson (2005)
[13] USDA-FS (2018a)
[14] Christensen et al. (2016)
[15] Melson et al. (2011)

Figure 1. Example of the national FIA hexagonal grid (hexagon area ~ 6,000 acres), extracted for Tehama County. The grid serves as the foundation for field plot assignment (one per hexagon). In this figure, hexagons are shaded according to which year-specific measurement panel it belongs. All plots in one panel are measured in the given year.



Source: Christensen et al. (2008)

Figure 2. Schematic diagram of a panel measurement schedule. Arrow denotes 10-year cycle for a panel re-measurement.

Measurement Year	Plot Panel
2001	1
2002	2
2003	3
2004	4
2005	5
2006	6
2007	7
2008	8
2009	9
2010	10
2011	1
2012	2
2013	3
2014	4
2015	5
2016	6
2017	7
2018	8
2019	9
2020	10

CARB NWL APPROACH [LANDFIRE-C]

The forest ecosystem carbon inventory approach used by CARB integrates USDA-FS FIA data and vegetation attribute data from federal LANDFIRE raster geodatasets, which are models of vegetation classes based on remote sensing and plot data, through a regression approach to estimate live and dead carbon pools from vegetation type, canopy cover class and height class. Ancillary data from the LANDFIRE reference database, from MODIS products, and from literature are used to develop carbon stock estimates for non-forest natural land vegetation types. This approach is geospatially and temporally explicit, provides wall-to-wall coverage of all land types, uses public datasets that are refreshed bi-annually, is able to detect short-term disturbances, enables geospatially explicit analysis of the effects of human actions and environmental factors, and provides a geospatially explicit baseline dataset. This method of accounting is consistent with IPCC guidelines and provides outputs in IPCC inventory categories. Limitations of relying on satellite-based data products include a limited ability to measure growth, data latency period of 4 years for LANDFIRE products, uncertainty increasing at higher spatial resolution, and limited ability to provide information about detailed forest attributes.

These methods were also used to quantify natural land above-ground live (AGL) carbon stocks in years 2001 and 2010, and net change over the period.[16] In 2016, CARB obtained the LANDFIRE-C GIS-based

[16] Gonzalez et al. (2015)

tool that made the methods developed in 2011 operational using internal CARB capacity[17]. The tool enabled analysts to recalculate estimates of stocks and net change for 2001-2010 (above- and below-ground live and dead pools, not including soil organic carbon), to develop estimates for other time periods of interest as new LANDFIRE products are released, and to report for all six IPCC land categories[18,19]. This tool estimates aboveground live vegetation carbon sequestration even when changes are not detected in the LANDFIRE product (described further in the "AGL net carbon stock change" section), and to attribute stock-changes to disturbance processes. A separate tool was also developed to account for carbon persisting in wood products post-harvest.

BOF APPROACH [FIA]

The BOF forest ecosystem carbon stocks and net change estimates are derived using direct measurements on forested plots throughout the state of California as part of the USDA-FS FIA program and a statistical upscaling approach. The permanent field plot remeasurement system directly captures and quantifies individual tree growth, removals, mortality, drivers of mortality and change (i.e., land-use, forest structure, composition, type, etc.), results in sampling errors of less than 0.5%, and provides detailed information on forest attributes. FIA datasets become the public dataset that several other modeling methods rely upon (such as remote sensing-based approaches like LANDFIRE-C). Use of FIA data is consistent with forest carbon inventory data and reporting nationally and among Pacific Coast states. This method of accounting is consistent with IPCC guidelines and provides outputs in IPCC inventory categories. Limitations include possible delay in the detection of disturbances if plots are not scheduled for remeasurement immediately following a disturbance, uncertainty increases at smaller spatial scales, and non-sampled plots may introduce bias.

FIA uses panels to measure both current inventory and change. Estimates of carbon stocks physically present in the forest are based on a rolling 10-year average for the reporting time period (2017 reporting period example: 2008-2017) and given in metric tons (MT) of carbon (C). Change can be estimated in a multitude of ways. A simple stock-change method uses the net difference between two sequential, but different, panels. However, the estimates of average annual net carbon stock change in the BOF Inventory are based on actual growth, removals and mortality (i.e., the GRM approach) on plots and trees initially measured during the first FIA measurement cycle and remeasured in the second measurement cycle (2017 reporting period example: plots and trees initially measured between 2001 and 2007 then re-measured 10 years later between 2011 and 2017; net change from each of the seven re-measured panels is averaged). In the FIA program, the GRM approach is preferable to a simple stock-change approach because it is a direct observation of individual components of change, making it statistically robust[20] (i.e., resulting in lower sample errors around estimates of change).

While the averaging approach can be difficult to understand as it does not correspond to a specific year, forests experience great interannual variability in growth, removals and mortality. The BOF Inventory is designed to ascertain large-scale, long-term decadal trends (i.e, over the 10-year measurement cycle).

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[17] CARB (2016a)
[18] CARB (2016a)
[19] CARB (2016b)
[20] Bechtold and Patterson (2005)

Consequently, in order to prevent a single year of change in forest conditions (such as one large wildfire year) leading to incorrect conclusions about long term trends, IPCC Good Practice Guidance[21] suggest using average, cumulative measurements or smoothing over several years to get representative results. The downside from this approach is that actual growth in a single year may be under- or overestimated, making it difficult to account for changes from specific events (such as one large wildfire year). However, it is important to note that continued trends or trends of large magnitude, such as mortality from extended drought or several large wildfire years, will eventually be reflected in the estimates of carbon stocks and net change.

The BOF Inventory reports on above- and below ground carbon for live and dead vegetation pools, litter, soil organic carbon, and harvested wood product pools for various reporting domains of interest. To do so, FIA methods categorize the plots into the potential domains of interest. These domains include forest types, forest land status (reserved/unreserved, timberland), ownership groups, counties, CA Forest Practice Districts, and ecoregions. Reporting carbon pools for these various categories allows the BOF to identify trends in carbon stocks and change to ensure the California forest practice rules are sufficient for meeting state forest sector carbon sequestration targets.

Forest land definitions

The BOF reporting and CARB's LANDFIRE-C tool utilize FIA data but employ different definitions for Forest Land (Table 1). FIA defines Forest Land as areas ≥ 1 acre in size and at least ≥ 120 ft. wide exhibiting ≥ 10% live tree canopy cover, or formerly had such cover in the last 30 years and will be artificially or naturally re-generated, and excludes FIA plots in urban land-uses.[22] The BOF Inventory and the U.S. National Greenhouse Gas Inventory (NGHGI) reporting classifies woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, as Grassland if they do not meet the criteria for Forest Land.[23] Land use is explicit in the FIA definition of Forest Land. In the FIA framework, only permanent changes in land use can shift plot classification from Forest to Non-forest. Transitory changes in vegetation composition lasting less than 30 years – such as resulting from management or natural disturbance – are situated conceptually in a stable Forest Land base.

CARB's LANDFIRE-C approach defines Forest Land as an area ≥ 0.22 acres (900 m^2) exhibiting ≥ 10% canopy cover live trees or shrubs[24] at the time stamp of the LANDFIRE geodata[25] (Table 1). Plant communities exhibiting less than 10% canopy cover are classified as Other Land. In the LANDFIRE-C approach, Forest (and other land) classification is based on the dominant, existing vegetation. Formally, LANDFIRE designates an Existing Vegetation Type (EVT) for each pixel (i.e., 30 meter cell). EVT is determined using decision tree models, ground- and remote sensing-based data[26]. LANDFIRE EVT considers only the extant vegetation, not the land use or potential future vegetation. With LANDFIRE's approach, land cover at a location may change with each map vintage, with LANDFIRE-C estimates of

[21] IPCC (2003)
[22] USDA-FS (2018a)
[23] USEPA (2018)
[24] CARB (2016c); Also: IPCC (2006)
[25] Since the LANDFIRE-C definition of Forest Land includes shrub-dominated vegetation types, the tool employs an additional set of functions to predict shrub land biomass and carbon stocks.
[26] LANDFIRE (2018a)

changes in carbon stocks associated with a land transition category. Vegetation classification errors introduce uncertainties in stock and change estimates.

While different, the two Forest Land definitions considered here are individually consistent with IPCC guidance, as land categories may be defined based on land cover type, land use, or a combination of the two, and there is flexibility in whether to include shrub lands in Forest or Grassland definitions[27]. However, it is important to understand the implications of the differences in the definition of Forest Land used in the two inventories. The following examples are provided to illustrate these differences:

Example 1:
By considering existing land cover, an intensively grazed pasture where trees are dominant will be classified as Forest Land by LANDFIRE in the CARB NWL Inventory but by considering land-use the same area would be classified as Agricultural Land by FIA in the BOF Inventory.

Example 2:
A recently clear-cut forest where shrubs are the dominant plant life form will be classified as a shrub land by LANDFIRE but as a Forest by FIA's definition. However, by including shrub-dominated land in the definition of Forest Land in the CARB NWL Inventory, carbon stock changes associated with transitions between tree- and shrub-dominance are conceptually associated with the IPCC category of Forest Land Remaining Forest Land, as in the example of the clear-cut forest.

Example 3:
In the CARB NWL Inventory, a change from tree-dominated Forest Land to Grassland following a high-severity fire is reported as a forest carbon stock loss. Under this method, the area is assigned to a "forest land-to-grassland" transitional category and carbon remaining in dead wood is not counted. Also, the changed area is attributed to a carbon density value using the new land cover type (i.e., Grassland cover type), that generally has a lower carbon density. In the BOF Inventory, if the carbon transitioned to dead wood is less than the carbon contained in the live vegetation after the fire, there would be a stock loss associated with the loss of forest cover but such changes would not be considered a Forest Land conversion unless the vegetation did not recover to 10% tree canopy cover after 30 years or the land was converted to a non-forest land use. The FIA program would classify these disturbed plots as early seral (i.e., "non-stocked" forest type); however forest type is not directly used to calculate the carbon stock nor stock-changes. The land cover/land-use distinction is a common source of confusion about whether disturbances reflect a change in land-use (e.g., forest to grassland) or a change in successional status (e.g., mature to seedling stage (e.g., Coulston et al. 2014) with associated changes in carbon density.

Example 4:
In the CARB NWL Inventory, a change from shrub-dominated Forest Land to Grassland would be considered a source of forest carbon stock loss and assigned to a "forest land-to-grassland" transitional category. If the state sees high levels of chaparral wildland fires, this could represent a significant source of forest carbon stock loss in the CARB NWL Inventory. However, in the BOF Inventory carbon in shrub-

[27] IPCC, 2006

dominated lands are not quantified, so high levels of chaparral wildland fires would not be quantified or considered a forest carbon stock loss nor a forest land conversion. In this way, loss of shrub-dominated communities would indicate forests are losing more carbon in the NWL estimate when compared to estimates based on the FIA definition of forests.

Table 1. Forest land definitions

Attribute	BOF Inventory (FIA)	CARB NWL Inventory (LANDFIRE-C)
Canopy cover minimum	≥ 10% canopy cover (live trees)	≥ 10% canopy cover (live trees or shrubs)
Area minimum	≥ 1 acre (4,047 m^2) and	≥ 0.22 acre (900 m^2)
	120 ft. (36.57 m) minimum width	Not applicable
Additional criteria	Formerly had such cover in the last 30 years, and will be artificially or naturally regenerated	Not applicable
	Excludes areas surrounded by development*	Not applicable

*Considered part of the IPCC "Settlements" category

Table 2 displays forest area estimates from FIA and from the CARB NWL Inventory. The CARB NWL Inventory estimate for tree-dominated forest land in 2010 is less than 2% lower than the FIA estimate for the BOF 2017 reporting period. The NWL definition for Forest Land includes land dominated by trees (Table 2) and land dominated by shrubs (not shown). In the CARB NWL Inventory, shrub-dominated lands contribute an additional 30+ million acres to total Forest Land area. Future NWL inventories will delineate forests by tree-dominated and shrub-dominated lands.

Table 2. Forested area (acres)

BOF Inventory (FIA)	CARB NWL Inventory (LANDFIRE-C)
31,746,000 ± 200,000 (SE)[a]	31,180,847 (2010 tree-dominated forest land)
	32,877,986 (2001 tree-dominated forest land)

[a] Area of forest land 2017 reporting period, from Table A9 in Christensen et al. (2019)

Forest type definitions

In the western United States, most FIA forest type definitions are based on the predominant tree species, as estimated from data on tree species, diameter, and other attributes measured on the plot from the ground. In the BOF Inventory, there are 15 explicit softwood and hardwood forest types and 4 generalized softwood and hardwood categories based on FIA forest types or groupings of FIA forest types (Table 3). Plot estimates are then expanded based on plot sample weights to quantify this population across the state. In the FIA program and the BOF Inventory, forest type is not used to calculate the carbon content of forests, it is only used in reporting the amount of carbon in meaningful ways for users.

LANDFIRE's existing vegetation types (EVTs) are based on a national hierarchical vegetation classification system employing decision tree models, field data, Landsat imagery, elevation, and climatic data.[28] For California, LANDFIRE defines over 160 vegetation cover types, with approximately 90 forest or woodland types. The LANDFIRE-C tool accounts for 18 explicit forest/woodland EVTs, while all other forest/woodland EVTs are aggregated to 5 generalized categories (Table 3, see also CARB (2013)). Carbon densities are calculated for EVTs to estimate the carbon content of forests and net changes over time.

Table 3. California forest and woodland categories used in BOF and CARB NWL frameworks.

BOF (FIA) forest type group
California mixed conifer
Ponderosa pine
Other western softwoods
Fir/spruce/mountain hemlock
Pinyon/juniper
Douglas-fir
Lodgepole pine
Redwood
Western white pine
Western hemlock/sitka spruce
Western juniper
Western oak
Tanoak/laurel
Other hardwoods
Woodland hardwoods
Alder/maple
Aspen/birch
Elm/ash/cottonwood
Exotic hardwoods

CARB NWL (LANDFIRE-C) vegetation type
Existing Vegetation Type (tree-dominated categories):
Mediterranean California mixed evergreen forest
Mediterranean California dry-mesic mixed conifer forest and woodland
Mediterranean California mesic mixed conifer forest and woodland
Klamath-Siskiyou upper montane serpentine mixed conifer woodland
California montane Jeffrey and ponderosa pine woodland
Northern Rocky Mountain ponderosa pine woodland and savanna
Mediterranean California red fir forest
Great Basin pinyon-juniper woodland
Sierra Nevada subalpine lodgepole pine forest and woodland
Mediterranean California subalpine woodland
California coastal redwood forest
California montane riparian systems
Mediterranean California mixed oak woodland
California lower montane blue oak-foothill pine woodland and savanna
Mediterranean California lower montane black oak-conifer forest & woodland
Central and southern California mixed evergreen woodland
Southern California oak woodland and savanna
EVT - NVCS Subclass (tree-dominated categories)
Deciduous open tree canopy
Evergreen closed tree canopy
Evergreen open tree canopy
Mixed evergreen-deciduous open tree canopy
Mixed evergreen-deciduous sparse tree canopy

Forest Carbon Pools

BOF reporting and the CARB NWL Inventory provide estimates for a common set of forest carbon pools[29], with some variation in data sources and methods (Tables 4a and 4b). Pools include above- and below-ground live (AGL, BGL) tree (or other dominant vegetation), above- and below-ground live understory, and above- and below-ground dead wood (standing and downed). For the AGL tree pool, both BOF reporting and the CARB NWL Inventory rely upon FIA regional tree allometric equations to

[28] LANDFIRE (2018a)

[29] A category containing carbon mass, e.g., live trees, down wood, harvested wood products.

relate tree dimensions to volume and biomass. BOF tree dimensions are collected through direct measurement using FIA plot data collection protocols.[30] The CARB NWL Inventory tree dimensions are collected through remote sensing. Foliage estimates are included for AGL tree carbon in the BOF Inventory but not in the CARB NWL Inventory. BOF reporting for dead wood pools is based upon recent plot data, while dead pools represented in the CARB NWL Inventory are derived from modeled quantities in an older FIA database version 5.1 (FIADB 5.1, the database version available during the CARB NWL Inventory's development). BOF reporting includes modeled estimates for soil organic carbon (a large pool) and litter, while the CARB NWL Inventory includes estimates for carbon contained in litter from an older FIA-based model (i.e., FIADB 5.1). The newer FIA-based models for forest floor and SOC included in BOF are based in part on FIA data collected in the 2000s. The LANDFIRE-C tool does not include SOC. CARB quantifies soil organic carbon separately outside of the LANDFIRE-C tool. Because the LANDFIRE-C tool also assesses non-forest lands, it includes pools associated with land dominated by grasses/herbaceous vegetation, and with sparsely vegetated lands.

Table 4a. Included Forest Carbon Pools

	Carbon Pool	**BOF Inventory (FIA)**	**CARB NWL Inventory (LANDFIRE-C)**
FIA Forest and NWL tree-dominated Forest Land			
Live Biomass	Tree Bole, Bark, Stems	✓	✓
	Tree Foliage	✓	
	Below-ground-live tree (roots)	✓	✓
	Understory, above- and below-ground live*	✓	✓
Dead Biomass	Dead tree standing, above-ground	✓	✓
	Dead tree standing, below-ground (roots)	✓	✓
	Dead down	✓	✓
	Litter (i.e., forest floor)	✓	✓
Soil Organic Carbon		✓	quantified separately outside of LANDFIRE-C
FIA nonforest, NWL shrub-dominated Forest Land			
Live Biomass	Live shrub, above- and below-ground		✓
	Live understory		✓
	Grass/herbaceous		✓
Dead Biomass	Woody debris		✓
	Litter		✓
Soil Organic Carbon			quantified separately outside of LANDFIRE-C

*includes trees < 1.0" dbh, shrubs/woody vines/forbs and graminoids

[30] Bechtold and Patterson 2005

Table 4b. Data Sources, Methods, and References for BOF Inventory (FIA-based) and CARB NWL Inventory (LANDFIRE-C based)

	BOF Inventory (FIA)	CARB NWL Inventory (LANDFIRE-C)
Parameters		
Forest Field Data Source	FIADB 6.1 + recent data [O'Connell et al. (2014), Christensen et al. (2017)]	FIADB 5.1 [O'Connell et al. (2011)] LANDFIRE geodata and reference database [Ryan and Opperman (2013)]
Wood Density Factors	Regional FIA [Woudenberg et al. (2010)]	Regional FIA [Zhou and Hemstrom (2009)]
Disturbance Activity	FIADB 6.1 + recent field data [O'Connell et al. (2014), Christensen et al. (2017)]	LANDFIRE geodata, CDF Forest Practice GIS [Ryan and Opperman (2013), CALFIRE (2018)]
Carbon Fraction of Wood	Default value of 0.5 [IPCC (2003)]	0.47 ± [McGroddy et al. (2004)]
Data Source and Method for Carbon Pool		
Trees, AGL and BGL	Regional FIA field data [Bole, Bark, Branch: Zhou and Hemstrom (2010), Means et al. (1994), Snell and Little (1983); foliage: Jenkins et al. (2003) ratios to total tree biomass as implemented in Woodall et al. (2011), added aboveground wood biomass before calculating AGL tree C; BGL: Woudenberg et al. (2010)]	AGL: Regional FIA BGL: Difference between AGL and Total Tree Biomass using Component Ratio Method (CRM, described in [Zhou and Hemstrom (2009)]
Understory, AGL and BGL	FORCARB2 model [Smith et al. (2006)]	Regional FIA model (FORCARB) [Woudenberg et al. (2011)]
Dead Standing, Above- and Below-Ground	AG: Flewelling (1994), Barrett (2006), Harmon et al. (2011), Regional FIA field data; BG: Jenkins et al. (2003) as implemented in Woodall et al. (2011), Woudenberg et al. (2010)	Domke et al. (2011), modified
Dead Down	Woodall and Monleon (2008), Woudenberg et al. (2011), FIA field data	Regional FIA model (FORCARB) [Woudenberg et al. (2011)]
Litter	Domke et al. (2016)	Regional FIA model (FORCARB) [Woudenberg et al. (2011)]
Soil	Domke et al. (2017)	quantified separately outside of LANDFIRE-C
Shrubs	Part of understory measurements	For tree-dominated land: shrubs are part of FIA understory. For shrub-dominated land: LANDFIRE geodata and reference database [Ryan and Opperman (2013)], [Mokany et al. (2006)]
Grass/Herbaceous	Part of understory measurements	For tree-dominated land: g/h is part of FIA understory. For g/h-dominated land [separate from forestland]: LANDFIRE geodata, MODIS NPP (MOD17A3) Ryan and Opperman (2013), Mokany et al. (2006), Running et al. (2004), USGS (2014)

Forest Ecosystem Pools: Results Comparisons

Carbon Stocks

Overview

The CARB NWL Inventory published in December 2018 covering the 2012-2014 time-period reports approximately 4.5 billion metric tons for forest carbon stock (including SOC, excluding harvested wood products). Based on the definition of forests used in the CARB NWL Inventory, this stock estimate includes contributions from 30+ million acres of shrub-dominated lands. The following sections will adjust the 4.5 billion MT C to a carbon fraction of biomass of 0.5, yielding a value of 4.8 billion metric tons C for better comparison to BOF stocks. Of the 4.8 billion MT C, approximately 2.1 billion MT C are described in the following sections for tree-dominated lands only, excluding SOC and live roots - live tree and shrub roots are lumped into the total biomass estimate from the CARB NWL Inventory and cannot be separated for this analysis, hence excluding them from totals for comparison.

The 2017 reporting period for the BOF Inventory reports forest ecosystem and harvested wood product carbon stocks are approximately 3.4 billion metric tons. For just the forest ecosystem, carbon stocks are approximately 3.3 billion metric tons, comprised of approximately 1.4 billion metric tons for forest pools excluding SOC and live roots.

Although the CARB NWL Inventory does not provide a measure of uncertainty in the estimates, previous Monte Carlo analysis on LANDFIRE-C estimates for AGL from Gonzalez et al.[31] reported a carbon stock of 840 ± 210 MMT C in 2010. This equates to an approximate uncertainty of 25% (at the 95% confidence interval) associated with the LANDFIRE-C stock estimate.

The FIA-based estimate for the 2001-2010 reporting period for the BOF Inventory estimates slightly higher AGL stocks of 1,025 ± 28 MMT C, representing an approximate uncertainty of 3% (at the 95% confidence interval) associated with the stock estimate.

Above-ground Live (AGL) Tree carbon stock

Regional FIA tree allometric equations inform both BOF reporting and the CARB NWL Inventory estimates for the above-ground live (AGL) tree pool. While shared features invite comparisons, underlying differences in methods suggest that AGL tree comparisons should be treated with caution. Temporal scopes also differ: BOF reporting employs ten-year moving averages, while the CARB NWL Inventory stocks are "snapshots" linked to LANDFIRE geodata vintage. Table 5 displays estimates for AGL tree carbon stocks reported in the BOF Inventory for eight FIA averaging periods; for a separate FIA estimate (based on tree allometric national equations rather than regional equations) centered on 2014; and for three CARB NWL Inventory vintages, including estimates for tree- versus shrub-dominated forest lands in 2001 and 2010. Separation of tree- and shrub-dominated lands from the CARB NWL Inventory is completed for this analysis, but is not separated in the CARB NWL Inventory. Forest lands dominated by trees comprise over 90% of forest land AGL carbon stocks estimated by the CARB NWL Inventory. AGL tree comparisons can be useful while still treated with caution due to varying analysis periods. For tree-dominated lands only, the the CARB NWL Inventory estimates are approximately 16% below FIA estimates. Tree foliage may contribute to some of the differences in Table 5 between FIA and the CARB

[31] 2015

NWL Inventory estimates, if foliage comprises approximately 3-5% of the FIA estimate[32]. Including tree foliage in future NWL inventories is a possible improvement. Further research is needed to determine what constitutes the remaining 9-13% difference.

Table 5. Statewide Forest Land carbon stock estimates: Above-ground Live (AGL) (MMT C)

AGL	Vintage	Source
1,025.30 ± 14.01 (SE)[b]	10-yr average, 2001-2010	Christensen et al. (2019) Table C9.1
1,034.59 ± 14.12 (SE)[b]	10-yr average, 2002-2011	Christensen et al. (2019) Table C9.2
1,035.19 ± 13.53 (SE)[b]	10-yr average, 2003-2012	Christensen et al. (2019) Table C9.3
1,045.34 ± 13.67 (SE)[b]	10-yr average, 2004-2013	Christensen et al. (2019) Table C9.4
1,054.83 ± 13.63 (SE)[b]	10-yr average, 2005-2014	Christensen et al. (2019) Table C9.5
1,061.02 ± 13.73 (SE)[b]	10-yr average, 2006-2015	Christensen et al. (2019), Table C9.5
1,064.87 ± 13.89 (SE)[b]	10-yr average, 2007-2016	Christensen et al. (2019) Table C9.7
1.063.85 ± 13.95 (SE) [b]	10-yr average, 2008-2017	Christensen et al. (2019) Table C9.8
990[c]	2014	FIADB v 6.0/CCT v6.0[33]
975.1[d]	2001 tree & shrub dominated	LANDFIRE-C, Table 1[34]
880.8	*tree dominated*	
94.3	*shrub dominated*	
948.7[d]	2010 tree & shrub dominated	LANDFIRE-C, Table 1[35]
878.7	*tree dominated*	
70.0	*shrub dominated*	
948.6[d]	2012 tree & shrub dominated	LANDFIRE-C
877.6	*tree dominated*	
71.0	*shrub dominated*	
951.3[d]	2014 tree & shrub dominated	LANDFIRE-C
882.8	*tree dominated*	
68.5	*shrub dominated*	

[a] Includes bole, bark, stems of live trees

[b] Includes bole, bark, stems, foliage of live trees

[c] Includes bole, bark, stems of live trees, saplings, and understory

[d] Includes bole, bark, stems of live trees or shrubs. LANDFIRE-C forest land includes land dominated by shrubs. Estimates adjusted to carbon fraction of biomass = 0.5

Dead (AGD) Tree Carbon Stocks

Mass contained in standing dead trees reported under BOF is based on field measurements and new FIA methods to account for wood decay and snag degradation rates, drawn from Harmon et al. (2011).[36] Biomass of coarse wood was calculated using the equations in Woodall and Monleon (2008)[37] with species-specific wood density and decay-class reduction factors[38]. A potential improvement for future

[32] see Table 8 footnote a; also O. Kuegler, personal communication, January 13, 2020
[33] USDA-FS (2018a)
[34] CARB (2016c)
[35] CARB (2016c)
[36] Harmon et al. (2011)
[37] Woodall and Monleon (2008)
[38] from the REF_SPECIES table, Woudenberg et al. (2010)

BOF reports would involve using the hardwood/softwood decay-reduction parameters from Harmon et al. (2011) instead (as described above for snags), as they seem less variable among similar species than the species-specific variables, which were also derived from Harmon et al. (2011). For the smaller size classes of down wood ("fine wood") procedures in Woodall and Monleon (2008) were followed. Currently, pile data are not included in the down wood calculations, but may be added in future inventories. CARB's LANDFIRE-C tool relies on prior national FIA practice, which modeled down dead pools and did not account for wood decay. The recent FIA-based mass for standing dead wood is approximately 1.4 times greater than the CARB NWL Inventory estimates (Table 6). By contrast, the CARB NWL Inventory estimates for downed dead wood are approximately a factor 2 times greater than field-based estimates, despite the fact that FIA includes small and large down wood whereas estimates for the CARB NWL Inventory only include large (coarse) wood. The CARB NWL Inventory estimates for standing and downed dead wood combined are a factor 3 times greater than field-based estimates. These results illustrate that LANDFIRE-C's estimates for standing and down dead wood depart from recent field-based data, and suggest areas for LANDFIRE-C's further development.

Table 6. Forest land dead tree pool estimates (MMT C)

Pool (MMTC)	BOF Inventory (FIA)[a]	CARB NWL Inventory (LANDFIRE-C)[b]			
		2001	2010	2012	2014
Standing dead[c]	116.28 ± 3.43 (SE)	63.61	60.56	60.85	61.68
Down dead	115.24 ± 2.03 (SE)	275.55	261.17	261.82	263.04

[a] Average for 2008-2017 from Table 4.27 in Christensen et al. (2019)

[b] Tree-dominated forest lands only. Estimates adjusted to carbon fraction of biomass = 0.5

[c] LANDFIRE-C based Standing Dead Tree carbons stocks include above- **and** below-ground (dead roots), and cannot be separated. FIA reports above- (94.13 ± 2.81 (SE) MMT C) and below- (22.15 ± 0.62) dead tree carbon separately, but have been combined here for comparison.

Litter and Soil Organic Carbon Stocks

Carbon estimation for litter and soil organic carbon (SOC) pools remains an area of active research in both inventories. The CARB NWL Inventory estimates for litter are a factor 6 times greater than BOF estimates (table 7). The BOF 2017 reporting period added information for the carbon contained in litter (i.e., forest floor) pools[39]. The CARB NWL Inventory estimates are from an older FIA-based model which includes fine down wood less than 3" diameter in the litter pool. The BOF estimate for forest floor, from a newer FIA-based model, does not include fine wood; this material is reported in the down dead wood pool. These results illustrate an opportunity to align the estimates by using the most recent FIA approach for this pool. The newer FIA-based models for forest floor and SOC included in BOF estimates are based in part on FIA data collected in the 2000s. The LANDFIRE-C tool does not include SOC. CARB quantifies soil organic carbon separately outside of the LANDFIRE-C tool. The 2010 SOC estimate for tree- and shrub-dominated land is non-spatial and is approximately 2009.37 MMT C[40]; however, estimates for tree-dominated lands only are not currently available.

Table 7. Forest land litter and SOC pool estimates (MMT C)

[39] Christensen et al. (2019)

[40] CARB SOC estimate for forest provided here is a custom extract to exclude "other natural lands" as is reported in the 2018 CARB NWL Inventory. M. Miranda, pers. communication, May 7, 2020.

Pool (MMTC)	BOF Inventory (FIA)[a]	CARB NWL Inventory (LANDFIRE-C)[b]			
		2001	2010	2012	2014
Litter	136.26 ± 1.01 (SE)	908.26	866.10	870.57	893.98
SOC	1,578.63 ± 9.91 (SE)				

[a] Average for 2008-2017 from Table 4.29 in Christensen, G. et al. (2019)

[b] Tree-dominated forest lands only. Estimates adjusted to carbon fraction of biomass = 0.5

Net Carbon Stock Change

Overview

The CARB NWL Inventory published in December 2018 covered the 2012-2014 time period[41]. In the IPCC category, Forest Land Remaining Forest Land, this inventory reported a net forest carbon stock change for tree- and shrub-dominated lands (live and dead pools, excluding SOC) of approximately 1.82 MMT C/yr. When these values are adjusted to a carbon fraction of biomass equal to 0.5 for better comparison in this analysis, the value is 1.93 MMT C/year. Net change due to forest land conversions was approximately 5.99 MMT C/yr, with the adjusted value at 6.37 MMT C/yr.[42] Considering the information in table 10c below, in tree-dominated lands due to forest land conversion there is a loss of -0.93 MMT C/yr in the aboveground live pool while in shrub-dominated lands there is a loss of -0.54 MMT C/yr, for a total loss to the AGL pool of -1.46 MMT C/year. Based on this information, to reach a net change of 6.37 MMT C/yr due to forest land conversions there must be an increase of 7.84 MMT C/yr in dead pools across tree- and shrub-dominated forest lands. Net change for forest land remaining forest land combined with net change due to forest land conversions is approximately 7.8 MMT C/year, with the adjusted value being 8.3 MMT C/year.[43] The CARB NWL Inventory tracks carbon from harvest originating during the analysis period and persisting in solid wood products during the analysis period only, for informational purposes only (0.68 MMT C/yr). Inclusion of non-CO_2 emissions from wildfires is a planned improvement for future NWL inventories.

The BOF Inventory for the 2017 reporting period[44] demonstrated that California's forests remain net sinks, sequestering 7.6 ± 1.4 MMT C/yr. This value includes changes in forest ecosystem pools (8.0 ± 1.3 MMT C/yr, excluding SOC and forest floor), harvested wood product pools (0.2 MMT C/yr), non-CO_2 emissions from wildfires (-0.1 ± 0.03 MMT C/yr), and forest land conversions (-0.5 ± 0.3 MMT C/yr). There is a loss of -0.27 MMT C/yr from the aboveground live tree pool due to forest land conversions, compared to a loss in the AGL pool in tree-dominated lands in NWL of -0.93 MMT C /yr. When looking at net changes in just forest ecosystem pools in Forest Land Remaining Forest Land and net changes from forest land conversions combined, total net change is 7.5 MMT C/yr. This value is approximately 10% lower than net change in forests in the CARB NWL Inventory, which also includes shrub-dominated lands.

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[41] CARB (2018a)

[42] Totals for two-year period: 27.85 MMT C from grassland transitioning to forestland and -15.87 MMT C from forestland transitioning to grassland, Table 10 in CARB (2018a)

[43] Adjusted to carbon fraction biomass = 0.5.

[44] Christensen et al. (2019)

Although LANDFIRE-C does not provide a measure of uncertainty in the estimates, previous Monte Carlo analysis on LANDFIRE-C estimates from Gonzalez et al.[45] reported a net loss in aboveground live (AGL) carbon of 29 ± 10 MMT C (95% confidence interval) in California Forests Remaining Forests for the time-period of 2001-2010. There is an approximate uncertainty of 35% associated with the net change estimate.

The FIA-based estimate for the 2017 reporting period for the BOF Inventory estimates an annual AGL gain of 5.0 ± 1.2 MMT C/yr[46]. There is an approximate 23% uncertainty (95% confidence interval) associated with the net change estimate.

AGL net carbon stock change – Forest land remaining Forest land

Both the FIA-based estimates for BOF net stock change reporting and the LANDFIRE-C based estimates for net stock change rely on the stock-difference method.[47] BOF reporting for AGL annual net stock changes (MMT C/yr) are based on actual growth, removals and mortality recorded on plots and trees initially measured during the first FIA measurement cycle and remeasured in subsequent measurement cycles. LANDFIRE-C estimates for AGL net stock-change are based on raster subtraction between two modeled points in time.

In table 8, the BOF Inventory estimate from the 2017 reporting period for AGL *tree* net carbon stock change in Forest Land remaining Forest Land is compared to LANDFIRE-C estimates for three different time periods in the CARB NWL Inventory for AGL *forest* stock change which includes both aboveground live trees *and* shrubs. Net change in foliage and understory are excluded from the BOF values reported in table 8 for more closely comparing to the NWL LANDFIRE-C estimates of stock change. The NWL LANDFIRE-C AGL net stock change estimate incorporates an adjustment to 2010 AGL stocks in forest land that remained tree-dominated in both 2001 and 2010, to account for approximately 6% decadal AGL biomass increase undetected by LANDFIRE canopy height geodata.[48] The 6% decadal AGL increment rate was based on FIA data and is applied in annualized form to undisturbed tree-dominated areas in subsequent inventory years as well. Updating growth factors applied to undisturbed tree-dominated lands using the latest FIA data is a possible improvement to future NWL inventories.

Because the LANDFIRE-C definition of forest land includes shrub-dominated land, forest land AGL stock change includes changes associated with forest lands that have alternated between tree- and shrub-dominance. In tables 9a-c, the LANDFIRE-C AGL tree component is separated from the shrub component of the NWL estimate. For the LANDFIRE-C category Forest Land remaining Forest Land, lands that remained tree-dominated throughout 2001-2010 (and other periods) exhibited net gains in AGL carbon (Table 9a-c). Meanwhile, land that transitioned from tree to shrub dominance exhibited net losses in AGL carbon. Shrub dominated forest land that transitioned to tree dominance exhibited declines in AGL carbon. The declines are due to carbon density assignments for mature shrub-dominated systems (averaging 18.9 metric tons C/ha, derived from non-FIA data) that are greater than carbon densities assigned for systems dominated by young trees (averaging 11.5 metric tons C/ha). This result

[45] 2015
[46] Christensen et al. (2019); Table 4.3
[47] IPCC (2003)
[48] CARB (2016b)

underscores challenges associated with integrating vegetation carbon data derived from different sources. LANDFIRE-C estimated AGL stock change for 2001 – 2010 is therefore sensitive to a common driver of tree- versus shrub-dominance: fires that occurred in the analysis period (approximately 6 x 10^6 acres).[49] By contrast, the LANDFIRE-C estimate for annualized forest AGL stock change (6.13 MMT C) is three times greater during 2010-2012 (Table 8), a period which featured less fire activity (≈ 1.1 x 10^6 acres). The LANDFIRE-C estimate for AGL change is reduced for 2012-2014 (Table 8), associated with greater fire activity in the period (1.9 x 10^6 acres). These results suggest that the LANDFIRE-C approach is sensitive to disturbances such as wildfire, since remote sensing detects abrupt changes in vegetation type, canopy height and cover[50]. However, as disturbances become more frequent decadal averages will still reflect those trends - increased tree mortality and decreased growth from the extended drought in California, compounded by several large wildfire seasons are being reflected in the annual BOF estimates of change. A planned reduction in the 10-year FIA re-measurement cycle to 5-years will improve the timeliness of disturbance detection in the FIA data.

Table 8. Statewide forest land AGL carbon stock change (MMTC/yr)

AGL	Time period	Source	Pools Included
4.96 ± 0.59 (SE)[a]	2001-2007 initial measure 2011-2017 re-measure	Christensen et al. (2019), Table 4.24	live tree bole, bark, stems[a]
2.06[b]	2001-2010	LANDFIRE-C CARB 2018a Table 17	live shrub, tree bole, bark, stems[b]
6.13[b]	2010-2012	LANDFIRE-C, CARB 2018a Table 17	live shrub, tree bole, bark, stems[b]
2.64[b]	2012-2014	LANDFIRE-C, CARB 2018a Table 17	live shrub, tree bole, bark, stems[b]

[a] Foliage change reported separately (0.26 ± 0.03 MMTC/yr)
[b] Estimates adjusted to carbon fraction of biomass = 0.5 and annualized

Table 9a. LANDFIRE-C forest land AGL stock changes for tree and shrub transitions, Forest Land remaining Forest Land, 2001-2010 (MMTC)

Category	Area (km^2)	MMTC[a]	MMTC/yr[b]
Forest Land remaining Forest Land	**6,869**	**18.62**	**2.06**
Tree dominated remaining tree dominated	*122,986*	*31.39*	
Tree dominated to shrub dominated	*4,336*	*-7.67*	
Shrub dominated to tree dominated	*2,364*	*-1.85*	
Shrub dominated remaining shrub dominated	*116,025*	*-3.25*	

[a] Estimates adjusted to carbon fraction of biomass = 0.5
[b] Annualized over 9 elapsed years

[49] Gonzalez et al. (2015)
[50] Gonzalez et al. (2015)

Table 9b. LANDFIRE-C forest land AGL stock changes for tree and shrub transitions, Forest Land remaining Forest Land, 2010-2012 (MMTC)

Category	Area (km^2)	MMTC[a]	MMTC/yr[b]
Forest Land remaining Forest Land	**234,079**	**12.26**	**6.13**
Tree dominated remaining tree dominated	*124,744*	*11.29*	
Tree dominated to shrub dominated	*270*	*-2.06*	
Shrub dominated to tree dominated	*NA*	*NA*	
Shrub dominated remaining shrub dominated	*109,065*	*3.03*	

[a] Estimates adjusted to carbon fraction of biomass = 0.5
[b] Annualized over 2 elapsed years

Table 9c. LANDFIRE-C forest land AGL stock changes for tree and shrub transitions, Forest Land remaining Forest Land, 2012-2014 (MMTC)

Category	Area (km^2)	MMTC[a]	MMTC/yr[b]
Forest Land remaining Forest Land	**232,681**	**5.28**	**2.64**
Tree dominated remaining tree dominated	*123,587*	*11.29*	
Tree dominated to shrub dominated	*610*	*-4.57*	
Shrub dominated to tree dominated	*1,249*	*-1.44*	
Shrub dominated remaining shrub dominated	*107,235*	*< 0*	

[a] Estimates adjusted to carbon fraction of biomass = 0.5
[b] Annualized over 2 elapsed years

AGL net carbon stock change - Forest Land Conversions

The BOF Inventory and the CARB NWL Inventory both address forest land conversions differently. In the BOF Inventory, the FIA program considers *land-use* and does not consider a loss of trees from one time period to the next as a forest land-use conversion unless live tree canopy is less than 10% for 30 years or there is a change to a non-forest land use (e.g., developed or agriculture). The CARB NWL Inventory considers *land cover*, so if there is a loss of trees between time periods of any length such that the remaining tree and shrub cover is less than 10%, it is considered a forest cover conversion. In this way, the BOF Inventory reports much lower amounts of change in forest carbon in aboveground live pools due to conversion (-0.27 MMT C/yr, table 11) compared to the CARB NWL Inventory (-1.46 to -4.88 MMT C/yr, Tables 10a-c). The land-use/land-cover distinction is a common source of confusion about whether disturbances reflect a change in land-use (e.g., forest to grassland) or a change in successional status (e.g., mature to seedling stage (e.g., Coulston et al. 2013). Differences in time periods for analysis are a contributing factor here as well.

Additionally, since the NWL definition of forests includes shrub-dominated lands, changes in these lands contributes to the amount of carbon considered lost as a result of conversions. For example, if there are great disturbances to shrub-dominated lands, such as from wildfire, higher stock loss for forests would be reported in the CARB NWL Inventory than in the BOF Inventory, which does not consider shrub-dominated lands at all.

Table 10a. LANDFIRE-C forest land AGL stock changes for tree and shrub transitions, Forest Land Conversions, 2001-2010 (MMTC)

Category	Area (km^2)	MMTC[a]	MMTC/yr[b]
Forest Land changing to non-forest land	**23,570**	**-45.29**	**-5.03**
Tree dominated to non-forest	*5,730*	*-27.22*	
Shrub dominated to non-forest	*17,840*	*-18.07*	
Non-forest land changing to Forest Land	**6,869**	**1.36**	**0.15**
Non-forest to shrub dominated	*6,035*	*0.24*	
Non-forest to tree dominated	*834*	*1.12*	
Net change		**-43.93**	**-4.88**

[a] Estimates adjusted to carbon fraction of biomass = 0.5

[b] Annualized over 9 elapsed years

Table10b. LANDFIRE-C forest land AGL stock changes for tree and shrub transitions, Forest Land Conversions, 2010-2012 (MMTC)

Category	Area (km^2)	MMTC[a]	MMTC/yr[b]
Forest Land changing to non-forest land	**17,790**	**-5.35**	**-2.67**
Tree dominated to non-forest	*1,125*	*-4.49*	
Shrub dominated to non-forest	*16,664*	*-0.86*	
Non-forest land changing to Forest Land	**10**	**0.01**	**<0.01**
Non-forest to shrub dominated	*7*	*<0.01*	
Non-forest to tree dominated	*3*	*<0.01*	
Net change		**-5.34**	**-2.67**

[a] Estimates adjusted to carbon fraction of biomass = 0.5

[b] Annualized over 2 elapsed years

Table 10c. LANDFIRE-C forest land AGL stock changes for tree and shrub transitions, Forest Land Conversions, 2012-2014 (MMTC)

Category	Area (km^2)	MMTC[a]	MMTC/yr[b]
Forest Land changing to non-forest land	**1,408**	**-6.44**	**-3.22**
Tree dominated to non-forest	*550*	*-5.35*	
Shrub dominated to non-forest	*857*	*-1.09*	
Non-forest land changing to Forest Land	**3,951**	**3.51**	**1.76**
Non-forest to shrub dominated	*6*	*0.01*	
Non-forest to tree dominated	*3,945*	*3.50*	
Net change		**-2.93**	**-1.46**

[a] Estimates adjusted to carbon fraction of biomass = 0.5

[b] Annualized over 2 elapsed years

Table 11. BOF FIA forest land AGL stock changes, Forest Land Conversions, 2017 Reporting Period, 2008-2017 (MMTC)[51]

Category	Area (km^2)	MMTC/yr[a]
Forest Land changing to non-forest land	-112	-0.55
Non-forest land changing to Forest Land	45	0.28
Net change	**-66**	**-0.27**

[a] Annualized over 10 elapsed years

Disturbance Effects on Stock Change

The BOF reporting and CARB NWL Inventory consign additional considerations to changes in land carbon associated with two general IPCC categories of disturbance. These disturbance processes act to transfer land carbon to other pools on the landscape, to off-site destinations, and/or to the atmosphere. Categories include, but are not limited to, tree removals and biomass burning on land (prescribed burning and wildfire).

Tree removals or commercial harvests initiate processes which transfer AGL carbon contained in live trees to other forest ecosystem or harvested wood product carbon pools. Carbon in harvested wood products (dimensional lumber, panels, etc.) can persist in solid form for varying periods of time. On-site harvest residues (slash) comprise new dead organic material, destined to either decay in place or to burn by management action. Mill processes convert harvested logs to products, in the process generating residues that are combusted for generating heat and power. At the end of useful product life, discarded wood products enter solid waste management systems, destined for material recycling or internment in landfills. In the anaerobic environment of landfills, wood products undergo decay, generating CO_2 and CH_4 gas. At the end of the anaerobic decay process, a fraction of the wood carbon persists in solid form indefinitely. At the end of product use-life, products can also remain in use through recycling, burned for energy, or burned as waste[52].

Fire consumes portions of live and dead vegetation, releasing carbon to the atmosphere as CO_2, other GHG and non-GHG gases, and as particulate matter. Aboveground post-fire carbon pools remaining on the land include unconsumed dead fuel, killed vegetation, live vegetation, cinders and ash.

In the BOF reporting, data from FIA plots form the basis for estimating carbon stock change associated with tree removals, a portion of which constitute commercial harvest. Per IPCC Good Practice Guidance[53], forest products industry and product life cycle data are used to estimate carbon stocks contained in wood products in use and in solid waste disposal sites. BOF estimates for carbon stocks contained in harvested wood products are included beginning with the 2017 reporting period[54] and are discussed further in the "Harvested Wood Products" section below. Carbon stock changes associated with tree mortality attributed to fire, disease, insect pest or other processes are also based on observations recorded at FIA plots. This information is useful for land managers and policy makers to understand the drivers of change in the forest.

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[51] From Tables 4.8 and 4.9 Christensen et al. (2019)
[52] Stockmann et al. 2012
[53] IPCC (2014)
[54] Christensen et al. (2019)

For the CARB NWL Inventory, geospatial data are used to attribute changes in AGL and Total carbon stocks (not including soil organic carbon) to wildfire, prescribed burning, and varieties of harvest (clearcut, thinning and uncategorized harvest). GIS format disturbance data sources include the LANDFIRE DISTYEAR product[55] and the CAL FIRE Forest Practice Geographical Information System[56]. For cases where fire and harvest occurred in the same location during an analysis period, LANDFIRE-C attributes stock change to harvest. Stock changes associated with mechanical treatments of vegetation fuels, such as by mastication, are assumed to oxidize rapidly to the atmosphere, generating no HWP nor transitioning to other forest carbon pools. The CARB NWL Inventory reports stock changes attributed to harvests and fires for informational purposes only.

Disturbance: Biomass Burning on Land

Statewide stock changes attributed to fire reported for the BOF Inventory are based on data from plots measured in 2001-2007 and re-measured in 2011-2017[57]. LANDFIRE-C estimates for carbon stock changes attributed to fire are tabulated in a GIS by overlaying fire perimeters (from the LANDFIRE DISTYEAR product) atop the AGL and Total stock-change rasters[58]. The LANDFIRE-C stock changes reflect only the difference between vegetation before and (often years) after fire. The post-fire vegetation mapped by the LANDFIRE EVT, EVC and EVH products have limited memory of the pre-fire vegetation type (surviving vegetation), therefore the LANDFIRE-C stock change estimates do not account for potential remnant carbon persisting in unburned dead fuels or in killed trees[59]. A potential improvement to future NWL inventories is to apportion potential remnant carbon into dead carbon pools. The LANDFIRE-C estimate for 2001-2010 stock change attributed to wildfire is associated with over 6 million acres of mostly tree- and shrub-dominated forest land burned in the period. The total wildfire area in the state mapped by LANDFIRE for 2001-2010 was approximately 4% greater than an area total derived from the CAL FIRE fire perimeter geodatabase.[60] Table 12 displays annual average stock changes (MMT C/year, all pools except soils) associated with wildfires estimated from FIA data and from LANDFIRE-C. The LANDFIRE-C estimate for 2001-2010 is approximately a factor 8 greater than the rate for the FIA "fire only" category. However, the LANDFIRE-C area burned estimate for all vegetation types is 3-4 times larger than estimates for forest-only area burned for this time period[61]. The LANDFIRE-C estimate for 2010-2012 (a shorter period that exhibited modest fire activity) is greater than the BOF 2017 reporting period estimates.

While few conclusions can be drawn from the limited information presented here, several aspects should be noted. The LANDFIRE-C estimates presented here for convenience include all natural land cover types and contain contributions from low carbon-density non-forest cover types. Again, as shrub-

[55] LANDFIRE (2018b)
[56] CAL FIRE (2018)
[57] Christensen et al. (2019)
[58] CARB (2016c)
[59] Gonzalez et al. (2015)
[60] 5.7 million acres from CAL FIRE FRAP (2017)
[61] Approximately 1.6 million acres from CAL FIRE (2017) fire perimeter data and vegetation layers (2015); approximately 2.2 million acres from FIA plot, disturbance data from A. Gray, personal communication, August 3, 2020

dominated lands are included in the NWL definition of forests, fires in this vegetation type are included in the CARB NWL Inventory but not in the BOF Inventory. Future NWL inventories may separate fires in tree-dominated lands from shrub-dominated lands for reporting. A large number of wildfires were mapped for 2001 – 2010 and the LANDFIRE-C approach is sensitive to disturbance, since remote sensing detects abrupt changes in canopy cover and height associated with wildfires. The LANDFIRE-C approach currently does not account for remnant carbon that may persist post-fire, whereas such pools are recorded in affected FIA field plots. The LANDFIRE-C approach also assumes greater quantities of pre-fire dead carbon in forest lands, compared to FIA estimates reported to date. LANDFIRE-C also counts disturbances of any size, including disturbances on small forests not classified as forest by FIA. Taken together, these may contribute to some of the differences between estimated stock changes attributed to fires.

Table 12. Statewide annual average carbon stock changes (not including soils) associated with wildfires (MMT C /yr).

BOF Inventory (FIA)[a]	Analysis Period	CARB NWL Inventory (LANDFIRE-C)[b]	Analysis Period
1.86 ± 0.25 (S.E.) fire only	2017 reporting period	14.54	2001 - 2010
0.59 ± 0.16 (S.E.) cut & fire		5.0	2010 - 2012
2.46 ± 0.30 (S.E.) total		10.48	2012-2014

[a] From Table 4.7 in Christensen et al. (2019), converted from CO_2e, forests (tree-dominated) only.
[b] Estimate for wildfires that occurred in tree and shrub-dominated forests and other natural lands, adjusted to carbon fraction of 0.5; tables 11-13, CARB (2018a).

In a recent analysis, researchers combined data from field plots and remote sensing (Light Detection and Ranging [LIDAR] and Landsat) to estimate changes in AGL carbon stocks within the 257,314-acre footprint of the Rim Fire[62]. The Rim Fire started in August 2013, was contained in October 2013 (approximately 1,040 km^2), and declared fully extinguished almost a year later. Researchers estimated the amount of AGL carbon stocks affected by the fire as the difference between the pre-fire AGL stocks (based on Landsat), and the post-fire AGL stocks (based on LiDAR and Landsat). For comparison, CARB staff extracted from LANDFIRE-C pixel-level estimates of AGL stock change for 2012 - 2014 associated with the Rim Fire footprint. Two fire footprint-wide sums were evaluated from the collected pixels: positive and negative values together (the sum of AGL stock gains and losses), and negative values (stock losses) only. AGL stock-change estimated by LANDFIRE-C is within range of two estimates provided in the Rim Fire Analysis[63] (Table 13). The AGL stock-change estimate for this single large wildfire is comparable to the decadal annual statewide average reported for the BOF (3.35 MMTC/yr [12.27 $MMTCO_2e$/yr][64], which suggests that large-scale wildfires play a significant role in statewide land carbon quantification. However, there are additional points to consider when comparing the Garcia et al. (2017) estimate of Rim Fire above-ground biomass stock-change of 3.29 ± 0.02 MMT C (12.06 ± 0.06 MMT CO2e) to the BOF estimates of stock change due to fire. The Rim Fire burned 104 thousand ha, so the Garcia et al. estimate translates to 31.6 metric tons C/ha. The statewide estimates of net change in the

[62] Garcia et al. (2017)
[63] Garcia et al. (2017)
[64] from Table 4.6a in Christensen et al. (2019)

BOF report for the 2017 reporting period are 14.1 metric tons C/ha for aboveground wood[65] or 26.4 metric tons C/ha for live trees. Garcia et al.'s estimate is similar to the BOF estimate of live tree mortality. Indeed, the Rim Fire study only focused on live tree biomass, and even adjusted out the post-fire dead trees from affecting the LiDAR-based estimates of biomass to avoid bias. In effect, this study does not estimate fire emissions, but only the mortality of the live tree pool; at rates comparable to what the BOF estimates found in burned areas across the state. BOF results show that even after severe mortality events and the subsequent decay between the events and the plots being measured, the majority of the carbon is still present in dead wood.

Table 13. Estimated changes in above-ground live (AGL) stocks associated with the Rim Fire (MMT C).

Description	Stock change	Uncertainty estimate
$Landsat_{pre}$ – $Landsat_{post}$	1.96	± 0.09
$Landsat_{pre}$ - LIDAR	1.37	± 0.11
$Landsat_{pre}$ – $LIDAR_{corrected}$	3.29	± 0.02
LANDFIRE-C (gains + losses)[a]	1.72	
LANDFIRE-C (losses only)[a]	1.83	

[a] LANDFIRE-C estimates are adjusted for carbon fraction of biomass = 0.5

Disturbance: Harvest

LANDFIRE-C estimates for harvest area are comparable to timber yield tax harvest statistics reported by the California Department of Tax and Fee Administration (CDTFA). Total clearcut area on private forest land tabulated from LANDFIRE disturbance geodata for 2001-2010 (432,283 ac) was approximately 13% lower than a total derived from CAL FIRE timber harvest data (494,513 ac)[66]. For quality assurance purposes, the change in forest land AGL carbon attributed to harvest by LANDFIRE-C is converted to merchantable volume, for comparison with harvest volumes reported by other entities. Using data from partial and clearcut harvest sites on public and private timberlands, researchers derived average carbon removal intensities (Metric tons C/ha) and merchantable fractions associated with harvest types (Table 14)[67]. A single AGL carbon removal intensity (48.9 metric tons C/ha) was derived for clearcuts on both private and public timberlands. Thinning (partial cut) and uncategorized harvests are represented by reduced removal intensities and merchantable fractions, differentiated by ownership type. A factor of 572 metric tons C/mmbf was used to convert metric tons C to million board feet of roundwood.

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[65] derived from net change by disturbance Table B9 in Christensen et al. (2019) and the corresponding average annual area burned of 263,200 acres, from the plots where a fire was recorded between the first and second measurements (2001-2007 to 2011-17), using standard FIA estimation procedures

[66] CARB (2016a)

[67] CARB (2016a)

Table 14. Land carbon removal intensities and merchantable portions for harvest types on private and public timberland.

Ownership type	Harvest type	Mean total harvest (metric tons C/ha)	Mean merchantable (metric tons C/ha)	Percent merchantable
Private	Clearcut	48.9	43.4	89
Public	Clearcut	48.9	43.4	89
Private	Partial cut	21.0	7.3	42
Public	Partial cut	11.8	6.9	42
Private	Harvest (uncategorized)	N/A	N/A	72
Public	Harvest (uncategorized)	N/A	N/A	44

Using these factors (table 14), estimated changes in forest land AGL carbon stock for 2001-2010 attributed by LANDFIRE-C to clearcut, thinning and uncategorized harvest (11 MMTC) translated to an estimated total harvest volume of 12,445 mmbf (Table 15). This volume represents approximately 92% of harvest volume reported to the CDTFA[68] and 76% of the harvest volume reported from industry data in the BOF report[69] (Table 16). For 2010-2012, the LANDFIRE-C change in AGL tree carbon stocks attributed to harvests (1.45 MMTC) translated to an estimated harvest volume of 2,081 mmbf or 83% of the reported CDTFA volume and 75% of the harvest volume reported from industry data in the BOF report. Notwithstanding differences between CDTFA and BOF reporting, other factors may contribute to LANDFIRE-C's lower harvest volume estimates. These may include harvests that occur after the peak growing season, the time of year upon which the LANDFIRE products EVT, EVC and EVH (hence LANDFIRE-C's carbon stock and change estimates) are based. Moreover, EVC and EVH will reflect little change associated with harvests that have minor effects on canopy cover or height. Average removal intensities and merchantable fractions generalize the varying factors affecting actual harvest volumes such as forest type, site productivity, pre-harvest forest densities, etc.

Table 15. LANDFIRE-C AGL stock-changes (MTC) and merchantable volumes (mmbf) associated with harvests, 2001-2010. Estimates are adjusted for carbon fraction of biomass = 0.5

Harvest	Private		Public		Total	
Type	MTC	mmbf	MTC	mmbf	MTC	mmbf
Clearcut	3,309,174	5,135	310,423	482	3,619,598	5,617
Harvest	2,635,831	3,317	647,862	496	3,283,693	3,813
Thinning	1,850,283	1,359	2,268,812	1,657	4,119,095	3,015
Total	7,795,288	9,811	3,227,097	2,634	11,022,384	12,445[a]

[a] Volume represents 6/2001-6/2010. See footnote 52.

[68] Since LANDFIRE captures a portion of harvest activities compared to continuous data collection by the CDTFA, comparisons were made against the sum of all CDTFA reported harvest volumes for 2002-2009 and 50% of the harvest volumes for 2001 and 2010. (ARB 2016a)

[69] Christensen et al. (2019)

Table 16. Estimated harvest volumes, 2001-2010 (mmbf)

NWL LANDFIRE-C	CDTFA	BOF FIA
12,445	13,600[a]	16,434[b]

[a] Volume representing 6/2001-6/2010. Total reported volume for 2001-2010 is 14,982 mmbf. See footnote 52.
[b] Sum of years 2001 – 2010, from Table 6.1 in Christensen et al. (2019).

While estimated harvest volume for 2001-2010 across the three approaches are within 20% of one another (Table 16), the harvest volume reported for the BOF represents 27,677,628 MTC harvested merchantable wood,[70] 2.5 times greater than the LANDFIRE-C based estimate. Much of the difference appears attributable to factors used to convert harvested wood volume to carbon mass. In the LANDFIRE-C approach, the conversion factor 572 MTC/mmbf is based on a regional reference carbon density for softwood[71] of 15.11 Lb. C/ft^3 and a literal board foot to cubic foot conversion of 12 bf/ft^3. For BOF wood products reporting, analysts use a number of factors to account for changes in the sizes and species composition of trees harvested over time typical to wood products reporting. Principal among these are board foot/ft^3 volume ratios used to convert from harvest tallies reported in Scribner volume board feet (bf) to cubic foot wood values (values range from 3.95 to 6.02 bf/ft^3 depending on the era[72]) and carbon densities of primary wood products (ranging from 33-42 lb. C/ ft^3), rather than wood species. In the BOF Inventory, harvest volumes (mmbf Scribner) are converted to cubic foot volumes, then those volumes are allocated to timber product classes (i.e., sawlogs, pulp, etc.), then to primary product classes (i.e., lumber, veneer, etc.), and then converted to carbon from there. This approach, combined with the higher initial harvest volume used in the BOF Inventory, evaluates to harvested wood carbon quantities that are approximately 2.5 times greater than the LANDFIRE-C estimate.

In turn, the differences in estimates for carbon removed from forests via harvests extends to rates of removal. Table 17 displays annualized rates of AGL tree carbon stock change attributed to tree removal, based on FIA data reported for the BOF and from LANDFIRE-C. While these values correspond to different time periods of analysis, a few points are notable. In the BOF Inventory, this value represents the carbon associated with all cut trees and not necessarily just commercial harvest. Some amount of the tops, limbs and foliage of what is cut in commercial harvest remains in forest and some amount of what is cut is not associated with commercial harvest and also remains in forest. The amount of C specifically associated with commercial harvest for the 2017 reporting period is 2.8 MMT C/yr[73].

[70] from Table 6.1 in Christensen et al. (2019)
[71] from Joyce and Birdsey (2000)
[72] see Table 5.2 in Christensen et al. (2019)
[73] see section 6.1.1 in Christensen et al. (2019)

Table 17. AGL stock change (loss) rates attributed to tree removal (MMTC/year).

Timeframe	BOF Inventory (FIA)	CARB NWL Inventory (LANDFIRE-C)
2017 reporting period [a]	3.77 ± 0.33 (SE)	
2001-2010		1.23 [b]
2010-2012		0.74 [c]

[a] Plots measured in 2001-2007 and re-measured in 2011-2017. Annualized total "Cut" from Table 4.6a, Christensen et al. (2019). The amount of C specifically associated with commercial harvest for the 2017 reporting period is 2.8 MMT C/yr (see section 6.1.1 in Christensen et al. 2019).
[b] AGL tree gross stock-change of harvest, 2001-2010 (annualized). From Table 4 in CARB (2016c), converted to assume carbon fraction of biomass = 0.5
[c] AGL tree gross stock-change of harvest, 2010-2012 (annualized). Converted to assume carbon fraction of biomass = 0.5

In summary, several factors appear to contribute to divergent estimates of harvested carbon. In LANDFIRE-C, attribution of AGL stock-change to harvest activities for 2001-2010 relied on the LANDFIRE DISTYEAR product to delineate harvest areas. Using supplemental harvest geodatasets, CARB staff have begun to examine options to account for potential under-detection of harvests. Harvest activities that have little effect on an area's canopy height or canopy cover will also contribute to correspondingly reduced estimates of AGL stock-change by LANDFIRE-C. Together, these can contribute to reduced harvest-attributed AGL stock-change, and by extension harvest volume relative to CDTFA or other reporting. FIA data suggest that tree removal occurs at rates greater than that reflected in CDTFA harvest volume reporting because a portion of tree removals detected in FIA data are unrelated to commercial timber harvest, such as for pre-commercial thinning or hazard tree abatement. Differing approaches relating harvest volumes to carbon mass appear to contribute to most of the difference in estimates of harvested carbon.

These results suggest areas for further development in the NWL inventory to employing remote sensing based geospatial approaches, and in indirect assumptions about land carbon removal intensities and merchantable fractions by ownership type, to estimate AGL stock-changes associated with harvest activities.

Harvested Wood Products

Summary of Approaches

IPCC Good Practice Guidance[74] recommends accounting for the carbon stored in harvested wood products in-use and at solid waste disposal sites (SWDS). These pools are included in the BOF 2017 reporting period[75]. BOF reporting utilizes the IPCC production approach as described in Stockmann et al. (2012), which excludes imports and focuses on California-origin timber. This approach is consistent with the approaches used in the U.S. National Greenhouse Gas Inventory[76] for the forest sector. Harvest volumes (mmbf Scribner) are converted to cubic foot volumes, then those volumes are allocated to

[74] IPCC (2014)
[75] Christensen et al. (2019)
[76] USEPA (2018)

timber product classes (i.e., sawlogs, pulp, etc.), then to primary product classes (i.e., lumber, veneer, etc.), and then converted to carbon from there. Estimates are based on historic harvest volumes dating back to 1952, timber product ratios, primary product ratios, end-use product ratios, discarded products disposition ratios, end-use and discarded products half-lives, and landfill fixed-carbon ratios. This approach does not apply simple storage ratios to the harvest; rather it tracks carbon through the product life cycle from harvest to timber products to primary wood products to end use to disposal, applying best estimates for product ratios and half-lives at each stage. Cumulative stock results are provided for individual years; however, to remain consistent with FIA's forest ecosystem ten-year average reporting periods and to correspond with 2008-2017 annual harvests, the 10-year average of the cumulative HWP C stock for the years 2009-2018 is reported for the BOF 2017 reporting period (HWP-use, HWP-SWDS pools). Similarly, stock change results can be calculated from one year to the next, but in order to match the FIA plot remeasurement cycle to report change in the forest ecosystem, the average annual HWP C stock change (HWP-use, HWP-SWDS pools) for the seven ten-year intervals of 2002-2012, 2003-2013, 2004-2014, 2005-2015, 2006-2016, 2007-2017, and 2008-2018 is reported for the BOF 2017 reporting period.

The CARB NWL Inventory does not explicitly track HWP in-use nor the final fates of California forest-origin HWP. Carbon stocks, stock-change and GHG emissions associated with landfilled wood products of all origins are tracked in the waste sector of CARB's GHG inventory. Including landfilled wood products of all origins is a feature of the IPCC atmospheric flow approach. In the CARB NWL Inventory, harvested carbon is determined using LANDFIRE disturbance layers and converted back to harvest volumes as described in the previous section. CARB staff use storage factors[77] to estimate the amount of carbon persisting in solid form (as wood products in-use and as discards in landfills) generated from harvest associated with the reporting period. The estimation for persistent carbon takes into account harvest fractions (logs versus other components), wood density and mill efficiency. In turn, the carbon estimated to persist in solid form to the end of the analysis period (assumed to be in the form of long use-life products such as dimensional lumber and panels) is applied to the AGL gross stock change attributed to harvests, to estimate a net AGL stock change associated with harvests, and is reported in the CARB NWL Inventory (IPCC category 3D1) as an informational item. During the analysis period, the difference between harvested carbon and carbon that persists in solid form for products in-use represents the portion of AGL carbon transferred to the atmosphere associated with wood products.

Approach and Results Comparisons

HWP C Stocks and Stock Change

For the BOF 2017 reporting period[78], the average HWP C stock is approximately 78.3 MMT C for products in use (HWP-use), 55.0 MMT C for products in SWDS (HWP-SWDS), and approximately 133.4 MMT C for both HWP pools. This stock represents approximately 4% of the total forest carbon storage associated with the California forest sector.

For the 2017 BOF reporting period, the average change in HWP carbon stocks is approximately -0.30 MMT C for products in use, 0.56 MMT C for products in SWDS, and 0.26 MMT C for both pools

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[77] from Stewart and Nakamura (2012)

[78] Christensen et al. 2019

combined. From the forest ecosystem portion of the inventory, net change in carbon stocks in forest land remaining forestland excluding non-CO_2 emissions from fires is approximately 7.96 MMT C. The change in HWP C pools represents 3.1% of the total change in carbon stocks associated with forest land remaining forest land.

HWP C emissions data for HWP burned with and without energy capture are generally not explicitly reported because they are implicitly accounted for in forest sector carbon stock and change accounting. Such emissions may be reported in other sectors (i.e., waste, energy). Cumulative emissions associated with these pools (HWP-energy, HWP-without energy) are provided in the BOF report for informational purposes only and may prove useful to the statewide NWL or waste sector inventories.

In the CARB NWL Inventory, stock changes for analysis periods are reported in paired tables. For each analysis period, the first ("long form") table reports stock changes by land and land cover change categories, without attribution by change agent[79]. The reported stock changes represent the sums of gains and losses on the land, and do not include estimates for quantities of carbon coursing through the wood products system. The second table reports the subset of stock changes that are attributed to biomass burning and to timber harvesting[80]. For informational purposes, the second table includes an estimate of the amount of carbon that was harvested during the analysis period that persists in solid form as wood product; carbon stocks and emissions associated with discarded wood products are tracked in the waste sector of CARB's statewide GHG inventory[81]. When the persistent fraction is applied to the land "gross" stock change attributed to timber harvests, the difference represents the amount of carbon transferred to the atmosphere that is associated with wood products that were generated and consumed in the analysis period. For harvests associated with 2001-2010, carbon persisting as wood product evaluates to approximately 7.6 MMT. For 2010-2012 it is approximately 1.04 MMT C, and for 2012-2014 it is approximately 1.35 MMT C[82].

It is difficult to compare the BOF HWP C stocks and stock change to the NWL estimates for several reasons. A major difference in the two approaches is that in the BOF Inventory, harvest volumes are allocated to timber product classes and primary products and then primary product volumes are converted to metric tons of carbon that various use, discard and half-life ratios are applied to over time. In the CARB NWL Inventory, harvested carbon is determined directly from LANDFIRE-C disturbance layers and storage factors are applied to the harvested carbon values; volumes are back-calculated from harvested carbon but are not necessary for the carbon calculations. The process of allocating harvested carbon to one category of solid wood products is described in further detail below. Additionally, the BOF Inventory includes cumulative results for carbon stored in wood products in-use and in solid waste disposal sites from harvests going back to 1952. The CARB NWL Inventory only considers carbon stored in wood products in-use and in SWDS from harvests associated with the analysis period only, and only for informational purposes. According to the system boundaries of the IPCC Atmospheric Flow Approach used in the CARB NWL Inventory, CO_2 emissions associated with decaying wood products (of all origins) at solid waste disposal sites are considered an emission from the forest sector. Additionally, the BOF

[79] Tables 3a and 4a in CARB (2018b)
[80] Tables 6a and second 5b in CARB (2018b); tables 11-13 in CARB (2018a)
[81] CARB (2022)
[82] CARB (2018a), carbon fraction of biomass = 0.47

approach considers stock change among the HWP pools separately from stock change in forest ecosystem pools. The emission from harvested carbon from cutting trees in forests and that do not become wood product is inherent in the resulting forest carbon stock, harvested wood product carbon stock and associated stock changes between time periods. In the CARB NWL Inventory, this emission is explicitly accounted for as a forest emission associated with harvest. In this way, the HWP C "stock-change" in the BOF Inventory is the change in the amount of carbon stored in wood products in use and at solid waste disposal sites. The HWP C "stock-change" in the CARB NWL Inventory is the difference between the gross change in the aboveground live tree pool associated with harvesting, and the amount of harvested carbon contained in harvested wood products in-use and in SWDS during the analysis period.

In the CARB NWL approach, table 18 displays carbon fractions contained in wood products in-use and in landfills over time, expressed as percentages of initial wood product carbon stock, adapted from the UC Berkeley Carbon Sequestration Tool for THPs[83]. The table also displays carbon persisting in solid form as percentages of initial harvested carbon (i.e. before milling), based on a factor for sawmill efficiency. These factors are applied to a given quantity of AGL tree carbon removed from the landscape (as determined by the LANDFIRE-C approach described above for calculating removals) to track carbon allocation to solid wood products over time for each LANDFIRE-C harvest cohort, estimate the amount of carbon persisting in solid form by the end of the analysis period, and estimate the net forest stock change associated with harvests during the 2001 - 2010 period. Since LANDFIRE-C attributes AGL stock changes to harvest by analysis period rather than individual year, an average persistence factor is used. Using an average persistence factor of 73.49 percent for the analysis period and adjusting to a carbon biomass fraction of 0.5, of the 11,022,395 MTC of harvested carbon, the amount of carbon persisting in solid wood product form by 2010 evaluates to 8,100,631 MTC for a net forest stock-change associated with harvests equal to -2,921,764 MTC (Table 21).

[83] Stewart and Nakamura (2012)

Table 18. NWL Wood product carbon allocation.

Year	Percent of initial wood product carbon		Percent of initial harvested carbon persisting in solid form[a]
	In-use	In landfills	
0	100	0.00	76
1	98.47	0.77	75.42
2	96.97	1.52	74.85
3	95.48	2.26	74.29
4	94.02	2.99	73.73
5	92.59	3.71	73.19
6	91.17	4.42	72.65
7	89.78	5.12	72.12
8	88.41	5.80	71.60
9	87.06	6.48	71.09
10	85.72	7.14	70.58
		Average persistence factor:	**73.49**

[a] Equal to [(in-use) + (in landfill)] x (1 – 0.24), where sawmill energy, product and waste ratios are 0.24, 0.75 and 0.01 (UC Berkeley 2012). Displayed percentages are truncated.

The amount of carbon that persists in solid wood form for the 2001-2010 time-period in the BOF report[84], the amount of carbon stored in HWP C pools (132,385,466 MTC at the end of the 10-year period, table 19) is significantly higher than that in the NWL analysis because it includes all the carbon from wood products generated by harvests going back to 1952.

[84] Christensen et al. 2019, excerpted from Table 6.2

Table 19. BOF HWP C inventory 2001-2010 (includes cumulative totals from harvests dating back to 1952).

Inventory year[1]	Products in use (metric ton C)	SWDS (metric ton C)	TOTAL remaining in HWP Pool (metric ton C)
2002	81,275,533	48,542,699	**129,818,232**
2003	81,076,267	49,141,885	130,218,152
2004	80,901,596	49,744,851	130,646,447
2005	80,837,280	50,312,157	131,149,437
2006	80,827,860	50,875,753	131,703,613
2007	80,750,592	51,440,696	132,191,288
2008	80,529,571	52,004,397	132,533,968
2009	80,110,589	52,563,202	132,673,791
2010	79,245,849	53,114,937	132,360,786
2011	78,743,395	53,642,072	**132,385,466**
HWP Pool stock change associated with harvests 2001-2010			**2,567,234**

[1] HWP C inventory years from the model are output for the year following the harvest year, i.e., 2001 harvested carbon shows up in inventory year 2002.

To get a better sense of the comparison to the NWL approach in this review, the BOF harvest volume for the corresponding time period[85] can be run through the HWP C model without including historic harvests. When this occurs, approximately 58% of the harvested carbon in 2001 (2,729,861 MTC) enters the harvested wood products in-use pool (1,581,604 MTC). As additional harvest years from this time-period adds carbon to the products in-use pool and some carbon associated with previous harvest years shifts to the solid waste disposal site pool, is burned, or decays, approximately 53% of the harvested carbon (27,618,540 MTC) remains in storage in products in-use or at solid waste disposal sites (14,581,136 MTC) at the end of the 10-year period compared to 74% in the CARB NWL Inventory. Table 20 below shows the disposition of harvested carbon for the 2001-2010 period from the HWP C model used in the BOF Inventory (excluding historic harvests).

[85] Christensen et al. 2019, harvest volumes for 2001-2010 from Table 6.1.

Table 20. Cumulative disposition of California HWP C for 2001-2010 (excluding historic harvests) using the IPCC Production Approach. This table shows the fate of all carbon removed from the ecosystem by harvesting.

YEAR	FIA Harvest Volumes (MBF)	Timber product output (metric ton C)[1]	CUMULATIVE C Products in use (metric ton C)	CUMULATIVE C Products in SWDS (metric ton C)	CUMULATIVE TOTAL C remaining in HWP Pools (IN-USE + SWDS) (metric ton C)[1]	CUMULATIVE C Emitted with energy capture (metric ton C)	CUMULATIVE C Emitted without energy capture (metric ton C)	CUMULATIVE TOTAL C Emitted With and Without Energy Capture (metric ton C)[1]
2001	1,751,800	2,729,861	1,581,604	0	1,581,604	1,010,727	30,257	1,040,984
2002	1,838,753	2,927,226	3,239,252	94,283	3,333,534	2,094,586	74,759	2,169,345
2003	600	2,885,759	4,825,591	229,444	5,055,035	3,163,095	135,841	3,298,936
2004	1,875,287	2,985,609	6,425,397	394,007	6,819,404	4,268,489	212,605	4,481,094
2005	1,889,454	3,008,052	7,992,672	591,905	8,584,577	5,382,233	304,840	5,687,074
2006	1,774,600	2,825,202	9,411,055	821,030	10,232,085	6,428,277	409,914	6,838,191
2007	1,776,300	3,317,489	10,611,919	1,072,135	11,684,054	8,159,912	525,425	8,685,337
2008	1,497,513	2,796,902	11,546,526	1,337,902	12,884,428	9,619,771	649,447	10,269,217
2009	915,095	1,709,183	11,972,461	1,613,234	13,585,695	10,511,856	775,201	11,287,056
2010	1,302,764	2,433,257	**12,702,871**	**1,878,265**	**14,581,136**	**11,781,862**	**912,923**	**12,694,785**
Total[1]	**16,434,279**	**27,618,540**						

[1] The sum of the HWP C storage pools and emitted pools do not currently add up to the sum of the harvested C due to time lags in SWDS emissions. In later versions of the model these time lags have been removed to better facilitate quality control/quality assurance of calculations.

The harvest volume for the 2001-2010 period of analysis in the BOF Inventory (16,434 mmbf, Table 16) is approximately 1.3 times greater than the harvest volume calculated from LANDFIRE-C removals in the CARB NWL Inventory (12,445 mmbf, Table 16). There is also approximately 2.5 times more harvested carbon in the BOF Inventory (27.6 MMT C, table 21) compared to the CARB NWL Inventory (11.0 MMT C, Table 21), and approximately 1.8 times the amount of carbon persisting in harvested wood product pools at the end of the ten-year period of analysis in the BOF Inventory (14.6 MMT C, Table 21) compared to the CARB NWL Inventory (8.1 MMT C, Table 21) despite a higher percentage of initial harvested carbon persisting at the end of the analysis period in the CARB NWL Inventory (74%) than in the BOF Inventory (53%). However, the BOF Inventory shows a 4.5 times greater net carbon loss to the atmosphere (-13.0 MMT C, table 21) compared to the CARB NWL Inventory (-2.9 MMT C, table 21). Of the harvested carbon that is transferred from the forest to the atmosphere in the BOF Inventory, approximately 93% was burned with energy capture and may represent some level of fossil fuel substitution. It should also be noted that more recent iterations of HWP C accounting in the BOF Inventory have removed lag times in when carbon was allocated to certain pools and decay was applied to improve the ability to complete quality control and quality assurance checks on the data. Consequently, current analyses may differ slightly from the results presented here.

Another important difference is that in the BOF Inventory, the number that would be reported for harvested wood product carbon “stock change” would be the difference between the cumulative harvested wood product carbon storage contributed by each harvest vintage year between 2001 and 2010 – i.e., the difference between 14,581,136 MT C stored in harvested wood products in 2010 and 1,581,604 MT C in 2001, which is 12,999,532 MT C (Table 20). This means that the harvested wood products in-use and at solid waste disposal site pools increased by 12,999,532 MTC in these ten years. The CARB NWL Inventory only addresses the net forest carbon stock change associated with harvests that is not transferred to HWP C pools or does not persist in HWP C pools, rather than explicitly providing an inventory for HWP C pools. In the BOF Inventory, the carbon loss to the atmosphere as a result of harvest that is not transferred to or is lost from the HWP C pools over time is inherent in the forest ecosystem and HWP C net stock change estimates.

Table 21. Net stock-change of harvests for NWL LANDFIRE-C and BOF, 2001-2010 (MTC).

Description	LANDFIRE-C (MTC)[a]	BOF (MTC)
Carbon removed via harvest, 2001-2010	11,022,395	27,618,540[b]
Carbon persisting in solid form at period end	8,100,631	14,581,136
Net forest stock-change associated with harvest	-2,921,764	-13,037,404

[a] Adjusted to carbon fraction of biomass = 0.5
[b] this number is slightly different from the sum total for 2001-2010 in table 6.1 in Christensen et al. (2019) due to an error in the report for the harvested carbon in 2001.

Opportunities to incorporate data from the BOF HWP C inventory to the CARB NWL Inventory are being explored.

Summary

Carbon stocks

The following carbon stock comparisons are depicted in table 22 and figure 2. The latest NWL inventory published in December 2018[86] covering the 2012-2014 time-period reports a forest carbon stock of 4.5 billion metric tons carbon (MT C) (including tree- and shrub-dominated lands, SOC). The NWL forest carbon stock is 4.8 billion MT C after adjusting to a carbon fraction of biomass equal to 0.5 (from 0.47) to better compare with BOF results. This total forest carbon stock is higher compared to the 2017 reporting period for the BOF Inventory[87] of 3.3 billion MT C (including tree-dominated lands, SOC). However, of the 4.8 billion MT C reported by NWL, approximately 2.1 billion MT C were described for tree-dominated lands only (excluding SOC and live roots). The BOF Inventory reports 1.4 billion MT C for tree-dominated lands (excluding SOC and live roots). In general, CARB's NWL LANDFIRE-C based estimate for statewide above-ground live and standing dead tree carbon stocks are lower than the estimates based on FIA data reported under the BOF Inventory. NWL LANDFIRE-C estimates for down dead tree and litter are higher than the BOF estimates. Overall, while NWL estimates for AGL tree C are approximately 16% lower than BOF estimates, NWL estimates for total carbon for tree-dominated lands is approximately 33% higher.

There are several pools that cannot be directly compared. For example, BOF reporting currently includes estimates for soil organic carbon but CARB quantifies SOC separately outside of the LANDFIRE-C tool and estimates are not available for tree-dominated lands only. NWL SOC estimates for shrub and tree-dominated lands are approximately 21% greater than BOF SOC estimates for tree-dominated lands. Live tree and shrub roots are lumped into the total biomass estimate from LANDFIRE-C and also cannot be disaggregated from dead pools on shrub-dominated lands for this analysis, hence excluding them from tree-dominated land totals for comparison. LANDFIRE-C also lumps understory vegetation into aboveground live tree estimates on tree-dominated land, so it cannot be compared to understory vegetation estimates from the BOF Inventory. Lastly, LANDFIRE-C provides an estimate for understory vegetation on shrub-dominated lands, but there is no estimate for this pool from the BOF Inventory because those lands are excluded from analysis. Nevertheless, values for these pools are provided in table 22 and figure 2 below.

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[86] CARB (2018a)

[87] Christensen et al. 2019

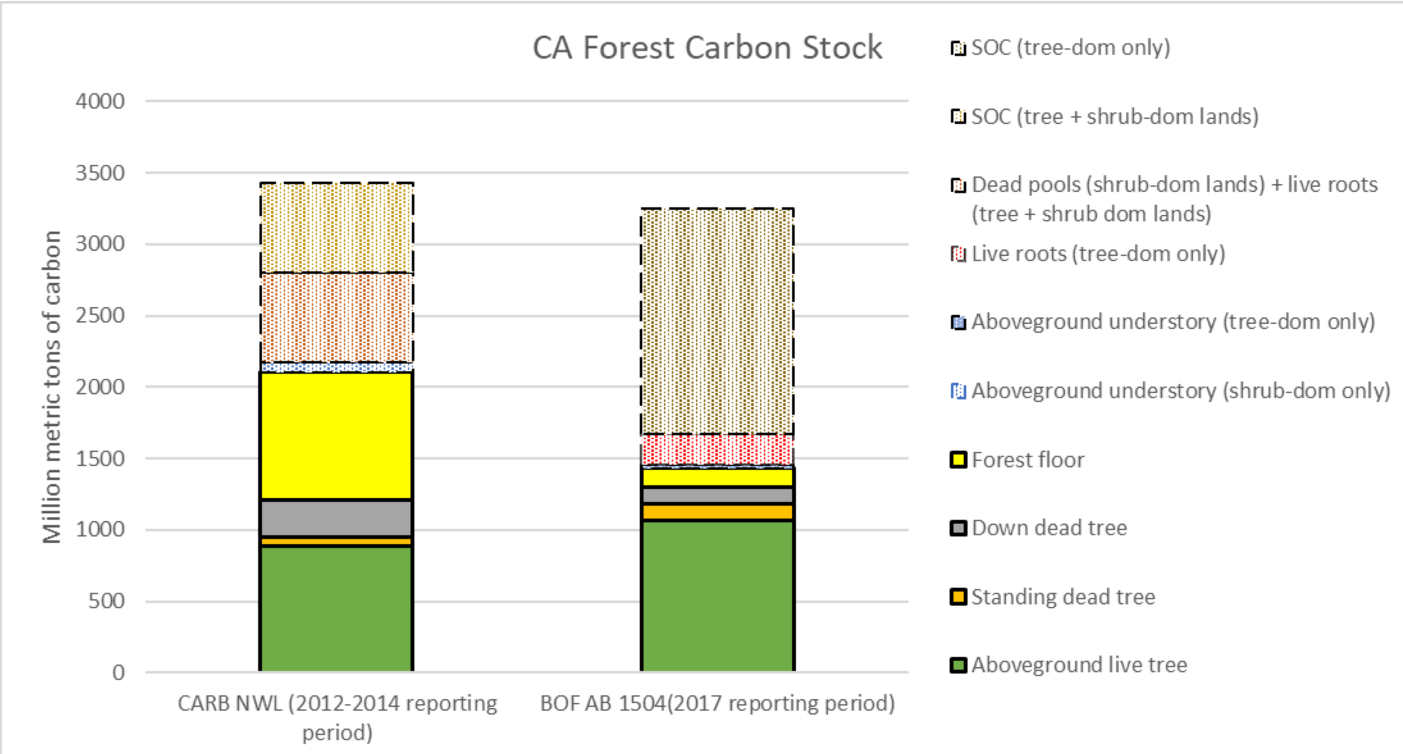
Table 22. Summary of BOF and NWL forest carbon stocks by pool. Where possible, pools for tree-dominated and shrub-dominated lands have been separated in the CARB NWL Inventory.

	Carbon stocks, Million Metric Tons Carbon (MMT C)			
	NWL[1] (2012-2014)			**BOF** (2017 reporting period)
Pools that can be compared:	**Tree + shrub**	**Shrub only**	**Tree only**	**Tree only**
Aboveground live tree		n/a	883	1,064[2]
Standing dead tree + roots		n/a	62	116
Down dead tree		n/a	263	115
Forest floor (i.e., litter)		n/a	894	135
Aboveground understory		70	Included in AGL tree pool	30
Total		**70**	**2102**	**1460**
Pools that cannot be directly compared:				
Live tree/understory roots	Unable to disaggregate from dead pools on shrub-dominated lands	Unable to disaggregate from live roots on tree-dominated lands and dead pools on shrub-dominated lands	Unable to disaggregate from live roots and dead pools on shrub-dominated lands	210
Dead pools (*shrub-dom lands)* + live roots (*tree/shrub dom lands*)	630	n/a	n/a	n/a
Soil Organic Carbon	2,009	Unable to disaggregate from tree-dominated lands	Unable to disaggregate from shrub-dominated lands	1,579
Total	**2,639**	**70**	**n/a**	**210**
	4,811 all pools			**3,256 all pools**

[1] adjusted to carbon fraction of biomass = 0.5 rather than 0.47 in CARB NWL Inventory reports

[2] 2014 reporting period value for comparison is 1,055

Figure 2: Comparison of CARB's NWL and the BOF's BOF carbon stocks by pool. Pools that are more directly comparable are shown with dark black outline whereas pools that are not directly comparable are shown with a dashed outline.



Net change in carbon stocks

Table 23 below displays the following comparisons. The CARB NWL Inventory demonstrates differences in net carbon accumulation or loss depending on the time-period of analysis and whether tree-dominated lands are evaluated separately from shrub-dominated lands. For the most recent CARB NWL Inventory time period of 2012-2014 time period, there is a lower amount of net forest carbon accumulation each year for live and dead forest pools (1.82 MMT C/yr, excluding SOC; adjusted value of 1.93 MMT C/yr) compared to the BOF Inventory for the 2017 reporting period[88] (8.0 MMT C/yr for just forest ecosystem pools excluding SOC and forest floor). The CARB NWL Inventory reports positive net change due to forest conversions of approximately 5.99 MMT C/yr, adjusted values of 6.37 MMT C/yr. The BOF Inventory reports a net loss of -0.5 ± 0.3 MMT C/yr due to forest land-use conversions. In the CARB NWL Inventory, net change for Forest Land Remaining Forest Land combined with net change due to forest conversions is approximately 7.8 MMT C/yr, with the adjusted value of 8.3 MMT C/yr, compared to 7.6 MMT C/yr in the BOF Inventory. This value is approximately 10% lower than net change in forests in the CARB NWL Inventory[89], which also includes 30+ million acres of shrub-dominated lands.

[88] Christensen et al. 2019

[89] Compared to the value adjusted to carbon fraction of biomass = 0.5

Due to different analysis periods and inventory components, comparing estimated changes in statewide above-ground live tree carbon stocks between the two approaches must be treated carefully. In general the CARB NWL Inventory attributes greater losses of carbon in disturbed areas, and fewer gains of carbon in undisturbed areas, than the analysis in the BOF report. Differences in how each inventory address forest land conversions (land-use change vs. land cover change) results in the BOF Inventory reporting much lower amounts of change in AGL pools due to forest land conversion (-0.27 MMT C/yr) compared to the CARB NWL Inventory (-1.46 to -4.88 MMT C/yr). Additionally, since the NWL definition of forests includes shrub-dominated lands, changes in these lands contributes to the amount of carbon considered lost due to forest conversions. For example, if there are great disturbances to shrub-dominated lands, such as from wildfire, higher emissions for forests would be reported in the CARB NWL Inventory than in the BOF Inventory, which does not consider shrub-dominated lands at all. When comparing changes in the AGL pool for tree-dominated lands only due to forest land conversions, the differences are less pronounced. Comparing the most recent CARB NWL Inventory (2012-2014) there is a loss of -0.93 MMT C/yr in the AGL pool compared to a loss of -0.27 MMT C/yr in the BOF Inventory due to forest land conversions. Generally, carbon losses from fire are much higher in the CARB NWL Inventory compared to the BOF Inventory. Lastly, forest land carbon stock changes associated with timber harvest activities appear better captured in BOF reporting compared to the LANDFIRE-C approach, which relies on remote sensing detection of pronounced changes in forest structure.

Table 23. Summary of BOF and NWL net forest carbon stock changes.

Carbon stock-change	NWL (LANDFIRE-C)[1] Tree + shrub-dom lands, Live + Dead pools (no SOC) (MMT C/yr)			BOF (FIA) Tree-dom lands only, Live + Dead pools (no SOC, forest floor) (MMT C/yr)
	2001-2010	2010-2012	2012-2014	2017
Net forest C accumulation, forest land remaining forest land	-1.98	+7.9	+1.93	+8.0
Net change forest land conversions	-16.5	-9.53	+6.37	-0.45
Total: Net change forest land remaining forest land + forest land conversions	-18.48	-1.63	+8.3	+7.55
	Tree + shrub-dom lands, AGL only			
AGL net change, forest land remaining forest land	+2.06	+6.13	+2.64	see below
AGL net change due to forest land conversions	-4.88	-2.67	-1.46	
Total: AGL Net change forest land remaining forest land + forest land conversions	-2.82	+3.46	+1.18	
	Tree-dom lands, AGL only			Tree-dom lands, AGL only
AGL net change, forest land remaining forest land	+2.43	+4.62	+2.64	+4.96
AGL net change due to forest land conversions	-2.9	-2.25	-0.93	-0.27
Total: AGL Net change forest land remaining forest land + forest land conversions	-0.47	+2.37	1.71	4.69

[1] adjusted to carbon fraction of biomass = 0.5 rather than 0.47 in CARB NWL Inventory reports

Harvested wood product carbon

Table 24 below summarizes the following comparisons. For the 2017 reporting period, the 1504 inventory reports net changes in the harvested wood product pools of 0.2 MMT C/yr. The CARB NWL Inventory tracks carbon persisting in solid wood products during the analysis period only, for informational purposes only (0.68 MMT C/yr). There are several differences in the methods to attribute harvested to carbon stored in wood products, making it very difficult to compare the estimates. Special analysis in this report show that, despite a greater harvest volume for the 2001-2010 period of analysis in the BOF Inventory (16,434 mmbf) compared to the CARB NWL Inventory (12,445 mmbf), approximately 2.5 times more harvested carbon is reported in the BOF Inventory (27.6 MMT C) compared to the CARB NWL Inventory (11.0 MMT C), and approximately 1.8 times the amount of carbon persisting in harvested wood product pools at the end of the ten year period of analysis in the BOF Inventory (14.6 MMT C) compared to the CARB NWL Inventory (8.1 MMT C). The BOF Inventory shows a 4.5 times greater amount of harvested carbon loss to the atmosphere (13.0 MMT C) compared to the CARB NWL Inventory (2.9 MMT C). However, of the harvested carbon that is transferred from the forest to the atmosphere in the BOF Inventory, approximately 93% was burned with energy capture and may represent some level of fossil fuel substitution.

Table 24. Summary of HWP C comparison for the BOF and CARB NWL inventories.

	HWP C Comparison, 2001-2010	
	NWL[1]	**BOF[2]**
Harvest volume (mmbf)	12,445	16,434
Harvested carbon (MMT C)	11.0	27.6
C persisting in solid wood products at end of 2001-2010 period (MMT C)	8.1	14.6
Net loss to atmosphere from harvested C not stored in HWP (MMT C)	-2.9	-13.0[3]

[1] adjusted to carbon fraction of biomass = 0.5 rather than 0.47 in CARB NWL Inventory reports
[2] HWP C analysis in the BOF Inventory includes cumulative amounts of carbon stored in wood products as a result of historic through current harvests. Harvest from only 2001-2010 time period analyzed separately for this comparison.
[9] 93% of the net loss is burned for energy and may represent some level of fossil fuel substitution

Conclusions

FIA and LANDFIRE-C statewide estimates for above-ground live (AGL) tree-dominated forest carbon stocks are comparable in the BOF and the CARB NWL inventories, with NWL LANDFIRE-C generally lower than estimates reported by FIA in the BOF Inventory: an expected result given uncertainties in mapping land cover and forest structure, differing data vintages, definitions for forest, approaches to up-scaling estimates to statewide, and sensitivity to disturbance. LANDFIRE-C estimates of forest carbon contained in standing dead tree pools are lower than FIA estimates in the BOF Inventory, whereas LANDFIRE-C estimates for down dead tree and litter pools are higher than the BOF estimates. Total forest carbon stock in tree-dominated lands in the CARB NWL Inventory are higher than total forest carbon stock in the BOF Inventory. The expanding amount of FIA data available in 2020 is greater than it was during LANDFIRE-C's development, affording opportunity for updating reference biomass densities for forest land AGL and other live (including tree foliage) and dead pools, for updating modeled growth in LANDFIRE-C, and for representing emerging dead pool dynamics. Remote sensing advances (e.g. LiDAR) offer options for improving biomass estimates that are dependent on key structural variables, such as forest canopy height.

Estimates for statewide annual average forest land AGL tree stock-change variously differ between LANDFIRE-C and FIA, depending on the period of interest and contributions from wildfire. The timing and scale of disturbances present challenges but are key to estimating changes in forest carbon over large areas[90]. Some low-intensity disturbances may register more easily in the field than with remote sensing, while potentially large-area disturbances may occur outside of ground networks. In turn, stock-change with attribution is highly dependent on assumed pathways taken by disturbed carbon.

Several differences exist in how the BOF and NWL inventories address harvested carbon, from how removals are determined, how they are related to timber volumes, how they are allocated to harvested wood product pools, and how those pools are treated within the inventories themselves. While the chosen inventory methods of the IPCC Production Approach in the BOF Inventory and the Atmospheric Flow Approach in the CARB NWL Inventory have inherent methodological differences, opportunities may exist to share data between inventories to improve harvested wood product carbon accounting.

Through on-going inter-agency collaboration on sources and methods, FIA-based BOF reporting and CARB NWL Inventory serve as complementary efforts to statewide monitoring and reporting forest land carbon.

[90] Fisher et al. 2008, Harris et al. 2016

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