CALIFORNIA
AIR RESOURCES BOARD

# An Inventory of Ecosystem Carbon in California's Natural & Working Lands

2018 Edition

# Acknowledgements

CARB staff wishes to express their appreciation to the many organizations and government agencies that were an integral part of developing the NWL Inventory. We would like to thank the following organizations for providing their technical support:

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**Errata**

Three minor typos were identified and corrected on February 27, 2020.

Figure E-3 on page 10 and Figure 8 on page 38 listed disturbances by type in units of acres. The correct unit is hectares.
The first sentence in the fourth paragraph of section 3B.1 – Forest and Other Natural Lands on page 35 referenced Table 7. The sentence should have referenced Table 9.

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# Executive Summary

## Background

The California Air Resources Board's (CARB) Natural and Working Lands (NWL) Inventory is a quantitative estimate of the existing state of ecosystem carbon stored in the State's land base. It provides estimates of carbon stocks, stock-change, and resulting greenhouse gas (GHG) flux associated with stock change in California's landscape, and attributes stock changes to disturbances. The NWL inventory is an important tool for tracking the impacts of interventions, such as projects funded by California Climate Investments and bond funds, and informing how California's land base contributes to the State's climate goals. It supports the implementation of the California NWL Climate Change Implementation Plan (California State Agencies, 2018) by serving as the inventory of record for NWL and tracking statewide progress toward the State's long-term objectives for NWL.

The Earth's carbon cycle involves the exchange of carbon between the atmosphere, biosphere (plants, animals, and other life forms), hydrosphere (water bodies), pedosphere (soils), and lithosphere (Earth's crust and mantles, including rocks and fossil fuels). Carbon moves between land types (e.g., forests and grasslands) and carbon pools[1] (e.g., wood, roots, and soils) due to natural processes (growth, decay, and succession) and disturbances (e.g., wildfire) or anthropogenic forces such as land use change. The NWL Inventory tracks how much carbon exists in California's ecosystems, where that carbon is located, and estimates how much carbon is moving in and out of the various land types and carbon pools. It provides stored carbon "snapshots" and gives insight into the location and magnitude of NWL carbon stocks at discrete moments in time.

NWL plays an important role in the State's climate strategy by contributing to carbon sequestration and GHG reduction, and the NWL Inventory is a key tool for tracking the impacts of these strategies. The NWL Inventory was developed based on the Guidelines for National Greenhouse Gas Inventories of the United Nations Intergovernmental Panel on Climate Change ("the IPCC Inventory Guidelines"), which includes quantification of direct emissions from human activities, as well as ecosystem carbon stock change on land. To track changes in carbon stock across the State, CARB developed a NWL Inventory focused on ecosystem carbon accounting to meet the following design objectives: geospatially and temporally explicit, utilizes input datasets that are refreshed regularly, and allows continual inventory improvements as science advances and new data become available. For the past 8 years, CARB staff collaborated with the research community and other State agencies to develop inventory methodologies for all land types in California. The methodologies utilize a combination of remote sensing data and ground-based measurement data, as well as other default assumptions where California-specific data are not available. The NWL inventory includes:

- Forest and other natural lands (woodland, shrubland, grassland, and other lands with sparse vegetation): live and dead plant materials and their roots
- Urban land: trees in urban area
- Cropland: woody biomass in orchards and vineyards

[1] "Carbon pools" are Above-Ground Live Biomass (boles, stems, and foliage in shrubs, trees, grasses, and herbaceous vegetation), Below-Ground Live Biomass (roots in shrubs, trees, grasses, and herbaceous vegetation), Dead Organic Matter (standing or downed dead wood and litter), Harvested Wood Products (all wood and bark material that leaves harvest sites regardless of whether it is eventually incorporated into merchandisable products), and Soil Organic Matter (organic carbon in the top 30 cm of soil).

- Soil Carbon: organic carbon in soils for all land types
- Wetlands: $CO_2$ and $CH_4$ emissions from wetland ecosystem

## Current NWL Inventory

There are approximately 5,340 million metric tons (MMT)[2] of ecosystem carbon in the carbon pools that CARB has quantified.[3] (To put it into context, 5,340 MMT of carbon in land is equivalent to 19,600 MMT of atmospheric $CO_2$ currently existing as carbon in the biosphere and pedosphere as carbon cycles through the Earth's carbon cycle.) Forest and shrubland contain the vast majority of California's carbon stock because they cover the majority of California's landscape and have the highest carbon density of any land cover type. All other land categories combined comprise over 35% of California's total acreage, but only 15% of carbon stocks. Roughly half of the 5,340 MMT of carbon resides in soils and half resides in plant biomass. **Figure E-1** shows carbon distribution by land category (inner ring of the pie chart) and by carbon pool (outer ring of the pie chart). **Table E-1** summarizes carbon stocks by land category and the fractions of total State land area in each land category.

[2] The 5,340 MMT of carbon figure is a preliminary approximation for 2014 that was partially extrapolated from data for older years. Data for biomass were estimated using empirical data for the year 2014. Data for soils were extrapolated from the 2001–2010 soil carbon inventory to 2014. At the time of finalizing this document, CARB staff is still working on developing a soil carbon inventory for years after 2010.

[3] There are other known carbon pools that have not been quantified due to lack of data or method. These include soil carbon at greater than 30-centimeter depth, fine roots of plants, foliage, and herbaceous plants in urban area. Therefore, the 5,340 MMT of carbon figure does not capture all ecosystem carbon in California's landscape.

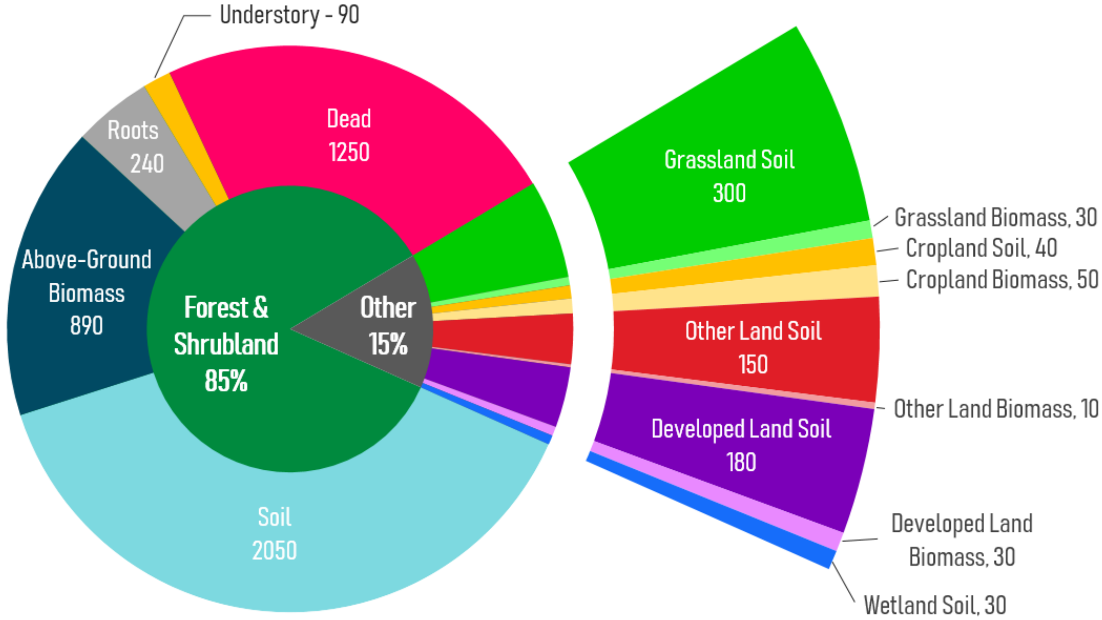


**Figure E-1.** 2014 distribution of biomass and soil carbon stocks on the California landscape in MMT carbon (rounded to the nearest 10 MMT). There is approximately 5,340 MMT of carbon in the carbon pools for the year 2014.[4]

**Table E-1. 2014 Total Carbon Stocks and Percent of Total Land Area by Land Category**

| Land Category | Total Carbon Stocks [a] (MMT C) | % of Total Carbon Stocks [d] | % of Total Land Area [d] |
|---|---|---|---|
| *Forest and Shrubland* | 4,520 | 85% | 54% |
| *Grassland* | 330 | 6% | 10% |
| *Other Natural Land [b]* | 160 | 3% | 19% |
| *Cropland* | 90 | 2% | 9% |
| *Developed Land [c]* | 210 | 4% | 9% |
| *Wetland* | 30 | 1% | << 1% |
| **TOTAL** | **5,340** | **100% [d]** | **100% [d]** |

[a] Total carbon stocks include biomass of living and dead plants, as well as soil organic carbon. Data for biomass were estimated using empirical data for the year 2014, and data for soils were extrapolated from the 2001 – 2010 soil carbon inventory to 2014.

[b] Other natural land includes areas of sparse vegetation, such as desert, bare soil, rock, ice/snow, and land areas that do not fall within the other categories.

[c] Developed land includes urban area, human development in non-urban area, and transportation infrastructure (e.g., roadways) that traverses either urban or non-urban area.

[d] Numbers may not add up to 100% de to rounding errors.

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[4] See footnotes 2 and 3 on the previous page for additional information regarding extrapolating 2014 soil carbon estimates using the trends for 2001-2010 and other known carbon pools that have not been quantified to date.

**Figure E-2** presents the trends in carbon stock change over time. Soil is the largest carbon reservoir. Using the IPCC default assumptions, most of the estimated net change in soil carbon was due to microbial oxidation of organic soil on the Sacramento-San Joaquin Delta. Disturbance caused by tillage and other agricultural management practices, land conversion, and land degradation also contributed to the soil carbon loss. Forest and shrubland carbon stocks in 2010 was 6% lower than in 2001 due to a number of large wildfires that occurred during the 2001-2010 period. (Future inventory editions will capture the impacts of large fire events seen in recent years.) Woody crops and urban forest both gained carbon, as these trees are generally well maintained due to their economic and aesthetic values. Part of the carbon gain seen in urban forests came from expansion of the urban footprint over this period of time. Movement of carbon among land types and carbon pools is a dynamic process. Carbon gain in one land type may be a result of carbon loss in another land type, and vice versa.

Although carbon that leaves the land base is counted as a carbon stock loss in the NWL Inventory, not all carbon stock loss becomes emissions released into the atmosphere. Some of the carbon leaving the land base continue to retain carbon as durable wood products (e.g., furniture and building materials). To help readers put carbon stock numbers into context, one MMT of carbon stock loss is equivalent to foregoing 3.7 MMT of $CO_2$ that was previously sequestered in plants and soils. For example, for forest and other natural lands (**Figure E-2**), the 155 MMT decrease in carbon stock during the 2001–2010 period is equivalent to foregoing 568 MMT of $CO_2$ that was previously sequestered in plants and soils, and the 16 MMT increase in carbon stock during the 2012–2014 period is equivalent to sequestering 57 MMT of $CO_2$ from the atmosphere.

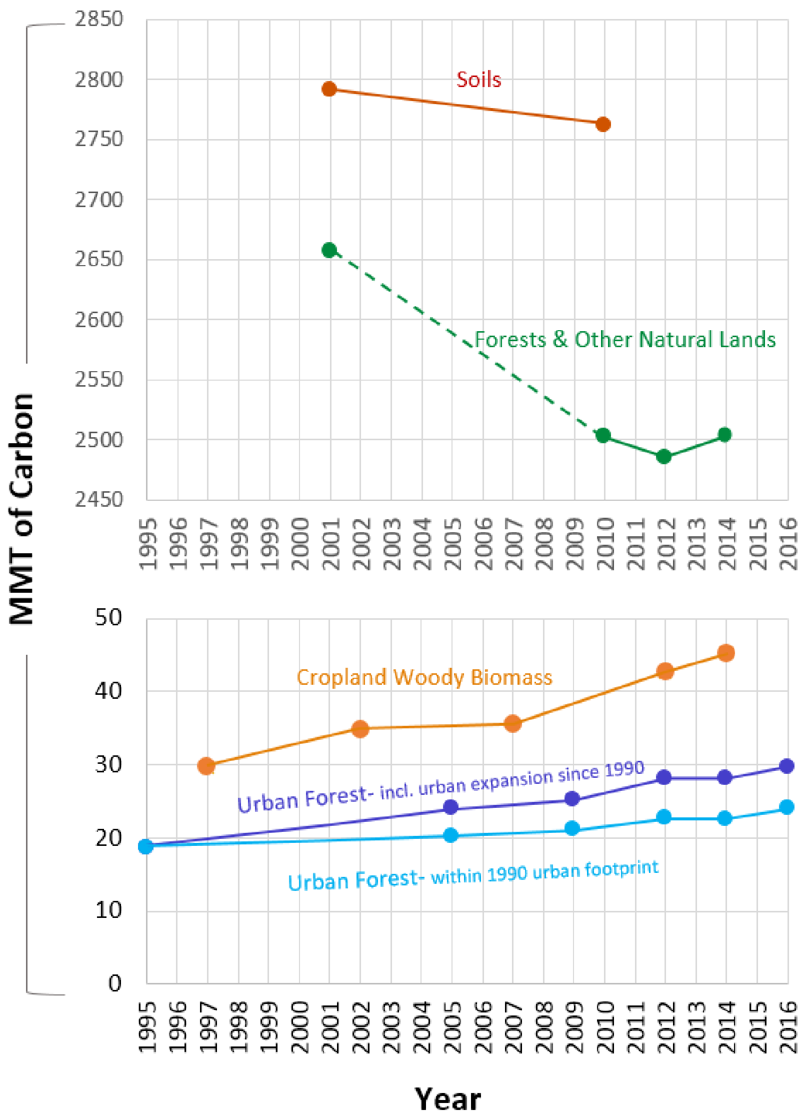


**Figure E-2.** Trends in carbon stocks over time (MMT of carbon). Due to the large difference in scale, soils and FONL are shown in the top panel, and cropland woody biomass and urban forest are shown in the bottom panel. Each solid circle represents a "snapshot" of inventory estimate based on available empirical data. The 2001–2010 period for FONL is shown as a dotted line because large year-to-year variations during that period are not represented by a straight line.

## Disturbances in Forest and Other Natural Lands

Geospatially explicit carbon stock change information can be related to the different types of disturbance on land. During the 2001–2014 period, wildfire accounted for 74% and prescribed fire accounted for 3% of the areas that experienced disturbance. The impact of wildfire can be seen throughout the State, in both rural areas and urbanized areas near shrublands and forest. Harvest and clearcut accounted for 11%, and fuel reduction activities (thinning, mechanical, and mastication) accounted for 14% of the disturbed area. **Figure E-3** presents a map of disturbances that occurred on California landscape in 2001–2014.

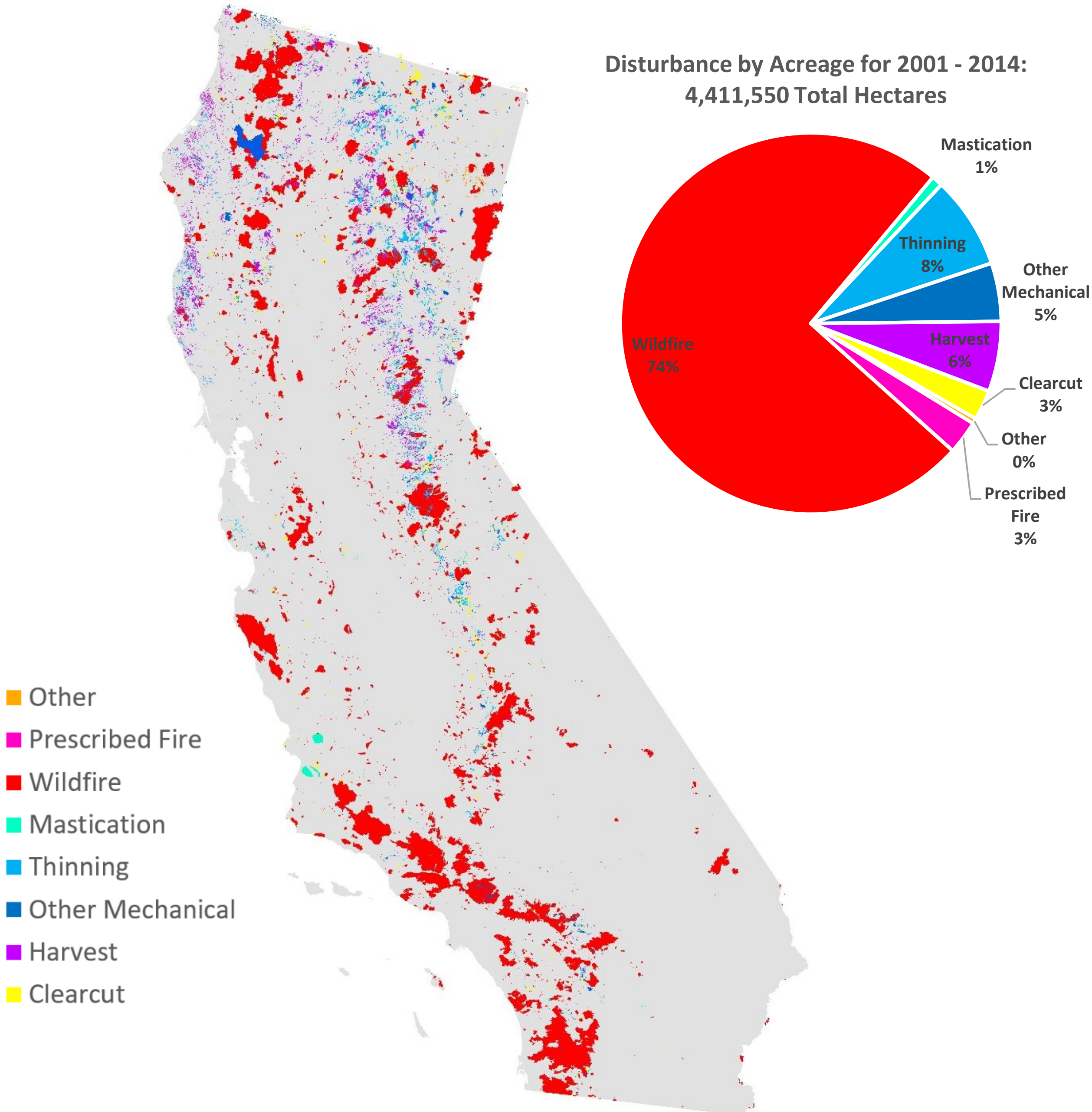


**Figure E-3**.** Map of disturbances that occurred on the California landscape during the 2001–2014 period. Wildfire accounted for most of the disturbances by area during this period. The impact of wildfire can be seen throughout the State, in both rural areas and urbanized areas near shrubland and forest.

***Errata: Figure E-3 was updated on February 26, 2020 to correct the reported units in the Disturbance by Acreage pie chart. The original version reported Disturbance by Acreage in acres, which has been updated to the correct unit of hectares in this version.*

## Future Work

***Uncertainty of the Inventory Estimates*** The science, method, and technique for accounting of ecosystem carbon are relatively new and still rapidly advancing. Although significant progress has been made in the inventory development, more work still needs to be done. The parts of the NWL Inventory that have been in development for more years generally have a reasonably constrained uncertainty (between 15% and 40%), but other parts of the inventory that CARB started to develop more recently contain significant uncertainties (**Table E-2**). As CARB continues to improve inventory methods and data over time, the inventory estimates published in this document will be revised in the future.

**Table E-2. Preliminary Estimate of Uncertainty Range of the NWL Inventory**

| Land Type/Carbon Pool | Estimate of Uncertainty Range |
|---|---|
| Forest & Other Natural Lands: | |
| *Above-Ground Live Biomass* | ±20%–40% |
| *Dead Biomass* | 2 orders of magnitude |
| Cropland Biomass | ±15% |
| Urban Forest | ±15% |
| Soil Carbon | at least ±90% (likely more) |

***Future Inventory Improvements*** During the development of the NWL Inventory, CARB consulted with other State agencies and conducted a public workshop seeking input from members of the public. The comments and suggestions collected during the consultation process are incorporated into a list of inventory improvements that CARB staff plans to undertake in the coming years. These include:

- Move to using biogeochemical modeling for soil carbon flux estimates
- Improve vegetation classification and mapping of wetland and cropland to reduce the errors in satellite-based data
- Incorporate more recent U.S. Forest Service- Forest Inventory and Analysis (FIA) field data to update carbon densities
- Implement a standard work flow to break out of forest land into common categories (e.g., woodland, shrubland), and report stock and changes for forest and shrubland separately
- Improve estimate for harvested wood products using more updated mill survey and industry data
- Improve estimation of carbon after fires, tree mortality events, and other disturbances
- Analyze the carbon loss and gain at the interfaces of urban and non-urban lands
- Annualize the inventory for years that do not have remote sensing data
- Integrate the different segments of the inventory by reconciling spatial boundaries of input data

CARB will continue to work with other State agencies and the scientific community to improve the inventory estimates. As improvements are made to methods and additional data are incorporated, CARB staff will look into updating the entire inventory series, including older years that have been quantified in previous editions of the inventory.

### *Scenario Modeling Analysis*

The NWL inventory work described in this document represents California's NWL for a specific time period in the past. It is a retrospective inventory, and it does not include a future scenario projection.

Moving forward, CARB intends to develop in-house technical capability to conduct policy scenario analyses by integrating existing modeling tools into a modeling system. These tools may be used for understanding how policies or programs may impact future NWL carbon stock, and for informing the trajectory of NWL carbon under various climate and policy scenarios. The retrospective inventory provides initial conditions for projection modeling and can be used for validating the model.

### *Historical Baseline of Natural Fire Regime*

In 2018, the California Legislature enacted SB 901 (Dodd, Chapter 626, Statutes of 2018), which requires CARB to develop a historical baseline of natural fire regime reflecting conditions before modern fire suppression to better understand the level of carbon loss expected from naturally occurring fire. CARB staff will be working with the research community to develop a historical fire baseline pursuant to SB 901.

# 1 – Introduction

The California Air Resources Board's (CARB) Natural and Working Lands (NWL) inventory is a quantitative estimate of the existing state of ecosystem carbon stored in the State's land base. It provides a retrospective estimate of carbon stocks, stock-change, and resulting greenhouse gas (GHG) flux associated with stock change in California's landscape, and attributes stock changes to disturbances. This inventory provides stored carbon "snapshots" and gives insight into the location and magnitude of NWL carbon stocks at discrete moments in time. It informs how carbon is transferred between the different land types, carbon pools, and the atmosphere as human actions lead to relocation of carbon in the landscape. It can be used to track NWL's contribution to the State's effort in addressing climate change and inform how California's land base can demonstrably contribute to the State's ambitious climate goals.

CARB has been publishing a statewide GHG inventory annually since 2007, but the science and technique for accounting of ecosystem carbon is relatively new and still rapidly advancing. For the past 8 years, CARB staff collaborated with the research community and other State agencies to develop inventory methodologies for all land types. Significant progress has been made in the inventory development, but more work still needs to be done. The parts of the NWL Inventory that have been in development for more years generally have a reasonably constrained uncertainty (between 15% and 25%), but other parts of the inventory that CARB started to develop more recently contain significant uncertainties that staff will continue to reduce through future inventory improvements. These include an uncertainty of at least ±90% (likely more) for the soil carbon inventory and a two orders of magnitude uncertainty for dead biomass carbon stock. As CARB continues to improve inventory methods and data over time, the inventory estimates published in this document are expected to be revised in the future.

This document presents the NWL Inventory development work completed to date and describes future work that CARB staff has planned to continually improve inventory estimates over time. The document is organized as follows:

- **Section 1** provides background information about the legislative directives, the evolution of NWL Inventory development at CARB, and the scope of the NWL Inventory.
- **Section 2** presents the fundamentals of the inventory accounting framework, including an introduction to the carbon cycle, a summary of the IPCC Inventory Guidelines (IPCC, 2006), and a discussion on the use of California-specific information within the inventory framework.
- **Section 3** summarizes the current understanding of ecosystem carbon stocks in California based on the NWL Inventory work that CARB staff has completed to date.
- **Section 4** discusses future work that CARB staff has planned to continually improve inventory estimates.
- **Section 5** includes a discussion comparing CARB's NWL Inventory with other inventory estimates of California ecosystem carbon.

In addition, Appendix 1 presents a guide to which IPCC inventory categories are included in the NWL Inventory versus the annual statewide GHG inventory, and Appendix 2 includes a list of acronyms used in this document. This document is intended to provide a summary of the NWL Inventory and does not capture the detailed methods, data, parameters, and assumptions used in the NWL Inventory. Detailed technical information can be found in the NWL Inventory Technical Support Document (TSD) (CARB, 2018) available at: https://www.arb.ca.gov/cc/inventory/sectors/forest/forest.htm.

## 1A – Legislative Directives and NWL Inventory Development

Emission inventory is the foundation for all emission reduction programs. It is an important tool for tracking progress towards the State's air resource management goals. In 2006, Assembly Bill (AB) 1803 (Health & Safety Code Section 39607.4) transferred responsibility for maintaining a statewide GHG inventory from the California Energy Commission (CEC) to CARB, and the California Global Warming Solutions Act of 2006 (AB 32) (Nunez, Chapter 488, Statutes of 2006) designated CARB as the lead agency to work with State agencies and stakeholders to address climate change. In implementing the requirements of AB 1803 and AB 32, CARB has followed the GHG inventory framework of the IPCC since 2006 to ensure consistency and comparability with other jurisdictions. A jurisdiction-wide GHG inventory that is consistent with the IPCC Inventory Guidelines (IPCC, 2006) includes quantification of direct emissions from human activities, as well as ecosystem carbon stock change on land.

The first edition of CARB's GHG emission inventory was published in 2007 and included an estimate of carbon sequestration in forests and rangelands based on the best available information at the time: a 2004 CEC-funded study which quantified carbon stocks and change in forests and rangelands in the northern part of the State from 1994 to 2000 (CEC, 2004). Results from that study were extrapolated to include the entire State and to other years. The estimation approach contained significant uncertainty and afforded few options for updating.

CARB recognized that further technical development was needed to quantify ecosystem carbon stock across California's landscape. CARB created a team to focus on the development of the ecosystem carbon portion of the GHG inventory. This portion of the inventory work that focuses on ecosystem carbon stocks is called "Natural and Working Lands Inventory," and the other parts of the inventory that focus on direct emissions from human activities are included in CARB's annual statewide GHG inventory. CARB's goal for developing a NWL Inventory is to provide an understanding of the location and quantity of carbon stocks on California's landscape and how those stocks are changing due to disturbances, climate change, and human activity. To meet these goals, an ecosystem carbon inventory should be geospatially and temporally explicit, have "wall-to-wall" coverage of the whole State, utilize input datasets that are refreshed regularly, enable CARB staff to periodically generate inventory estimates using in-house resources, and allow continual inventory improvements as science advances and new data become available.

CARB began collaboration with University of California–Berkeley, the National Park Service (NPS), U.S. Department of Agriculture (USDA) Forest Service - Pacific Southwest Research Station (USDA-FS PSW), and Spatial Informatics Group to develop methods for generating geospatially explicit estimates of carbon stocks and change on forests and other natural lands (FONL) across the State (Battles, et al. 2013; Gonzalez, et al. 2015). Using these new methods, in 2016 CARB published the first edition of a FONL inventory that covered the 2001-2010 time period (the most recent years of data at the time of method development). More recently, CARB staff has also:

- developed an original methodology for cropland woody biomass inventory;
- produced an extended time series of urban forest inventory by further refining the methodology of Bjorkman, et al. (2015);
- generated a soil carbon inventory using a combination of spatial datasets, IPCC default assumptions, and biogeochemical modeling; and
- produced one vintage of wetland inventory using best available spatial dataset and IPCC emission factors.

In 2016, the California Legislature enacted Senate Bill (SB) 859 (Committee on Budget and Fiscal Review, Chapter 368, Statutes of 2016) requiring CARB to publish a NWL Inventory by December 30, 2018, in consultation with the California Natural Resources Agency (CNRA) and the California Department of Forestry and Fire Protection (CAL FIRE). CARB consulted with sister agencies and conducted a public workshop seeking input from members of the public. The comments and suggestions collected during the consultation process are incorporated into a list of inventory improvements that CARB staff plans to undertake in the coming years (see **Section 4** – Future Work). Like all the inventories developed and maintained by CARB that are constantly being improved over time, staff will look for opportunities to continually improve the NWL Inventory in the future. This continual inventory improvement process is also consistent with the IPCC Inventory Guidelines, which instruct jurisdictions to generate inventory estimates based on the best data and methods available at the time of each inventory compilation, but continually to refine inventory estimates for current as well as older years in future inventory editions.

## 1B – Inventory Scope

CARB's NWL Inventory covers all land areas within the borders of California (regardless of land ownership). The work completed by CARB staff today consists of five segments: forest and other natural lands, cropland biomass, urban forest, soil carbon, and wetland.

**The Forest and Other Natural Lands (FONL)** part of the inventory quantifies the biomass carbon stored in forest, woodland, shrubland, grassland, and other natural lands (i.e., desert). It quantifies live biomass (which includes trunk, branches, and bark of trees), understory (shrubs and plants growing beneath the main canopy of a forest), and their roots. It also includes a preliminary estimate of dead biomass, which includes standing and down dead trees, roots, and litter (leaves, bark, needles, twigs that have fallen to the forest floor), that contains high uncertainty and will continually be refined in the future.

**The Cropland Biomass** part of the inventory quantifies the biomass carbon stored in woody crops in orchards and vineyards, such as almonds, walnuts, pistachios, grapes, and oranges. Most of this carbon pool is found in trunks and branches of these trees. Annual herbaceous crops are not included because they are planted and harvested within the same year; therefore, their crop growing cycle results in a negligible amount of net biomass carbon change on an annual basis. GHG emissions associated with direct human activities on cropland, such as fertilizer use, liming, rice cultivation, fuel combustion in agriculture equipment, are quantified in the annual statewide GHG inventory (CARB, 2018a) and not in the NWL Inventory.

**The Urban Forest** part of the inventory quantifies the biomass carbon stored in urban trees and their roots. It does not include herbaceous plants like grasses and shrubs, which have relatively small carbon sequestration capacity compared to woody trees. Similar to the cropland biomass inventory, annual plants are not included because their growing cycle results in a negligible amount of net biomass carbon change on an annual basis.

**The Soil Carbon** part of the inventory quantifies the amount of soil organic carbon (includes fresh and decomposed remains of plants and animals; excludes mineral carbon in soils) on all land types: forest/shrublands, grasslands, other natural lands (e.g., desert), croplands, and urban lands. It does not include inorganic mineral carbon from weathering of rocks or soil minerals formed by reaction with atmospheric carbon dioxide ($CO_2$). The inventory estimates soil organic carbon stock change resulting from disturbance, land conversion, land degradation, and soil management activities.

This initial version of the soil carbon inventory represents a preliminary estimate of soil carbon only up to 30-centimeter depth for the 2001-2010 period, and CARB staff is further developing this inventory. For croplands outside of the Sacramento-San Joaquin Delta ("the Delta"), a biogeochemical model is available and was used to generate soil carbon estimate. For croplands in the Delta and other non-agricultural lands, staff produced estimates using a combination of available spatial data and IPCC default factors (IPCC, 2006). Because IPCC default factors contain significant uncertainty and are only applicable to a depth of 30 centimeters (the soil depth specified in the IPCC Inventory Guidelines for jurisdictions to quantify, and the layer generally considered as most impacted by disturbance), this preliminary soil carbon inventory only includes the top 30-centimeter and contains high uncertainty. CARB staff is actively developing the soil carbon inventory, but at the time of finalization of this document, soil carbon inventory for years after 2010 is not yet available. For completeness and to facilitate comparison with other parts of the NWL inventory for the 2014 base year, CARB staff extrapolated 2014 soil carbon stock estimate by applying the trend in 2001-2010 forward to 2014 in some graphs and tables contained in this document.

**The Wetland** part of the inventory includes three categories identified in the IPCC inventory guidelines: rewetted organic soils, coastal wetlands, and inland wetland mineral soils. CARB staff generated the wetland inventory for 2016 using a combination of IPCC default emission factors and wetland mapping data from the San Francisco Estuary Institute (SFEI, 2016). Staff estimates that California's wetlands released less than an estimated 1 million metric tons of $CO_2$ equivalent (MMT $CO_2e$) in $CO_2$ and methane ($CH_4$) in 2016. The wetland segment of the inventory is not currently integrated with the soil carbon segment of the inventory because of a known land cover classification error that exists in the 2001-2010 LANDFIRE dataset that impacts wetland land cover classification specifically in California. Instead of the LANDFIRE dataset, the SFEI dataset was used to create an order of magnitude understanding of wetland emissions in California for the year 2016. Therefore, some graphs and tables showing soil carbon stock change numbers in this document do not include wetland inventory estimate. CARB staff plans to develop methods to improve wetland land cover classification over time.

### *1B.1 – Retrospective Inventory, Prospective Inventory, and Scenario Analysis*

Accounting for past, present and future ecosystem carbon throughout California NWL involves two related but separate quantification processes: a retrospective inventory and a future projection. A retrospective inventory is used to track the State's carbon stock and GHG emissions over time based on observable and past events; whereas a prospective inventory involves projecting the future state from the current scientific understanding of complex systems and a defined set of assumptions about various natural and human factors that influence the future state.

The NWL Inventory presented in this document is a retrospective inventory, and it does not include a future scenario projection. CARB staff uses empirical data that represents California's NWL for a specific time period in the past. This retrospective NWL Inventory and other ancillary data will track the State's progress toward meeting the long-term climate goal for maintaining our lands as a resilient carbon sink.

Moving forward, CARB intends to develop in-house technical capability to conduct policy scenario analyses by integrating existing modeling tools into a modeling system. These tools may be used for understanding how policies or programs may impact future NWL carbon stock, and for informing the trajectory of NWL carbon under various climate and policy scenarios. The retrospective inventory provides initial conditions for projection modeling and can be used for validating the model.

# 2 – Inventory Framework

This section presents the fundamentals of the inventory framework, including an introduction to the carbon cycle, a summary of the IPCC GHG inventory framework, and a discussion on the use of California-specific information within the inventory framework.

## 2A – Carbon Cycle

The NWL Inventory tracks how much carbon exists in California's ecosystems, where that carbon is located, and estimates how much carbon is moving in and out of the various land types (e.g., forests and grasslands) and carbon pools (e.g., wood, roots, and soils).[5] Carbon can move between ecosystem components due to natural processes (growth, decay, and succession) and disturbances (e.g., wildfire) or anthropogenic forces such as land use change. Carbon cycling transfers carbon between different ecosystem components.

The Earth's carbon cycle involves the exchange of carbon between five main carbon reservoirs. These main reservoirs include the atmosphere, biosphere (plants, animals, and other life forms), hydrosphere (water bodies), pedosphere (soils), and lithosphere (Earth's crust and mantles, including rocks and fossil fuels). Additional information and illustrations on the carbon cycle can be found in NWL Inventory TSD (CARB, 2018). On a global scale, the largest carbon reservoirs are the hydrosphere and lithosphere which comprise an estimated 66% and 28% of the Earth's total carbon stock, respectively. The atmosphere comprises just over 1%, the biosphere just under 1%, and soils comprise 4% of the Earth's carbon stock (Reibeek, 2011). Carbon is cycled between these pools due to both natural and anthropogenic processes and occurs on two general timescales, called the slow and fast carbon cycles.

The slow cycle operates on the time scale of a few hundred million years and largely consists of carbon cycling between the atmosphere, hydrosphere, pedosphere, and lithosphere. The fast carbon cycle occurs on approximately the same time scale as the human lifespan. It is the fast carbon cycle that is the focus of the NWL Inventory.

The fast carbon cycle is characterized by the exchange of carbon in and out of the biosphere as it is cycled between carbon reservoirs, such as the biosphere, atmosphere, and pedosphere. The biosphere takes up carbon via organisms such as plants, phytoplankton, and photosynthetic algae, which use photosynthesis to capture energy from sunlight by converting $CO_2$ to sugar and eventually to other carbon-based molecules that are used to build and sustain life. The carbon is then moved up the food chain as the plant tissues are consumed by herbivores, which are consumed by carnivores. Carbon is returned to the atmosphere when plants and animals die and their tissues decompose. The decomposition process also incorporates carbon into the pedosphere in the form of soil organic carbon.

The NWL Inventory quantifies the amount of carbon being transferred between carbon reservoirs and carbon pools via these processes. It provides a picture of where California's ecosystem carbon is located, how much is contained within the system, and how much is accumulating or being removed. The following

[5] "Carbon pools" are Above-Ground Live Biomass (boles, stems, and foliage in shrubs, trees, grasses, and herbaceous vegetation), Below-Ground Live Biomass (roots in shrubs, trees, grasses, and herbaceous vegetation), Dead Organic Matter (standing or downed dead wood and litter), Harvested Wood Products (all wood and bark material that leaves harvest sites regardless of whether it is eventually incorporated into merchandisable products), and Soil Organic Matter (organic carbon in the top 30 cm of soil).

sections describe the framework that CARB follows for quantifying ecosystem carbon stocks and stock change in California's landscape.

## 2B – IPCC Inventory Accounting Framework

The IPCC has created a standardized GHG accounting framework for governing entities to produce robust, comparable GHG emissions estimates (IPCC, 2006). CARB utilizes this framework's guidance in developing the NWL Inventory (as well as the annual statewide GHG inventory). The IPCC Inventory Guidelines (IPCC, 2006) identified four broad categories for inventory development: Energy; Industrial Processes and Product Use (IPPU); Agriculture, Forestry, and Other Land Use (AFOLU); and Waste. The NWL Inventory addresses the ecosystem carbon portions of the AFOLU category, while the annual statewide GHG inventory covers other emitting processes and activities.

Under the IPCC framework, inventory accounting focuses on quantifying the land-atmosphere exchange of GHGs associated with carbon stock changes in biomass and soils. For the AFOLU category, the GHG of interest include $CO_2$, $CH_4$, and nitrous oxide ($N_2O$).[6] Land-atmosphere exchange of $CO_2$ is associated with plant photosynthesis and respiration, decomposition of dead organic matter, and combustion. $N_2O$ emissions are associated with nitrification and denitrification in soils, while $CH_4$ is associated with the activity of methanogenic bacteria in anaerobic soil conditions. $N_2O$ and $CH_4$ emissions are also associated with combustion. Carbon stock changes that involve exchange with the atmosphere are reported in $CO_2$ global warming potential (GWP) equivalents whereas estimates of carbon stocks and change between terrestrial carbon pools are evaluated in units of carbon mass. CARB's NWL Inventory represents the latter, and reports carbon stock and stock change in units of carbon mass.

Carbon pools defined for GHG accounting are more granular than the overarching pools defined in the carbon cycle. The principal carbon pools defined by the IPCC are listed in **Table 1**. All pools used for GHG accounting in the AFOLU category are in the biosphere with the exception of soil organic matter (SOM), which is part of the pedosphere.

**Table 1.** IPCC defined pools for carbon accounting (IPCC, 2006).

| Pool | Acronym | Description |
|---|---|---|
| *Above-Ground Live Biomass* | AGL | Boles, stems, and foliage in shrubs, trees, grasses, and herbaceous vegetation |
| *Below-Ground Live Biomass* | BGL | Roots in shrubs, trees, grasses, and herbaceous vegetation |
| *Dead Organic Matter* | DOM | Standing or downed dead wood and litter |
| *Harvested Wood Products* | HWP | All wood material, including bark, that leaves harvest sites |
| *Soil Organic Matter* | SOM | Organic carbon material in the top 30-centimeter of soil |

[6] **Section 2B.2** provides more information on CARB's customization of the IPCC inventory framework. CARB's NWL Inventory only accounts for carbon stock and stock change, and the annual statewide GHG inventory accounts for other GHG emissions. Black carbon is quantified separately and not currently routinely included in either inventory.

### *2B.1 – IPCC System Boundaries*

System boundaries are used to define which categories and emissions are included in the inventory. The IPCC Inventory Guidelines provides for three system boundary schemes: the Atmospheric Flow Approach (**Figure 1**), the Production Approach, and the Stock-Change Approach. CARB has chosen the Atmospheric Flow Approach for the inventory because its accounting of land-atmosphere exchange of carbon is most analogous to the way emissions are accounted for in other sectors of the economy (in the Energy, IPPU, and the Waste categories). Moreover, the Atmospheric Flow Approach conservatively overestimates emissions by accounting for the carbon lost from land as $CO_2$ released into the atmosphere (or alternatively, as foregoing the $CO_2$ previously taken up by plants and soils in the form of carbon), and by accounting for California releases of emissions resulting from decomposition of wood products and organic wastes that originated outside of California. A more detailed description of these system boundary approaches and rationale for using the Atmospheric Flow Approach can be found in the NWL Inventory TSD (CARB, 2018b).

Harvested Wood Product (HWP) intersects the AFOLU, Energy, and Waste categories, and thus appears in both the NWL Inventory and annual statewide GHG inventory. The term “HWP” includes harvested boles that are incorporated into persistent wood products like furniture and building materials, saw dust that is burned in sawmills for energy, forest residues that are combusted in power plants, as well as decomposition of wood in landfills or in NWL. To avoid double counting of emissions, the IPCC Inventory Guidelines provides for reporting some emission categories for informational purposes only. For example, $CO_2$ emissions associated with combustion of forest residues in a power generation facility may be reported as an informational item in the Energy category, but the carbon stock loss is accounted in the AFOLU category, while the methane and $N_2O$ emissions from combusting HWP for energy are reported in the Energy category. The $CO_2$ releases associated with the decomposition of wood products discarded at waste disposal sites are reported as information item in the IPCC Waste category, but the change in carbon stock is accounted for in the AFOLU category. The associated $CH_4$ emissions are reported in the Waste category. **Figure 1** illustrates the system boundary for Atmosphere Flow Approach as defined by the IPCC inventory framework. **Section 2B.2** explains CARB’s customization of the IPCC inventory boundaries.

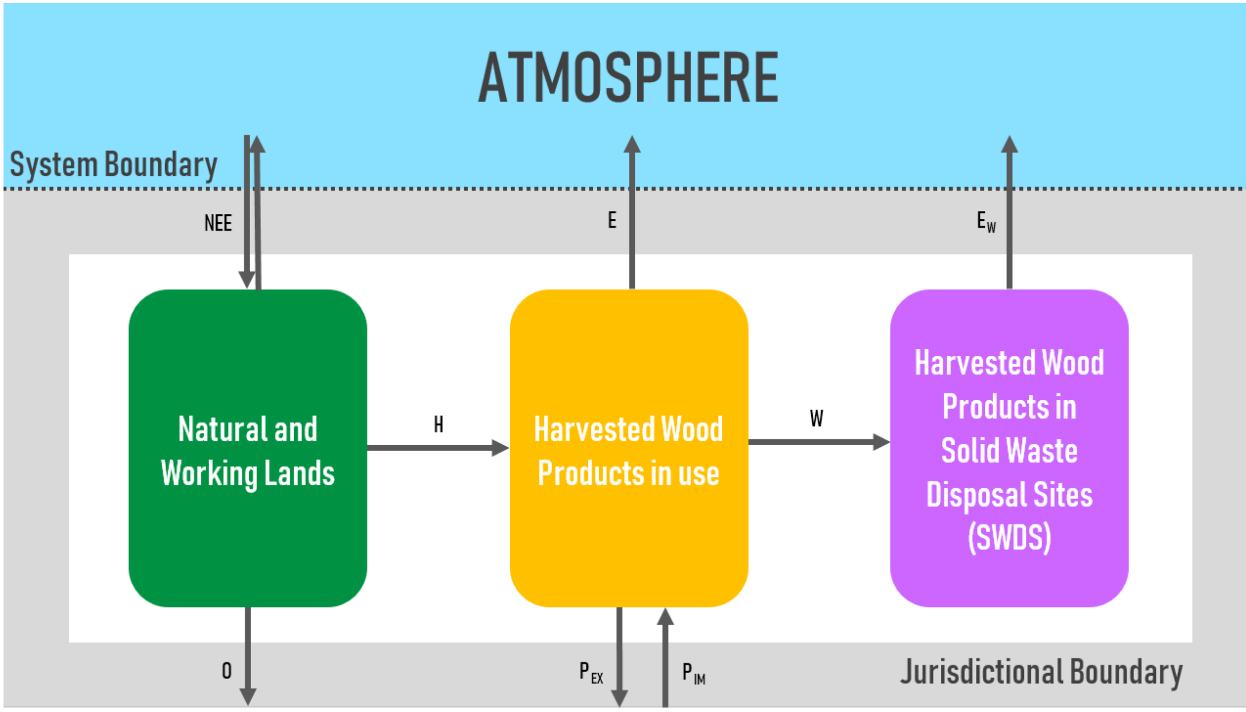


**Figure 1.** Diagram of IPCC system boundary and flows for the Atmospheric-Flow Approach (adapted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Chapter 12).

*Where:*

NEE = Net ecosystem exchange, which is the sum of all ecosystem carbon gains from the atmosphere by processes such as photosynthesis and ecosystem carbon losses to the atmosphere by processes such as respiration.

O = Cross-border carbon transfers from AFOLU outside of the jurisdictional boundary

H = Carbon transfer from the AFOLU ecosystem carbon stock via harvest of wood products (e.g. logging)

E = Carbon release to the atmosphere from harvest wood products in use via combustion or decomposition

$P_{EX}$ = Carbon transfer via exported wood products

$P_{IM}$ = Carbon transfer via imported wood products

W = Carbon transfer from disposal of harvested wood products in use to solid waste disposal sites (landfill)

$E_W$ = Carbon emissions to the atmosphere from the decomposition or combustion of harvested wood products in solid waste disposal sites

Natural and Working Lands = All biomass and soil organic carbon stocks, not including carbon stocks in harvested wood products. Forest biomass carbon becomes HWP after a harvest event which converts forest biomass into HWP (e.g. logging and subsequent lumber milling)

Harvested Wood Products in use = All harvested wood products in the use phase of the life cycle (e.g. lumber, wooden furniture, paper products, diapers)

Harvested Wood Products in Solid Waste Disposal Sites (SWDS) = All wood products (e.g. lumber and paper products) that have reached end-of-life and are disposed of in solid waste disposal sites, or landfills

### *2B.2 – CARB Customization of System Boundaries*

In addition to the IPCC defined system boundaries, CARB has tailored the framework to help meet State programmatic needs. CARB's NWL Inventory accounts for ecosystem carbon stock and stock change, and the annual statewide GHG inventory tracks direct emissions from human-made equipment, vehicles, structures, and products and includes selected categories of agriculture. The emitting activities under the AFOLU category that are accounted for in the annual statewide GHG inventory include enteric fermentation (IPCC Inventory Category 3A1), manure management (IPCC Inventory Category 3A2), and categories from aggregate sources/non-$CO_2$ emission sources on land such as fertilizer application and tillage (IPCC Inventory Category 3C). The NWL Inventory concentrates on land carbon stocks and stock-change (including HWP and soil organic carbon). Carbon stock change is reported in the format of IPCC land cover/change categories. The removal of carbon from land associated with HWP is accounted in the NWL Inventory through quantification of carbon stock change, and the annual statewide GHG inventory also includes this carbon as $CO_2$ as an informational item if it enters the atmosphere through human-made equipment, vehicles, structures, and products. Its treatment as an informational item in the annual statewide GHG inventory avoids double-counting of carbon that leaves the land base, which is already accounted as a carbon loss for in the NWL Inventory.

Using the same examples in **Section 2B.1** to illustrate CARB's customization of inventory boundaries: $CO_2$ emissions associated with combustion of forest residues in a power generation facility are reported as an informational item in the energy sector of the annual statewide GHG inventory. The carbon stock loss associated with removal of forest residues from NWL is accounted for in the NWL Inventory. Methane and $N_2O$ emissions from combusting HWP for energy are reported in the energy sector of the annual statewide GHG inventory. The $CO_2$ releases associated with the decomposition of wood products discarded at waste disposal sites are reported as information item in the waste sector of the annual statewide GHG inventory, but the removal of carbon from land is accounted for in the NWL Inventory. The associated $CH_4$ emissions are reported in the waste sector of the annual statewide GHG inventory. **Appendix 1** provides a reference for which IPCC inventory categories can be found in the NWL Inventory, and which can be found in the annual statewide GHG inventory (which is often colloquially referred to as the "anthropogenic inventory," as how it is labeled in **Appendix 1**).

**Figure 2** and **Figure 3** depict CARB's customization of the IPCC inventory framework. **Figure 2** shows how the carbon contained in HWP transfers from land to the atmosphere via various emitting processes. **Figure 3** shows how carbon and nitrogen transfer between biomass, soils, and atmosphere in the agricultural sector. CARB's inventories account for emissions from the perspective of the atmosphere. In other words, only emissions represented by an arrow that crosses the "system boundary" line (i.e., enters the atmosphere) are quantified in the inventories. These figures also show which emissions are accounted for in the NWL Inventory versus the annual statewide GHG inventory. Readers could use them as a guide in looking up inventory data published on the CARB's website.

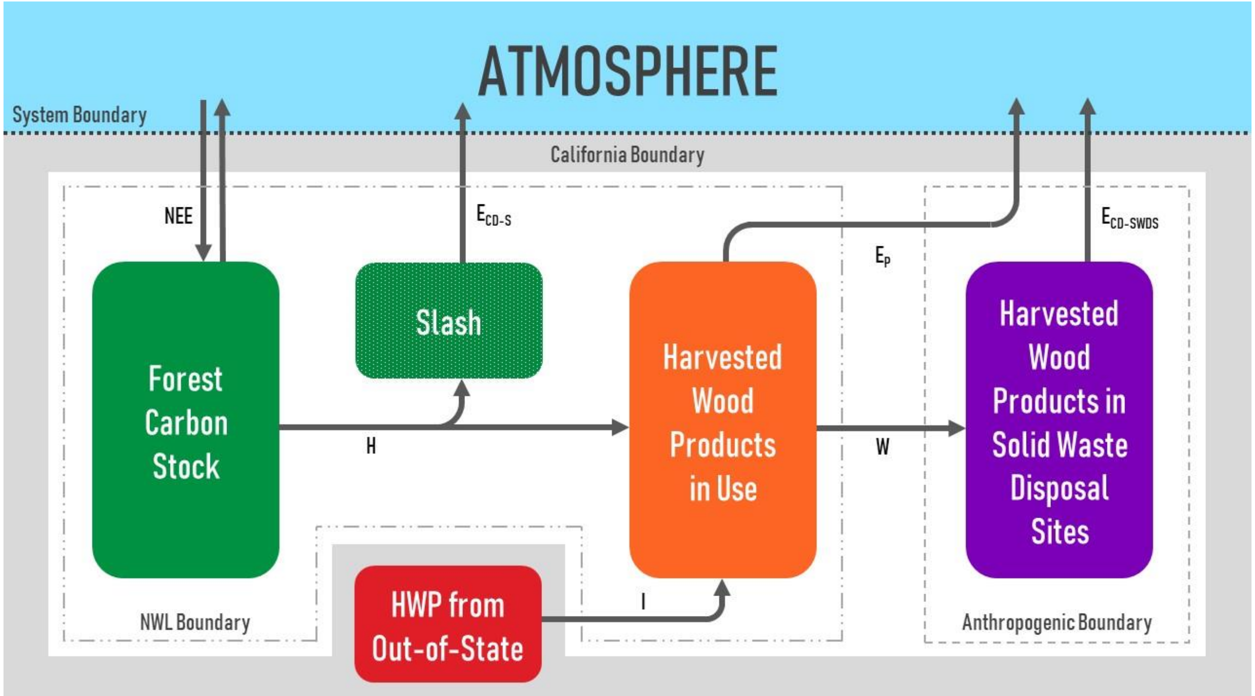


**Figure 2.** CARB's customization of the IPCC Atmosphere Flow Approach for accounting of ecosystem carbon and harvested wood products. The "NWL Boundary" box on the left shows the boundary of CARB's NWL Inventory. The "Anthropogenic Boundary" box on the right shows the boundary of CARB's annual statewide GHG inventory. Direct emissions from human activities related to harvest, such as transport and fossil fuel combustion, are not shown in this diagram.

*Where:*

System Boundary = Boundary depicting which emissions, processes, and stocks related to HWP are accounted for in the Atmospheric Flow Approach framework

California Boundary = Boundary depicting which emissions, processes, and stocks are accounted for in CARB's GHG inventory for the State of California

NWL Boundary = Boundary depicting which emissions, processes, and stocks are accounted for in the Natural and Working Lands (NWL) Inventory

Anthropogenic Boundary = Boundary depicting which emissions, processes, and stocks are accounted for in the Anthropogenic Inventory (CO2 emissions associated with HWP are reported as an information item, and CH4 and N2O emissions are reported as direction emissions in the anthropogenic inventory)

NEE = Net ecosystem exchange, which is the sum of all ecosystem carbon gains from the atmosphere by processes such as photosynthesis and ecosystem carbon losses to the atmosphere by processes such as respiration

$E_{CD-S}$ = Emissions from the combustion and/or decomposition of slash

$E_P$ = Emissions from the production and use of harvested wood products, e.g., combustion of sawmill residues for energy

$E_{CD-SWDS}$ = Emissions from combustion and/or decomposition of harvested wood products in solid waste disposal sites, or landfills (the annual statewide GHG inventory reports CO2 as an informational item, and reports $CH_4$ and $N_2O$ as emissions from the Waste category.)

H = Carbon transfer from the AFOLU ecosystem carbon stock via harvest of wood products (e.g. logging)

W = Carbon transfer from disposal of harvested wood products in use to solid waste disposal sites (landfill)

I = Carbon transfer from AFOLU ecosystem carbon outside of California's jurisdiction via import

Forest Carbon Stock = Carbon contained in biomass on Forest Lands

Slash = Forest carbon that is left in the forest as a residue after a harvest event (e.g. trimmed branches)

Harvested Wood Products in use = All harvested wood products in the use phase of the life cycle (e.g. lumber, wooden furniture, paper products, diapers)

Harvested Wood Products in Solid Waste Disposal Sites (SWDS) = All wood products (e.g. lumber and paper products) that have reached end-of-life and are disposed of in solid waste disposal sites, or landfills

HWP from Out-of-State = Harvested wood products in the use phase of the life cycle that were harvested from Forest Carbon Stocks outside of the California jurisdictional boundary

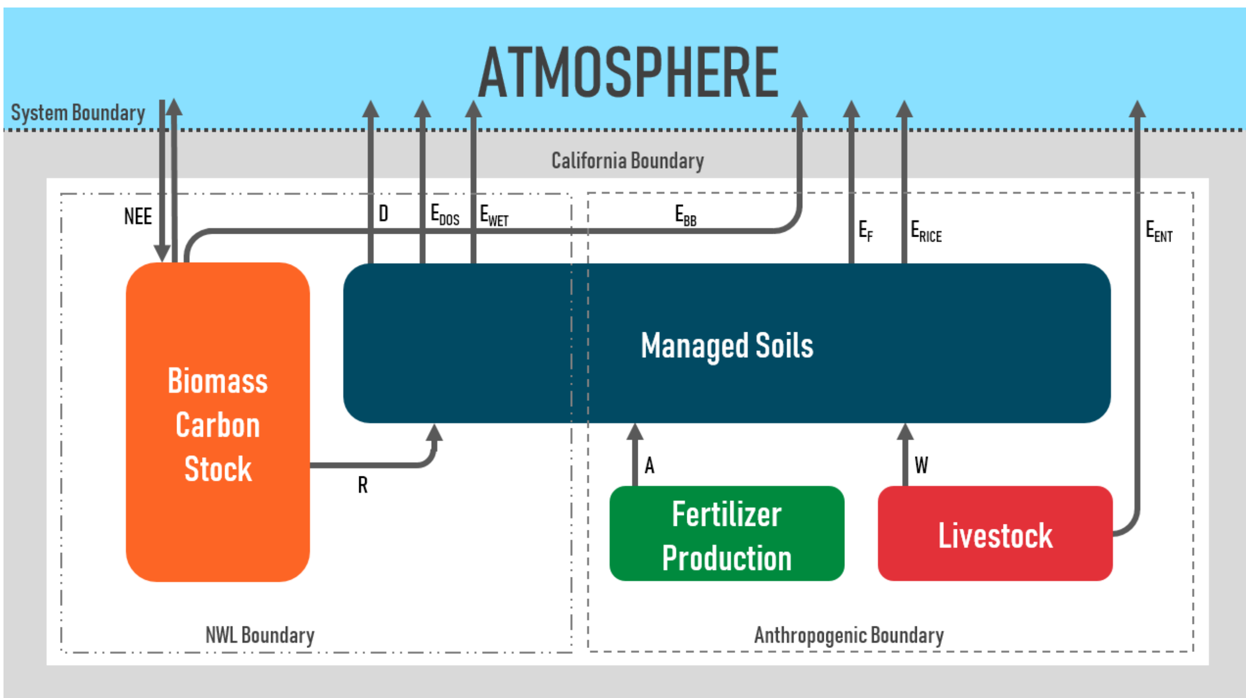


**Figure 3.** CARB's customization of the IPCC Atmosphere Flow Approach for the carbon and nitrogen in the agricultural sector. The "NWL Boundary" box on the left shows the boundary of CARB's NWL Inventory. The "Anthropogenic Boundary" box on the right shows the boundary of CARB's annual statewide GHG inventory. Direct emissions from human activities, such as farming equipment that burns fossil fuel, transport of agricultural products, and energy consumption of feritilizer manufacturing facilities are not shown in this diagram.

*Where:*

System Boundary = Boundary depicting which emissions, processes, and stock related to soil management are accounted for in the Atmospheric Flow Approach framework

California Boundary = Boundary depicting which emissions, processes, and stocks are accounted for in CARBs GHG inventory for the State of California

NWL Boundary = Boundary depicting which emissions, processes, and stocks are accounted for in the Natural and Working Lands (NWL) Inventory

Anthropogenic Boundary = Boundary depicting which emissions, processes, and stocks are accounted for in the Anthropogenic Inventory

NEE = Net ecosystem exchange, which is the sum of all ecosystem carbon gains from the atmosphere by processes such as photosynthesis and ecosystem carbon losses to the atmosphere by processes such as respiration.

D = Soil organic carbon stock loss from degradation

$E_{DOS}$ = Emissions from drained organic soils

$E_{WET}$ = Methane emissions from managed wetlands

$E_{BB}$ = Emissions from burning of agricultural residues

$E_F$ = Direct and indirect emissions from fertilizer and soil amendment (e.g. urea and lime) application to soils

$E_{RICE}$= Methane emissions from rice cultivation

$E_{ENT}$ = Emissions from enteric fermentation

R = Soil organic carbon stock increase through biomass return to soils

A = Application of soil amendments, including: synthetic fertilizer, organic fertilizer, compost, urea, and lime

W = Deposition of livestock wastes (e.g. manure and urine) onto soils

Biomass Carbon Stock = Carbon stock contained in biomass

Managed Soils = Soil organic carbon stock in soils (up to a depth of 30 cm)

Fertilizer Production = Production of soil amendments, including: synthetic fertilizer, organic fertilizer, compost, urea, and lime

### *2B.3 – Land Categories*

For ease of reporting, the IPCC conceives of six broad land categories for jurisdictions to estimate carbon stocks and land-atmosphere exchange of GHGs: Forests/Shrublands, Grasslands, Croplands, Wetlands, Settlements, and Other Lands. The IPCC Inventory Guidelines provides land category definitions based on land cover type, land use, or a combination of the two. It aggregates forests, woodlands, and shrublands into one "Forest" category. The CARB NWL Inventory follows the IPCC definitions of land categories:

- **Forest/ShrubLand** includes land exhibiting greater than or equal to 10% canopy cover comprised of live trees and/or shrubs. This includes both tree-dominated land and shrub-dominated land.
- **Cropland** comprises areas planted in annual or perennial crops (including orchards and vineyards) and fallow land.
- **Grasslands** include areas dominated by grasses or herbaceous vegetation and exhibiting tree or shrub canopy cover below 10%.
- **Wetlands** include land that is covered or saturated by water for all or portions of a year, and do not otherwise fall within Forest Land or other categories.
- **Settlements (also known as "developed land")** include all developed land such as urban area, human developments in non-urban areas, and transportation infrastructure (e.g., roadways) that traverses either urban or non-urban areas.
- **Other Land** includes areas of sparse vegetation such as desert, bare soil, rock, ice/snow, and land areas that do not fall within the other categories.

Taken together, the IPCC framework for natural and working lands inventory provides for 67 reporting categories, including 26 categories associated with fertilizer use and livestock[7] which are included in the annual statewide GHG inventory (**Figure 4**, **Appendix 1**).

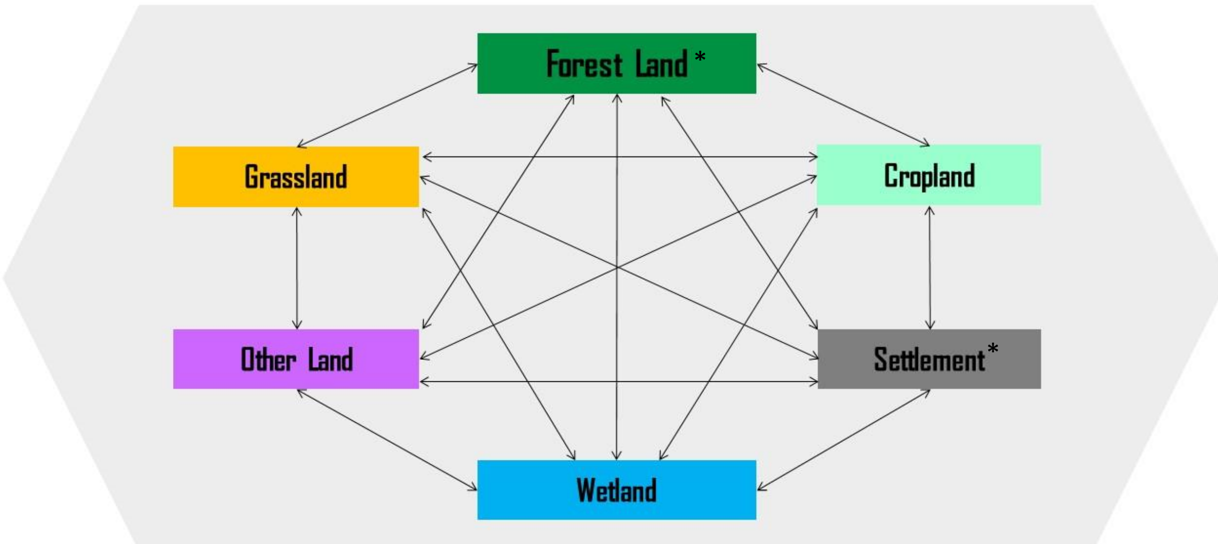


**Figure 4.** IPCC land cover / cover change categories. *Forest Land includes forest and shrubland. Settlement refers to developed land, including urban area, human developments in non-urban areas, and transportation infrastructure (e.g., roadways) that traverses either urban or non-urban areas.

### *2B.4 – Tier of Methodology*

IPCC provides three methodology tiers in its GHG Inventory Guidelines. Lower tiers are less resource intensive and are designed for ease of use, whereas higher tiers are generally regarded as more accurate, but require significantly more resources to produce. In order to encourage the use of higher tier methods whenever possible, the IPCC methods allow a combination of tiers to be used for different sections; this allows an inventorying jurisdiction to create a complete inventory while simultaneously providing greater accuracy for key categories or categories for which higher quality data is available. Wherever possible, higher tier methodologies were used to create the NWL Inventory (**Figure 5**).

[7] Other categories in the IPCC framework for land-based inventory include $N_2O$ emissions associated with fertilizer application; $CO_2$ emissions associated with lime and urea application to managed soils; $CH_4$ emissions from rice cultivation; $CH_4$ emissions from livestock (enteric fermentation), and; GHG emissions associated with manure management.

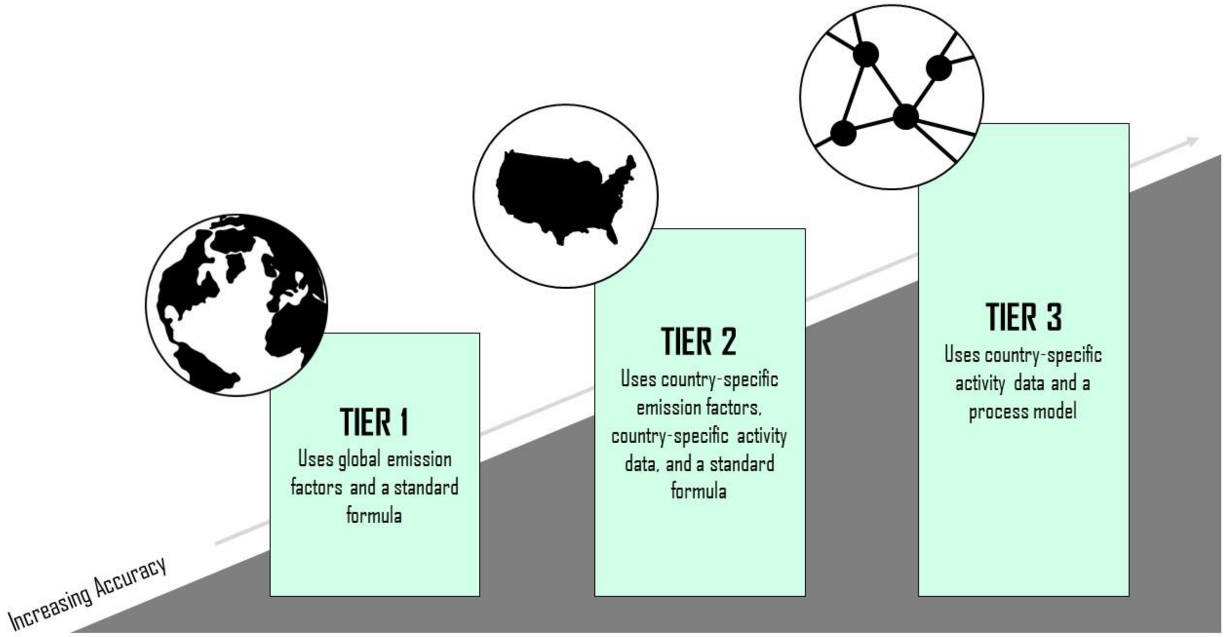


**Figure 5.** IPCC methodology tier hierarchy (IPCC, 2006).

The tiers are defined by the IPCC as follows (IPCC, 2006):

**Tier 1** methods are designed to be the simplest to use, for which equations and default parameter values (e.g. emission factor and stock change factor) are provided in the IPCC Inventory. Country-specific activity data are needed for this method. In CARB's NWL Inventory, Tier 1 emission factors were used to calculate the emissions from drained organic soils in the soil organic carbon segment of the inventory.

**Tier 2** methods use the Tier 1 methodological approach but utilizes country-specific emission factors and stock change factors for the most impactful (i.e. highest emitting) land-use and livestock categories. Higher resolution temporal and spatial data are often used to correspond with factors for specific regions and specialized land-use categories. In CARB's NWL Inventory, Tier 2 factors were developed to calculate soil organic carbon stock change due to land management.

**Tier 3** features custom measurement systems and/or models repeated over time and driven by high-resolution activity data that are disaggregated at the sub-national level. Such systems may include comprehensive field sampling repeated at regular time intervals and/or geographic information system (GIS) based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. Pieces of land where a land-use change occurs can usually be tracked over time, at least statistically. In most cases, these systems have a climate dependency, and thus provide source estimates with inter-annual variability. In CARB's NWL Inventory, Tier 3 methods were used to quantify biomass carbon stocks of FONL, cropland, and urban forest, as well as soil organic carbon stock change on croplands except the Delta.

## 2C – Methodology and Data

CARB staff generated inventory estimates by utilizing scientifically rigorous modeling methods and the best available empirical data that provide a complete inventory that can be updated regularly. CARB's goal for GHG inventory development is to create a geospatially and temporally explicit statewide inventory with "wall to wall" coverage. Producing such an inventory has some specific design and data requirements. These include the use of input data that provide complete, statewide coverage and are published on a recurring schedule (i.e. a high-quality data product that is available for only one year would not be suitable for this application) and can be processed to achieve consistency with the IPCC Inventory Guidelines. Geospatial data must also have moderate to fine resolution and not require resource intensive data processing prior to analysis. Therefore, CARB's inventory methodology has integrated ground-based measurements and remote sensing technology to identify land cover and quantify biomass carbon stocks over time.

***Forest and Other Natural Lands.*** CARB's FONL segment of the inventory uses sources and methods developed under a contract with the University of California (Battles et al., 2013), which was published in Gonzalez et al. (2015), and developed further under a follow-up contract (Saah, et al., 2016). CARB refinements to the methods include: 1) accounting for carbon stock increases from live tree growth that are currently undetected by the satellite-derived LANDFIRE products (see the NWL Inventory TSD (2018) for additional information) and 2) quantifying the post-harvest carbon persisting in wood products. This geospatially and temporally explicit statewide "wall to wall" approach delineates land carbon exchange across all land types and is able to estimate the carbon implications of disturbances and management practices at regional scales (Woodall, et al., 2015).

***Cropland Biomass.*** The cropland biomass carbon segment of the Inventory also uses remotely sensed, survey and field-based data sets. These datasets include: DigitalGlobe (DigitalGlobe, 2018), Google street view (Google, 2018), National Agricultural Survey Service data (USDA - NASSb, 2018), Landsat (USGSb, 2018), and Cropscape (USDA - NASSa, 2018). The model used to implement the cropland carbon estimation method using the above-mentioned data is called the Diameter Estimated Method for Even-aged Trees Examined Remotely (DEMETER), a methodology developed by CARB staff (Dingman, in prep). It uses aerial photography, remote sensing and Google street view to obtain age to height and diameter ratios for various orchard species and age of orchard to tree density. This information is then used along with allometric equations to obtain a per acre estimate of orchard carbon. Then, census data that provide the number of acres of each crop type in California are used to scale the per acre estimates to a statewide total. A more detailed explanation of the model and method can be found in the NWL Inventory TSD (CARB, 2018b).

***Urban Forest.*** The urban forest carbon estimates incorporate various localized urban forest inventories, orthophotos, U.S. Census urban boundaries (USCB, 2010) and National Agriculture Imagery Program data (USDA - FSA, 2018). To quantify urban forest carbon, CARB staff developed an urban canopy cover map and used allometric equations to convert canopy cover within the U.S. Census urban boundary to estimate the amount of carbon stored in trees. The model used to implement the urban forest carbon estimation method is called the Municipal Estimated Tree Rate Of Productivity on Lands in the State (METROPOLIS). This method uses a previous study (Bjorkman, et al., 2015), which estimated California urban forest carbon for 2010, as a baseline. CARB staff uses remote sensing and U.S. Census urban boundaries to map urban forest canopy cover periodically to adjust the baseline with changing canopy cover. A more detailed explanation of the model and method can be found in the NWL Inventory (CARB, 2018b).

***Soil Carbon.*** The soil carbon inventory utilizes a composite of method tiers to calculate stock change. Tier 3 biogeochemical modeling using the Denitrification Decomposition (DNDC) model (Liet al., 1992; Li C.,

2000) was conducted to estimate soil organic carbon stock change on agricultural mineral soils for cropland outside of the Delta. For all other land types (croplands in the Delta and non-agricultural areas) emissions from organic soils were calculated using Tier 1 methods, and stock change on all other soil/land cover types was calculated using Tier 2 methods.

***Wetland.*** Soil carbon stock change for wetlands was calculated using IPCC Tier 1 methods (IPCC, 2006) (IPCC, 2013), which are emission factor based. The California Aquatic Resources Inventory (SFEI, 2016) and EcoAltas Habitat Project Tracker (SFEI, 2017) geospatial datasets were used to identify wetlands areas in the State of California. CARB staff crosswalked the SFEI wetland classifications to the seven IPCC wetland classifications for analysis: 1) Peatlands for peat extraction, 2) Flooded lands, 3) Drained inland organic soils, 4) Rewetted organic soils, 5) Coastal wetlands, 6) Inland wetland mineral soils, and 7) Constructed wetlands for wastewater treatment. The cross-walked wetland acreages by type were used with the IPCC Tier 1 emission factors for temperate climates to calculate soil organic carbon stock change.

### *2C.1 – Availability and Limitations of Input Data*

Currently, one of the limitations to the inventory methods is the ability to update the data more frequently. Many datasets are collated to produce CARB’s NWL Inventory. These data sets range from surveys and field-based sampling to remotely-sensed satellite data. Data products from field or satellite data are collected and processed at various time intervals. An inventory resulting from various data sets with different release frequencies requires some level of harmonization to produce one estimate of carbon for all NWL in California. **Table 2** shows the data used to estimate each segment of the NWL Inventory, the frequency at which the data are published by other entities, and the latest release year of each data product at the time of this document’s creation. The inventory currently harmonizes data with LANDFIRE’s release dates since LANDFIRE is the data set that determines the land cover classes used for reporting according to the IPCC Inventory Guidelines. Therefore, the LANDFIRE dataset is the limiting factor in obtaining more frequent updates.

**Table 2.** Data sources and availability used for the NWL inventories.

| Inventory | Method Tier | Data | Publication Frequency | Latest Year |
|---|---|---|---|---|
| *Forest and Other Natural Lands* | Tier 3 | USFS FIA Data | Annual | 2016 |
| | | LANDFIRE | 2 years | 2014 |
| | | MODIS | Annual | 2012 |
| *Wetland* | Tier 2 | San Francisco Estuary Inst. | Undefined | 2016 |
| | | gSSURGO | Annual | 2016 |
| | | LANDFIRE | 2 years | 2014 |
| *Cropland Biomass* | Tier 3 | Digital Globe | Varies * | 2018 |
| | | LANDSAT | 16 days | 2018 |
| | | Google Street | ~5 years for rural areas* | 2018 |
| | | USDA NASS | Census – 5 years<br>Survey – 1 year | Census - 2012<br>Survey - 2017 |
| | | USDA Cropscape | Annual | 2017 |
| *Urban Forest Biomass* | Tier 3 | USDA NAIP data | Usually every 2 years | 2016 |
| | | USGS DOQQ data | No longer refreshed* | 1999 |
| | | USFS Urban FIA data | 5 years | 2015 |
| | | UFORE | Not refreshed* | (2003-2015) Varies |
| | | Municipal tree inventories | Varies / Decadal* | (2003-2015) Varies |
| *Soil Carbon* | Tier 3 for croplands outside of the Delta<br><br>Tier 1 for all other lands | DayMET | Annual | 2017 |
| | | NASS Census | 5 years | 2012 |
| | | NASS Survey | Annual | 2017 |
| | | LANDFIRE | 2 years | 2014 |
| | | gSSURGO | Annual | 2016 |
| | | National Atmospheric Deposition Program | Annual | 2017 |
| | | California Ag Commissioner | Annual | 2017 |
| | | SoilGrids | Annual | 2017 |

*Not needed for annual/biannual refresh

# 3 – Current Understanding of Carbon on the Landscape

This section presents NWL Inventory estimates produced using the various methodologies introduced in **Section 2C** and documented in detail in the NWL Inventory TSD (CARB, 2018b). Some of the quantities presented in this section contain significant uncertainty and will likely change in future editions of the NWL Inventory. A list of inventory improvements that CARB staff has planned is discussed in **Section 4**.

## 3A – Carbon Stock by Land Type and Carbon Pool

Carbon distribution on the landscape can be conceptualized in two key ways, 1) as distributed among carbon pools, such as biomass and soil organic matter, and 2) as existing in different land cover categories, such as forest land and cropland. There is approximately 5,340 million metric tons (MMT) of carbon in the carbon pools that CARB has quantified to date. There are other known carbon pools that have not been quantified due to lack of data or method, and these include soil carbon at greater than 30-centimeter depth, fine roots of plants, foliage, and herbaceous plants in urban area. (See **Section 1B** for a discussion on the scope of this first edition of the NWL Inventory.) Roughly half of the 5,340 MMT of carbon existing on the total California landscape resides in soils and half in total biomass (above ground live, below ground live, dead biomass, and litter). As shown in **Table 3** and **Figure 6**, Forests/Shrublands contain the vast majority of California's carbon stock. This is because Forests/Shrublands cover the majority of California's landscape and have the highest carbon density of any land cover type for both the biomass (**Table 4**) and soil organic carbon pools (exempting the peat soils in the Delta). All other land categories combined comprise over 35% of California's total acreage, but only 15% of carbon stocks. With the exception of croplands, all non-forest land cover types contain the majority of their carbon stocks within the soil organic carbon pool. Carbon distribution disaggregated by IPCC land cover category is listed in **Table 3** and illustrated in **Figure 6**.

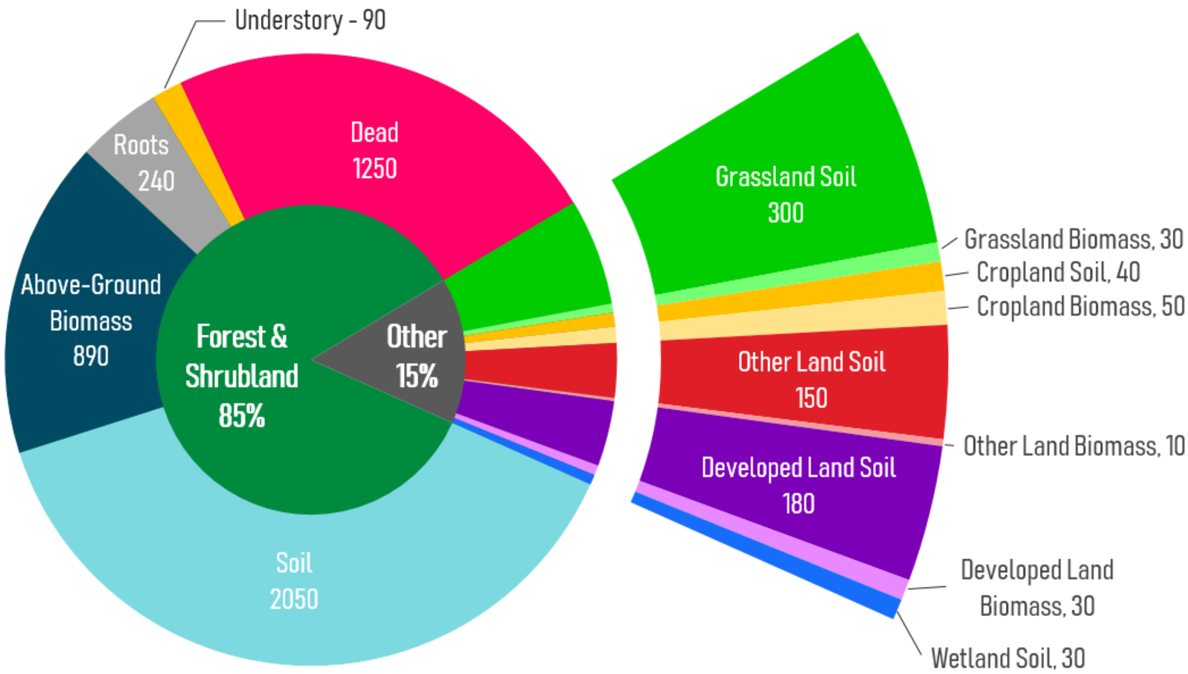


**Figure 6.** 2014 distribution of biomass and soil carbon stocks on the California landscape in MMT carbon (rounded to the nearest 10 MMT). Approximately 5,340 MMT of carbon are quantified for the year 2014. Data for biomass were estimated using empirical data for the year 2014, and data for soils were extrapolated from the 2001 – 2010 soil carbon inventory to 2014.

*Where:*

Above Ground Biomass = trees trunk, branches, and bark; as well as the parts of shrub and herbaceous plant that are above ground and that are not understory (i.e., on land that does not have a main canopy)

Understory = shrubs and plants growing beneath the main canopy, including above-ground live biomass and roots

Dead = Standing dead biomass, downed dead biomass, and litter

Other Land = natural areas of sparse vegetation such as desert, bare soil, rock, ice/snow, and land areas that do not fall within the other FONL categories

Developed Land = IPCC's "Settlements" category, including urban area, human developments in non-urban areas, and transportation infrastructure (e.g., roadways) that traverses either urban or non-urban areas.

Soil = Soil organic carbon to a depth of 30 cm

**Table 3.** 2014 total carbon stocks and percent of total land area by land category

| Land Category | Total Carbon Stocks [a] (MMT C) | % of Total Carbon Stocks [d] | % of Total Land Area [d] |
|---|---|---|---|
| *Forest and Shrubland* | 4,520 | 85% | 54% |
| *Grassland* | 330 | 6% | 10% |
| *Other Natural Land* [b] | 160 | 3% | 19% |
| *Cropland* | 90 | 2% | 9% |
| *Developed Land* [c] | 210 | 4% | 9% |
| *Wetland* | 30 | 1% | << 1% |
| **TOTAL** | **5,340** | **100%** [d] | **100%** [d] |

[a] Total carbon stocks include biomass of living and dead plants, as well as soil organic carbon. Data for biomass were estimated using empirical data for the year 2014, and data for soils were extrapolated from the 2001 – 2010 soil carbon inventory to 2014.

[b] Other natural land includes areas of sparse vegetation, such as desert, bare soil, rock, ice/snow, and land areas that do not fall within the other categories.

[c] Developed land is IPCC "Settlement" category, and includes urban area, human development in non-urban area, and transportation infrastructure (e.g., roadways) that traverses either urban or non-urban area.

[d] Numbers may not add up to 100% due to rounding errors.

**Table 4.** Biomass density disaggregated by IPCC land cover types (MT / hectare). Reference values (live and dead pools) compiled for 2014 per Battles et al. (2013) and Saah et al. (2016), averaged by IPCC land category.

| IPCC Land Cover | Min. Biomass Density | Max. Biomass Density | Avg. Biomass Density |
|---|---|---|---|
| *Forest Land – Tree* | 107 | 2,055 | 351 |
| *Forest Land – Shrub* | 0.38 | 269 | 55 |
| *Grassland* | 11 | 20 | 13 |
| *Other Land* | 0 | 7.4 | 3.5 |
| *Wetland* | | | 148* |
| *Cropland* | TBD† | | |
| *Developed Land* | | | |

*Wetland biomass density is an annual average of net primary productivity (NPP, MT/hectare) from MODIS satellite data (Gonzalez et al. 2015).

†Cropland and Developed Land biomass carbon stocks and change are currently quantified using different methodologies from the one used to quantify FONL biomass. The methods are not yet integrated and cannot be reported in the same table, but this is an area that CARB staff is actively working on. Inventory integration is discussed further in **Sections 4A.7 and 4B**. For more information on the methodology used to calculate carbon stock and change for Croplands and Developed Land, please refer to **Section 3B.3**, **Section 3B.4**, and the NWL Inventory TSD (CARB, 2018b).

## 3B – Carbon Stock Change Over Time

**Figure 7** shows the trends in carbon stock change over time, as quantified using CARB's NWL Inventory methods. Soil is the largest carbon reservoir. Using a combination of spatial data and IPCC default assumptions, most of the estimated net change in soil carbon was due to microbial oxidation of organic soil on the Sacramento-San Joaquin Delta. Disturbance caused by tillage (which makes the previously sequestered and undisturbed soil organic carbon available to microbes, which oxidize the soil organic carbon and produce $CO_2$, other agricultural management practices, land conversion, and land degradation also contribute to the change. Forest/Shrubland carbon stocks declined due to a number of large wildfires that occurred during the 2001-2010 period.[8] The Forest/Shrubland Converted to Grassland category drove further declines during the 2010-2012 period, while gains in the Grassland Converted to Forest/Shrubland category are the primary contributor to the net carbon stock increase during the 2012-2014 period. Woody crops and urban forest both gained carbon, as these trees are generally well maintained due to their economic and aesthetic value. Part of the carbon gain seen in urban forests came from expansion of the urban footprint over time. Staff has not spatially evaluated the net carbon impact of land conversion. While new urban landscaping that incorporates woody trees can potentially regain the initial carbon loss due to converting non-urban land to urban land, conversion decisions should appropriately weigh all environmental and economic factors. This highlights the need to have a comprehensive view of the movement of carbon between land types, as the carbon gain in one land type may result in carbon loss in another land type, and vice versa.

Some segments of the NWL Inventory have a longer history of development than others. Inventories that have had a longer development have more vintages reported, such as with the FONL biomass, woody crop biomass, and urban forest biomass. Only one vintage (for the 2001-2010 period) is currently available for soil carbon.

[8] The current methodology uses broad assumption about the amount of biomass that was transferred from live biomass carbon pool to dead biomass carbon pool after wildfire. The assumption was calibrated based on an older vintage of FIA data, and could be refined by incorporating more recent FIA data. This inventory improvement is further discussed in **Section 4A.4**. This first edition of the NWL inventory accounts for carbon stock change, and does not estimate black carbon, methane, and nitrous oxide emissions from wildfire.

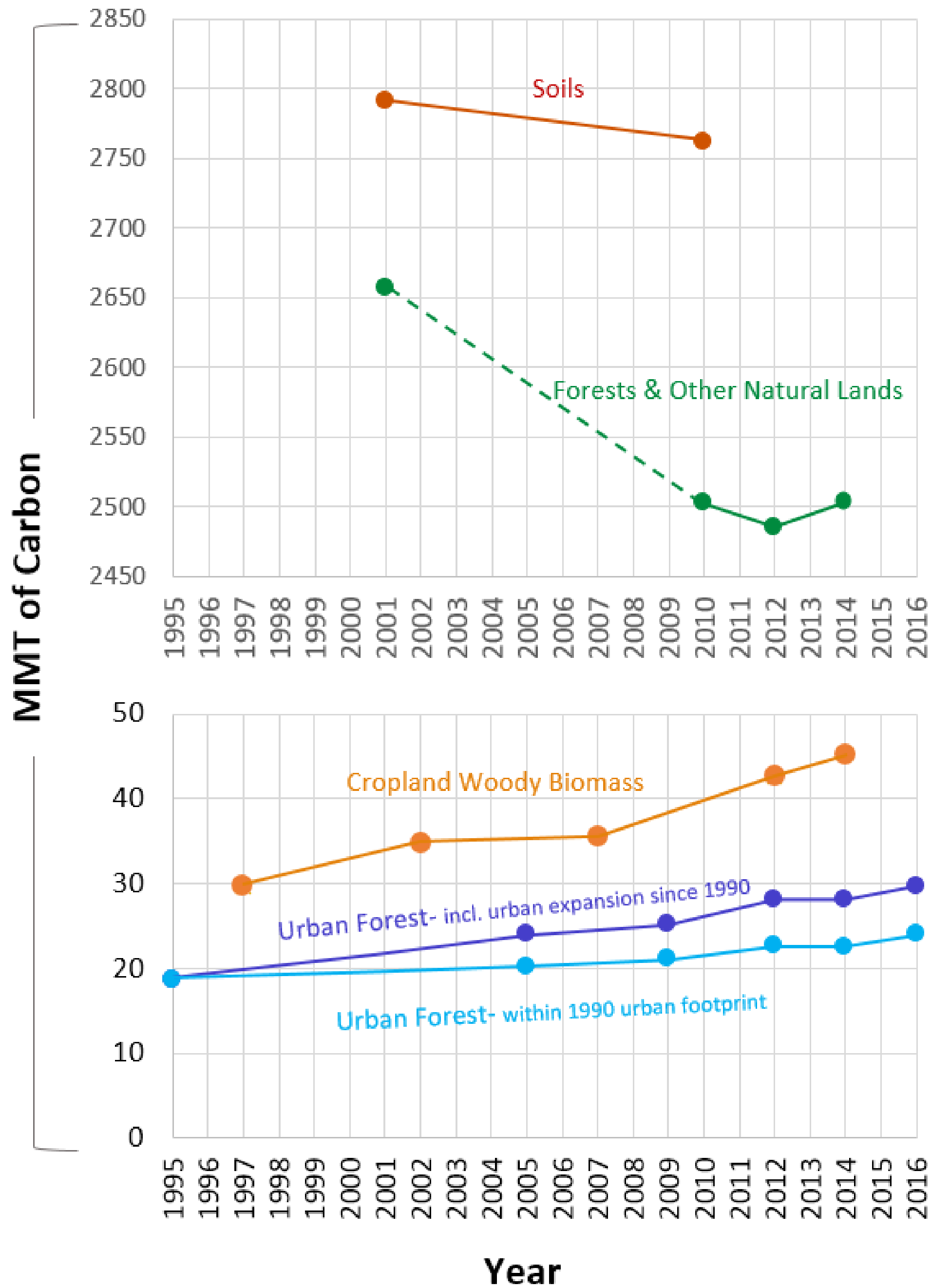


**Figure 7.** Trends in carbon stocks over time (MMT of carbon). Due to large difference in scale, soils and FONL are shown in the top panel, and cropland woody biomass and urban forest are shown in the bottom panel. Each solid circle represents a “snapshot” of inventory estimate based on available empirical data. The various remote sensing datasets used in the NWL inventory are not consistently available for the same years (see **Section 2C.1** for more information). The 2001-2010 period for FONL is shown as a dotted line because large year-to-year variations during that period are not represented by a straight line. CARB staff plans to annualize the inventory to better understand the temporal trend during this 9-year period—as see **Section 4A.8** for more information.

### *3B.1 – Forest and Other Natural Lands*

**Tables 5 through 10** present the results of FONL biomass inventory estimates for carbon stock changes and transfers to different land cover types, shown in IPCC inventory category format. IPCC category format categorizes land cover changes as either remaining the same cover type or converted into a different cover type. For example, a category may be described as "Land Cover A Remaining Land Cover A" or "Land Cover A Converted to Land Cover B." A positive number indicates a gain in carbon stock, and a negative number indicates a loss in carbon stock.

There are two tables for each of the three time periods evaluated (2001-2010, 2010-2012, and 2012-2014). For each time period, the first of the two tables summarizes results for above-ground live (AGL) biomass, and the second table summarizes results for total live and dead biomass and their roots. Cropland biomass and urban forests are quantified separately and not included in these FONL tables (see **Sections 3B.3 and 3B.4** for cropland biomass and urban forest inventory estimates), but default carbon density values were used in the FONL segment of the Inventory when estimating the carbon stock change of land converting to and from cropland and urban land. **Figure 8** presents a map of disturbance for the entire existing FONL inventory time period of 2001 - 2014.

Net carbon stock change can be calculated by summing all the numbers in each table. Net stock change for AGL biomass was a loss of 23 MMT C from 2001 to 2010 (**Table 5**). This loss was driven largely by the areal extent of fire during the 2001 – 2010 period (**Figure 8**), much of which was high severity. These fires were the principal driver in the conversion of forest/shrubLand (particularly shrublands) to grass/herbaceous cover (Grasslands), which has a lower carbon density. Overall net stock change for total carbon (AGL, BGL, dead, and litter pools combined) was a loss of 155 MMT C for the 2001 – 2010 period (**Table 6**). Fire contributes to the magnitude of net loss for total carbon stocks due to consumption of the large pool of dead organic matter that is composed of dead plants and litter, as well as killing live vegetation. Losses associated with fire in shrub-dominated lands are included in the tabulation for the Forest/Shrubland Remaining Forest/Shrubland category.

For the 2012 – 2014 period, the Forest/Shrubland Remaining Forest/Shrubland category exhibited a net gain in AGL carbon that was nearly half the magnitude for 2010 – 2012, approximately 5 MMT (**Table 9**)**. Elsewhere, carbon losses are associated with Forest/Shrubland that changed to land dominated by grasses, driven largely by fire. Also for the 2012 – 2014 period, carbon gains are associated with Grasslands that became Forest/Shrubland during the period. These changes were observed in locations within regions of the southern Cascades and central and southern coasts, where areas classified by LANDFIRE as grassland in 2012 were classified in 2014 as woodlands.

Net stock change in AGL carbon for the 2010 – 2012 and 2012 – 2014 periods are smaller compared to 2001 – 2010 because of shorter inventory time intervals. There were more cumulative fire activities during the 9-year period of 2001 – 2010 compared to the 2-year periods for 2010 – 2014 and 2012 – 2014. Stock loss from Forest/Shrubland Converting to Grassland were again associated with wildfire; however, in 2010 – 2012, AGL FONL biomass carbon stocks rose by approximately 6 MMT C (**Table 7**), and by 2 MMT C in 2012 – 2014 (**Table 9**). These gains suggest that the AGL pool functioned as a net sink for these two periods. When total biomass stocks are taken into consideration, FONL biomass stocks show a net loss of 4.8 MMT C for 2010–2012 (**Table 8**) and a net gain of 15.6 MMT C for 2012–2014 (**Table 10**).

***Errata: The sentence was updated on February 26, 2020 to correct the table reference. The original version referenced **Table 7** which has been updated to correctly reference **Table 9**.*

**Table 5.** Carbon stock change for FONL AGL biomass (MMT of carbon) for the 2001–2010 period.

| | | **2010** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| **2001** | *Forests/Shrublands* | 17.50 | -35.44 | -1.54 | -4.65 | -0.11 | |
| | *Grasslands* | 0.38 | 0.34 | -0.11 | -0.02 | -0.01 | |
| | *Croplands* | TBD | | | | | |
| | *Other Lands* | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | |
| | *Developed Lands* | | | | | TBD | |
| | *Wetlands* | 0.89 | 0.03 | -0.05 | 0.00 | 0.00 | |

**Table 6.** Carbon stock change for FONL total live and dead biomass (MMT of carbon) for the 2001–2010 period.

| | | **2010** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| **2001** | *Forests/Shrublands* | -16.85 | -112.49 | -7.54 | -22.46 | -0.52 | |
| | *Grasslands* | 3.45 | 1.45 | -0.19 | -0.09 | -0.02 | |
| | *Croplands* | TBD | | | | | |
| | *Other Lands* | -0.07 | | 0.02 | 0.03 | | -0.01 |
| | *Developed Lands* | | | | | TBD | |
| | *Wetlands* | | | | | | 0.00 |

**Table 7.** Carbon stock change for FONL AGL biomass (MMT of carbon) for the 2010–2012 period.

| | | **2012** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| **2010** | *Forest/Shrublands* | 11.53 | -3.67 | -0.49 | 0.23 | -1.10 | |
| | *Grasslands* | $6. \times 10^{-6}$ | -0.30 | -0.03 | $6 \times 10^{-4}$ | -0.02 | |
| | *Croplands* | TBD | | | | | |
| | *Other Lands* | | | -0.00 | 0.00 | -0.00 | |
| | *Developed Lands* | | | | | TBD | |
| | *Wetlands* | | | | | | 0.00 |

**Table 8.** Carbon stock change for FONL total live and dead biomass (MMT of carbon) for the 2010–2012 period.

| | | **2012** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| **2010** | *Forests/Shrublands* | 14.85 | -10.87 | -2.56 | 0.94 | -5.42 | |
| | *Grasslands* | $2 \times 10^{-5}$ | -1.54 | -0.11 | $-3 \times 10^{-3}$ | -0.09 | |
| | *Croplands* | TBD | | | | | |
| | *Other Lands* | | | 0.02 | 0.00 | $3 \times 10^{-3}$ | |
| | *Developed Lands* | | | | | TBD | |
| | *Wetlands* | | | | | | 0.00 |

**Table 9.** Carbon stock change for FONL AGL biomass (MMT of carbon) for the 2012–2014 period.

| | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|
| **2012** | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| | *Forests/Shrublands* | 4.96 | -6.05 | | | | |
| | *Grasslands* | 3.18 | | | | | |
| | *Croplands* | TBD | | | | | |
| | *Other Lands* | | | | $4 \times 10^{-7}$ | | |
| | *Developed Lands* | | | | | TBD | |
| | *Wetlands* | | | | | | |

**Table 10.** Carbon stock change for FONL total live and dead biomass (MMT of carbon) for the 2012–2014 period.

| | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|
| **2012** | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| | *Forests/Shrublands* | 3.63 | -15.87 | | | | |
| | *Grasslands* | 27.85 | $4 \times 10^{-3}$ | | | | |
| | *Croplands* | TBD | | | | | |
| | *Other Lands* | | | | $4 \times 10^{-7}$ | | |
| | *Developed Lands* | | | | | TBD | |
| | *Wetlands* | | | | | | 0.00 |

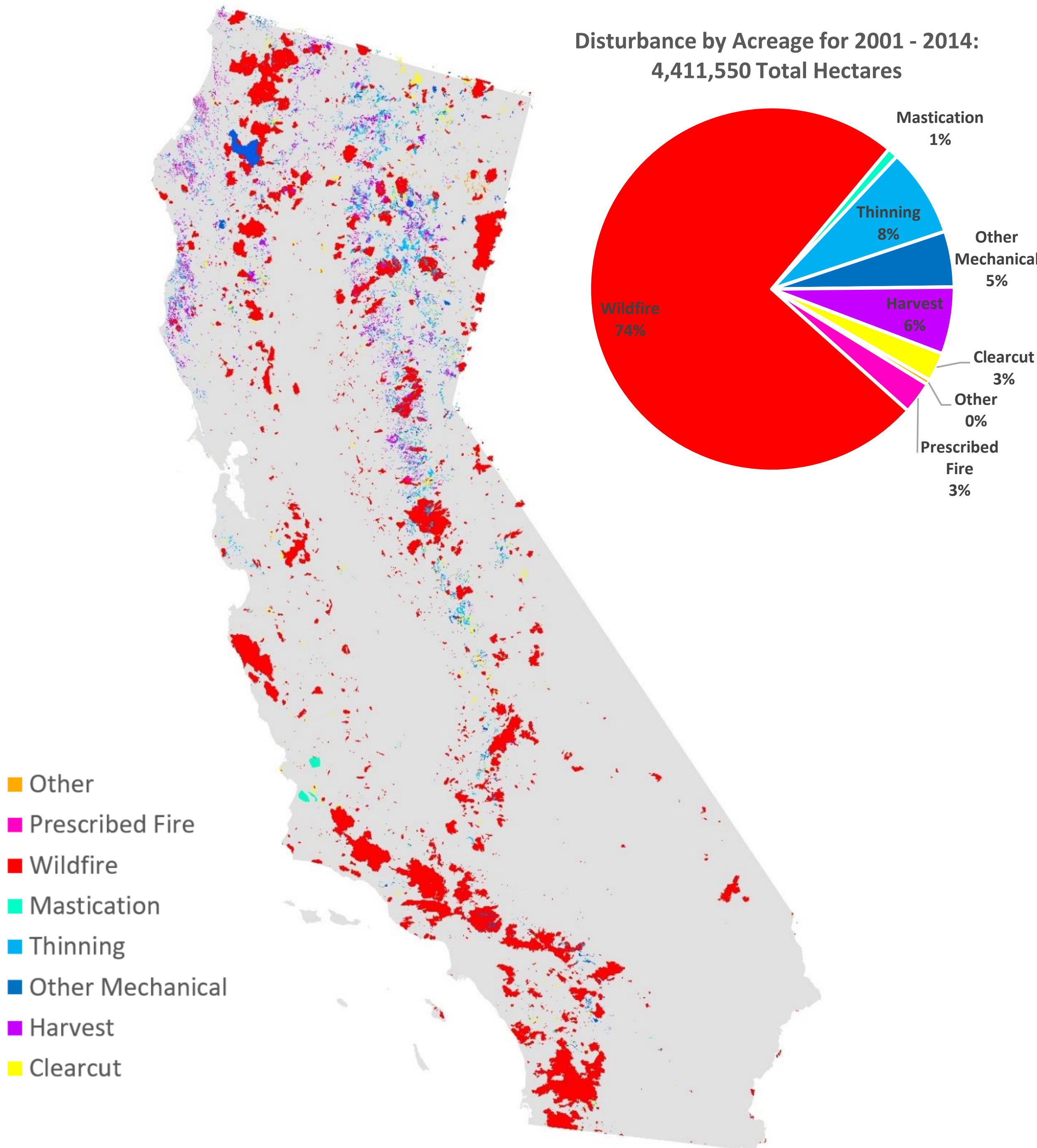


**Figure 8**.** Map of disturbances that occurred on the California landscape during the 2001–2014 period.

***Errata: Figure 8 was updated on February 26, 2020 to correct the reported units in the Disturbance by Acreage pie chart. The original version reported Disturbance by Acreage in acres, which has been updated to the correct unit of hectares in this version.*

In addition to reporting net stock changes by land category, the IPCC Inventory Guidelines provides for attributing and reporting stock changes by disturbance processes: biomass burning on land (IPCC Inventory Category 3C1) and harvests (IPCC Inventory Category 3D1). Estimated stock changes by disturbance process for periods 2001 – 2010, 2010 – 2012, and 2012 – 2014 are displayed in **Tables 11, 12, and 13**. Stock changes attributed to fires and harvests were estimated using procedures in Geographical Information Systems (GIS) and geospatial disturbance data such as shown in **Figure 8**. Stock changes by disturbance process represent a subset of the net stock changes (sums of gains and losses) reported in **Tables 5-10**. For example, stock changes associated with biomass burning in the 2012 – 2014 period (**Table 13**) are greater than the net stock change represented in **Tables 9 and 10**. Biomass burning categories include wildfires, prescribed burning, and wildland fires managed for resource benefit.[9] Estimates for $CH_4$ and $N_2O$ emissions associated with biomass burning are in development. Net stock change of harvest accounts for carbon persisting as solid wood product, generated from AGL biomass extracted from forest lands. The net stock change of harvest represents the transfer of carbon to the atmosphere as a result of harvest activity and mill processes. For all three analysis periods, stock changes associated with fires are several times greater in magnitude than changes associated with harvests.

**Table 11.** Stock change attribution by IPCC category for the 2001–2010 period. Net stock change of harvest accounts for 7.6 MMT post-harvest carbon persisting as wood product.

| IPCC Category Code | Category Description | $10^6$ Metric Tons Carbon (MMT C) | |
|---|---|---|---|
| 3C1 | Biomass Burning<br>Forest Land (3C1a), Grassland (3C1c) and Other Land (3C1d) | Above-Ground Live (AGL) | Total (Live & Dead) |
| | | -43.6 | -123 |
| 3D1 | Harvest, Thinning and Clearcut gross stock change | -10.4 | -19.4 |
| | Net stock change | -2.7 | -11.8 |

**Table 12.** Stock change attribution by IPCC category for the 2010–2012 period. Net stock change of harvest accounts for 1.04 MMT post-harvest carbon persisting as wood product.

| IPCC Category Code | Category Description | $10^6$ Metric Tons Carbon (MMT C) | |
|---|---|---|---|
| 3C1 | Biomass Burning<br>Forest Land (3C1a), Grassland (3C1c) and Other Land (3C1d) | Above-Ground Live (AGL) | Total (Live & Dead) |
| | | -3.5 | -9.4 |
| 3D1 | Harvest, Thinning and Clearcut gross stock change | -1.4 | -5.0 |
| | Net stock change | -0.3 | -1.2 |

[9] "Wildland fires managed for resource benefit" is the management of naturally ignited wildland fires to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in Fire Management Plans (USDA-FS, 2018). Where communities are not at risk, allowing natural fires to burn may be the most appropriate management response. In rugged, steep, or highly inaccessible terrain where people are not threatened, wildland fire use can help avoid putting firefighters at unreasonable risk (US FWS, 2018).

**Table 13.** Stock changes attribution by IPCC category for 2012 – 2014. Net stock change of harvest accounts for 1.35 MMT post-harvest carbon persisting as wood product.

| IPCC Category Code | Category Description | $10^6$ Metric Tons Carbon (MMT C) | |
|---|---|---|---|
| 3C1 | Biomass Burning<br>Forest Land (3C1a), Grassland (3C1c) and Other Land (3C1d) | Above-Ground Live (AGL) | Total (Live & Dead) |
| | | -8.3 | -19.7 |
| 3D1 | Harvest, Thinning and Clearcut | | |
| | Gross stock change | -1.77 | -6.49 |
| | Net stock change | -0.43 | -5.15 |

### *3B.2 – Soil Carbon*

Net stock change for the soil organic carbon pool for 2001 – 2010 amounted to a loss of 30 MMT of carbon, which is about 3 MMT of carbon lost per year. The six categories that showed the most significant stock changes were: Croplands Remaining Croplands, Forests/Shrublands Converted to Croplands, Grasslands converted to Croplands, Other Lands Converted to Forests/Shrublands, Grasslands Remaining Grasslands, and Forests/Shrublands Converted to Other Lands (**Table 14**). For an in depth explanation of the methods used to calculate stock change for the soil carbon pool and the results, please refer to the NWL Inventory TSD (CARB, 2018b). The explanation of IPCC reporting category format presented in **Section 3B.1** also applies to these soil carbon estimates.

**Table 14.** Carbon stock change for soils in the 2001 – 2010 period for all lands (MMT C). Empty cells indicate that the designated land use change category did not exist in the 2001 – 2010 time-step. Wetlands are not included in this iteration of the inventory and are an active are of work by CARB staff.

| | | **2010** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Forests/ Shrublands* | *Grasslands* | *Croplands* | *Other Lands* | *Developed Lands* | *Wetlands* |
| **2001** | *Forests/Shrublands* | -0.02 | -1.56 | -7.10 | -6.98 | -0.09 | |
| | *Grasslands* | $4 \times 10^{-3}$ | -4.74 | -4.05 | -0.28 | -0.08 | |
| | *Croplands* | $2 \times 10^{-3}$ | $8 \times 10^{-5}$ | -14.18 | -0.12 | -1.13 | |
| | *Other Lands* | 12.59 | 0.05 | -0.49 | $-2 \times 10^{-3}$ | $-1 \times 10^{-3}$ | |
| | *Developed Lands* | | | | | -1.47 | |
| | *Wetlands* | TBD | | | | | |

### *3B.3 – Cropland Biomass*

CARB staff quantified the carbon stored in orchards and vineyards from 1997 through 2014 by integrating remotely sensed and field data within allometric equations. The orchards included in this analysis were almond, orange, pistachio, and walnut orchards. Detailed information on how carbon in woody crops was quantified can be found in the NWL Inventory TSD. As mentioned in **Section 2B.2**, emissions from direct human activities (e.g., agriculture equipment, fertilizer use, etc.) are not included in the NWL inventory, and soil carbon is quantified separately. Although the carbon contained in woody materials that leave the croplands is estimated in the inventory estimate, the fate of the wood after the trees or vineyards are removed is also not quantified.

The inventory estimates indicate that carbon stored in orchard biomass has been increasing since 1997 in all woody crops except oranges (**Figure 9**). Statewide totals show an overall increase in carbon stores. Almonds, in particular, have increased their carbon stores while grapes show little change. Changes in these crops are driven by many factors, including changes in crop price and water availability.

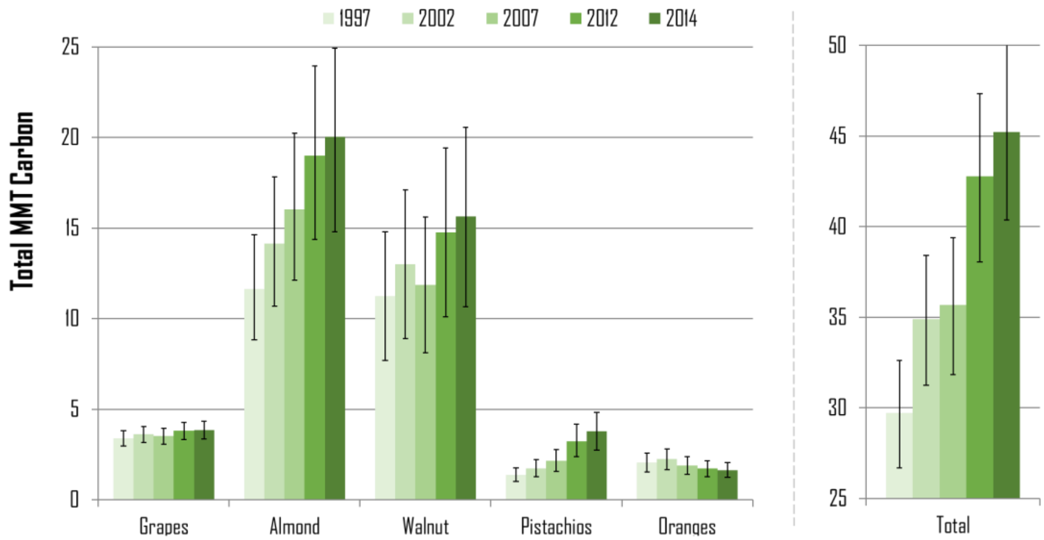


**Figure 9.** Carbon stocks (MMT C) in grapes, almonds, walnuts, pistachios, and oranges through time (left) and the statewide total across all orchard and vineyard types through time (right). The black lines show the uncertainty associated with the estimates.

### *3B.4 – Urban Forests*

CARB defined urban forests for the NWL Inventory to include all trees within U.S. Census urban areas. This segment of the inventory does not include direct emissions related to any aspect of urbanization, including the emissions from transportation, industrial facilities, and homes. Biomass carbon losses from conversion of other cover types to urban are accounted for in the FONL inventory.

The urban forest inventory indicates that carbon stocks within California's urban forests are increasing (**Figure 10**). The dual drivers behind this trend are tree canopies within existing city limits and the expansion of urban areas. As trees grow, they accumulate more carbon in their biomass, thus increasing the urban forest carbon stock. Additionally, as urban areas expand, more trees are counted in the urban forest inventory, which also increases the carbon stock for this inventory.

Expanding urban boundaries can affect the carbon previously held in FONL, croplands and rangelands. CARB staff compared urban footprint areas between 2000 and 2010 (where urban expansion is defined by the U.S. Census urban boundaries and CARB's 2001 FONL inventory), and estimated that the land areas that were once classified as FONL or cropland in 2000 but reclassified to urban land in 2010 had contained approximately 7.7 MMT of carbon. (This represents the amount of ecosystem carbon that may potentially be impacted by urban expansion, but after accounting for what happened to these lands to assess the net change in carbon stock, the actual number may be smaller than 7.7 MMT.) This carbon estimate includes biomass but not soil carbon. CARB staff plans to analyze the longer-term implications of urbanization on carbon stock and GHG emissions. See **Section 4A.7** for additional discussion. While some carbon loss may be regained over time if the new urban landscaping includes larger woody trees, conversion decisions should appropriately weigh all environmental and economic factors.

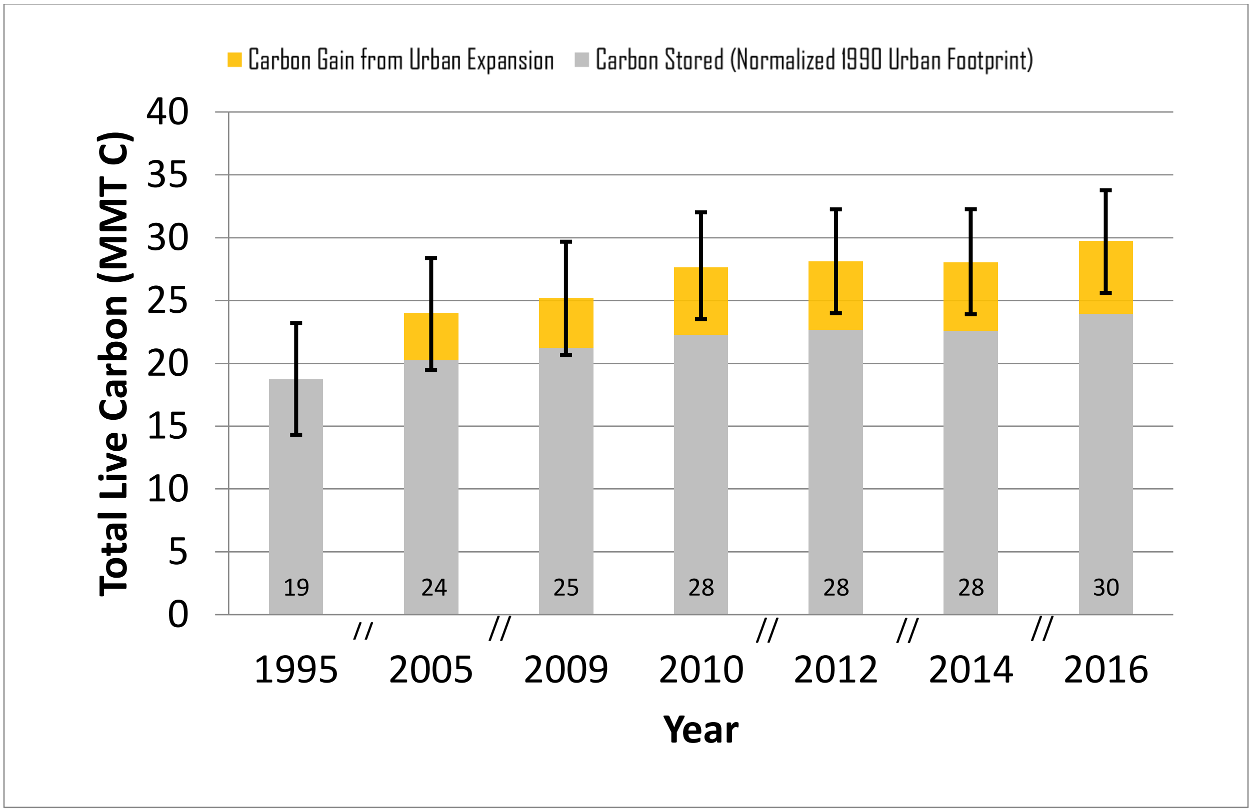


**Figure 10.** Carbon stocks (MMT C) in urban forests through time. Grey portion indicates the carbon within the 1995 urban boundary. The yellow portion represents urban forest carbon within the expanding urban area since 1995. The black lines represent the combined uncertainty associated with each estimate. This graph does not include emissions associated with any other urban activities or the carbon lost due to urbanization.

### *3B.5 – Wetlands*

CARB staff quantified soil organic carbon stock change and methane emissions from wetlands using IPCC Tier 1 methods and the California Aquatic Resources Inventory (CARI) geospatial dataset (SFEI, 2016) for the year 2016. Tier 1 methods are emission factor based, meaning that emissions are calculated by multiplying the IPCC default emission factor by the land area in each wetland category.

IPCC identifies 7 wetland types: 1) peatlands, 2) flooded lands, 3) drained organic soils, 4) rewetted organic soils, 5) coastal wetlands, 6) inland wetland mineral soils, and 7) constructed wetlands for wastewater treatment (IPCC, 2006) (IPCC, 2013). CARB staff identified that three of these seven types exist in California: 1) rewetted organic soils, 2) coastal wetlands, and 3) inland wetland mineral soils. The remaining four wetland categories either did not exist in California during the 2016 analysis year or existed in such small acreages as to be negligible (< 500 acres statewide).

CARB staff calculated that wetlands in California emitted just under 1 MMT $CO_2e$ during 2016 (**Table 15**).

**Table 15.** 2016 wetland emissions. Positive numbers indicate carbon stock increase in the soil and negative numbers indicate carbon loss via methane emissions and/or microbial oxidation.

| IPCC Wetland Category | $CH_4$ Emissions[1] (MMT $CO_2e$) | SOC C Stock Δ[2] (MMT $CO_2e$) | Net Emissions[3] (MMT $CO_2e$) |
|---|---|---|---|
| *Coastal Wetlands* | 0.00 | -0.19 | -0.19 |
| *Inland Wetland Mineral Soils* | 0.47 | 0.17 | 0.64 |
| *Rewetted Organic Soil* | 0.35 | 0.13 | 0.49 |
| ***Total*** | | | **-0.94** |

## 3C – Geospatially Explicit Carbon Density Estimates

In addition to quantifying carbon stocks by IPCC land cover category, CARB has mapped carbon stocks to the ecoregions used in the California Forest Carbon Plan (which were based on Bailey's ecoregions developed by USDA-FS Rocky Mountain Research Station) (FCAT, 2018). Ecoregions are classification and mapping frameworks for stratifying the Earth into "smaller areas of increasingly uniform ecological potentials" (McNab & Avers, 1994). Ecoregions represent associations of biotic and environmental factors that regulate the structure and function of ecosystems. Factors used to define ecoregions include climate, topography, soils, and hydrology.

**Table 16** displays area-average carbon densities in eight ecoregions defined for California. For FONL, area-average AGL carbon densities are high for regions with climates that support forests: North Coast, Klamath/Interior Coast Ranges and the Sierra Cascades. In the North Coast and Klamath/Interior Ranges, maximum AGL densities exceed 500 metric tons (MT) of carbon (C) per hectare (MT/hectare) (**Figure 11**) and maximum total biomass carbon densities exceed 900 MT/hectare (**Figure12**). Also in the North Coast, Gonzalez et al. (2010) reported AGL carbon densities of 600 (± 230) MT/hectare for an old-growth Redwood forest. Drier regions, where grasses, shrubs, and sparse woodlands predominate, exhibit lower densities. A similar pattern holds true for soils. Soil carbon densities in FONL and cropland are generally higher in areas that support tree growth and/or wetland ecosystems and are undisturbed by activities such as tillage. Areas that do not support much plant growth, often due to lower rates of precipitation, have lower soil organic carbon densities. This can be seen in the Eastside and Desert ecoregions as compared to the North Coast and Sierra/Cascades. In the Sacramento-San Joaquin Delta, which is dominated by high carbon-density histosol soils, soil carbon densities can exceed 900 MT/hectare (**Figure 13**).

**Table 16.** Area-average carbon densities (MT / hectare) by ecoregion.

| Ecoregion | AGL Biomass C | Total Biomass C | Soil C |
|---|---|---|---|
| *North Coast* | 71 | 164 | 147 |
| *Klamath/Interior Coast Ranges* | 50 | 134 | 114 |
| *Sierra/Cascades* | 42 | 121 | 105 |
| *Central Coast and Interior Ranges* | 14 | 50 | 85 |
| *South Coast and Mountains* | 8 | 35 | 75 |
| *Eastside* | 7 | 31 | 56 |
| *Central Valley* | 1 | 13 | 75 |
| *Deserts* | < 1 | 4 | 22 |

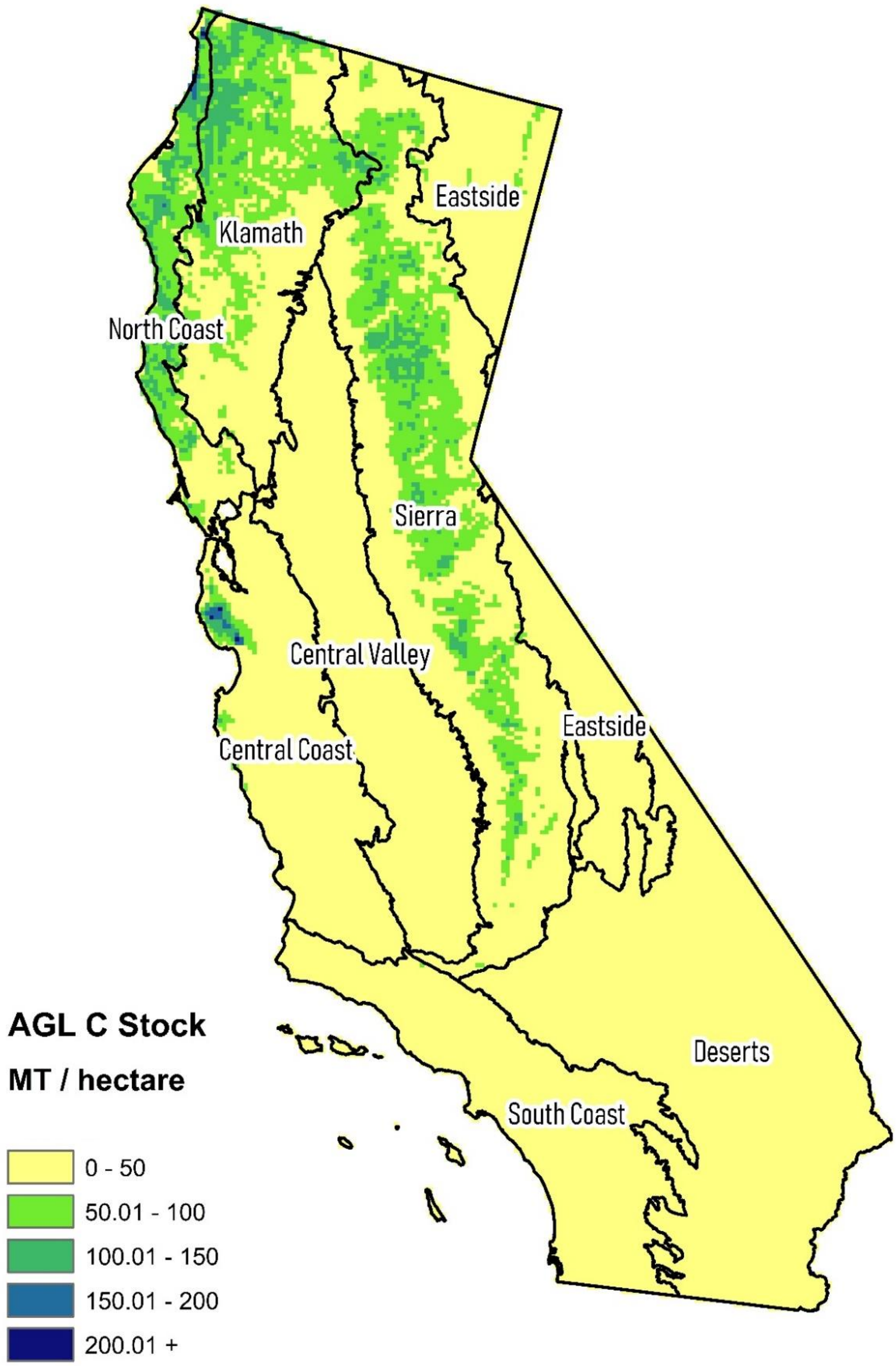


**Figure 11.** Forest and other natural lands above-ground live (AGL) carbon density (MT / hectare) by ecoregion. (Reference values for 2014)

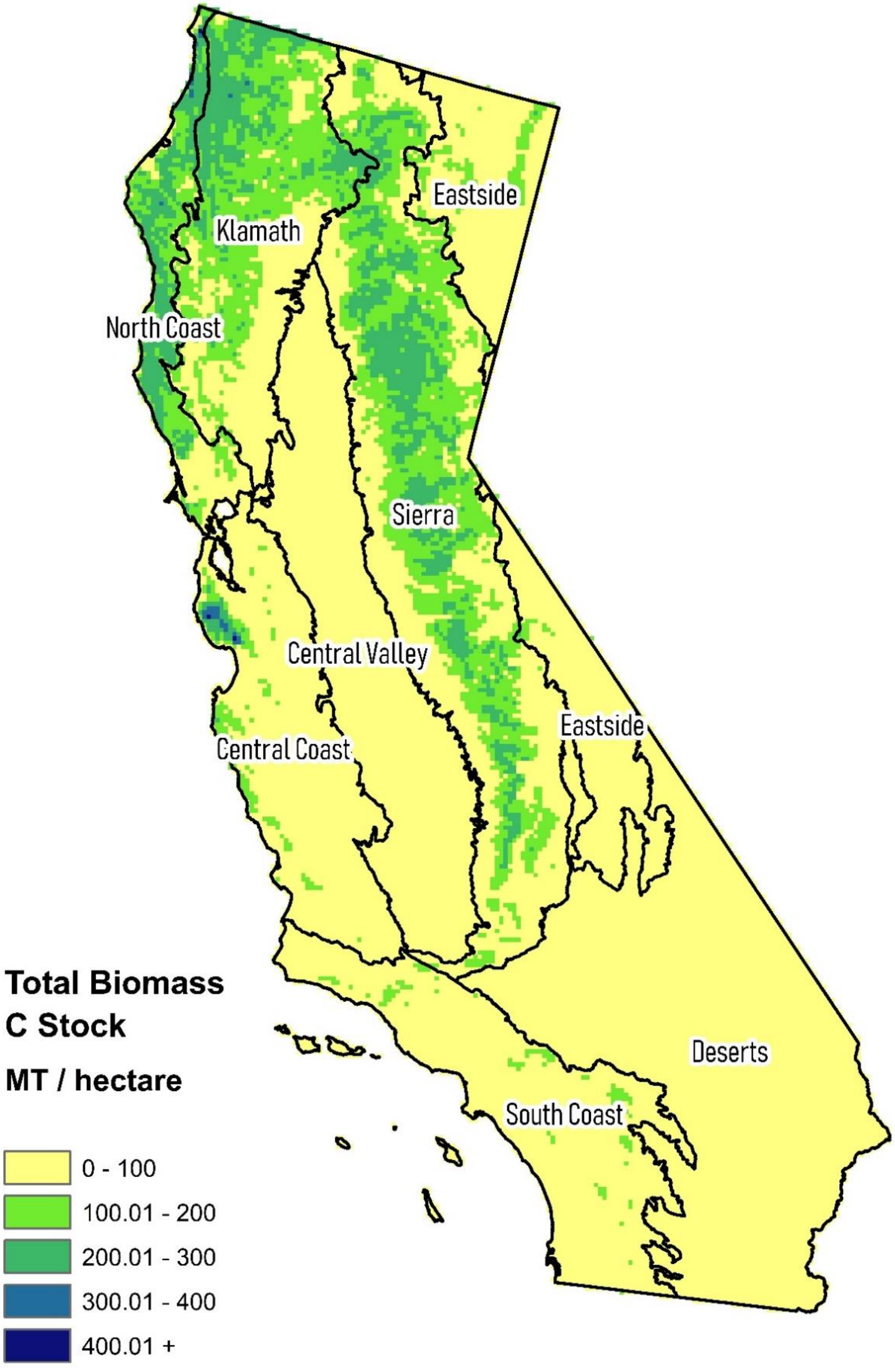


**Figure 12.** Forest and other natural lands total (live and dead pools, not including soils) carbon density (MT / hectare) by ecoregion. (Reference values for 2014)

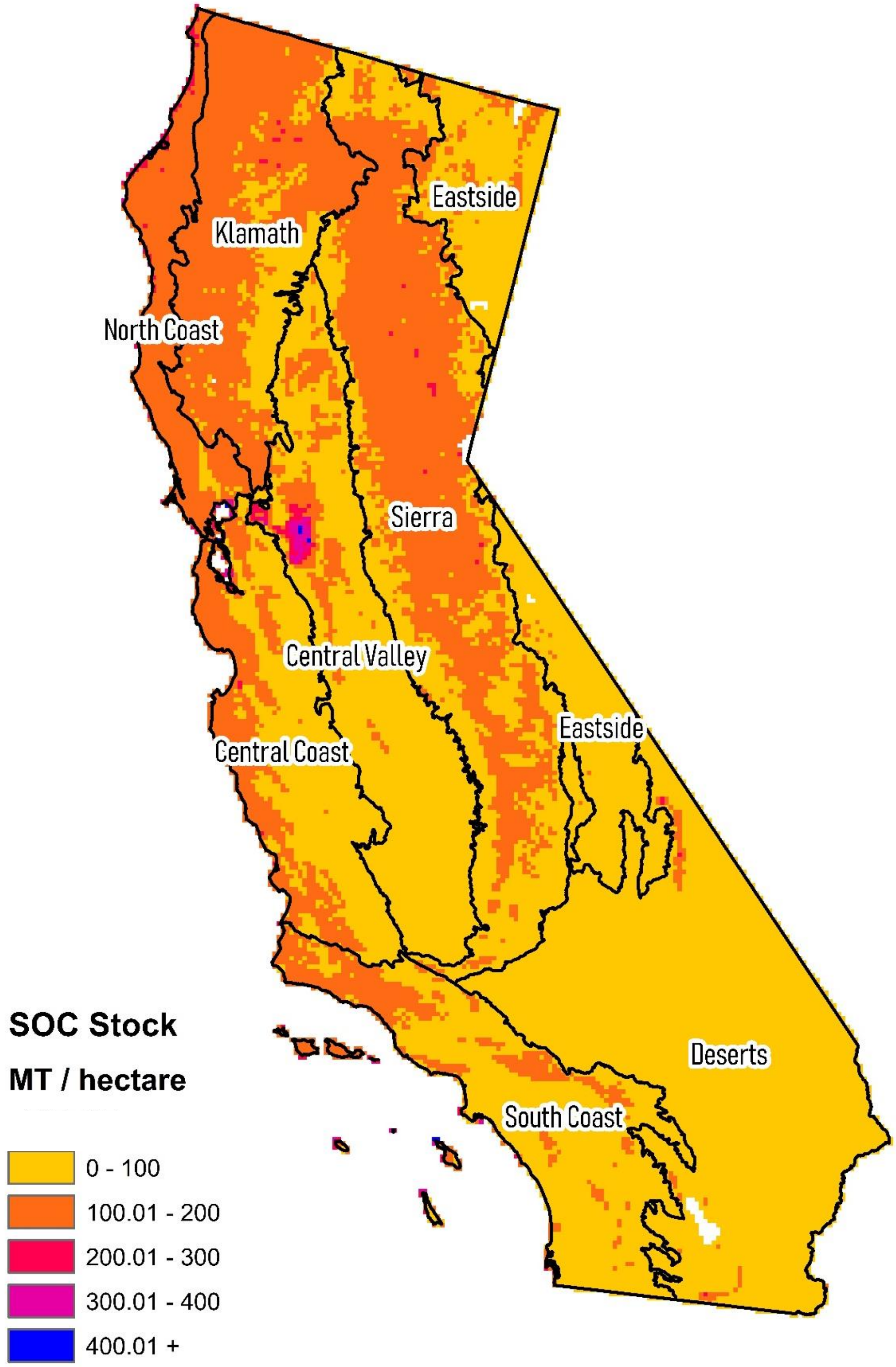


**Figure 13.** Soil organic carbon density to a depth of 30 cm (MT / hectare) by ecoregion for forest and other natural lands and croplands (reference values for 2001).

# 4 – Future Work

## 4A – Continual Inventory Improvement

CARB plans to continually work with sister agencies and the scientific community to improve the inventory estimates. This includes moving from lower to higher methodology tiers as data and modeling resources become available, identifying the highest quality data for use in creating the inventory, and incorporating expertise from the scientific community and sister agencies. As improvements are made to methods and additional data are incorporated, CARB staff will look into updating the entire inventory series, including older years that have been quantified in previous editions of the inventory. This inventory update practice is recommended by the IPCC inventory guidelines.

### *4A.1 – Tier 3 Biogeochemical Modeling for Soil Carbon*

CARB staff plans to move towards Tier 3 biogeochemical modeling of soil organic carbon (SOC) stock change in order to both reduce uncertainty in the inventory and be able to better capture the effects of weather and management practices. The current inventory will be used as a guide to prioritize modeling efforts based on the land cover category's contribution to the total annual soil carbon stock flux, pending data/calibrated model availability. The first expansion of Tier 3 methods will be applied to the Croplands Remaining Croplands cateogry in the San Joaquin-Sacramento Delta, as microbial oxidation of the Delta's histosol soils was shown to be the largest contributor to stock change in SOC. The model currently under consideration for achieving this task is SUBCALC (Deverel & Leighton, 2010; Deverel, Ingrum, & Leighton, 2016). SUBCALC was specifically created to model $CO_2$ emissions from crop cultivation on the San Joaquin-Sacramento Delta and currently presents the best opportunity to quantify the Deltaic soil organic carbon fluxes with greater accuracy.

The planned next step is to model SOC stock change using a vetted biogeochemical model such as DNDC or DayCENT. Modeling SOC stock change at the Tier 3 level will be iterative, with future editions of the inventory to include more land cover types modeled at Tier 3 as data and calibrated biogeochemical models become available.

Other planned improvements include moving the non-cropland portions of the soil carbon inventory to Tier 3 and identifying methods to improve the mapping accuracy of the LANDFIRE product on California landscapes. Additional work is needed to integrate the natural lands, urban forest and cropland carbon components into a single geospatial framework. This will necessitate improvements to the LANDFIRE EVT product and resolving conflicts among natural land, cropland and urban forest datasets.

### *4A.2 – LANDFIRE Land Category Classifications*

LANDFIRE geospatial products are evolving as the consortium expands its resource management capacity beyond wildfires. With each update, LANDFIRE endeavors to respond to requests for a variety of improvements. LANDFIRE vegetation mapping also abides by guidelines in the federal National Vegetation Classification System (NVCS). As a result, LANDFIRE has become a central clearinghouse of national vegetation mapping data. Consequently, continual modification of the Existing Vegetation Type (EVT) product is likely as user needs and standards change. EVT classification is based mainly on vegetation spectral characteristics from Landsat remote sensing data calibrated against field data (Ryan & Opperman, 2013). Uncertainties inherent in remote sensing approaches contribute to uncertainties in vegetation classification. LANDFIRE has reported a vegetation classification area standard error of 61% of the mean against field-observed land cover (PQWT, 2008). In turn, the major source of uncertainty in CARB's land carbon quantification method is due to EVT classification (Battles et al. 2013; Gonzalez et al. 2015). Future work will explore options for improving EVT products used by CARB. Special attention will be paid to increasing the accuracy of wetlands and cropland mapping so that land-use change from these categories can be included in future iterations of the inventory.

### *4A.3 – Incorporating FIA Data*

CARB staff is working with CAL FIRE staff to explore options for utilizing the growing body of FIA field data to update reference carbon densities for live and dead pools and for tree growth rates used in the LANDFIRE-C tool. Other efforts will be devoted to accounting for post-disturbance carbon pools that persist on the landscape and in wood products. Monte Carlo methods from Gonzalez et al. (2015) to estimate stocks and stock-change at 95% confidence intervals also need to be implemented within the LANDFIRE-C tool, for all natural land carbon pools. Potential options for including new FIA data within CARB's forest inventory include updating the models used within LANDFIRE-C to reflect the new data and/or improving the method used to interpolate FIA data across California. Additionally, as new statewide remote sensing technologies become available, such as Light Detection and Ranging (LiDAR), then new and innovative methods may be used to interpolate FIA data, which may further increase the accuracy of CARB's forest carbon inventory

### *4A.4 – Post-Disturbance Carbon*

The stock change estimates attributed to wildfire are based on the difference between carbon stocks (live and dead) contained in vegetation types mapped before and after fire. However, post-fire landscapes feature less stable carbon stocks in the form of residual unburned dead fuels and killed trees, in addition to post-fire live vegetation mapped by LANDFIRE. Not accounting for killed trees and other post-disturbance pools may contribute to biases in current estimates of stock-change attributed to fire. Other disturbances, such as mass tree mortality associated with drought or insect/disease outbreaks, also convert carbon from live to dead forms which persist on the landscape for varying lengths of time (Harmon et al., 2011). The current inventory estimates for dead biomass rely on assumptions based on an older vintage of the FIA data. The growing body of field data accumulating from the FIA program affords opportunities for CARB to improve its representation of these pools and the timing and magnitudes of carbon exchanges associated with wildfires and other events (Hurteau & Brooks, 2011).

Mortality from drought, insect, and disease does not immediately remove carbon from the landscape; as the dead wood is still present in the form of snags and down woody debris. As time goes on, dead carbon material will decompose and be released into the atmosphere as $CO_2$ and turn into humus, which add organic carbon to the soils. The current inventory methodology uses broad assumptions about dead biomass, and additional opportunities exist for better capturing the movement of carbon between dead biomass carbon pool, soils, and the atmosphere. Refinement of dead biomass carbon estimate would also enable CARB to quantify the carbon impact of tree mortality in recent years, by comparing living plant's carbon uptake with the transfer of carbon from dead biomass to the atmosphere due to decomposition.

### *4A.5 – Disaggregation of Forest and Shrubland*

The LANDFIRE-C tool, which CARB uses for estimating FONL biomass carbon, was developed as an inventory tool that matches the IPCC inventory framework (**Section 2B**). In the LANDFIRE-C tool, the great diversity of vegetation communities in California are aggregated into the six IPCC land categories (**Section 2B.3),** where forest and shrubland are aggregated into the IPCC "Forest" category. While shrub-dominated land such as chaparral and coastal sagebrush are included in the IPCC definition of Forest land, they are different from forest in important ways: their structure and characteristics (such as burn behavior during a wildfire) are different from forest. They are also not managed like forest. To help inform California NWL's contributions to the State's effort in addressing climate change, it would be useful to disaggregate inventory results for forest and shrubland. Currently, to distinguish between forest and shrubland in the FONL inventory methodology requires a series of manual post-processing steps. Going forward, staff will implement a standard work flow that will enable the break out of forest land into common categories (e.g., woodland, shrubland), and report stock and changes for forest and shrubland separately.

### *4A.6 – Refinement of HWP Estimates*

In the current FONL inventory methodology, HWPs are estimated from the change in AGL carbon stock associated with harvest activities using broad assumptions that were built into the LANDFIRE-C tool (Saah, et al., 2016), which accounted for estimated mill efficiency factors from Stewart and Nakamura, 2012. This estimation approach could potentially lead to underestimation of HWP if the geospatial input data underestimate harvest activities. CARB staff will continue to work with CAL FIRE to improve alignment of estimates from CARB's geospatial approach and the estimates based on mill survey and industry data employed by CAL FIRE and the California Board of Forestry and Fire Protection.

### *4A.7 – Carbon Stock Change at the Interfaces of Urban Development, Cropland, and FONL*

To estimate carbon stock-change associated with conversions from natural to developed categories (IPCC category 3B5, Settlements), CARB's LANDFIRE-C tool employs a default set of 58 urban forest above-ground live (AGL) carbon densities (MT C/ha) drawn from Bjorkman et al. (2015) and averaged by county (Saah, et al., 2016). (A separate set of 46 annual row crop carbon densities are used for estimating stock-change associated with cropland conversions to developed.) The set of urban forest AGL carbon densities are derived from data on existing urban forest tree canopy cover, rather than (sparse, immature) tree canopy cover associated with newly developed areas. These densities may in turn bias stock-change estimates associated with conversion, as in cases where development extends into grasslands. To improve stock-change estimates for natural-to-developed conversions, future work could develop carbon densities representative of newly developed areas.

In addition, to better understand carbon losses and gains at the interfaces of urban land, cropland, and FONL, CARB staff plans to spatially analyze changes in carbon stored on lands that were once classified as cropland or FONL in an earlier year, but are reclassified as urban at a later time. The geospatially explicit data of the NWL Inventory can be used to quantify the net impact of urban expansion on biomass carbon sequestration, and enable an evaluation of urban forest's potential in recovering the initial loss of carbon at the time of land conversion.

### *4A.8 – Annualizing the Inventory*

As explained in **Section 2C.1**, given that the satellite-based datasets used to create the inventory are relatively nascent, data availability was limited for earlier years. For example, LANDFIRE has only made 2001, 2010, 2012, and 2014 data available to date, resulting in the FONL inventory having a 9-year (2001-2010) time-step with no information about the years in-between. In an effort to estimate NWL carbon between periodic empirical inventory releases, CARB staff are beginning the process of modeling the annual NWL carbon beginning 2001 to present. Creating these modeled annual estimates is intended to facilitate a better understanding of NWL carbon dynamics within the State of California, including temporal trends and drivers of carbon stock changes.

CARB staff envisions building a model based on statistical methods using the inventories from the 2001-2010 period as a basis for growth and disturbance severity estimates. The 2001 inventory will be used as the initial conditions for the modeling. Disturbance data collected from the LANDFIRE data product defines where and when disturbance will occur on an annual basis. In this way, the statistical model is based on empirical data and consistent with the retrospective NWL Inventory.

The model can be run for the time period where disturbance data are available. This would allow CARB staff to use the later empirical inventories as validation and calibration points. Validation gives CARB staff a sense of certainty and confidence in the modeling and its results. Adjusting the model as new empirical inventory data are derived allows CARB staff to change parameters, such as disturbance severity, as environmental conditions change.

This modeling is designed to give a general idea of annual trends when remote sensing data are not available between inventory vintages. It can also be used to estimate current carbon stocks until an empirical inventory can be complete due to the 4-year delay in data availability (see **Section 2C.1** for additional discussion). The estimates from this modeling are expected to have higher uncertainty than empirical inventory estimates.

## 4B – Integration of Inventory Segments

Each segment of the NWL Inventory (FONL, cropland, and urban forest) uses data with different spatial and temporal resolutions and different carbon stock quantification methods. Each inventory segment was constructed separately using the most appropriate data and methods for its respective methodology. The spatial boundary of each inventory segment depends on the spatial coverage of the input data that was used. When all the segments are put together, these spatial boundaries may not complement each other perfectly. In this first edition of the NWL Inventory, staff has not reconciled the difference in spatial boundaries between the inventory segments, but expects that any discrepancies due to potential double-counting or under-counting of pixels would be negligibly small.

In the future, CARB staff plans to integrate the inventory segments by following a decision tree to determine how each piece of land in California should be classified and which method should be used to quantify its carbon stock (**Figure 14**). Using this decision tree, all lands defined as within the US Census urban areas are to be classified as "developed," or urban. The remaining lands are further classified as either natural land (which would fall under FONL), non-natural lands, or water bodies. Further, non-natural lands can be disaggregated into agricultural lands and developed/urban lands. The remainder is not classified (amounts to 1% of California's total acreage) and is not addressed in this first edition of the inventory. CARB staff plans to use this decision tree to reconcile the spatial inventory results for presentation in a visualization tool (see **Section 4C** for further discussion). Future work includes reconciling spatial boundaries using this decision tree before the start of inventory data processing for more recent data vintages. The integration will result in each inventory segment's boundary complementing each other without any double-counting or under-counting.

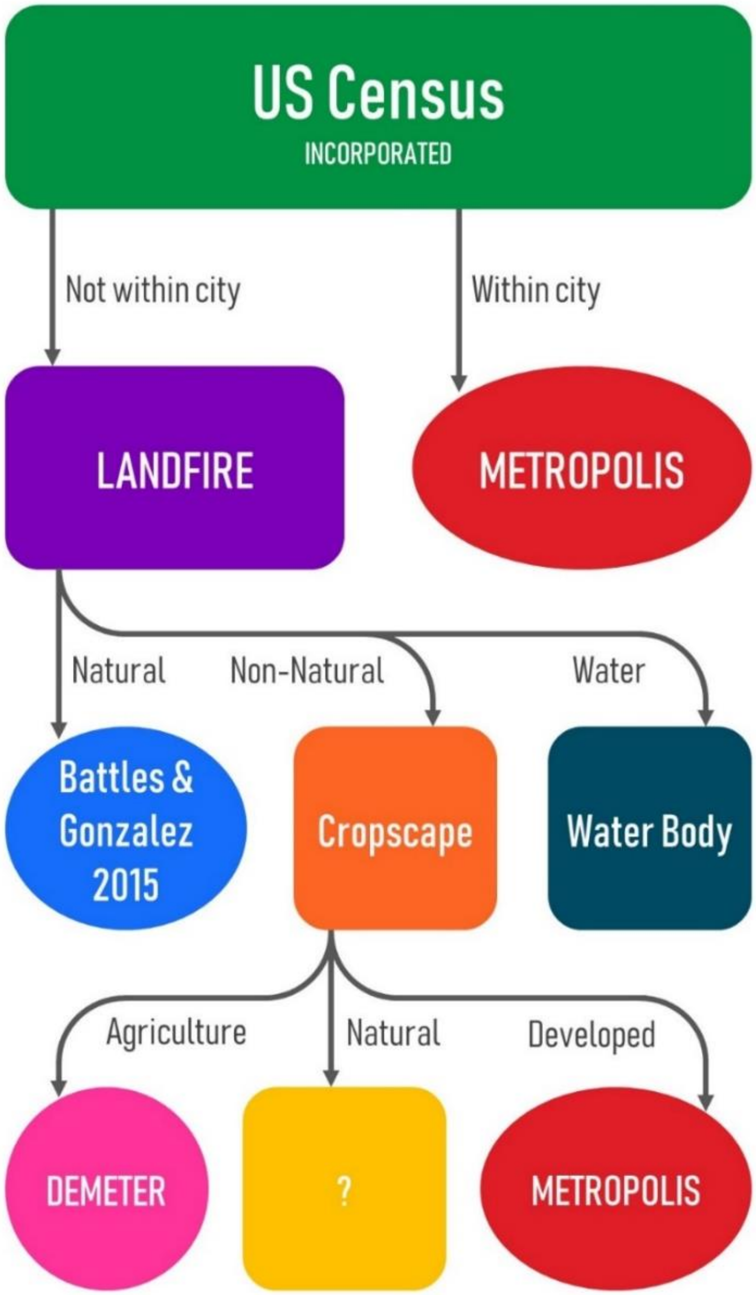


**Figure 14.** Decision tree for assigning each pixel in the spatial data to one of the inventory methodologies. Rectangles represent dataset with spatial land use classification information. Circles/ovals represent inventory methodology. The yellow square with "?" represents undetermined pixels, which make up <1% of land area and are not analyzed in this first edition of the NWL Inventory.

## 4C – Data Dissemination and Visualization

Through the course of deriving and analyzing the NWL Inventory, CARB staff produced various data sets in the form of maps, graphs and charts. CARB staff plans to make these geospatially explicit data available to the public through a web-based data visualization tool. CARB staff is currently working with data visualization tool providers to explore options for creating a data visualization platform and data clearinghouse. The tool is still under development and options exist on the how it will function and appear.

## 4D – Potential Uses of Inventory Data

The NWL Inventory's geospatially explicit carbon estimates provide information about what vegetation type is present on land, how carbon density varies in different areas, how much live and dead biomass carbon are present on the landscape, and what changes are occurring on land. It can help identify areas where additional investment could result in more impact, thereby helping to inform project prioritization and level of investment needed on our lands to meet our long-term climate goals. For example, the inventory could direct ecosystem restoration efforts toward areas currently serving as carbon sources, or direct preservation efforts to ecosystems that contain large carbon pools vulnerable to loss. In the future, spatially-explicit information from the inventory could also be used to support investment decisions and help the State better meet goals for NWL management. The satellite-based data can also be used to verify project status and monitor productivity and canopy cover. However, because remote monitoring techniques have limited resolution and do not yet capture detail metrics that must be measured in the field (e.g., tree diameter), it can only complement and does not replace monitoring and tracking required by existing programs. Over time, CARB's NWL inventory will capture the effects of implemented interventions, along with any impacts from regulatory and policy changes and other gains or losses that occur over the same timeframe.

## 4E – Historical Baseline of Natural Fire Regime

Fire has performed a natural function in California's diverse ecosystems for millennia, such as facilitating germination of seeds for certain tree species, replenishing soil nutrients, clearing dead biomass to make room for living trees to grow, and reducing accumulation of fuel that lead to high-intensity wildfires. Modern-era fire suppression practice has limited fire's function in natural ecosystems and resulted in accumulation of fuel in the forest. In 2018, the California Legislature enacted SB 901 (Dodd, Chapter 626, Statutes of 2018), which requires CARB to develop a historical baseline of natural fire regime reflecting conditions before modern fire suppression to better understand the level of carbon loss expected from naturally occurring fire. CARB staff will be working with the research community to develop a historical fire baseline pursuant to SB 901.

# 5 – Comparison with Other Inventory Approaches

This section discusses how CARB's NWL Inventory compares with other inventory methods. CARB's methodology enables geospatially explicit "all lands" reporting by IPCC categories, as well as comparisons with regional and statewide estimates generated by other institutions. Differences and similarities exist between CARB carbon stock estimates and other inventory estimates driven by their methods and scale of focus.

CARB's goal is to quantify all carbon stocks in all NWL, whereas other inventories may focus on a particular NWL land category, such as forests. CARB's expansive view on carbon requires the incorporation of estimates on all NWL into one statewide outlook. The difference in scale of focus may make it difficult to cross-walk between inventories developed by different institutions for serving their respective objectives.

## 5A – CAL FIRE's Forest Carbon Inventory

Assembly Bill 1504 (Skinner, 2010) directs the California Board of Forestry and Fire Protection to ensure that its rules and regulations that govern commercial forestry also consider the capacity of forests to sequester carbon sufficient to meet or exceed the State's 5 MMT $CO_2e$ goal identified in the 2008 Scoping Plan. As directed by AB 1504, the California Department of Forestry and Fire Protection (CAL FIRE) initiated a collaboration with the USDA Forest Service (USDA-FS) Pacific Northwest Research Station (PNW) Forest Inventory and Analysis (FIA) program in 2016 to generate and report estimates of California forest and harvested wood product carbon stocks and changes. The AB 1504 reporting effort relies on analysis products from the USDA-FS FIA program, analyzed specifically for CAL FIRE. Analyses are based upon FIA plot-level data on forest and ownership type, use status, tree species and dimensions, above- and below-ground live and dead carbon pools (reported as moving ten-year averages for statewide, ecoregions, FIA-defined forest types, and ownership categories), soil carbon, and wood products industry data (Christensen et al., 2017).

While both CAL FIRE's and CARB's forest carbon estimates (which represents the greatest portion of live vegetative terrestrial carbon) are based on FIA data, the way the data are used is quite different. FIA data are empirical measurements by the U.S. Forest Service that sample forested lands in the state with small, discrete plots. The CAL FIRE and CARB inventories both derive estimates for the AGL tree pool from a common set of FIA regional allometric equations and wood density factors. Statewide totals from Christensen et al. (2017) are statistical design-based estimates with no implied relationship between plot and remotely-sensed data, whereas the CARB method employs regression modeled estimates that depend on the accuracy of the correspondence between the FIA plot data and geospatial vegetation data. The difference in how each inventory chooses to use these points is the primary differences between the two inventories. Other notable differences include:

- The FIA program and CAL FIRE inventory defines forest as any land that has had at least 10% tree canopy cover in the past 30 years. The CARB inventory defines forests as any land that currently has at least 10% live tree or shrub canopy cover regardless of what that land had in the previous time-step.
- The CARB inventory uses IPCC Atmospheric Flow Approach, which accounts for carbon fluxes to/from the atmosphere for lands and wood products pools, including imported products. The CAL FIRE inventory uses IPCC Production Approach, which reports changes in ecosystem carbon stocks and wood products produced in the reporting country (changes in wood products exported

from the producing country are also reported, while products imported to the reporting country are not counted).

- The CARB inventory includes shrub-dominated land under the forest category. The CAL FIRE inventory does not include these land types in forestland unless they meet the minimum tree cover requirements.
- The 2018 edition of the CAL FIRE inventory does not include the litter pool due to issues with initial measurements of this pool (but they plan to include litter in the 2019 edition). The CARB inventory includes the litter pool.

**Table 17** lists selected AB 1504 report estimates from Christensen et al. (2017) and CARB's FONL estimates for AGL forest carbon stock flux, and **Table 18** shows values for carbon stock. CARB estimates are approximately 100 MMT C (~10%) lower than the Christensen et al. estimates, which is within the expected range of uncertainty. Estimates for forest carbon trends vary between AB 1504 reporting and CARB's LANDFIRE-C tool, depending on wildfire activity associated with time periods of analysis. Further discussion comparing sources and methods is contained in the NWL Inventory TSD (CARB, 2018).

**Table 17.** Statewide AGL carbon flux on Forest Lands (MMT C).

| AGL | Time period | Source | Pools Included |
|---|---|---|---|
| 6.82 ± 0.63 (SE) | 2001-2005 initial measure<br>2011-2015 re-measure | Christensen et al. (2017), Table 4.1 | live tree bole, bark, stems, foliage, and understory |
| 6.08 ± 0.59 (SE)[a] | 2001-2006 initial measure<br>2011-2016 re-measure | Christensen et al. (2018), Table 4.24 | live tree bole, bark, stems[a] |
| 2.06[b] | 2001-2010 | LANDFIRE-C Table 3 | bole, bark, stems[b] |
| 6.13[b] | 2010-2012 | LANDFIRE-C (DRAFT) | bole, bark, stems[b] |
| 4.96[b] | 2012-2014 | LANDFIRE-C (DRAFT) | bole, bark, stems[b] |

[a] Foliage change reported separately (0.32 ± 0.03 MMTC/yr)

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

**Table 18**. Statewide Forest Land AGL carbon stock estimates (MMT C)

| AGL | Vintage | Source | Pools Included |
|---|---|---|---|
| 1,014.4 ± 13.4 (SE) | 10-yr average, 2001-2010 | Christensen et al. (2016) Table A2-79 | live tree bole, bark, and stems |
| 1,025.37 ± 14.01 (SE) | 10-yr average, 2001-2010 | Christensen et al. (2018) Table C9.1 | live tree bole, bark, stems, and foliage |
| 1,034.66 ± 14.11 (SE) | 10-yr average, 2002-2011 | Christensen et al. (2018) Table C9.2 | live tree bole, bark, stems, and foliage |
| 1,035.28 ± 13.52 (SE) | 10-yr average, 2003-2012 | Christensen et al. (2018) Table C9.3 | live tree bole, bark, stems, and foliage |
| 1,045.40 ± 13.67 (SE) | 10-yr average, 2004-2013 | Christensen et al. (2018) Table C9.4 | live tree bole, bark, stems, and foliage |
| 1,054.90 ± 13.63 (SE) | 10-yr average, 2005-2014 | Christensen et al. (2018) Table C9.5 | live tree bole, bark, stems, and foliage |
| 1,061.89 ± 13.74 (SE) | 10-yr average, 2006-2015 | Christensen et al. (2018), Table C9.5 | live tree bole, bark, stems, and foliage |
| 1,066.14 ± 13.87 (SE) | 10-yr average, 2007-2016 | Christensen et al. (2018) Table C9.7 | live tree bole, bark, stems, and foliage |
| 990 | 2014 | FIA 2014 | bole, bark, stems of live trees, saplings, and understory |
| 975.1[a] | 2001 | LANDFIRE-C, Table 1 | bole, bark, stems of live trees or shrubs |
| 948.7[a] | 2010 | LANDFIRE-C, Table 2 | bole, bark, stems of live trees or shrubs |
| 951.3[a] | 2014 | LANDFIRE-C (DRAFT) | bole, bark, stems of live trees or shrubs |

[a] LANDFIRE-C forest land includes land dominated by shrubs. Estimates adjusted to carbon fraction of biomass = 0.5

## 5B – Biomass Carbon Densities

Using a geographic information system (GIS), CARB staff analyzed geospatial datasets (raster format) obtained from two research organizations in order to compare with LANDFIRE-C estimates of above-ground live carbon stocks in forested lands and shrublands, by ecoregions across the State.

### *5B.1 LEMMA*

LEMMA (Landscape Ecology Modeling, Mapping and Analysis) is a research collaboration of the USDA-FS Pacific Northwest Research Station and Oregon State University. The project utilizes Gradient Nearest Neighbor (GNN) techniques for mapping vegetation in ecoregions of the western U.S. The GNN method uses statistical techniques to link field plot data, satellite imagery, and maps of environmental variables in a raster GIS database. Individual pixels are associated with forest inventory plots that have the most similar spectral and environmental characteristics. A suite of plot variables are imputed to each pixel, predicting a wide range of vegetation attributes, including above-ground biomass of live (AGL) trees (Ohmann et al. 2014, 2011, 2005). Using a GIS, CARB staff extracted AGL tree biomass densities (MT/hectare) circa 2008 mapped at 30-meter pixel resolution, converted the biomass values to carbon, and applied a zonal statistics tool using ecoregions for zones (FCAT, 2018). Ecoregion statistics were also generated on a LANDFIRE-C AGL dataset (Battles et al. 2013). Data are summarized in **Table 16** by ecoregion. Ecoregion area-average AGL tree carbon densities from the CARB approach (Battles et al., 2013) are approximately 10% greater in the Sierra/Cascades and 20% greater in the Eastside region, compared to the GNN-based estimates. Area-average densities agree well for the North Coast, Klamath/Interior Coast Ranges, and Central Coast and Interior Ranges. Overall, AGL tree biomass densities for the CARB approach average approximately 2% greater than the GNN based estimates. These results suggest that the CARB approach produces spatially explicit estimates of AGL tree biomass that are comparable to the GNN based approach. Recently, the GNN approach has been expanded to track vegetation through time (Kennedy et al. 2018; Battles et al. 2018).

### *5B.2 LANDCARBON*

To fulfill reporting requirements of Section 712 of the federal Energy Independence and Security Act of 2007, the US Geological Survey (USGS) LANDCARBON program (USGSa, 2018) periodically produces regional analyses of ecosystem carbon stocks and GHG flux trends. Sources and methods include integration of ground-based data (including FIA) together with remote sensing and models. CARB staff extracted AGL tree carbon densities for California from raster data (temporal average of 2001-2005) provided by USGS (Zhu & Reed, 2012) (**Table 19**) and applied a zonal statistics tool the data using ecoregions for zones. Overall, the LANDCARBON ecoregion area-average AGL tree carbon densities are within a few percent of the Battles et al. (2013) and LEMMA estimates. This suggests that FIA, in combination with geospatial approaches, can produce comparable estimates of AGL tree carbon density.

**Table 19.** Area-average above-ground live (AGL) tree biomass densities (MT / hectare).

| Ecoregion [a] | Battles et al. (2013) | LEMMA | LANDCARBON |
|---|---|---|---|
| *Sierra/Cascades* | 145.0 | 131.1 | 126.8 |
| *Central Valley* | 50.9 | 64.0 | 25.8 |
| *North Coast* | 242.1 | 251.9 | 246.7 |
| *Klamath/Interior Coast Ranges* | 185.4 | 184.8 | 191.9 |
| *Central Coast and Interior Ranges* | 116.2 | 123.1 | 134.1 |
| *South Coast and Mountains* | 77.5 | 72.0 | 77.2 |
| *Deserts* | 18.6 | 18.3 | 9.1 |
| *Eastside* | 62.7 | 51.1 | 67.0 |

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# Appendix 1: IPCC Reporting Categories

The IPCC has created a standardized GHG accounting framework with defined inventory categories for governing entities to report GHG emissions and carbon stock change. CARB has tailored the framework to help meet State programmatic needs. CARB's NWL Inventory accounts for ecosystem carbon stock and stock change, and the annual statewide GHG inventory tracks direct emissions from human-made equipment, vehicles, structures, and products and includes selected categories of agriculture. In the table below, the three columns on the left show the hierarchy of IPCC inventory categories, and the "CARB's Inventory" column indicates which CARB inventory (the NWL Inventory or the annual statewide GHG inventory) contains emissions or carbon stock information for each inventory category. CARB's annual statewide GHG inventory is often colloquially referred to as the "anthropogenic inventory," and is therefore shown as "Anthropogenic" in the table.

| IPCC Category Name | Code | Sub-Category Name | CARB's Inventory |
|---|---|---|---|
| *3A1 – Enteric Fermentation* | 3A1ai | Dairy Cows | Anthropogenic |
| | 3A1aii | Other Cattle | |
| | 3A1b | Buffalo | |
| | 3A1c | Sheep | |
| | 3A1d | Goats | |
| | 3A1e | Camels | |
| | 3A1f | Horses | |
| | 3A1g | Mules and Asses | |
| | 3A1h | Swine | |
| | 3A1j | Other (please specify) | |
| *3A2 – Manure Management* | 3A2ai | Dairy Cows | Anthropogenic |
| | 3A2aii | Other Cattle | |
| | 3A2b | Buffalo | |
| | 3A2c | Sheep | |
| | 3A2d | Goats | |
| | 3A2e | Camels | |
| | 3A2f | Horses | |
| | 3A2g | Mules and Asses | |
| | 3A2h | Swine | |
| | 3A2i | Poultry | |
| | 3A2j | Other (please specify) | |
| *3B1 – Forest Land* | 3B1a | Forest Land remaining Forest Land | NWL |
| | 3B1bi | Cropland converted to Forest Land | |
| | 3B1bii | Grassland converted to Forest Land | |
| | 3B1biii | Wetlands converted to Forest Land | |
| | 3B1biv | Settlements converted to Forest Land | |
| | 3B1bv | Other Land converted to Forest Land | |
| *3B2 - Cropland* | 3B2a | Cropland remaining Cropland | NWL |
| | 3B2bi | Forest Land converted to Cropland | |
| | 3B2bii | Grassland converted to Cropland | |
| | 3B2biii | Wetlands converted to Cropland | |
| | 3B2biv | Settlements converted to Cropland | |
| | 3B2bv | Other Land converted to Cropland | |
| *3B3 - Grassland* | 3B3a | Grassland remaining Grassland | NWL |
| | 3B3bi | Forest Land converted to Grassland | |
| | 3B3bii | Cropland converted to Grassland | |
| | 3B3biii | Wetlands converted to Grassland | |
| | 3B3biv | Settlements converted to Grassland | |
| | 3B3bv | Other Land converted to Grassland | |
| *3B4 - Wetland* | 3B4ai | Peatlands remaining Peatlands | NWL |

| IPCC Category Name | Code | Sub-Category Name | CARB's Inventory |
|---|---|---|---|
| | 3B4aii | Flooded Land remaining Flooded Land | |
| | 3B4bi | Land converted for Peat Extraction | |
| | 3B4bii | Land converted to Flooded Land | |
| | 3B4biii | Land converted to Other Wetland | |
| *3B5 – Settlement* | 3B5a | Settlements remaining Settlements | NWL |
| | 3B5bi | Forest Land converted to Settlements | |
| | 3B5bii | Cropland converted to Settlements | |
| | 3B5biii | Grassland converted to Settlements | |
| | 3B5biv | Wetlands converted to Settlements | |
| | 3B5bv | Other Land converted to Settlements | |
| *3B6 – Other Land* | 3B6a | Other Land remaining Other Land | NWL |
| | 3B6bi | Forest Land converted to Other Land | |
| | 3B6bii | Cropland converted to Other Land | |
| | 3B6biii | Grassland converted to Other Land | |
| | 3B6biv | Wetlands converted to Other Land | |
| | 3B6bv | Settlements converted to Other Land | |
| *3c – Aggregate Sources and Non-$CO_2$ Emissions Sources on Land* | 3C1a | Biomass Burning in Forest Lands | NWL |
| | 3C1b | Biomass Burning in Croplands | Anthropogenic |
| | 3C1c | Biomass Burning in Grasslands | NWL |
| | 3C1d | Biomass Burning in All Other Lands | NWL |
| | 3C2 | Liming | Anthropogenic |
| | 3C3 | Urea Application | Anthropogenic |
| | 3C4 | Direct $N_2O$ Emissions from Managed Soils (Fertilizer) | Anthropogenic |
| | 3C5 | Indirect $N_2O$ Emissions from Managed Soils (Fertilizer) | Anthropogenic |
| | 3C6 | Indirect $N_2O$ Emissions from Manure Management | Anthropogenic |
| | 3C7 | Rice Cultivations | Anthropogenic |
| | 3C8 | Other (Please specify) | Anthropogenic |
| *3D – Other Agriculture, Forestry, and Land Use* | 3D1 | Harvested Wood Products | |
| | 3D2 | Other (Please Specify) | |

# Appendix 2: List of Acronyms and Abbreviations

AB – Assembly Bill
AFA – Atmospheric Flow Approach
AFOLU – Agriculture, Forestry, and Other Land Use
AGL – Above-ground live
BGL – Below-ground live
C – Carbon
CAL FIRE – California Department of Forestry and Fire Protection
CARB – California Air Resources Board
CEC – California Energy Commission
CH4 – Methane
CNRA – California Natural Resources Agency
CO2 – Carbon dioxide
DNDC – Denitrification Decomposition Model
DOM – Dead organic matter
EVC – Existing Vegetation Cover
EVH – Existing Vegetation Height
EVT – Existing Vegetation Type
FIA – Forest Inventory and Analysis National Program
FONL – Forests and Other Natural Lands
FS PSW – Forest Service Pacific South West Research Station
GHG – Greenhouse Gas
GIS – Geographic Information Systems
GNN – Gradient nearest neighbor
GWP – Global warming potential
ha – Hectare
HWP – Harvested wood products
IPCC – Intergovernmental Panel on Climate Change
IPPU – Industrial processes and product use
LEMMA – Landscape Ecology, Modeling, Mapping, and Analysis
Mg – Megagram
MMT – Million metric tons
MT – Metric tons
N2O – Nitrous oxide
NAIP – National Agricultural Imagery Program
NASS – National Agricultural Statistics Service
NPS – National Park Service
NVCS – U.S. National Vegetation Classification
NWL – Natural and Working Lands
SB – Senate Bill
SCA – Stock Change Approach
SOC – Soil organic carbon
SOM – Soil organic matter
TSD – Technical Support Document
UN – United Nations
USDA – United States Department of Agriculture