AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2006 – 2015

FINAL REPORT

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Prepared for:

California Department of Forestry and Fire Protection agreement no. 7CA02025

Suggested report citation:

Christensen, G.A.; Gray, A.N.; Kuegler, O.; Tase, N.A.; Rosenberg. M. 2017. AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2006 - 2015. Final Report. California Department of Forestry and Fire Protection agreement no. 7CA02025. Sacramento, CA: California Department of Forestry and Fire Protection and California Board of Forestry and Fire Protection. 390 p.

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Acronym List

AB – Assembly Bill

AGL – aboveground live

ALCI – attributional life-cycle inventory

Board; BOF – California Board of Forestry and Fire Protection

C – carbon

CALFIRE – California Department of Forestry and Fire Protection

CALGREEN – California Green Building Standards Code

CARB – California Air Resources Board

CALRECYCLE – California Department of Resources, Recycling, and Recovery

CBM – Canadian Carbon Budget Model

CFPP – California Forest Project Protocol

CH_4 - methane

CI – confidence interval

CLCI – consequential life-cycle inventory

CMAI – culmination of mean annual increment

CO - carbon monoxide

CO_2e – carbon dioxide equivalent

DBH – diameter at breast height

EPA – Environmental Protection Agency

FCAT – California Forest Climate Action Team

FCP – California Forest Carbon Plan

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-burned – harvested wood products burned without energy production

ICE – Image-based Change Estimation

InTEC – USFS Integrated Terrestrial Ecosystem Carbon Model

IPCC – Intergovernmental Panel on Climate Change

LCA – life-cycle analysis

LCI – life-cycle inventory

LF – Forest Land Conversions (IPCC terminology)

LULCF – Land-use, Land-use Change and Forestry (IPCC terminology)

mm - millimeter

MMT – million metric tons

MT – metric tons

NFS – National Forest System

NGHGI – National Greenhouse Gas Inventory

NMVOC – non-methane volatile organic compounds

N_2O – nitrous oxide

NO_x - nitrogen oxides

NPV – net present value

NRCS – Natural Resources Conservation Service

NRI – Natural Resources Inventory

PNW – Pacific Northwest Research Station

RPA – Resources Planning Act

RS – remote sensing

SOC – soil organic carbon

SWDS – solid waste disposal site

TBD – to be determined

TPO – Timber Products Output

µm – micrometer i.e., one millionth of a meter

UC – University of California

UNFCC – United Nations Framework Convention on Climate Change

USDA – United States Department of Agriculture

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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 report was written 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 first 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). The report establishes forest sector carbon accounting methods that comply with the Intergovernmental Panel on Climate Change Tier 3 good practice guidelines for carbon accounting (IPCC 2006, 2014) and is intended to assist the Board in evaluating and monitoring progress on meeting California's forest sector carbon sequestration target. This report 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 stocks will be based on an IPCC Tier 3 production accounting approach and will be completed for the upcoming inventory in 2018.

As of 2015, California's forests remain net sinks, sequestering 33.6 MMT CO_2e per year, excluding net flux from soils, forest land conversions, non-CO_2 emissions from wildfires, or harvested wood products. After accounting for these other sources (except HWP), the rate of carbon sequestration is 32.8 MMT CO_2e per year. Carbon stocks are just over 2 billion metric tons. However, 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.

Key Findings:

The data presented in this report are based on the 2006-2015 FIA inventory years. Carbon stocks physically present in the forest are based on a 10-year average for this time-period 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 2005 then re-measured 10 years later between 2011 and 2015. Calculating flux based on actual growth, removals and mortality (i.e., the GRM approach) allows for annual reporting and is more robust than a simple stock-change approach. Results of carbon flux are given in metric tons (MT) of carbon dioxide equivalent (CO_2e). Carbon can be converted to CO_2e by multiplying by 3.667. Ranges in the text (i.e., ±) represent a 95% confidence interval (CI), while values in the tables report the sampling error (SE; CI = 1.96*SE).

Forest land area:

- As of 2015 there are approximately 32 million acres of forest land across all ownerships.
- 16.9 million acres are classified as timberland with an additional 4.1 million acres of productive forest land in reserves.
- The federal government manages 58% of California's forest lands, with the remaining areas under state and local government (3.4%) or private management (39%) (Figure 2.4).
- Overall there was a net loss of forest land at the rate of 14.6 ± 10.6 thousand acres per year, primarily to developed land-uses (Table 4.8). 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" (68%), followed by timberland (28%), with little change occurring on reserved lands (4%).
- Western oak woodlands cover the greatest area of all forest types at approximately 8.9 ± 0.38 million acres, followed by California mixed conifer at approximately 8 ± 0.34 million acres (Table 4.11).

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.
- The 2015 statewide rate of forest carbon sequestration is 33.6 ± 5.3 MMT CO_2e per year, excluding net CO_2e contributions from other sources such as forest soils, harvested wood products, forest land conversions and non-CO_2 GHG emissions from wildfire (Table 4.1, 4.3).

- Soil organic carbon is estimated to sequester 0.8 ± 1.0 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 0.4 ± 0.1 MMT CO_2e per year (Table 4.2, 4.7).
- Changes in land-use between forest and non-forest land condition is estimated to have a net effect of emitting 1.2 ± 1.2 MMT CO_2e per year (Table 4.2, 4.9).
- After accounting for these other CO_2 and greenhouse gas sources the 2015 statewide rate of carbon sequestration on all forest land is 32.8 ± 5.5 MMT CO_2e per year (95% CI, table 4.2). This value currently 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 89% of the annual aboveground CO_2e flux on all forest land at a net rate of about 30 ± 4.7 MMT CO_2e per year (Table 4.3).
- Standing dead trees, fallen down wood, and understory vegetation make up the remaining 11% of aboveground CO_2e flux (Table 4.3).
- Some portion of the 13.6 ± 2.8 MMT CO_2e flux (Table 4.3) associated with harvested wood is not immediately emitted as CO_2, but is stored as sequestered C. Information for these HWP pools will be provided in the 2018 inventory.

Average net annual forest carbon dioxide sequestration – by owner:

- The national forests provide the largest contribution, accounting for 39% of the statewide annual flux at a rate of 13.2 ± 3 MMT CO_2e per year (figure 4.1).
- Individual noncorporate forest land owners account for 33% of the statewide annual flux at a rate of 10.9 ± 1.9 MMT CO_2e per year (figure 4.1).
- Corporate forest land accounts for 13% of the statewide annual flux at a rate of 4.3 ± 3.8 MMT CO_2e per year (figure 4.1).
- State and local governments contribute 2.6% of the statewide annual flux at a rate of 2.6 ± 0.96 MMT CO_2e per year (figure 4.1).
- Other federal lands contribute 7% of the statewide annual flux at a rate of 2.5 ± 1.2 MMT CO_2e per year (figure 4.1).
- Only on reserved forest lands managed by the Forest Service is live tree growth not currently estimated to exceed carbon losses from the live tree pool due to tree mortality (Figure 4.4, Table 4.4).
- 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 is greatest on timberland owned by private individuals at 1.33 ± 0.22 metric tons of CO_2e per acre per year (Figure 4.4, Table 4.4).
- Trees growing on all ownerships across all of California's forests are sequestering carbon at a net rate of 0.79 ± 0.15 metric tons CO_2e per acre per year (Table 4.4).

Average net annual forest carbon dioxide sequestration – by region:

- The Sierra/Cascades region has the greatest net live tree CO_2e flux due to higher total annual growth in its forests relative to growth from other regions. This region also has the greatest rate of mortality but after accounting for harvest, live trees in the Sierra/Cascades region are still sequestering 8.7 ± 3 MMT CO_2e per year, more than any other region (figure 4.6).
- The Southern Coastal Mountains and Deserts region is currently the only region where tree mortality is exceeding tree growth, resulting in a net carbon reduction of the live tree pool of 1.1 ± 0.7 MMT CO_2e per year (figure 4.6). Further analysis is needed to determine why this may be the case.

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

- Currently there are just over 2 billion metric tons of carbon stocks stored on forest land including forest soils across all ownerships in California (Table 4.12, figure 4.9, 4.10).
- Just over half of this stored carbon is found above ground in the live tree pool, which now includes foliage biomass and is different from previous FIA-based C estimates (1,062 ± 27 MMT C, Table 4.12, figure 4.9).
- Forest soils store about a quarter of the stored carbon (506 ± 6.7 MMT C, Table 4.12, figure 4.9).
- Approximately 10% of the stored carbon is found aboveground in dead wood pools (203 ± 6.3 MMT C, Table 4.12, figure 4.9). Equations for dead wood pools use decay factors for hardwood/softwoods, which is different from previous FIA-based C estimates which use species-level values. Differences in these decay factors are discussed in section 3.2.3.
- These estimates exclude forest floor C as data was limited for this pool at this time. Initial estimates of forest floor C based on FIA measurements compiled in Gray et al. (2016) for National Forests in Oregon and Washington suggested that the forest floor made up 10% of non-soil forest C, which would translate to 7% of total C (150 MMT C) in Table 4.12 if the same ratio held. We suspect this number is too high and will go down with a better estimation approach.

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

- Approximately two-thirds of the carbon stocks in the state are found on public forest land (1,346 MMT C), with approximately 80% of that on National Forest land (1,074 MMT C) (Table 4.12, figure 4.8).
- Private corporate forest land contains approximately 16% of the state's carbon stocks (324 MMT C, Table 4.12, figure 4.8).
- Private noncorporate forest land contains approximately 18% of the state's carbon stocks (368 MMT C, Table 4.12, figure 4.8).
- Approximately 62% of the forest carbon stores are found on unreserved timberland (273 MMT C, 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 953 MMT C (Table 4.19, figure 4.11).
- The next largest carbon store, the Klamath Interior and Coast Ranges region has about half the carbon stocks as found in the Sierra and Cascades and just over a quarter of those found in the state at 568 MMT C (Table 4.17, figure 4.11).
- For each of these regions the dead tree and down woody material pools are each about 10% 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 664 ± 22 MMT C (95% CI; Table 4.21, Figure 4.12).
- Western oak forests follow with 333 ± 12 MMT C (Table 4.20, figure 4.12).
- For most forest types the majority of carbon stores are found in live trees (Table 4.20, Figure 4.12).
- 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.

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, figure 4.15).

Harvested Wood Product (HWP) carbon

- Current data are through an agreement between CALFIRE, the USDA Forest Service Pacific Northwest Research Station (PNW), and the University of Montana, a detailed IPCC Tier 3 inventory of the harvested wood product carbon pools will be conducted for the AB 1504 Forest Ecosystem and Harvested Wood Products carbon inventory expected to be released in 2018.

Comparison of this inventory to other reports

- In 2013, the U.S. NGHGI estimates live tree net stock change at 36.2 MMT CO_2e per year for California (table 6.1). For this 2015 inventory we use similar methods to the U.S. NGHGI and estimate the rate to be 29.9 MMT CO_2e per year. Differences are likely due to use of national rather than regional biomass equations for the U.S. NGHGI. For non-soil stock changes with the aboveground live pools excluded, the U.S NGHGI reports slightly lower estimates, probably due to the use of models to determine down wood C based on forest type and stand age rather than direct measurements.
- In 2010, estimates from Gonzalez et al. 2015 adjusted for undetected growth show aboveground live tree stocks of 888 MMT C and an annual gain of 7.3 MMT CO_2e per year (Table 6.2). Later refinements by CARB put the stock at 892 MMT C and net flux at 7.1 MMT CO_2e per year. Errors with the initial Gonzalez et al. 2015 estimate prior to adjustment were approximately 25% for stock and 35% for flux and are likely similar for the adjusted estimates. In 2010, we estimate aboveground live tree stocks of 1,025 MMT C. Using 2015 data we show an annual AGL gain of 23.9 MMT CO_2e per year. Errors for our estimate were approximately 3% for stock and 19% for flux. Differences are likely due to the different time periods of analysis and a variety of differences in the methods discussed further in section 6.2.

Strategies to leverage forests for emissions reductions

The following strategies have been identified to reduce carbon emissions or increase sequestration from the atmosphere by forests including contributions from harvested wood products and by-product utilization:

- Promote afforestation/avoid deforestation associated with land-use change.
- Increase C stores in forests through sustainable forest management practices, considering the age of the stand and other forest management objectives.
- Manage forest densities and fuels where appropriate.
- Increase C in HWP pools including wood used for energy.
- Consider wood energy and material substitution effects.

Organization of the 1504 Forest Ecosystem and Harvested Wood Products Carbon Inventory

The California forest carbon policy background, carbon cycle overview, and overview of California's forests are provided in section 2. A description of inventory methods for forest ecosystem carbon pools is provided in section 3. Forest ecosystem carbon inventory results are provided in section 4. An overview of harvested wood product carbon is described in section 5. Differences between this inventory and other reports are described in section 6. Strategies to leverage forests for emissions reductions are described in section 7. Strategies to improve the 1504 Forest Ecosystem and Harvested Wood Product Carbon Inventory are described in section 8. Appendix 1 contains regional forest carbon stock data by forest type. Extensive inventory tables are provided in appendix 2 and summarized below.

Appendix 2:

Area

Sampled Area

- Sampled area by land status and ownership group for all of California (Table A1) and by region, 2006-2015 (Tables A2-A8)

Forest Area for Forest Land Remaining Forest (FF): by owner

- Forest land area by forest land status and ownership group for all of California (Table A9) and by region, 2006-2015 (Tables A10-A16)

Forest Area for Forest Land Remaining Forest (FF): by forest type

- Forest land area by forest type, forest land status and ownership group for all of California, 2006-2015 (Table A17) (regional tables will be included in future report)

Net forest carbon flux for forest land remaining forest (FF)

Net carbon flux for all pools by owner

- Annual net change for all forest carbon pools by owner for all of California (Table B1) and by region, 2001-2005 and 2011-2015 (Tables B2-B8)

Disturbance effects on net forest carbon flux

- Annual net change for aboveground pools by disturbance, forest land status and owner, 2001-2005 and 2011-2015 – total (Table B9) and per acre (Table B10)

Forest carbon stock for forest land remaining forest (FF): by owner and forest land status

Aboveground live tree pool

- All of California (Table C1) and by region, 2006-2015 (Tables C2-C8)
- All of California by 10-year averages (Tables C9-C14)

Aboveground dead tree pool

- All of California (Table C15) and by region, 2006-2015 (Tables C16-C22)
- All of California by 10-year averages (Tables C23-C28)

Aboveground live understory vegetation pool

- All of California (Table C29) and by region, 2006-2015 (Tables C30-C36)

Aboveground and belowground live understory vegetation pools, 10-year averages

- All of California by 10-year averages (Tables C37-C42)

Belowground live understory vegetation pool

- All of California (Table C43) and by region, 2006-2015 (Tables C44-C50)

Belowground live tree pool

- All of California (Table C51) and by region, 2006-2015 (Tables C52-C58)

Belowground live and dead tree pools, 10-year averages

- All of California by 10-year averages (Tables C59-C64)

Belowground dead tree pool

- All of California (Table C65) and by region, 2006-2015 (Tables C66-C72)

Soil organic carbon pool

- All of California (Table C73) and by region, 2006-2015 (Tables C74-C80)
- All of California by 10-year averages (Tables C81-C86)

Aboveground down dead wood pool

- All of California (Table C87) and by region, 2006-2015 (Tables C88-C94)
- All of California by 10-year averages (Tables C95-C100)

Forest carbon stock for forest land remaining forest (FF): by forest type and forest land status

Aboveground live tree pool

- All of California (Table D1) and regions (Tables D2-D8), 2006-2015

Aboveground dead tree pool

- All of California (Table D9) and regions (Tables D10-D16), 2006-2015

Aboveground live understory vegetation pool

- All of California (Table D17) and regions (Tables D18-D24), 2006-2015

Belowground live understory vegetation pool

- All of California (Table D25) and regions (Tables D26-D32), 2006-2015

Belowground live tree pool

- All of California (Table D33) and regions (Tables D34-D40), 2006-2015

Belowground dead tree pool

- All of California (Table D41) and regions (Tables D42-D48), 2006-2015

Soil organic carbon pool

- All of California (Table D49) and regions (Tables D50-D56), 2006-2015

Aboveground down dead wood pool

- All California (Table D57) and regions (Tables D58-D64), 2006-2015

Forest land conversions (LF)

Changes in area from forest land-use conversions

- Annual change in forest land area to and from other IPCC land-use classes in California by forest land status for all of California, 2001-2005 to 2011-2015 (Table E1)

Net forest carbon flux from forest land-use conversions

- Annual change in carbon pools due to change in land-use between forest and non-forest in California, 2001-2005 to 2011-2015 (Table E2)

Net flux from other GHG emissions

- Annual net emissions of non-CO_2 greenhouse gasses from fire by owner group and class for all of California, 2001-2005 to 2011-2015 (Table F1)