CALIFORNIA
AIR RESOURCES BOARD

Natural and Working Lands
Carbon Inventory

2025 Edition

Acknowledgements

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Executive Summary

Natural and working lands (NWL) exchange carbon and other greenhouse gases (GHG) with the atmosphere and thus play a critical role in California's climate strategy. Conservation, restoration, and other land management actions offer opportunities to sustainably store carbon, buffer climate impacts, and promote additional co-benefits for California's landscapes and the communities that rely on them. As such, NWL have long been recognized and increasingly incorporated into California's climate strategy, including through the 2022 Scoping Plan update and the development of the AB 1757 Nature-Based Solution Climate Targets.

In support of these efforts, The California Air Resources Board's (CARB) NWL Carbon Inventory provides a quantitative estimate of organic carbon stored in California's landscapes, with the 2025 update reflecting conditions as of 2022. It captures the influence of climate, wildfire, other disturbances, land-use change, and management on carbon stocks and stock change, including in vegetation (hereafter called 'biomass'), soils, and harvested wood products (HWP). This information is used to evaluate progress towards California's climate and carbon neutrality targets, including the 2022 Scoping Plan NWL carbon target, which states that by 2045 losses in NWL carbon stocks should not exceed 4% compared to 2014 levels. By providing empirically based estimates on regional to statewide scales, the NWL Carbon Inventory serves as a tool for integrating lands into California's climate strategy, tracking the impact of nature-based solutions, and achieving carbon neutrality. The NWL Carbon Inventory also relies on the best science and tools available to ensure the public has accessible data for transparency on State efforts to address climate change.

The 2025 NWL Carbon Inventory shows that in 2022, California's NWL stored 4,953 MMT of carbon, with over half of that contained in forests (Figure E 1). Statewide, from 2001-2022, lands in California gained carbon, sequestering about 45 MMT, equivalent to less than 1% of 2001 carbon stocks. However, between 2014-2022, carbon stocks declined by 214 MMT, or about 4%. Biomass carbon was the greatest contributor to statewide declines, followed by soil carbon. In both cases, reductions were concentrated in forests and previously forested areas that converted to shrubland or grassland. Over the same time period, HWP experienced a slight increase in carbon stocks.
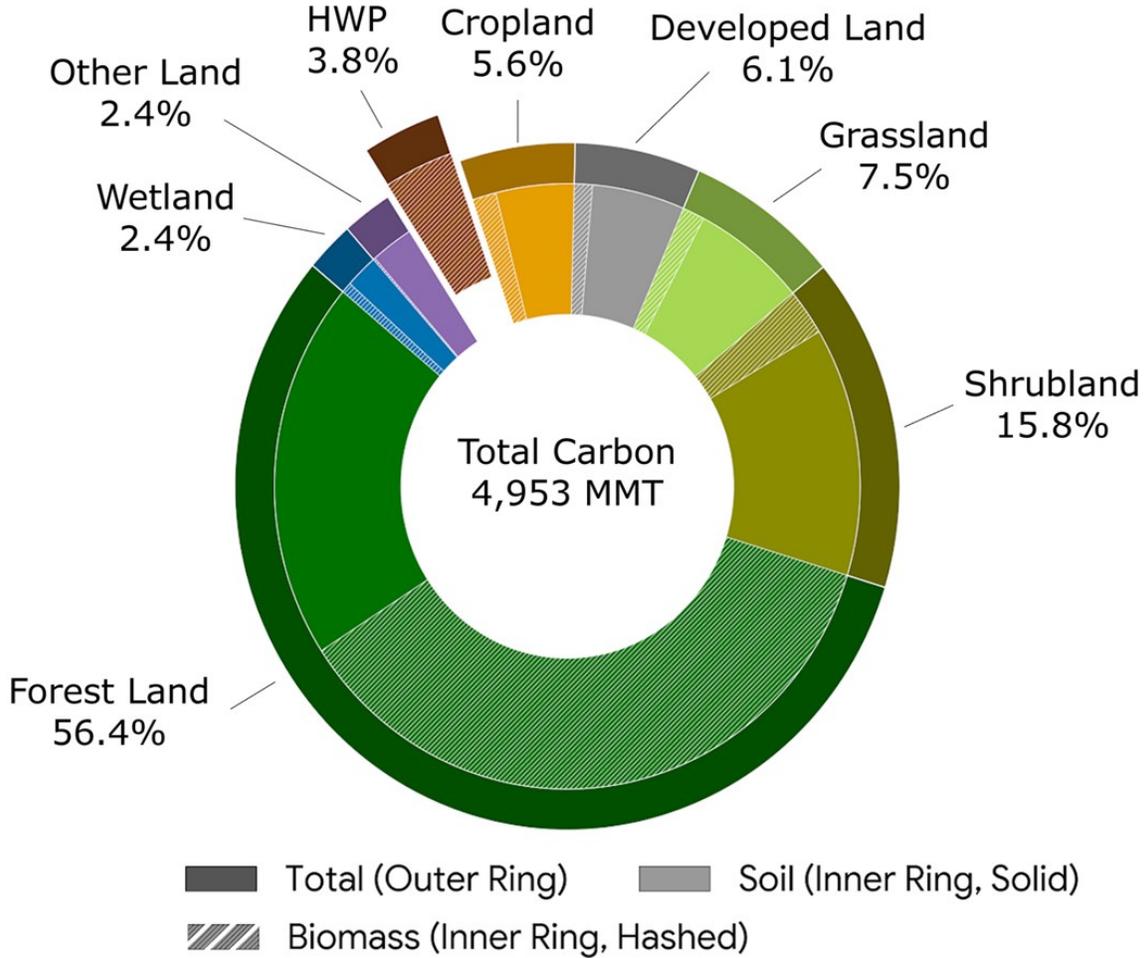
Figure E 1 - Total carbon stocks by land type in 2022, partitioned into soil (solid inner ring) and biomass (striped inner ring) carbon pools. The outer ring represents the combined carbon stocks for each land type, including domestically produced and retained harvested wood products (HWP). Percentages indicate each land type's contribution to the total statewide carbon stock (4,953 MMT).

The observed losses in biomass and soil carbon between 2014-2022 coincided with an increase in disturbances across the state and were due in large part to the extreme wildfire years of 2020 and 2021. While approximately 11 million acres were disturbed between 2001-2013, 2014-2022 saw that number grow to over 17 million acres, despite being a shorter time span. This was driven primarily by increased wildfire activity, with the most substantial declines in total carbon concentrated in forested areas that experienced extensive fire activity in the Sierra Nevada, Cascade Mountains, and Northern Coastal Range (Figure E 2). Some areas also experienced increases in carbon stocks between 2014-2022,

but those gains were outweighed by the larger losses elsewhere resulting in the net decline statewide.
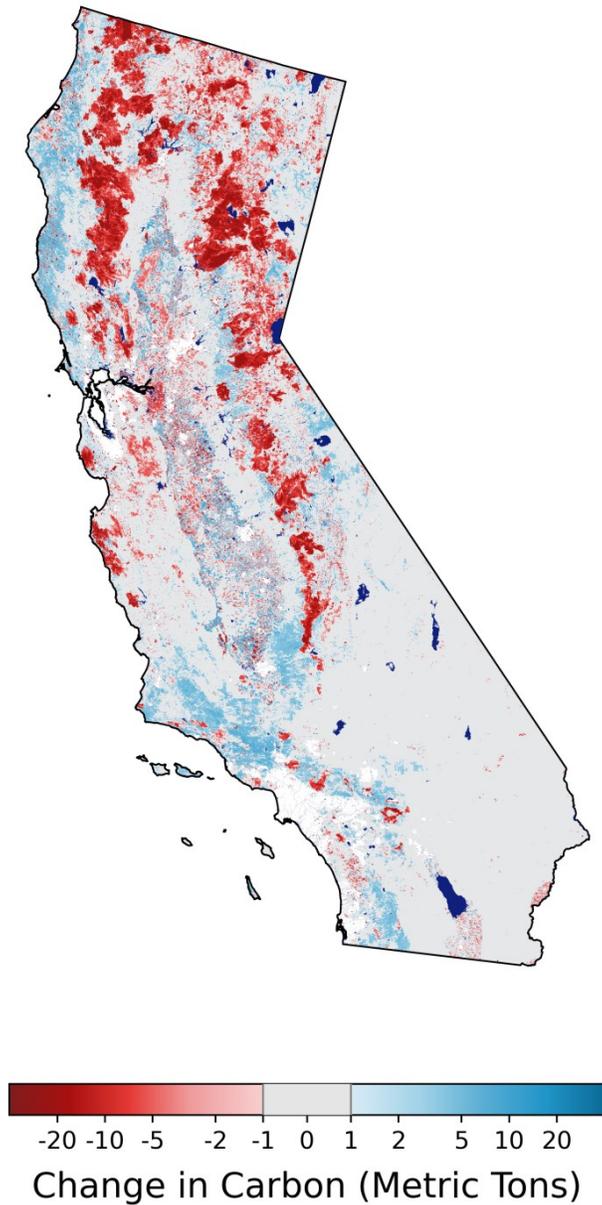
Figure E 2 - Change in total carbon stocks (biomass carbon and soil carbon combined) across California between 2014 and 2022. Values were derived by subtracting 2014 estimated values from 2022 estimated values. They are expressed in metric tons of carbon per pixel, where a pixel is equivalent to 0.22 acres (0.09 hectares). To convert values to metric tons per acre or per hectare, multiply by 4.5 or 11.11, respectively. The legend displays a symmetric log scale to visualize both subtler and larger changes. Gray denotes areas that changed by less than +/- 1 metric ton of carbon over the reporting period. White areas represent developed lands that did not have spatially explicit biomass carbon estimates for 2014. Dark blue areas denote open water where carbon stocks were not calculated.

While considerable progress has already been made to advance nature-based solutions and integrate NWL into California's climate strategy, the findings of the 2025 NWL Carbon Inventory underscore the importance of continued conservation, enhanced land management, and restoration to sustain resilient carbon stocks across California's lands and minimize future carbon losses. Importantly, however, not all net losses in carbon are inherently undesirable, as they can be associated with actions, such as prescribed fire or forest thinning, that lead to more resilient and healthy ecosystems.

Going forward, as part of the State's broader effort to track progress toward carbon neutrality, the NWL Carbon Inventory will continue to be refined and updated to provide the most accurate accounting possible. Planned improvements going forward include expanding the quality and coverage of field-based observations, leveraging state-of-the-art remote sensing technologies, and integrating more detailed data on disturbance and land management into modeling efforts. Together, these efforts will ensure California remains at the forefront of climate science, policy, and implementation as it relates to nature-based solutions and natural and working lands.

Table of Contents

Introduction

The Carbon Cycle

Carbon is an element that cycles through organisms, rocks, soils, oceans, and the atmosphere, making it essential to life and central to the functioning of Earth's ecosystems and climate. Carbon cycling occurs on two main timescales. The fast cycle involves the exchange of carbon between the atmosphere, plants, soils, and the surface ocean over years to millennia, and the slow cycle transfers carbon from rocks and sediments into and out of the fast cycle (Figure 1) [1]. The natural exchange of carbon between the slow and fast cycles is relatively small and occurs over geologic timescales (millions of years). The extraction and combustion of fossil fuel has changed this natural process. Fossil fuel use has transferred a significant amount of carbon from the slow to fast cycle, creating a major change in the natural carbon cycle that has resulted in rising atmospheric carbon dioxide (CO_2) concentrations and subsequent climate change [2].
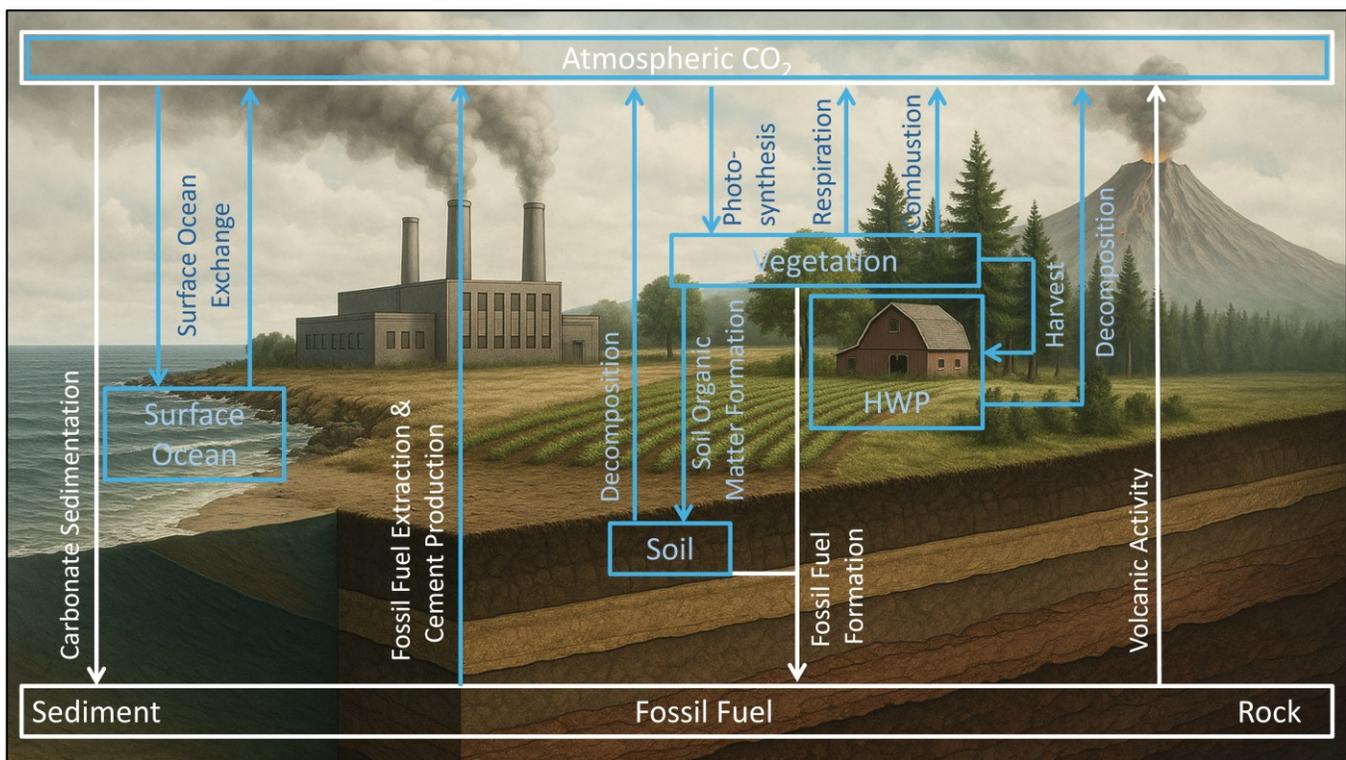

Figure 1 - Diagram of the carbon cycle, depicting the slow (white) and fast (blue) components. The NWL Carbon Inventory accounts for carbon stored in vegetation, soil, and HWP within California.

Within the fast cycle, the land base contains carbon in organic forms in vegetation and soils. Plants absorb CO_2 from the atmosphere through photosynthesis and store it as biomass, while dead plant material forms soil organic carbon (hereafter "soil carbon") through decomposition. Simultaneously, carbon is released back to the atmosphere as CO_2 through plant and microbial respiration. Carbon can also return to the atmosphere through combustion of biomass during fire, and to a lesser extent, through inorganic processes such as the breakdown of calcium carbonate. The rate and magnitude of these processes are affected by climate, soil type, environmental stress (e.g., extreme heat or drought), land use, and disturbance. Together, the balance between them determines whether lands act as a net sink, removing more carbon from the atmosphere than they emit, or a net source over time [3]. It is for this reason that the Natural and Working Lands (NWL) Carbon Inventory does not isolate a single individual flux, such as wildfire emissions. Rather, it focuses on the net balance between sequestration and emissions, which governs whether lands help mitigate or contribute to climate change. Carbon stocks and stock change provide an integrated measure of this net balance, and assessing it over time is what the NWL Carbon Inventory is designed to do.

The Purpose of the NWL Carbon Inventory: Tracking Progress toward Carbon Neutrality

The California Air Resource Board's (CARB) NWL Carbon Inventory provides a quantitative estimate of organic carbon stored in the State's land base and serves as a tool to support California's climate goals. The purpose of the NWL Carbon Inventory is to monitor carbon stocks across California through time in a way that captures the impacts of climate, wildfires, land use change and other land management activities.

The NWL Carbon Inventory complements CARB's Assembly Bill (AB) 32 GHG Inventory, which tracks GHG emissions from industry, transportation, electric power, commercial and residential operations, recycling and waste, and agriculture (livestock and fertilizer use) [4]. It also complements CARB's Wildfire and Prescribed Fire Emissions Inventory, which provides annual estimates of fire-related emissions. Combined with the SB 901 report on forest management and wildfire impacts (Appendix A), these efforts provide a more complete tracking of the state's GHG emissions and removals over time, and work together to provide transparency on the State's progress toward carbon neutrality (Figure 2).

Figure 2 - Reaching carbon neutrality by 2045 requires reducing statewide GHG emissions from AB 32 sources by 85% below 1990 levels, accounting for natural and working lands, and balancing any remaining emissions through carbon removal technologies [5]. The GHG Inventory tracks trends related to AB 32 emission sources and the NWL Carbon Inventory tracks trends in carbon related to lands.

In addition to tracking progress toward carbon neutrality, the NWL Carbon Inventory can also serve as a tool to support statewide climate action more broadly. For example, it can be used to inform county-level Climate Action Plans or, in the future, help assess the impact of the AB 1757 Nature-Based Solution Climate Targets; as these targets are implemented, any associated changes in carbon stocks are expected to be reflected in future inventory reports. However, the NWL Carbon Inventory is not designed to determine progress toward the AB 1757 targets themselves or to detect change at the scale of an individual project or site. Rather, it is designed to capture trends across larger geographic areas. By providing regional to statewide empirically based estimates of carbon stocks and trends across California, the NWL Carbon Inventory plays a critical role tracking progress towards the State's various climate targets.

The Scope of the NWL Carbon Inventory

The NWL Carbon Inventory provides a retrospective estimate of carbon stocks and stock change across California over time, and accounts for the effects of climate, natural processes, land cover change, wildfire, drought, other natural disturbances (e.g., insects and disease), as well as land management activities. The inventory also assesses greenhouse gas

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(GHG) fluxes from wetlands. Organic carbon stocks are estimated in vegetation and soil, covering all lands within the borders of California, regardless of ownership. This includes forests, shrublands, grasslands, croplands, wetlands, sparsely vegetated lands, cities, and other developed lands. Carbon stocks are also estimated in wood products harvested from the land base for lumber, other building materials, furniture, as well as paper and pulp. Estimates are produced for the inventory period 2001-2022, and where appropriate are grouped into two distinct reporting periods (2001-2013 and 2014-2022) to align with the 2022 Scoping Plan. More information on the specific carbon pools, disturbances, and management activities assessed are provided in the Methods section and Appendix B.

Inventory Estimates

Summary across California

Progress Toward Carbon Target

The 2022 Scoping Plan [5] established a carbon stock change target for NWL, which states that losses in carbon should not exceed more than 4% compared to 2014 values. The results of the 2025 NWL Carbon Inventory indicate that statewide carbon stocks have declined by 4.1% relative to 2014 levels, slightly exceeding the target threshold. While considerable progress has been made over the past 20 years to advance nature-based solutions and integrate NWL within California's climate strategy, this finding highlights the importance of continued conservation, land management, and restoration to minimize future losses and sustain resilient carbon stocks across California's diverse ecosystems.

In 2022, the final year of the inventory, California's natural and working lands stored 4,953 MMT of carbon. Despite occupying only 23% of California's land area (Figure 3), forests stored most of the carbon statewide, accounting for 56% of the total carbon stock (Figure 4). Shrublands, which covered the largest area of any land type (33%), stored about 16% of the state's carbon, reflecting lower carbon densities (metric tons of carbon per acre) compared to forests (Figure 3). Grasslands comprised roughly 12% of the land area and contributed 7.5% of total carbon stocks, while croplands and developed lands each represented 9-11% of California's land area and contributed between 5-6% of the total carbon in 2022. Wetlands, though limited in extent, stored about 2% of California's total carbon, and other lands stored a similar amount (Figure 3; Figure 4). Harvested wood products account for just under 4% of the statewide carbon stocks.

The relative contribution of biomass and soil carbon stocks to total ecosystem carbon varied considerably across land types. In 2022, biomass carbon comprised approximately 64% of the total forest carbon (Figure 4). In all other land types, including other woody-dominated categories such as shrublands, soil carbon comprised the greater share of total carbon stocks. Wetlands and croplands contained roughly three-quarters of the

carbon in soil, while shrublands, grasslands, and developed lands exhibited an even higher proportion (83-84%). Other lands showed the highest contribution of soil to the total, accounting for 96% of carbon in these sparsely vegetated systems.

Between 2001 and 2022, total carbon stocks increased from 4,908 to 4,953 MMT of carbon (Figure 5). On average, this translated to 2.1 MMT of carbon gained statewide per year. However, the rate and direction of change varied nonlinearly over time, with most gains occurring during the first portion of the inventory. Indeed, after peaking in 2016, total carbon stocks began to decline, showing a net loss of 214 MMT (4.1%) when compared to 2014 values.
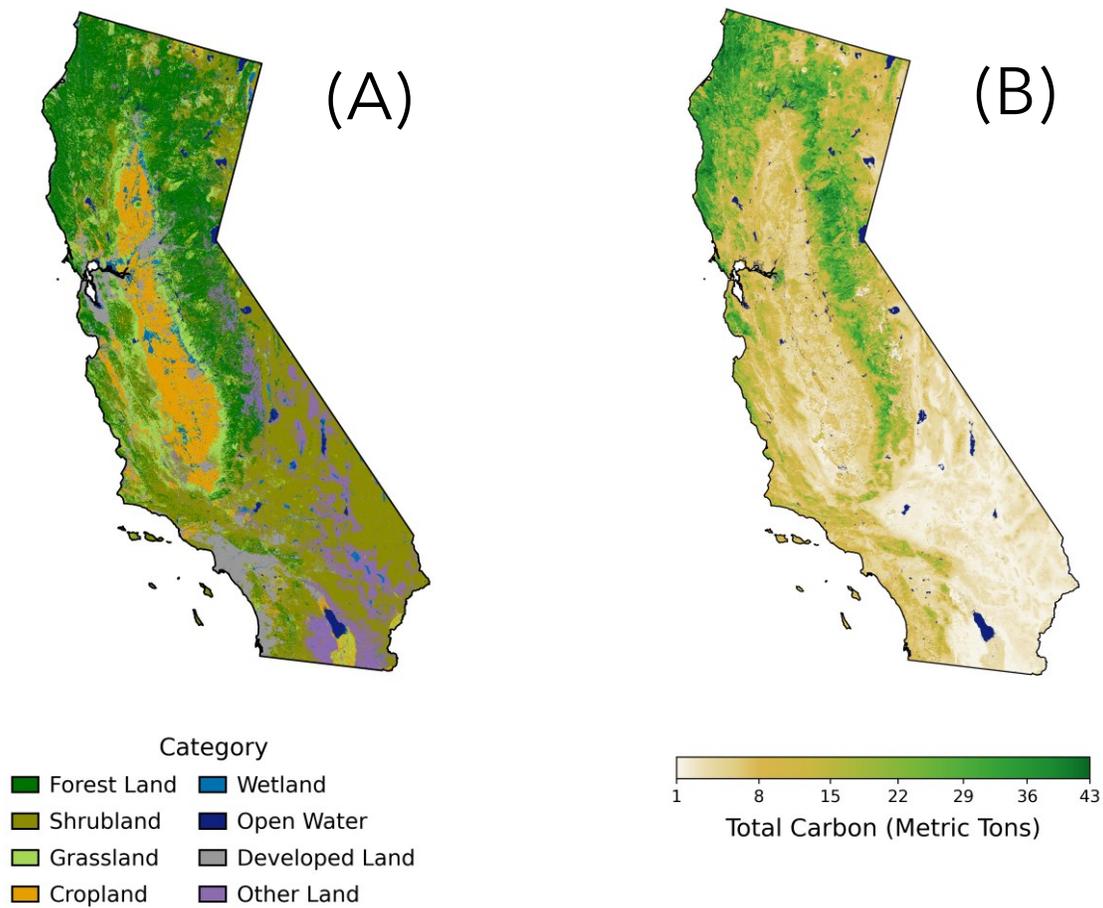
Figure 3 - (A) Land cover across California in 2022. This map does not show energy infrastructure (e.g., distribution and transmission lines, sub stations) though those areas are designated as developed land for quantification and reporting purposes. (B) Total carbon stocks (biomass carbon and soil carbon combined) across California in 2022. Values are expressed in metric tons of carbon per pixel, where a pixel is equivalent to 30 meters by 30 meters or 0.22 acres (0.09 hectares). To convert values to metric tons per acre or per hectare, multiply by 4.5 or 11.11, respectively. Dark blue areas denote open water where carbon stocks were not calculated.

Total Carbon Stocks by Land Cover Type in 2022

■ Soil Carbon ▨ Biomass Carbon
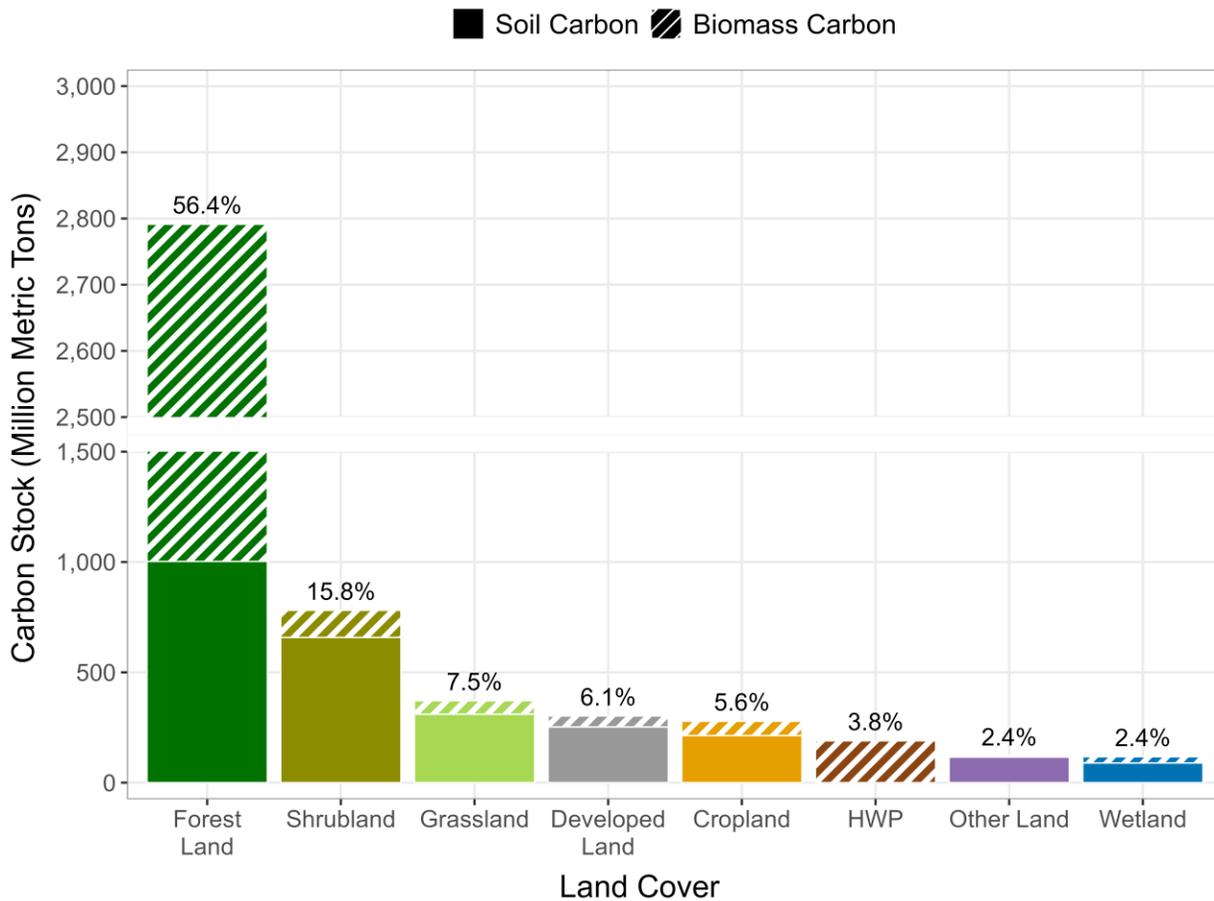
Figure 4 - Total carbon stocks by land cover type in 2022, partitioned into soil (solid) and biomass (striped) carbon pools. Bars represent the combined carbon stocks (in million metric tons of carbon) for each land cover category, including domestically produced harvested wood products. Percent labels above each bar indicate each land type's contribution to the statewide total across all carbon pools. The gap in the border along the Y axis highlights a break between 1,500-2,000 MMT C.

Biomass carbon was the largest contributor to statewide carbon losses, responsible for just over 62% of the total decline between 2014 and 2022 (Figure 5). Soil carbon also declined during this period, contributing approximately 41% of the overall reduction in total carbon stocks. Harvested Wood Products counterbalanced a small portion of this loss, increasing by an amount equivalent to 3.2% of the total statewide decline.

The change from a carbon sink to a carbon source was largely driven by an increase in disturbances after 2014. The period from 2001 to 2013 (13 years) experienced 11.2 million acres of disturbance while the period from 2014 to 2022 (8 years) experienced 17.1 million acres of disturbance, primarily due to an increase in wildfires (Figure 6). Spatial patterns in carbon stock change across California revealed both widespread losses and localized gains

that are reflective of this conclusion (Figure 7). Areas that experienced the greatest declines in total ecosystem carbon between 2014-2022 were concentrated in forested areas of the Sierra Nevada, Cascade Mountains, and Northern Coastal Range (Figure 3; Figure 7). These areas closely aligned with zones of high wildfire activity during the 2014-2022 period, when over 12 million acres burned statewide (Figure 6). In contrast, localized carbon gains were observed along the northern and southern coastlines as well as portions of the Central Valley.

Timeseries of Carbon Stocks by Carbon Pool
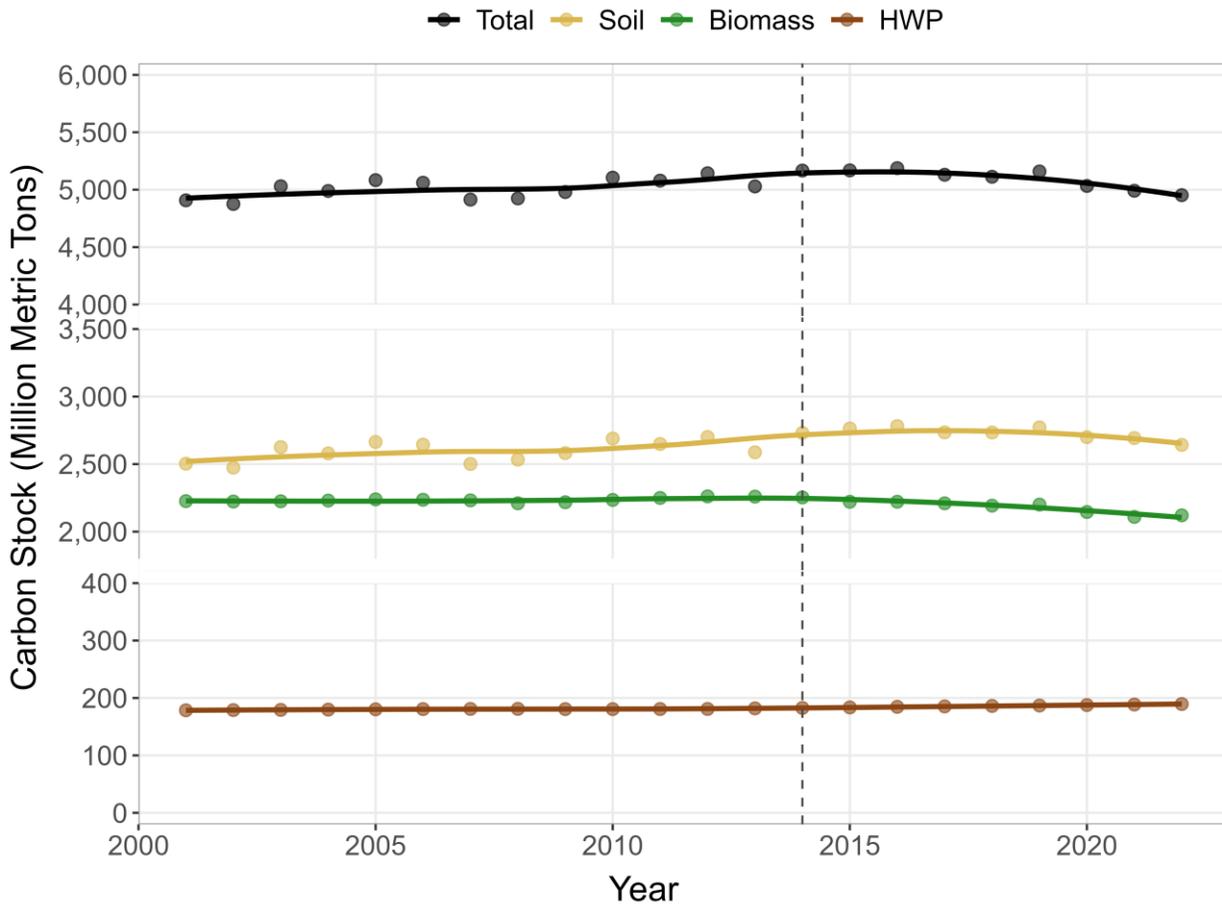
Figure 5 - Time series of carbon stocks by carbon pool. "Soil" denotes soil carbon to 30 cm depth, "Biomass" denotes total biomass carbon, "HWP" denotes domestically produced harvested wood products that are retained within California, and "Total" denotes all carbon pools combined. Each point represents an annual carbon stock estimate in million metric tons of carbon. Lines show LOESS-smoothed trends between 2001-2022. Gaps in the border along the Y axis highlight visual breaks between 400-2,000 and 3,500-4,000 MMT C. The vertical dashed line highlights 2014, which is the reference year for CARB's carbon stock target.

Annual and Cumulative Extent of Disturbance across California

Legend:
- Wildfire
- Insects
- Thinning
- Prescribed Fire
- Other Mechanical
- Mastication
- Harvest
- Clearcut
- Biol-Chem
- Disease
- Development
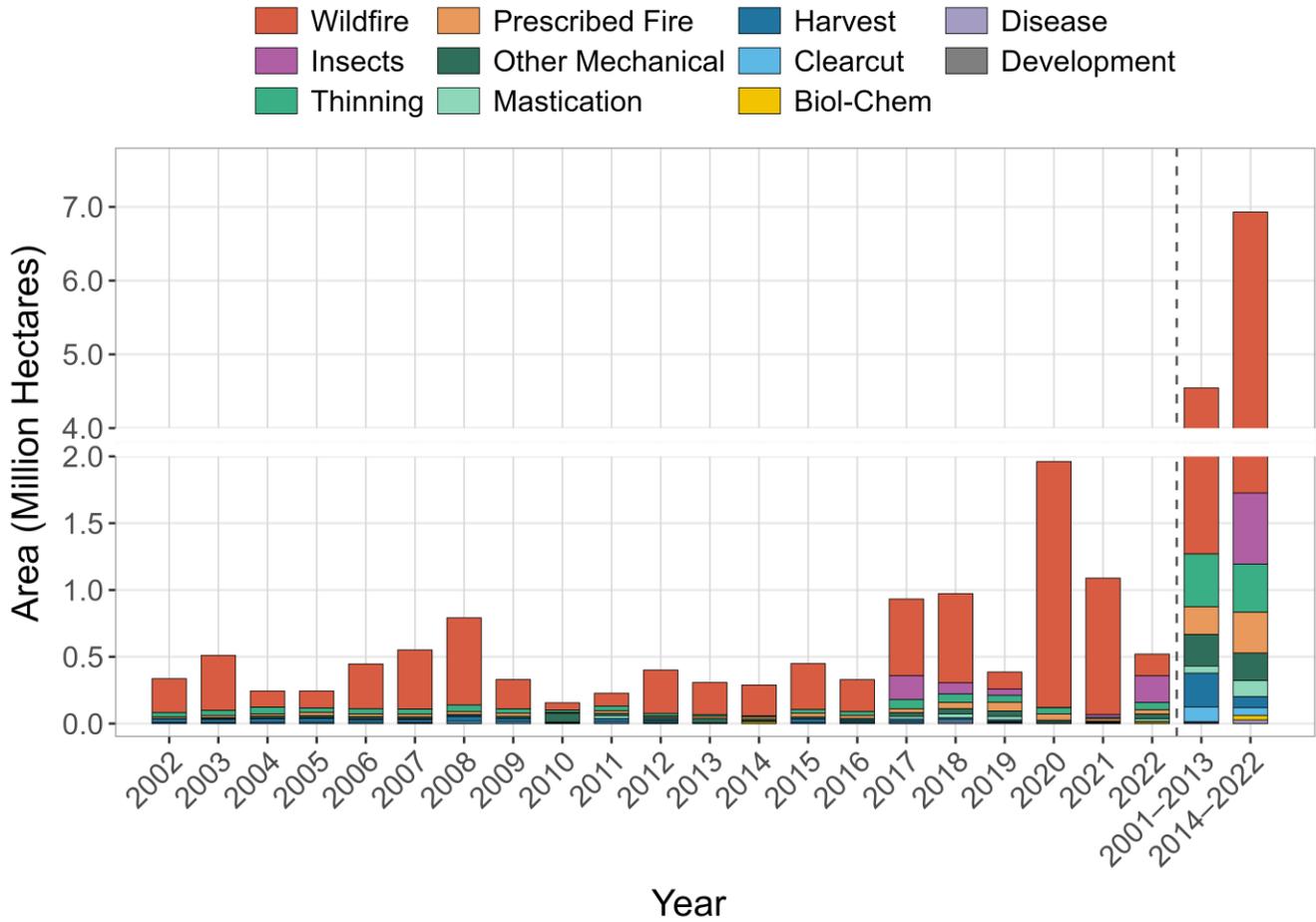
Figure 6 - Annual forest, shrubland, and grassland area affected by eleven disturbance types across California. Cumulative totals are also provided for the two inventory periods (2001-2013 [a thirteen-year period] and 2014-2022 [an eight-year period]) on the far right. The vertical dashed line separates the annual totals from the cumulative totals. The footprint of each disturbance type was determined using LANDFIRE's Annual Disturbance Layer. LANDFIRE disturbance data for 2020-21 were augmented with Cal Fire's Fire and Resource Assessment Program (FRAP) fire perimeters to better capture wildfires during that year.
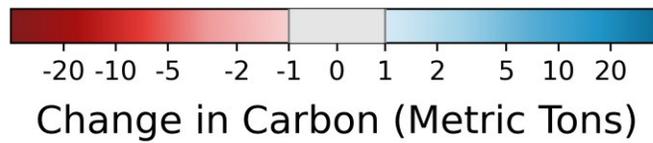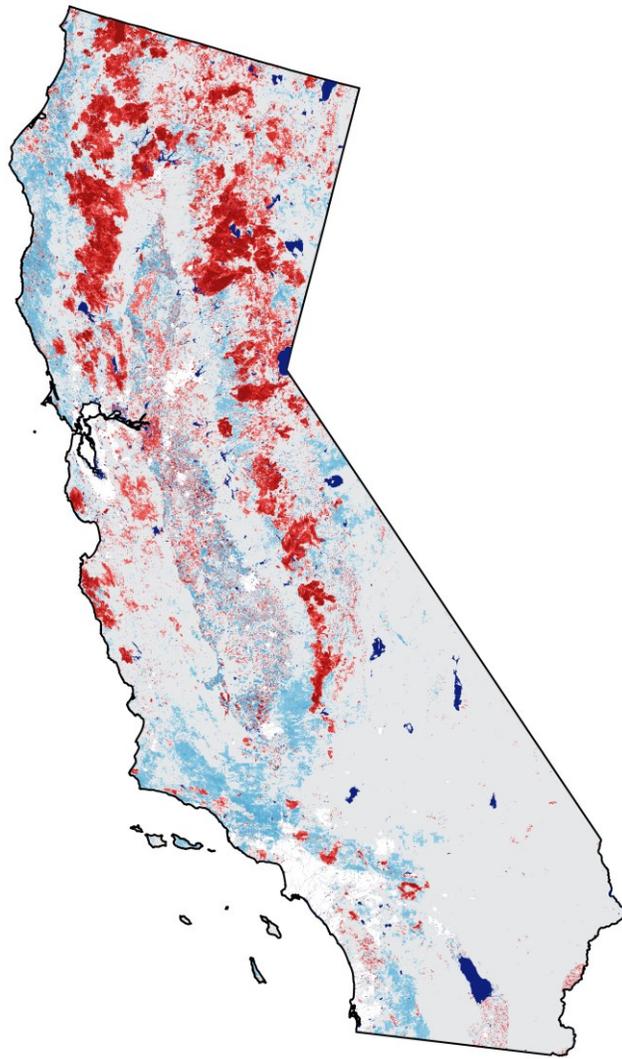
Figure 7 - Change in total carbon stocks (biomass carbon and soil carbon combined) across California between 2014 and 2022. Values were derived by subtracting 2014 estimated values from 2022 estimated values. They are expressed in metric tons of carbon per pixel, where a pixel is equivalent to 0.22 acres (0.09 hectares). To convert values to metric tons per acre or per hectare, multiply by 4.5 or 11.11, respectively. The legend displays a symmetric log scale to visualize both subtler and larger changes. Gray denotes areas that changed by less than +/- 1 metric ton of carbon over the reporting period. White areas represent developed lands that did not have spatially explicit biomass carbon estimates for 2014. Dark blue areas denote open water where carbon stocks were not calculated.

Statewide Biomass Carbon Stocks

In 2022, biomass from across California stored 2,121 MMT of carbon (Figure 8). Forests accounted for approximately 84% of the total biomass carbon statewide, totaling 1,789 MMT of carbon. Shrublands represented the next largest biomass carbon pool on average, storing roughly 6% of the total. Croplands, developed lands, grasslands, and wetlands each contained between 25-60 MMT and collectively stored 10% of the statewide biomass carbon. Other lands comprised a smaller portion of the total, with just 5 MMT of carbon (<1% of the total).

Figure 8 - Time series of total biomass carbon stocks by land cover type. "Total" denotes all land cover types combined. Each point represents an annual carbon stock estimate in million metric tons of carbon. Point estimates for developed land were linearly interpolated for 2001-2011, 2013-2017, and 2019-2021. Point estimates for cropland were linearly interpolated for 2001, 2003-2006, 2008-2011, 2013, 2015, and 2017. Lines show LOESS-smoothed trends between 2001-2022. The gap in the border along the Y axis highlights a break between 200-1,600 MMT C. The vertical dashed line highlights 2014, which is the reference year for CARB's carbon stock target.

Following a period of relative stability, California's overall biomass carbon stock began to decline in 2014 (Figure 8). Losses between 2014 and 2022 totaled on average 17 MMT per year. This trend was driven primarily by forests, which experienced a 10% reduction in biomass carbon stock in the same timeframe. These forest estimates were compared against several independent data sets from various private, governmental, and academic research groups, which showed similar spatial and temporal patterns in forest carbon stocks across California (Figure 23 in Appendix C).

At the same time that forests were losing biomass carbon, grassland biomass carbon stock more than doubled, increasing from 28 to 61 MMT. These changes are consistent with widespread tree mortality, wildfire, and forest-to-grassland transitions observed during the latter half of the inventory period (Figure 6; Figure 4 in Appendix C). Indeed, increases in grassland biomass carbon stock can be explained both by the expansion of grassland area into previously forested and shrub-dominated areas, as well as by an increase in the average biomass carbon density (metric tons of carbon per acre) within grasslands over time (Figure 10 in Appendix C). The increase in average carbon density was largely driven by dead trees and shrubs remaining on the landscape after wildfire in areas newly classified as grassland (Figures 6 and 53 in Appendix C).

Although the amount of biomass carbon associated with grasslands increased over the inventory period, areas that experienced wildfire or other disturbances and subsequently transitioned from forest or shrubland to grassland lost carbon over time (Figure 9). Losses associated with forest-to-grassland conversions were substantially larger in 2014-2022 than in 2001-2013, reflecting the increase in disturbances during this timeframe (Figure 6). Additional land cover dynamics influenced carbon stocks as well. For instance, stable forested areas (i.e., forest land remaining forest land) transitioned from accumulating large amounts of carbon between 2001-2013 to experiencing losses thereafter. In addition, as expected, areas that converted from grassland or shrubland to forest land gained biomass carbon over time. More information on biomass carbon dynamics over the inventory period can be found in Appendix C.

Cumulative Biomass Carbon Stock Change with Land Cover Transition

Cumulative net change (MMT C)

-50.0   -25.0   0.0   25.0   50.0

2001–2013

Starting Land Type	FL	SL	GL	CL	WL	DL	OL
OL	0.0	0.0	0.0	NE	0.0	NE	0.3
DL	NE	NE	NE	NE	NE	NE	0.0
WL	0.1	-0.0	0.0	NE	-0.1	NE	-0.0
CL	NE	NE	NE	NE	NE	NE	NE
GL	42.1	5.3	-0.0	NE	0.0	NE	-0.0
SL	11.6	2.8	-21.1	NE	0.0	NE	0.0
FL	89.5	-50.9	-57.8	NE	-0.1	NE	-0.0

2014–2022

Starting Land Type	FL	SL	GL	CL	WL	DL	OL
OL	0.0	0.0	0.0	NE	0.0	NE	0.2
DL	NE	NE	NE	NE	NE	NE	NE
WL	-0.0	-0.0	-0.0	NE	-0.5	NE	0.0
CL	NE	NE	NE	NE	NE	NE	NE
GL	9.6	1.0	0.5	NE	-0.0	NE	-0.0
SL	3.3	-1.5	-4.4	NE	0.0	NE	-0.0
FL	-6.7	-34.9	-106.8	NE	-0.0	NE	-0.1

Ending Land Type

Figure 9 - Cumulative biomass carbon stock change in million metric tons (MMT C) by land cover transition and reporting period (2001-2013 and 2014-2022). Each tile shows the cumulative net biomass carbon change associated with transitions between starting (rows) and ending (columns) land types. Positive values (blue) represent net carbon gains, while negative values (red) indicate carbon losses. The legend scale saturates at +/- 50 MMT C for visualization purposes. Values within each tile provide exact numbers for each combination. Abbreviations: FL = Forest Land; SL = Shrubland; GL = Grassland; CL = Cropland; WL = Wetland; DL = Developed Land; OL = Other Land. Cumulative values for developed lands and croplands were not estimated due to lack of a consistent time series.

Statewide Soil Carbon Stocks

In 2022, soil across California stored 2,642 MMT of carbon to 30 cm depth (Figure 10). Forest and shrublands accounted for roughly two-thirds of the soil carbon statewide, totaling 1,661 MMT of carbon. Of that, forests comprised 60% and shrublands comprised

40%, respectively. Grasslands represented the next largest pool in 2022, followed by developed lands and croplands, which each contained between 200-350 MMT of carbon. Other lands and wetlands comprised smaller proportions of the total, collectively storing less than 8% of the soil carbon stock statewide.

Timeseries of Soil Carbon Stocks by Land Cover Type
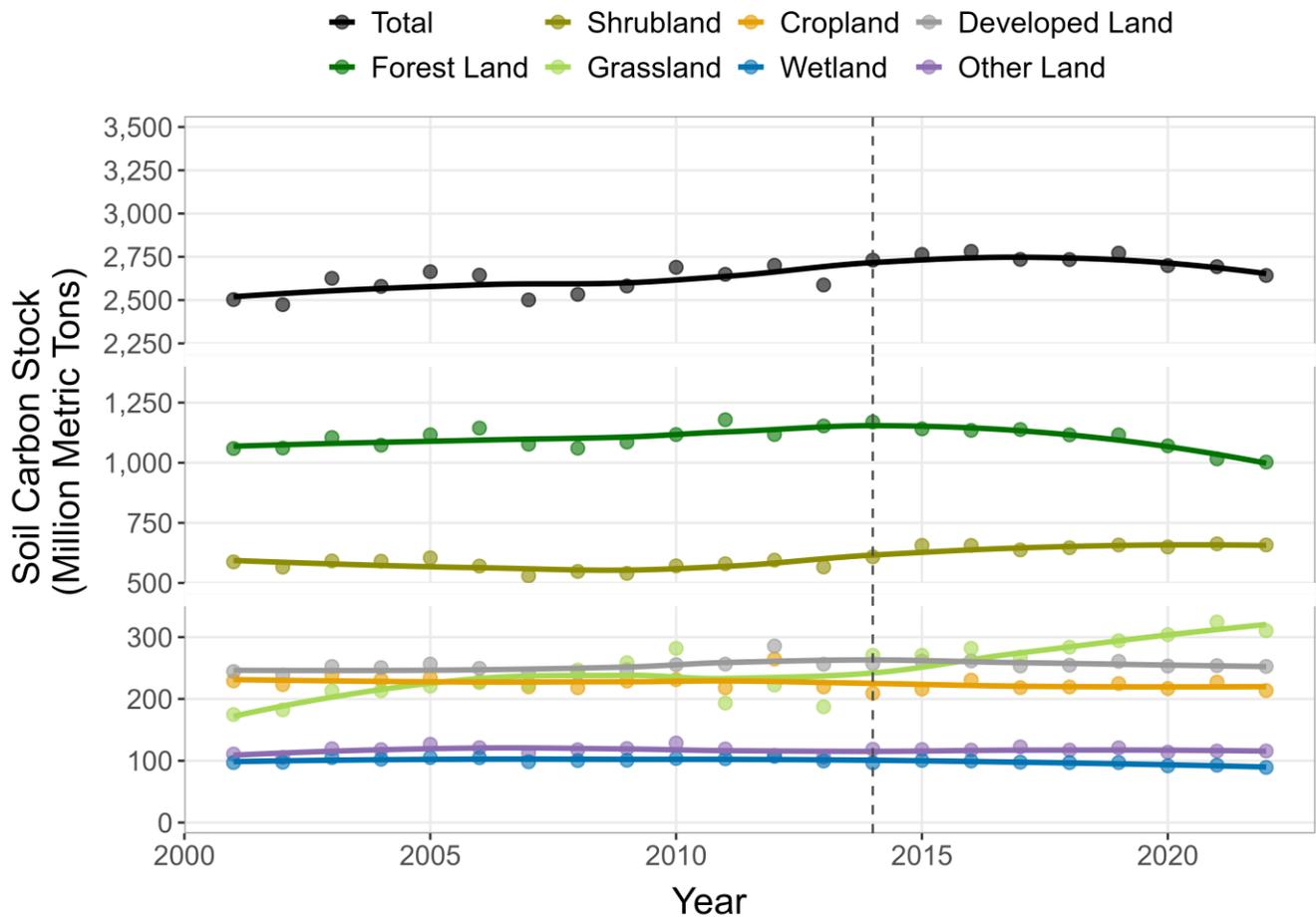
Figure 10 - Time series of soil carbon stocks by land cover type. "Total" denotes all land cover types combined. Each point represents an annual carbon stock estimate in million metric tons of carbon (MMT C) to 30 cm depth. Lines show LOESS-smoothed trends between 2001-2022. Gaps in the border along the Y axis highlight breaks between 350-500 and 1,400-2,250 MMT C. The vertical dashed line highlights 2014, which is the reference year for CARB's carbon stock target.

Between 2001-2022, soil carbon stocks increased by 139 MMT across California (Figure 10). On average, this equated to 6.6 MMT of carbon gained per year or 0.07 metric tons of carbon gained per acre per year. However, the rate and direction of change varied

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nonlinearly over time, with soil carbon stocks decreasing by 88 MMT between 2014 and 2022.

After experiencing a steady increase over the first portion of the inventory (2001-2013), forest soils lost 167 MMT of carbon, equivalent to 14% of the soil carbon stock stored in this land type (Figure 10). The loss from forest soils was partially counterbalanced by grasslands, which experienced a marked and consistent rise in soil carbon stock (40 MMT) beginning around 2014 and which increased nearly 80% over the entire inventory period. This increase was associated with both an expansion of grassland into previously forested and shrub-dominated areas, as well as an increase in the average carbon density (metric tons of carbon per acre) of grassland soils (Figure 13 in Appendix C). The latter dynamic reflects, in part, the conversion and reattribution of higher-carbon forest soils into the grassland category, which pulled the average carbon density up.

While the total soil carbon stock attributed to grasslands grew over the inventory period because of the factors described above, areas that transitioned from forest and shrubland to grassland due to wildfire or other disturbances (Figure 7) lost carbon over time (Figure 11). This was most pronounced between 2014-2022, in large part because the increased amount of land area that type converted (Figure 4 in Appendix C). Additional land cover dynamics influenced carbon stocks as well. During 2001-2013, all land types that remained unconverted, such as forest land remaining forest land, showed net carbon gains. This pattern largely disappeared in 2014-2022, when many unconverted land types exhibited near zero or negative changes (Figure 11). Most markedly, stable forested areas (i.e., forest land remaining forest land) transitioned from accumulating large amounts of carbon to experiencing significant losses, with 44% of the carbon added before 2014 later lost. An exception to this pattern was shrublands, which continued to gain carbon in the later inventory period both within areas that remained shrubland as well as in areas that transitioned from grassland. Additional information on soil carbon dynamics over the inventory period can be found in Appendix C.

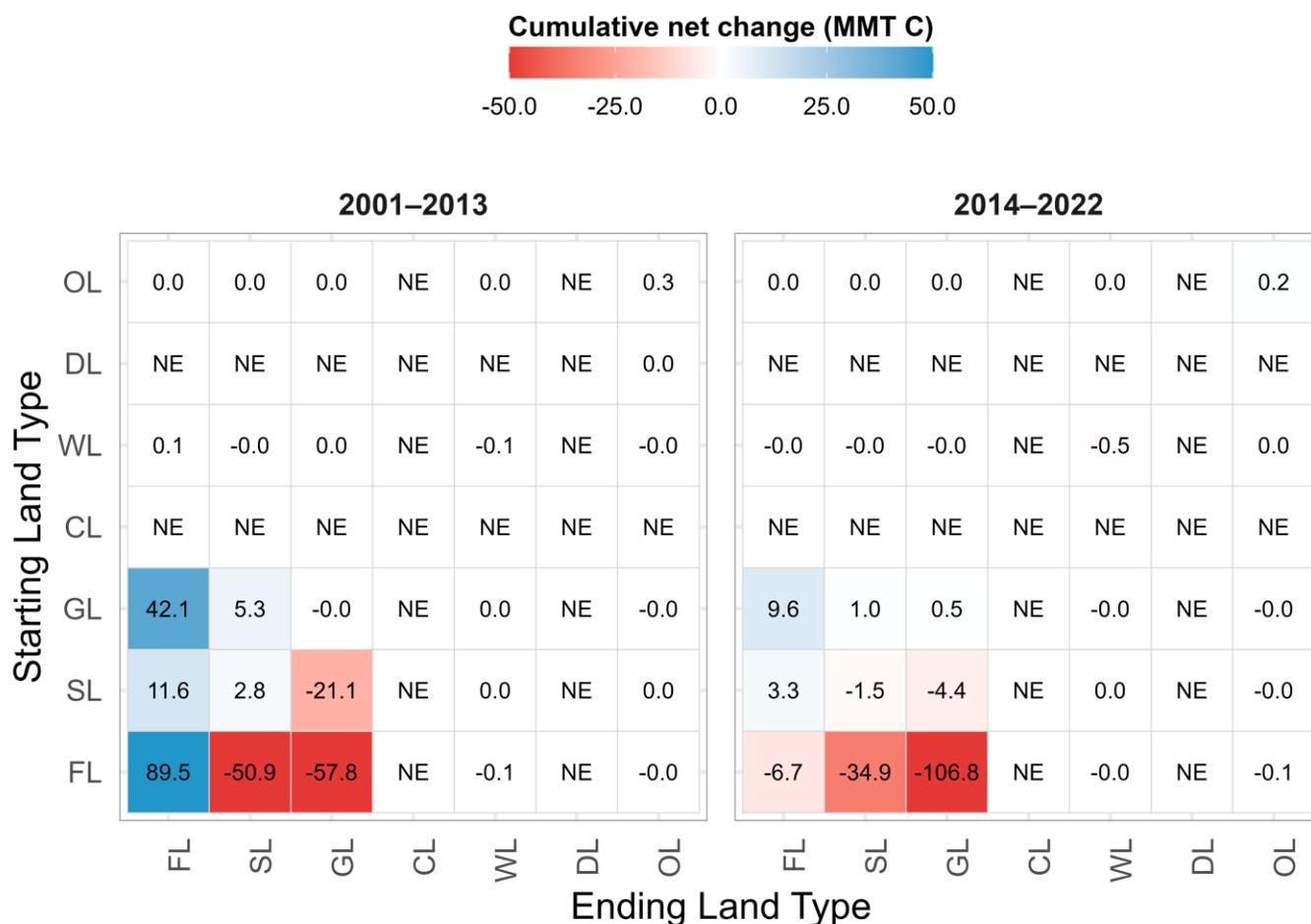# Cumulative Soil Carbon Stock Change with Land Cover Transition

Cumulative net change (MMT C)

-50.0   -25.0   0.0   25.0   50.0

2001–2013

Starting Land Type	FL	SL	GL	CL	WL	DL	OL
OL	-0.0	-0.0	0.0	0.0	-0.0	0.0	6.4
DL	0.0	-0.0	0.3	2.3	0.0	18.5	-0.0
WL	0.0	-0.0	-0.0	0.1	6.2	0.0	0.0
CL	0.1	0.1	4.2	7.3	0.0	0.2	0.0
GL	2.2	-0.6	10.8	0.3	-0.0	0.0	-0.0
SL	0.8	34.4	-3.0	0.2	-0.0	0.0	-0.0
FL	141.7	-3.2	-2.6	0.0	0.0	0.3	-0.0

2014–2022

Starting Land Type	FL	SL	GL	CL	WL	DL	OL
OL	-0.0	-0.0	-0.0	0.0	-0.0	0.0	-2.7
DL	-0.6	-0.2	-0.5	-0.3	-0.0	-0.7	-0.0
WL	-0.0	-0.0	-0.1	-0.0	-0.7	-0.0	-0.0
CL	-0.0	0.2	-3.7	-5.6	-0.2	-0.4	-0.0
GL	-0.5	8.0	0.8	-3.2	-0.2	0.0	0.0
SL	-0.3	9.2	-0.3	0.1	-0.0	-0.1	0.0
FL	-62.5	-5.0	-16.8	0.0	-0.0	-1.3	-0.0

Ending Land Type

Figure 11 - Cumulative soil carbon stock change in million metric tons (MMT C) by land cover transition and reporting period (2001-2013 and 2014-2022). Each tile shows the cumulative net soil carbon change associated with transitions between starting (rows) and ending (columns) land types. Positive values (blue) represent net carbon gains, while negative values (red) indicate carbon losses. The legend scale saturates at +/- 50 MMT C for visualization purposes. Values within each tile provide exact numbers for each combination. Abbreviations: FL = Forest Land; SL = Shrubland; GL = Grassland; CL = Cropland; WL = Wetland; DL = Developed Land; OL = Other Land.

Wetland Greenhouse Gas Fluxes

In contrast to other land types, the Intergovernmental Panel on Climate Change (IPCC) provides guidance for quantifying GHG fluxes from wetlands. As such, GHG fluxes were quantified for California wetlands in addition to carbon stocks. From 2001-2022, wetlands were a net source of GHG (Table 1). However, sink and source dynamics varied by wetland type. Coastal wetlands acted as a consistent sink, with fluxes declining in magnitude over

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time. In contrast, inland wetlands residing on mineral soils were a source of GHG to the atmosphere, showing the largest fluxes of all three wetland types. This was primarily driven by inland wetlands that were managed, such as drained mineral soils subject to rewetting or other mineral soils wetted by human intervention (Figure 115 in Appendix C). Rewetted organic soils also acted as a net source of GHG to the atmosphere, although the fluxes were an order of magnitude lower than inland wetlands on mineral soils. Additional information on GHG flux dynamics from wetlands in California over the inventory period can be found in Appendix C.

Table 1 – Estimated GHG fluxes from wetlands in California, expressed in million metric tons of CO_2 equivalents (MMT CO_2e) over the two reporting periods (2001-2013 and 2014-2022). Net flux exchange for each period combined CO_2 and methane (CH_4) using a 100-year global warming potential (1 metric ton of CH_4 = 28 metric tons of CO_2e). Negative values indicate net flux from the atmosphere to the land (sequestration) and positive values indicate net flux from the land to the atmosphere (emissions).

Wetland Category	GHG Flux (MMT CO₂e) 2001-2013	GHG Flux (MMT CO₂e) 2014-2022
Coastal Wetland	-4.3	-3.0
Inland Wetland Mineral Soil	10.6	7.2
Rewetted Organic Soil	2.5×10^{-3}	2.0×10^{-2}
Total	6.3	4.2

Harvested Wood Products

In 2022, 189.5 MMT of carbon was stored in the domestically harvested HWP pool, exceeding the size of most other biomass carbon pools (Figure 4). Of that 189.5 MMT of carbon, products in-use (PIU) accounted for 70% (132.0 MMT) and solid waste disposal sites (SWDS) accounted for 30% (57.5 MMT).

Between 2001-2022, HWP carbon stocks increased by 10.9 MMT within California (Figure 5). This net increase reflects the balance between annual carbon inputs from domestically harvested materials retained within California's borders and losses from the HWP pool over time. While carbon inputs to this pool declined from peak levels in earlier decades (Figure 118 in Appendix C), they remained relatively stable across the inventory period, averaging 2.7 MMT of carbon per year (Figure 12). Losses associated with combustion and decomposition in SWDS averaged 2.2 MMT of carbon per year and exceeded inputs only briefly during 2009-2011. The sustained inputs, combined with relatively smaller losses, led to the overall net increase in the HWP pool observed over time. Additional information about HWP carbon stocks, including imported materials and net CO_2 conversions, can be found in Appendix C.

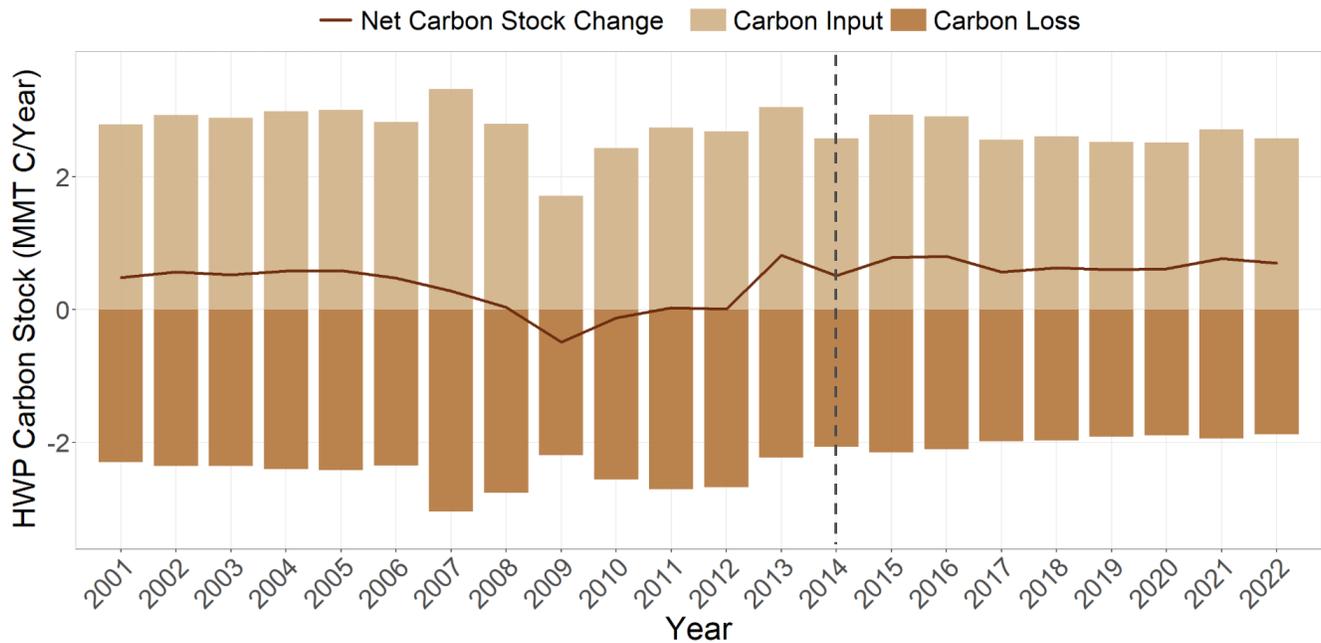## Annual Net Change in Harvested Wood Products Carbon Stocks

Figure 12 - Annual net change in California's HWP carbon stock (MMT C) from 2001-2022. Carbon inputs represent net gains of carbon stock from domestic harvest into the products in use pool remaining within California (e.g. housing, furniture, paper products), whereas carbon loss represents reductions in carbon stock through burning and/or decomposition from HWP in solid waste disposal sites. The net carbon stock change line represents the difference between inputs and losses for a given year. The vertical dashed line highlights 2014, which is the reference year for CARB's carbon stock target.

Methods

IPCC Framework

The NWL Carbon Inventory uses the IPCC's standardized GHG accounting framework that enables governing entities to produce robust and comparable estimates of net GHG emissions within their jurisdictional boundaries [6]. This framework is used by countries worldwide to compile their national GHG inventories under the United Nations Framework Convention on Climate Change (UNFCCC). The guidance is organized by sector and covers all major GHGs, including CO_2, methane (CH_4), nitrous oxide (N_2O), and other short-lived climate pollutants. CARB's NWL Carbon Inventory aligns with this framework by addressing the carbon (CO_2) component of the agriculture, forestry, and other land use (AFOLU) sector. A detailed description of the reporting categories that are covered by the NWL Carbon Inventory as well as the AB 32 GHG Inventory can be found in Appendix B.

IPCC Carbon Pools and GHG Fluxes

Within the AFOLU sector, IPCC guidelines are provided for defining and estimating changes in five carbon pools (Table 2) across all land types [6]. The NWL Carbon Inventory provides estimates for these pools as well as carbon stored in a harvested wood product (HWP) pool, which is described separately below. Consistent with IPCC guidance, the NWL Carbon Inventory also estimates CO_2 and CH_4 fluxes occurring in wetland systems [7].

Table 2 - IPCC-defined pools for carbon accounting used in the NWL Carbon Inventory.

Accounting Category	Pool	Definition
Biomass Carbon	Aboveground Live Biomass	Carbon in all biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.
	Belowground Live Biomass	Carbon in all biomass of live roots. Fine roots <2mm are excluded because they cannot be empirically distinguished from other pools.
	Dead Wood	Carbon in standing or downed dead wood.
	Litter	Carbon in plant litter >2mm in size.
Soil Carbon	Soil Organic Matter	Carbon in organic matter within the fine earth fraction of soil (<2mm in size).

IPCC Land Types

Land cover in the NWL Carbon Inventory is grouped into seven categories, including six IPCC defined land cover types: forest land, grassland, cropland, developed land, other land, and wetland (Table 3). The seventh category separates shrubland from forest land in order to provide a more accurate representation of California's diverse land cover and associated carbon dynamics. Each land cover category is further divided into land remaining in that category and land converted from one category to another over time. Additional subdivisions can be made within the IPCC framework based on land management, climate, or other factors. The subdivisions made for the 2025 NWL Carbon Inventory are listed in Appendix B. In addition, land cover categories are stratified by mineral and organic soil types for soil carbon reporting. This stratification follows IPCC guidance and is necessary because mineral and organic soils contain distinct physical and chemical properties that require separate methodological considerations (Table 4).

Table 3 - IPCC-defined land cover categories and their scope and definitions used in the NWL Carbon Inventory. These definitions generally align with the Climate Smart Land Strategy and AB 1757 Nature-Based Solution Climate Targets, with a few exceptions (see Appendix B for a detailed comparison).

Land Cover	Definition
Forest land	Forest lands include areas exhibiting ≥10% canopy cover of live trees, but that do not meet the criteria for wetlands or developed lands. Forested wetlands, such as montane meadows or riparian zones, are reported under the wetlands land class.

Shrubland	Shrublands include areas exhibiting ≥10% canopy cover of live shrubs and <10% live tree cover that do not meet the criteria for wetlands or developed lands. Shrub-dominated wetlands, such as montane meadows or riparian zones, are reported under the wetlands land class.
Grassland	Grasslands are ecosystems dominated by herbaceous plants with less than 10% tree or shrub cover, but that do not meet the criteria for wetlands or developed lands. This includes rangelands as well as irrigated pastures that fall outside the cropland definition. Herbaceous-dominated wetlands, such as vernal pools, are reported under the wetlands class.
Cropland	Croplands encompass all land managed for crop production, including annual and perennial crops, rice fields, crop-pasture rotations, and temporary fallow land. Agroforestry systems, including alley cropping and windbreaks, are considered cropland instead of forest as long as the dominant land use is crop production.
Developed land	Developed land encompasses areas where humans have built structures, installed energy infrastructure, or created roads. These areas span urban, suburban, exurban, and rural settings, including the wildland urban interface. Developed lands may support residential, transportation, manufacturing, and commercial, infrastructure of any size, as well as parks, golf courses, or other maintained green spaces that are surrounded by the built environment. Wetlands and croplands located within census-designated urban areas are classified according to their underlying land type rather than as developed land. The soil in developed lands may be sealed or unsealed.
Other land	Other lands include areas of sparse vegetation such as sand dunes, bare soil, rock, ice/snow, and land areas that do not fall within the other categories. This also includes unvegetated areas that experience intermittent or partial inundation (e.g., beaches), which lack the hydrologic or soil characteristics needed to be classified as wetland.
Wetland	Wetlands are defined as uncultivated land where soils are inundated by water for all or portions of a year, and include coastal wetlands and inland wetlands on mineral soils. Wetlands where the water table has been artificially changed or created through human activity, such as rewetted soils, are also considered wetlands.

Table 4 - IPCC-defined soil type categories and their scope and definitions used in the NWL Carbon Inventory.

Soil Type	Scope & Definition
Mineral Soil	Mineral soils are defined as all soils that do not meet the criteria for organic soils. They contain comparatively lower amounts of organic matter and typically occur under moderate to well-drained conditions. Most of California's land area sits on soil that is categorized as mineral.
Organic Soil	Organic soils are defined by the presence of a thick organic layer, with a minimum of 12 to 20 percent organic matter by weight. They develop in wetland environments under poorly drained conditions that limit decomposition. In California, organic soils are mostly found in the Delta ecoregion, where they have mostly been drained for

land use purposes. They can also be found in coastal wetlands outside of the Delta, such as in coastal salt marsh ecosystems.

Harvested Wood Products

In addition to the standard carbon pools and land categories defined by the IPCC, the NWL Carbon Inventory includes a separate reporting category for HWP. This category accounts for carbon that is removed from the land through woody biomass harvesting and tracks how that carbon is stored or released over time based on how the material is processed and used. It specifically accounts for carbon that originates from, and stays within, California. While imports are tracked and GHG fluxes are estimated, they are only reported as informational items in Appendix C. In this way, the HWP portion of the NWL Carbon Inventory estimates carbon stocks within California's borders that originate from California forest and orchard management over time.

Harvested Wood Products

Harvested Wood Products represent all wood and bark material that leaves harvest sites, regardless of whether it is eventually incorporated into merchandisable products. This category includes harvested boles that are incorporated into durable wood products such as furniture and building materials, forest and perennial crop woody residues used for advanced biofuels or converted for energy production in processing facilities and power plants, biomass carbon removal and storage technologies such as biochar and bio-oils, as well as decomposable wood in landfills or in landscapes outside of the original harvest sites. Harvested wood products does not include wood left in-place to decompose or burn.

Complementing the NWL Carbon Inventory, the SB901 report on forest management and wildfire impacts (Appendix A) provides estimates for HWP originating from within California, but includes both materials that remain within the state and those exported elsewhere. By extending HWP carbon accounting to include both in-state use and exported material, the SB901 report is able to quantify and report the total amount carbon harvested from California's forest and orchard management activities irrespective of their fate.

IPCC Tiered Methods

Within each reporting category, the IPCC framework outlines three methodological tiers for estimating carbon stock and stock change, which represent increasing levels of complexity. Tier 1 methods rely on globally available default values and are the least data intensive. Tier 2 approaches use region- or country-specific data to refine the default values and improve accuracy. Tier 3 methods involve the highest level of complexity, often using high-resolution data and empirical or process-based models. While higher-tier methods require more data and technical capacity, they are generally considered more accurate when applied appropriately. CARB's NWL Carbon Inventory aims to use the highest tier possible, with

methods varying by land category and carbon pool based on the state of the science and data availability.

Methods by Accounting Category

The methods adopted for each land cover category and carbon pool in the NWL Carbon Inventory were selected based on standardized criteria related to spatial and temporal scale, resolution, sensitivity, and other practical considerations. Using standardized criteria ensures the selected methods address the purpose of the inventory, maintain a high level of rigor and comprehensiveness, and can be reproduced by others. This section describes, in brief, the methods implemented for each carbon pool, land cover category, and soil type. More information can be found in Appendix B.

Biomass Carbon Estimation

Forest land: Forest biomass was quantified with a Tier 3 approach that used the LANDFIRE-C model, which estimates biomass based on LANDFIRE-derived existing vegetation type, height, and canopy cover products.

Shrubland: Shrubland biomass was quantified with a Tier 3 approach that used the LANDFIRE-C model, which estimates biomass based on LANDFIRE-derived existing vegetation type, height, and canopy cover products. LANDFIRE-C was calibrated using plot-level data for shrublands from the BLM Assessment, Inventory, and Monitoring (AIM) and LANDFIRE-DB programs

Grassland: Grassland biomass was quantified using a Tier 3 approach based on annual herbaceous biomass estimates from the Rangeland Analysis Platform (RAP). Belowground biomass was derived from aboveground biomass using ecosystem-specific root-to-shoot ratios derived from published literature, and the two components were summed to estimate total live biomass. Total biomass was then converted to carbon using a 0.45 carbon fraction, producing spatially explicit, annually varying estimates of grassland biomass carbon stock.

Methodological Criteria

Adheres to IPCC guidelines

Optimizes accuracy at statewide scales

Provides wall-to-wall coverage without double counting

Generates spatially explicit results

Allows for stratification by relevant factors, such as ecoregion or ownership

Produces annualized values

Includes as many carbon pools and fluxes as possible

Assesses directionality and magnitude of change

Is sensitive to major drivers of change

Uses transparent, repeatable, and free or low-cost tools

Relies on models that are publicly available and open source

Prioritizes input datasets that are validated, actively maintained, and require minimal pre-processing

Cropland: Woody perennial carbon biomass was estimated using a Tier 3 approach. Maps of perennial crop type and age were combined with crop-specific allometric equations to derive an estimate of carbon stored in aboveground and belowground biomass. Carbon biomass stored in annual crops was assumed to be ephemeral (i.e., grown and subsequently removed from the land within a year) and therefore considered negligible.

Developed land: Woody carbon biomass was quantified using a Tier 3 approach that used a CARB-developed dataset to create regionally stratified statistical relationships between tree density, canopy cover, and woody carbon biomass. The statistical relationships were then applied to maps of tree location and canopy cover to estimate total woody carbon biomass. Quantification of woody carbon biomass in developed lands was constrained to census-delineated urban areas due to data availability, but additional carbon was attributed to developed lands where roads and energy infrastructure overlapped other land types, including in the wildland urban interface.

Other land: Other land carbon biomass was quantified using a Tier 3 approach using the LANDFIRE-C model. LANDFIRE-C was calibrated for other lands using plot-level data from the BLM AIM and LANDFIRE-DB programs, scaled through the Rangeland Vegetation Simulator.

Wetland: Biomass carbon was not explicitly quantified for all wetlands. Where compatible estimates were produced with a Tier 3 approach using LANDFIRE-C or the Rangeland Analysis Platform methods, biomass carbon estimates were retained and reported in the wetlands category. This primarily includes inland wetlands (such as montane meadows, vernal pools, and riparian zones) that are embedded within forest, shrubland, grassland, and other land classes.

Soil Carbon Estimation

Mineral Soil: Mineral soil carbon stocks were estimated using a Tier 3 digital soil mapping approach. A neural network was trained and validated on thousands of soil samples from across California, using a suite of covariates to model spatial and temporal variation in soil carbon. The trained model was then applied to generate annual, wall-to-wall maps of carbon stocks in mineral soil from 2001-2022.

Organic Soil: Organic soil carbon stocks were estimated using a Tier 2 stock-change factor approach. Regionally derived stock-change factors were assigned by land cover to represent carbon dynamics associated with land transitions in organic soils. These factors were applied sequentially, statewide to the 2022 mineral soil carbon map, generating annual estimates of land-cover-specific organic soil carbon change from 2001–2022.

Greenhouse Gas Flux Estimation

Wetland: Wetland CO_2 and CH_4 fluxes were quantified using a Tier 2 emissions factor approach, with factors synthesized from Tier 1 factors, CARB-published values, and new

data. The new data included regionally derived emissions factors for coastal wetlands (spanning multiple salinity classes) and montane meadows from published eddy covariance and chamber-based annual budgets. All factors were assigned by land cover type and applied sequentially, statewide from 2001-2022.

Harvested Wood Product Carbon Estimation

Harvested wood products: Harvested wood product carbon estimates were derived using a Tier 3 approach with California-specific data and modelling parameters. The Harvested Wood Products Carbon Model (HWP-C vR) was used to estimate how domestically-produced carbon moves into, within, and out of California's HWP pool over time—including carbon stored in PIU and in SWDS. Exports were excluded from the reported estimates, as were imported products. However, information on exports and imports were provided in the SB901 report and as a supplemental, informational item in Appendix C, respectively.

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