AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2019 Reporting Period

DATA UPDATE

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Acronym List

AB – Assembly Bill

AGL – aboveground live

Board; BOF – California Board of Forestry and Fire Protection

BF – board feet

BLM – Bureau of Land Management

C – carbon

CAL FIRE – California Department of Forestry and Fire Protection

CF – cubic feet

CH_4 - methane

CI – confidence interval

CO - carbon monoxide

CO_2e – carbon dioxide equivalent

DBH – diameter at breast height

FF – Forest Land Remaining Forest (IPCC terminology)

FIA – Forest Inventory and Analysis

FIADB – FIA database

FMRL – Forest Management Reference Level

FS – Forest Service

GHG – greenhouse gas

GRM – Growth, Removals and Mortality

HWP – harvested wood product

HWP-use – harvested wood products in use

HWP-SWDS – harvested wood products at a solid waste disposal site

HWP-energy – harvested wood products burned for energy production

HWP-without energy – harvested wood products decayed or burned without energy production

IPCC – Intergovernmental Panel on Climate Change

LF – Forest Land Conversions (IPCC terminology)

MBF – thousand board feet

MMBF – million board feet

MMT – million metric tons

MT – metric tons

NFS – National Forest System

N_2O – nitrous oxide

NO_x - nitrogen oxides

PNW – Pacific Northwest Research Station

SOC – soil organic carbon

SWDS – solid waste disposal site

TBD – to be determined

TPO – Timber Products Output

U-MT BBER - University of Montana’s Bureau of Business and Economic Research

USDA – United States Department of Agriculture

USFS – United States Forest Service

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1 Executive summary and key findings

The state of California has enacted a variety of legislation establishing greenhouse gas (GHG) emissions reduction targets. Currently, the state has a net carbon sequestration target for the forest sector of 5 million metric tons (MMT) of carbon dioxide equivalent (CO_2e) annually until 2020, establishing a critical role for California's forests in meeting the state's targets. This data update was provided to inform several elements of the state's effort to meet GHG emissions reduction targets by compiling best-available data on GHG emissions, stock and flux from California's forest sector, identifying critical gaps in data, and suggesting strategies to reduce uncertainty in estimating the magnitude of stocks and flux within the forest sector.

This is the fifth release in a series of annual Assembly Bill (AB) 1504 Forest Ecosystem and Harvested Wood Product (HWP) Carbon Inventory reports to the California Board of Forestry and Fire Protection (also referred to as the Board). This report includes 90% remeasurement of all FIA plots in California. Values for 2019 include changes to the FIA post-stratification process to not only reduce overall sampling error, but also to reduce the potential for bias introduced by non-sampled plots. Based on the 2019 CA AB 1504 reporting period, California's forests remain net sinks, sequestering 25.2 MMT CO_2e per year. This value includes changes in forest ecosystem pools (26.0 MMT CO_2e per year), harvested wood product pools (0.8 MMT CO_2e per year), non-CO_2 emissions from wildfires (-0.6 MMT CO_2e per year), and forest land conversions (-1.0 MMT CO_2e per year).

In order to compare 2019 results to the previous reporting period, the 2018 reporting period had to be re-calculated using the new post-stratification process. Under the old process, the net sequestration rate for the 2018 reporting period was 24.9 MMT CO_2e per year. However, after the recalculation, the value was 26.2 which includes changes in forest ecosystem pools (27.5 MMT CO_2e per year previously calculated as 26.2), harvested wood product pools (0.7 MMT CO_2e per year), non-CO_2 emissions from wildfires (-0.6 MMT CO_2e per year), and forest land conversions (-1.5 MMT CO_2e per year). Net annual forest carbon sequestration in 2019 is down 1.0 MMT CO_2e when compared to the recalculated 2018 reporting period.

The 2019 reporting period annual rate of carbon sequestration for just the forest ecosystem pools is 26.0 MMT CO_2e per year. This value is down by approximately 1.5 MMT CO_2e per year from the re-calculated 2018 reporting period. This reduction in annual carbon sequestration is the result of several factors including improvements in inventory methodology but is also being driven by two complementary factors; a continued increased rate of tree mortality and decreased gross growth rate on live trees. Tree mortality regardless of cause, accounted for an additional 1.1 MMT of CO_2e converted to dead wood annually. Gross growth on trees measured 10-years earlier declined by 0.3 MMT CO_2e annually further reducing the net rate of sequestration. Of note, net change in the live tree pool on National Forest System lands decreased from +914 MMT CO_2e annually in 2018 to -692 MMT CO_2e annually in 2019, although the confidence intervals for these values include zero, making the change not statistically significant. Net change in the standing dead pool increased from +6,248 MMT CO_2e annually in 2018 to +6,926 MMT CO_2e annually in 2019. Changes in growth, removals, mortality and flux vary in each region, displaying different patterns amongst each category. Additional work is being completed to assess these differences in more detail.

The annual rate of forestland conversion (in acres) increases by approximately 18% from the 2018 reporting period due to an increase in forestland converting to grassland, overriding developed uses as the main land-use change. Although there is an increased shift to grassland, changes in carbon stocks due to forestland conversion do not change much from the previous reporting period as many of the areas classified in this reporting period as a conversion to grassland already had low tree stocking levels.

Forest ecosystem and harvested wood product carbon stocks are approximately 3.2 billion metric tons. For just the forest ecosystem, carbon stocks are approximately 3.1 billion metric tons. This is an increase of 1.7 million metric tons of forest ecosystem carbon compared to the re-calculated 2018 reporting period, representing an increase in line with previous results. Harvested wood products contribute an additional 135.2 MMT C to the forest ecosystem carbon stocks from current and historic harvests going back to 1952, representing about 4% of the total stock.

In many forest types, current stocking levels reflect over a century of fire suppression and may not represent stand densities that are resilient to disturbances common to California forests such as fire or pest outbreaks. Additionally, as the forests age in unharvested stands, growth rates slow. Older forests tend to store more carbon, but they might not accumulate new carbon as quickly as younger, fast-growing stands. Consequently, the stocks and flux represented in this report may not be sustainable into the future without forest management given the uncertainty in potential effects from climate change, the current level of forest disturbances from wildfire and pests, and aging of forests on federal lands. Compared to previous reporting periods, we continue to see drought effects on tree growth and mortality. Forests provide many other services beyond carbon sequestration and storage, so there are many other considerations beyond forest carbon dynamics when developing management actions.

This update includes changes to the FIA post-stratification process to not only reduce overall sampling error, but also to reduce the potential for bias introduced by non-sampled plots. This update also includes revisions to correct previous harvested wood product carbon stock Monte Carlo Analysis. Changes are described below under Section 2 - Improvements and methodological updates.

Key Findings:

FOREST ECOSYSTEM CARBON

Forest land area:

- As of 2019 there are approximately 31.6 million acres of forest land across all ownerships.
- 16.3 million acres are classified as timberland with an additional 4.1 million acres of productive forest land in reserves.
- The federal government manages 57% of California's forest lands, with the remaining areas under state and local government (3%) or private management (39%) (Figure 2.4).
- Overall there was a net loss of forest land at the rate of 30.5 ± 9.2 thousand acres per year. This represents an 18% increase in the rate of forestland conversion from the 2018 reporting period due to an increase in forestland converting to grassland, overriding developed uses as the main land-use change (Table 4.8/E1). Although there is an increased shift to grassland, changes in carbon stocks due to forestland conversion do not change much from the previous reporting period as many of the areas classified in this reporting period as a conversion to grassland already had low tree stocking levels. The confidence interval is high compared to the estimate because it is a relatively rare event at the scale of the inventory.
- Most of the forest land loss occurred on non-productive "other forest" (61%), followed by timberland (36%), with little change occurring on reserved lands (3%).
- Western oak woodlands cover the greatest area of all forest types at approximately 9.1 ± 0.35 million acres, followed by California mixed conifer at approximately 7.7 ± 0.32 million acres (Table 4.11; Appendix 2, Table A17). Western oak woodland estimates were improved by the updates to the post-stratification process to reduce the bias associated with denied access in hardwood and woodland areas, as described in section 2 – "Improvements and Methodological Updates."

Average net annual forest carbon dioxide sequestration - overview:

- Overall California forests are exceeding the 5 MMT CO2e target rate of annual sequestration established by AB 1504, sequestering 26.8 ± 4.2 MMT CO_2e per year (excludes confidence interval for HWP C net change; Table 7.1). This value includes changes in forest ecosystem pools (26.0 MMT CO_2e per year), harvested wood product pools (0.8 MMT CO_2e per year), non-CO_2 emissions from wildfires (-0.6 MMT CO_2e per year), and forest land conversions (-1.0 MMT CO_2e per year).
- Based on plots initially measured between 2001-2009 and re-measured between 2011-2019, the average statewide rate of forest carbon sequestration is 26.0 ± 4.1 MMT CO_2e

per year, excluding net CO_2e contributions from other sources such as, harvested wood products, forest land conversions and non-CO_2 GHG emissions from wildfire (Table 4.1, 4.3).

- Net change in the soil organic carbon pool is estimated at -0.3 ± 0.6 MMT CO_2e per year (Table 4.1-4.3).
- Combined annual net emissions of non-CO_2 GHGs (methane and nitrous oxide) from wildfire is estimated to be 0.6 ± 0.1 MMT CO_2e per year (Table 4.2a, 4.7).
- Changes in land-use between forest and non-forest land condition is estimated to have a net effect of emitting 1.0 ± 0.8 MMT CO_2e per year (Table 4.2a, 4.9).
- Based on the 2019 measurement period, after accounting for these other CO_2 and greenhouse gas sources the statewide rate of carbon sequestration on all forest land is 24.5 ± 4.0 MMT CO_2e per year (Table 4.2a), down from the 2018 re-calculated reporting period estimate of 26.4 ± 4.3 MMT CO_2e. This value cannot be directly compared to previous report values from the 2015 reporting period (32.8 ± 5.5 MMT CO_2e per year), the 2016 reporting period (30.7 ± 5.3 MMT CO_2e per year), or the 2017 reporting period (27.0 ± 5.5 MMT CO_2e per year) due to improved methods over time and the re-stratification that occurred in 2019. However, data suggest that the net annual sequestration rate is decreasing over time. This value excludes contributions from HWP pools.

Average net annual forest carbon dioxide sequestration – by pool:

- Growth on live trees, including foliage and live roots, makes up 63% of the annual CO_2e change on all forest land at a net rate of about 16.6 ± 3.7 MMT CO_2e per year (Table 4.3).
- Of the estimated 13.4 MMT CO_2e per year cut within the forest (Table 4.3, 4.6a), approximately 10.0 MMT CO_2e per year in the form of commercial timber was removed from the forest to either be stored long term in durable wood products or emitted from burning (Appendix 3, Table 3.14).

Average net annual forest carbon dioxide sequestration – by owner:

- Individual noncorporate forest land owners provide the largest contribution, accounting for 40% of the statewide annual net change at a rate of 10.4 ± 1.4 MMT CO_2e per year (figure 4.1).
- The national forests account for 29% of the statewide annual net change at a rate of 7.5 ± 2.5 MMT CO_2e per year (figure 4.1). This represents a decrease of approximately 0.4 MMT CO_2e per year from the previous measurement period.

- Corporate forest land accounts for 21% of the statewide annual net change at a rate of 5.6 ± 2.7 MMT CO_2e per year (figure 4.1). This represents a decrease of 0.3 MMT CO_2e per year from the previous measurement period.
- State and local governments contribute 8% of the statewide annual net change at a rate of 2.1 ± 0.7 MMT CO_2e per year (figure 4.1). This represents a decrease of 0.2 MMT CO_2e per year from the previous measurement period.
- Other federal lands contribute 2% of the statewide annual net change at a rate of 0.5 ± 1.1 MMT CO_2e per year (figure 4.1). This represents a decrease from the previous measurement period of 0.3 MMT CO_2e per year.
- On reserved forest lands managed by the Forest Service live tree growth is not currently estimated to exceed carbon losses from the live tree pool due to tree mortality, as in previous measurement cycles (Figure 4.4a, Table 4.4a). Additionally this year, unreserved low-productive forest lands managed by the Forest Service as well as other federal forest lands are exhibiting carbon losses from the live tree pool due to tree mortality (Appendix table B9.1, B10).
- As in previous measurement cycles, annual gross growth per acre on live trees is currently exceeding all other carbon losses from the live tree pool due to mortality or harvest on unreserved timberland for all ownerships including lands managed by the Forest Service.
- The annual net rate of carbon sequestration per acre in the live tree pool is greatest on timberland owned by state and local government at 4.7 ± 1.4 metric tons of CO_2e per acre per year (Appendix 2, Table B12).
- The next highest annual net rate of carbon sequestration per acre in the live tree pool is on timberland owned by private individuals at 2.5 ± 0.3 metric tons of CO_2e per acre per year (Figure 4.4b, Table 4.4b).
- Trees growing on all ownerships and productive classes across all of California's forests are sequestering carbon at a net rate of 0.4 ± 0.1 metric tons CO_2e per acre per year (Table 4.4a).

Average net annual forest carbon dioxide sequestration – by region:

- The Sierra/Cascades region has the greatest annual growth in its forests relative to growth from other regions. This region also has the greatest amount of mortality; after accounting for harvest, live trees in the Sierra/Cascades region are still sequestering 2.0 ± 2.4 MMT CO_2e per year (figure 4.6). This is down from the re-calculated 2018 measurement period which estimated a rate of 3.1 ± 2.5 MMT CO_2e per year (previously 3.1 ± 2.6 MMT CO_2e per year, note decrease in SE as result of improved post-stratification). This value cannot be directly compared to previous report values for live tree sequestration from the 2015 measurement period (8.7 ± 3.0 MMT CO_2e per year), the 2016 measurement period (7.8 ± 2.7 MMT CO_2e per year) or the 2017 measurement period (5.5 ± 2.7 MMT CO_2e per year) due to improved methods over time and the re-stratification that occurred in 2019. However, data suggest that the net annual sequestration in the live tree pool is decreasing over time.

- The North Coast region has the highest live tree net carbon sequestration at 7.7 ± 1.6 MMT CO_2e per year.
- The Southern Coastal Mountains and Deserts region continues to be the only region where tree mortality is exceeding tree growth, resulting in a net carbon reduction of the live tree pool of -0.8 ± 0.4 MMT CO_2e per year (figure 4.6). Further analysis is being conducted to determine why this region is experiencing an annual net loss of CO_2e and will be presented in a later report.

Average net annual forest carbon dioxide sequestration – Forest Practice Districts

- Net annual sequestration from forests in the Northern Forest Practice District is 9.0 ± 2.4 MMT CO_2e (15% lower than re-calculated 2018 reporting period); in the Southern Forest Practice District net annual forest sequestration is 2.2 ± 1.6 MMT CO_2e (12% lower than re-calculated 2018 reporting period); and in the Coastal Forest Practice District it is 10.6 ± 2.4 MMT CO_2e (13% lower than re-calculated 2018 reporting period) (Table 4.2b). These values include change from all forest ecosystem pools and non-CO_2 emissions from wildfires, but does not include change from harvested wood product pools or from forest land use conversions.
- The Southern Forest Practice District is experiencing carbon losses due to mortality primarily on forest land managed by National Forests and other federal agencies leaving this district susceptible to net carbon loss if the current rate of disturbance increases (Tables 4.6f). The Northern Forest Practice District is experiencing carbon losses due to mortality primarily on forest land managed by National Forests leaving this district susceptible to net carbon loss if the current rate of disturbance increases (Tables 4.6e).

Average net annual forest carbon dioxide sequestration – County

- Mendocino (5.2 ± 1.3 MMT CO_2e per year) and Humboldt (4.7 ± 2.0 MMT CO_2e per year) counties have the highest net carbon sequestration rates for all forest pools (Table 4.6b).
- By county, notable counties estimated in 2019 to have a net loss of forest carbon based on all pools are; Monterey (-0.3 ± 0.5 MMT CO_2e per year), San Bernardino (-0.4 ± 0.3 MMT CO_2e per year), Santa Barbara (-0.2 ± 0.2 MMT CO_2e per year), and Tuolumne (-0.8 ± 1.0 MMT CO_2e per year) (Table 4.6b).

Average net annual forest carbon dioxide sequestration – National Forests

- The Shasta-Trinity National Forest has the highest net annual carbon sequestration rate for all forest pools at approximately 2.3 ± 0.8 MMT CO_2e per year (Table 4.6c).
- There are five national forests in California currently experiencing a net loss of carbon based on all pools; Los Padres (-0.6 ± 0.5 MMT CO_2e per year), San Bernardino (-0.4 ± 0.3 MMT CO_2e per year), Klamath (-0.2 ± 1.0), Angeles (-0.1 ± 0.2 MMT CO_2e per year, Sequoia (-0.01 ± 0.6) (Table 4.6c).

Carbon stocks for forest land remaining forest land (FF) by pool:

- Currently the is just under 3.1 billion metric tons of carbon stocks stored on forest land including forest soils across all ownerships in California (Table 4.12a, figure 4.9, 4.10). This is an increase of 1.7 million metric tons of forest ecosystem carbon compared to the re-calculated 2018 reporting period, representing an increase in line with previous results.
- Approximately one third of this stored carbon is found above ground in the live tree pool (including foliage) (1,059 ± 26 MMT C, Table 4.12a, figure 4.9).
- Forest soils store about 45% of the carbon (1,395 ± 16 MMT C, Table 4.12a, figure 4.9).
- Approximately 7% of the stored carbon is found aboveground in dead wood pools (216 ± 7 MMT C, Table 4.12a, figure 4.9).
- Estimates of carbon on the forest floor contributed 134 ± 2 MMT C, Table 4.12a, figure 4.9).

Carbon stocks for forest land remaining forest land (FF) by owner:

- Approximately 64% of the carbon stocks in the state are found on public forest land (1,971 ± 39 MMT C), with approximately 81% of that on National Forest System lands (1,589 ± 30 MMT C) (Table 4.12a, figure 4.8).
- Private corporate forest land contains approximately 17% of the state's carbon stocks (517 ± 25 MMT C, Table 4.12a, figure 4.8).
- Private noncorporate forest land contains approximately 19% of the state's carbon stocks (582 ± 27 MMT C, Table 4.12a, figure 4.8).
- Approximately 60% of the forest carbon stores are found on unreserved timberland (1,837 ± 38 MMT C, Table 4.12a, Figure 4.10).

Carbon stocks for forest land remaining forest land (FF) by region:

- Nearly half of California's carbon stocks in all carbon pools are found in a single region, the Sierra and Cascade Mountain Ranges. This region represents 47% of the forest land area and contains 1,413 ± 37 MMT C (Table 4.19, figure 4.11). These stocks are roughly the same as the recalculated 2018 carbon stocks.

- The next largest carbon store, the Klamath Interior and Coast Ranges region has about 64% of the carbon stocks found in the Sierra and Cascades and close to 30% of those found in the state at 900 ± 35 MMT C (Table 4.17, figure 4.11). These stocks are roughly the same as the recalculated 2018 carbon stocks.
- For each of these regions the dead tree and down woody material pools are each about 8 of the live tree carbon pool.

Carbon stocks for forest land remaining forest land (FF) by forest type:

- The California mixed conifer forest type contains the largest carbon stock compared to all other forest types, storing approximately 962 ± 42 MMT C (Table 4.21, Figure 4.12). This represents an increase from re-calculated 2018 stocks of approximately 1 MMT C primarily in the dead and SOC pools.
- Western oak forests follow with 654 ± 28 MMT C (Table 4.21, Figure 4.12). This represents a slight decrease in most pools from re-calculated 2018 stocks of approximately 5 MMT C**.** Additionally, despite an increase in acres as a result of the updates to the post-stratification process to reduce the bias associated with denied access in hardwood and woodland areas, there is a decrease in carbon stocks due to increased acres in private non-corporate ownership which tend to have less biomass per acre compared to private corporate ownership.
- Notable exceptions of forest types where live tree carbon exceeds soil carbon includes the redwood, Douglas-fir, fir/spruce/mountain hemlock, western hemlock/Sitka spruce, and tanoak/laurel types.
- Most carbon stocks are found on unreserved timberland for most softwood forest types (Table 4.22, figure 4.13).
- The redwood forest type has the highest carbon density per acre (figure 4.14).
- Regional data by forest type is included in Appendix 1.

Carbon stocks for forest land remaining forest land (FF) by county:

- The counties with the highest carbon stocks are Siskiyou county with 324 ± 22 MMT C, Humboldt county with 244 ± 28 MMT C and Trinity county with 228 ± 21 MMT C (Table 4.12b). Stocks in Siskiyou county represent a slight decrease from 2018 recalculated stocks of approximately 3 MMT C. Stocks in Humboldt county represent a slight increase from 2018 recalculated values and Trinity county stocks are relatively stable compared to the previous reporting period.

Carbon stocks for forest land remaining forest land (FF) by National Forest:

- The Shasta-Trinity National Forest has the highest carbon stocks at 242 ± 13 MMT C and is also the largest National Forest at approximately 2.0 ± 0.1 million acres. (Table 4.12c).

Carbon stocks for forest land remaining forest land (FF) by Forest Practice District:

- The Northern Forest Practice District has the highest carbon stocks at 1,194 ± 40 MMT C (Table 4.12e). This represents a slight decrease of 150 MMT C across all pools compared to the 2018 recalculated values.
- In the Northern and Southern Forest Practice Districts, carbon on public lands make up the majority of the forest carbon, while in the Coastal Forest Practice District carbon on private lands make up the majority of the forest carbon (Table 4.12d, e, f).

Comparison to the Forest Management Reference Level (FMRL):

- FIA's initial 10-year forest inventory in California installed from 2001 - 2010 is the FMRL basis (i.e., baseline) to evaluate relative changes in California forest carbon stocks between measurement periods.
- Stock-change comparisons to the FMRL cannot determine net flux until the entire 10-year re-measurement period is complete in 2020. The GRM method is used to estimate annual net flux.
- Comparison to the FMRL show that overall California's forest carbon stocks are increasing over time with minor annual variations (table 4.31).

<u>HARVESTED WOOD PRODUCT CARBON</u>

This data update includes harvested wood product carbon stock and net change in harvested wood product carbon pools associated with harvests from 1952-2019. Harvest volumes for 2019 by owner are provided by the University of Montana, Bureau of Business and Economic Research (2020). 2019 reporting period HWP C estimates for stock and net change reflect revisions from the 2017 full report that included in erroneous input parameters (board foot to cubic foot conversion factor for 2013-2019 and end-use ratios for all years) and revisions in the HWP C model code to correct errors resulting in approximately 1% of the carbon disappearing from all storage and emission pools. These revisions were first applied in the 2018 data update and are described there (Christensen et al. 2020). Monte Carlo (MC) estimates of uncertainty in the HWP C estimates are updated in this data update to correct previous analyses resulting in narrower confidence intervals than expected based on input parameters. Revisions to the Monte Carlo analysis are described further below in Section 2 - "Improvements and methodological updates." A more detailed description of the MC Uncertainty Analysis methods is provided in Appendix 3.

HWP C stock

- For the 2019 California AB 1504 reporting period, the average HWP C stock is approximately 77.8 MMT C for Products in use (HWP-in use), 57.4 MMT C for Products in solid waste disposal sites (HWP-SWDS), and approximately 135.2 MMT C for both HWP pools (see Table 6.5).
- For the 2019 California AB 1504 reporting period, carbon stored from harvests originating from privately owned forestland comprises 67% of the HWP C stock at 91.0 MMT C. Carbon stored from harvest originating from National Forest System lands comprises 31% of the HWP C stock at 41.7MMT C, with the remainder of the HWP C stocks coming from Tribal, BLM, and State and other public land.

HWP C flux

- For the 2019 California AB 1504 reporting period, the average net change in HWP C pool is approximately -1.2 MMT CO2e for Products in use, 2.0 MMT CO2e for products in SWDS, and 0.8 MMT CO2e for all pools (see Table 6.6).
- For the 2019 California AB 1504 reporting period, for harvest originating from all ownerships, net change in the products in use pool is negative, representing a shift in HWP C from the Products in use pool to the SWDS pool faster than new carbon is being added to the products in use pool.

Harvest

- The weighted average annual harvest values associated with the 2019 California AB 1504 reporting period is approximately 2.7 MMT C (1.6 million MBF). This equates to approximately 10.0 MMT CO2e per year in the form of commercial timber removed from the forest (Appendix 3, Table 3.14). Based on the forest ecosystem portion of the inventory for the same time period, approximately 13.4 MMT CO2e per year is cut within the forest (Table 4.6a).

Monte Carlo Uncertainty Analysis

- The Monte Carlo simulation succeeded in introducing variability into the HWP model. The resulting confidence interval range (-17% to 22%) is slightly narrower than the 2010 Monte Carlo simulation interval for Stockmann et al. (2012) of -24% to +28% for non-emissions carbon pools. The Stockmann et al. (2012) simulation included a longer harvest time-series with greater uncertainty in several variables in earlier years, which were not evaluated in this analysis.
- After 2,000 iterations, the MC simulation fully converged on values for the mean and the 90% confidence intervals for the cumulative amount of carbon in the combined

HWP pools of Products in use and at SWDS (Figure 6.6). The MC simulation code succeeded in creating correlated random triangular variables.

- For 2019, the MC estimate for the mean of these two pools combined was 137.1 MMT C with a lower bound of 114.2 and an upper bound of 160.7 MMT C (table 6.7).
- The width of the confidence intervals through the time series reflected the effect of altering parameter values for ever-increasing amounts of carbon entering the model and being emitted or distributed to different pools (figures 6.6, 6.7, table 6.7). The precision of parameter estimates for harvest and the ratios for timber and primary products was modeled as improving over time (Appendix 3, table 3.8a). Between 1952 and 1982, the difference between both the lower and uppers bound relative to the simulated mean averaged about 21%. From 1982 to 2019, both the lower and upper bounds averaged about 17% relative to the mean.
- The difference between the MC simulation means and the HWP C model values for the combined pool of Products in use and at SWDS were less than 1% for most of the time series, except for the years prior to 1968, when it was slightly larger (table 6.7).
- Confidence intervals were generated separately for the cumulative amount of carbon in the Products in Use, at SWDS, Burned with Energy Capture, and Burned without Energy Capture pools (Figure 6.7). The small differences (< 2.2 MMT C) between the MC simulated means for these pools in 2019 and the respective estimates from the HWP C model (Table 6.8) indicate that the simulation operated as expected given the parameters in Appendix 3, table 3.8a. The 2019 MC confidence intervals for SWDS, relative to the mean, were the widest of these four disposition categories at about 19% and 21% for the lower and upper limits, respectively. Conversely, the width of the 2019 confidence intervals for Burned with Energy Capture were the smallest at about 17% and 18% of the mean, respectively.
- Most of the variability introduced into the simulation was achieved by affecting harvest, conversion ratios, and product and decay half-lives.

HWP C Emissions

- HWP C emissions data for HWP burned with and without energy capture are not included in forest sector C accounting, but are used in other sectors (i.e., waste, energy). Cumulative emissions associated with these pools (HWP-energy, HWP-without energy) for individual years can be found in table 6.2. However, without a greater understanding of the reporting timeframes and data needs from these other sectors, additional calculations on HWP emissions are not provided in this report at this time.

Background:

The forest sector carbon data provided in this update comply with the Intergovernmental Panel on Climate Change Tier 3 good practice guidelines for carbon accounting (IPCC 2006, 2014) and are intended to assist the Board in evaluating and monitoring progress on meeting California's forest sector carbon sequestration target. This update can inform policy decision-making, but is not intended to be a complex policy assessment framework. Forest ecosystem carbon stocks and flux are established using direct measurements on forested plots throughout the state of California as part of the United States Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. Harvested wood product carbon (HWP C) stocks are based on estimates from the California variant of the harvested wood product carbon accounting model based upon the IPCC Tier 3 production accounting approach.

The forest ecosystem data presented in this report are based on the 2010-2019 FIA measurement cycle. Carbon stocks physically present in the forest are based on a 10-year average for the time-period of 2010-2019 and given in metric tons (MT) of carbon (C). The estimates of average annual carbon sequestration (i.e., net flux) is based on plots and trees initially measured between 2001 and 2009 then re-measured 10 years later between 2011 and 2019. Calculating flux based on actual growth, removals and mortality (i.e., the GRM approach) allows for annual reporting and is more statistically robust than a simple stock-change approach.

Harvested wood product carbon estimates include contributions from current and historic harvests going back to 1952, the year annual harvest data was available for all ownerships. Harvested wood product carbon stocks are reported by the HWP C model in the year following harvest, i.e. harvested wood product carbon stock associated with 2019 removals is reported in year 2020. To be consistent with FIA's forest ecosystem ten-year average reporting periods and correspond with 2010-2019 annual harvests, the 10-year average of the HWP C stock for the years 2010-2019 is reported. Harvested wood product carbon flux for the 2018 reporting period is reported as the average annual flux for the nine ten-year intervals of 2002-2012, 2003-2013, 2004-2014, 2005-2015, 2006-2016, 2007-2017, 2008-2018, and 2009-2019 to match the removals associated with the 2019 FIA plot remeasurement cycle.

Forest ecosystem and harvested wood product carbon stock and flux results associated with these time periods are referred to as 2019 results, 2019 reporting period results, or 2019 measurement cycle results throughout the report. To more clearly describe the time periods covered in the stock and flux estimates in this report, please note that the title has been changed to reflect the "2019 reporting period," rather than specific ranges of years.

In this analysis results of carbon physically present in the forest or in harvested wood products in use or at solid waste disposal sites are given in metric tons (MT) of carbon (C). Results of carbon flux are given in metric tons (MT) of carbon dioxide equivalent (CO_2e). Net changes in individual carbon pools are also shown in units of CO_2e to provide insight into the components of change, even if they aren't a direct flux with the atmosphere (e.g., tree mortality, which is a conversion from live to dead wood that initially stays in the ecosystem; transition from harvested wood products in use to harvested wood products in solid waste disposal sites). Carbon can be converted to CO_2e by multiplying by 3.667 or the fraction 44/12[1]. Ranges in the text presented for forest ecosystem results (i.e., ±) represent a 95% confidence interval (CI), while values in the tables report the sampling error (SE; CI = 1.96*SE). Confidence intervals around forest ecosystem flux estimates tend to be slightly smaller than in the previous year's report because estimates are based on more plots (9/10ths of the full cycle compared to 8/10ths).

Reports released to date include:

- AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2006 – 2015 FINAL REPORT (Christensen et al. 2017).
- AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2006 – 2015 ERRATUM SHEET (Christensen et al. 2018a).
- AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2007 – 2016 DATA UPDATE (Christensen et al. 2018b).
- AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2017 Reporting Period FINAL REPORT (Christensen et al. 2019).
- AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2018 Reporting Period DATA UPDATE (Christensen et al. 2020)
- AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2019 Reporting Period DATA UPDATE (i.e., this report)

2 Improvements and methodological updates

Errors found after release of the initial inventory (Christensen et al. 2017) are detailed in Christensen et al. 2018a and are also corrected in subsequent reports. Please note that due to refinements in the methodology over the years and recent changes in the FIA post-stratification process, it is not possible to compare all the results from this report to previous reports. To facilitate some level of comparison to previous inventories, forest carbon stocks for each 10-

[1] Throughout the forest ecosystem portion of the inventory, results are converted from C to CO_2e by multiplying by 3.667. Throughout the harvested wood product portion of the inventory, results are converted from C to CO_2e by

year inventory period are recalculated to include all methodological updates in tables 4.31-4.33.

Changes to this data update from the previous data update include modifications to the FIA post-stratification process for the forest ecosystem estimates and modifications to how the HWP C model executes the Monte Carlo uncertainty analysis, as described below.

FIA Post-stratification

Non-sampled inventory plots due to FIA inventory crews being denied permission to access the plot or finding conditions at the plot location too hazardous to collect field measurements can lead to a statistical bias in the compiled estimates. FIA uses post-stratification to not only reduce overall sampling error, but also to reduce the potential for bias introduced by non-sampled plots. Post-stratification is applied to the inventory by grouping similar forest land areas into the same strata, such as ownership. Previously, PNW-FIA used strata based on a forest/non-forest layer, ownership groups (private, federal land, state and local), and reserved areas such as National Forest wilderness areas and National Parks to reduce the effects of bias.

In recent years there has been a trend toward a distinctly higher non-sampled rate for FIA plots located on smaller acreages of privately held ownerships. Additionally, owners of smaller privately held forest land tend to manage their land differently than owners of larger privately held forest land resulting in differences such as in harvest rates. In response to potential bias this difference could have on estimates of change, PNW-FIA responded by grouping all privately held forest land into one of three strata based on holding size class; small, medium and large.

Additionally, for the 2019 inventory update PNW-FIA also incorporated a newer NLCD forest cover map, additional vegetation layers, and updated NFS boundary layers. These updated layers also serve to improve post-stratified estimates. For example, hardwoods and woodland areas have higher non-sampled response rates due to higher access denied. Updated spatial information on hardwoods and woodlands improves the estimates by reducing the bias associate with access denied.

These changes resulted in a statewide decrease of approximately 5.0 MMT C in the aboveground live tree pool, and a reduction in the sampling error of approximately 0.8 MMT C. This re-stratification therefore improves the estimated values as well as the confidence in the estimated values.

Monte Carlo Uncertainty Analysis

The previous HWP C model code resulted in narrower confidences intervals than expected based on the parameters set for the Monte Carlo Uncertainty Analysis. For example, a range of

±5-30% was specified for values in 17 input variables used to calculate harvested wood product carbon stocks. However, resulting Monte Carlo confidence intervals for harvested wood product carbon stocks were less than 0.1% different from the mean. These errors were corrected through re-coding the model in the R (2020) programming environment through an agreement between Oregon Department of Forestry, Oregon State University, and Groom Analytics, LLC.

The corrected Monte Carlo simulation to estimate the uncertainty associated with estimates generated with HWP C model follows methods described by Skog (2008) and used by Anderson et al. (2013) and Stockmann et al. (2012). The goal of the MC simulation was to produce 90% confidence intervals for the cumulative amount of carbon classified in four categories: Solid Waste Disposal Sites (SWDS), Products in use (PIU), emissions without energy capture (EWOEC), and emissions with energy capture (EEC) from fuelwood. To achieve this goal, the MC simulation directly altered 16 different variables within the model according to their associated parameters (Appendix 3, table 3.8a). These 16 variables were allowed to vary by amounts that were based on estimates from Skog (2008) and professional judgement. Random values were drawn from triangular distributions that have a peak value of 1.0 (Appendix 3, table 3.8a) and symmetrically taper to given 90% confidence interval bounds. The random values from the triangular distribution were used as proportions for adjusting parameter values for each iteration of the simulation. A full description of the methods for the MC simulation is provided in Appendix 3.

To view the balance of the 2019 updated report, visit :
https://bof.fire.ca.gov/projects-and-programs/ab-1504/