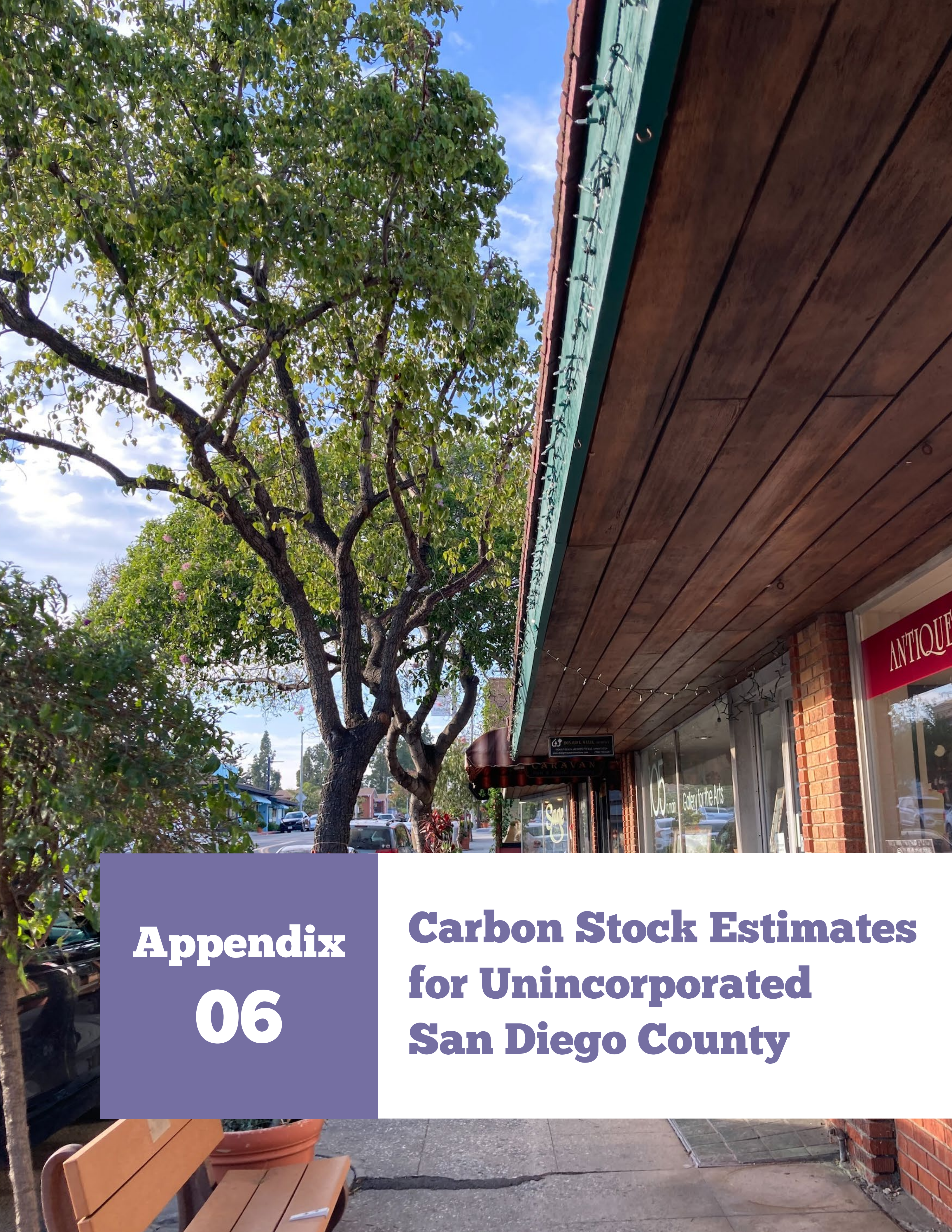

Appendix 06

Carbon Stock Estimates for Unincorporated San Diego County

Memo

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Date: October 10, 2023

To: Meghan Kelly, County of San Diego

From: Liz Luck, Hannah Kornfeld, Andrew Martin, Poonam Boparai, Fred Hochberg (Ascent)

Subject: Carbon Stock Estimates for Unincorporated San Diego County

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This technical memorandum presents an estimate of existing carbon stock in unincorporated San Diego County (unincorporated county) in 2016. The estimates account for carbon stored in vegetation and soils on natural (e.g., grasslands, forests) and working (i.e., agricultural) lands within the unincorporated county, but excludes tribal lands and Marine Corps Base Camp Pendleton because the County of San Diego does not have jurisdiction over these areas (the study area is hereinafter referred to as "unincorporated county"). The estimates of carbon stock are calculated based on carbon stock changes between 2001 and 2016 from the *Carbon Storage and Sequestration Study for San Diego County*[1] prepared by the San Diego Association of Governments (SANDAG) for the entire San Diego region.

As discussed in the Climate Action Plan's Appendix 5, the State of California's 2022 Scoping Plan for Achieving Carbon Neutrality shows that, statewide, natural and working lands are projected to be a net emissions source in 2030 and 2045. Actions that increase carbon storage, such as through improved natural and working (e.g., agricultural) land management practices, contribute to reaching net zero emissions.

This memorandum includes the following sections:

- **Section 1: Overview of Carbon Stock and Sequestration** provides an overview of carbon stock and sequestration and other concepts and key terms referenced in this memo.
- **Section 2: Summary of Estimated Existing Carbon Stock in the Unincorporated County** presents the estimated carbon stock of all land cover types in the unincorporated county in 2016.
- **Section 3: Methods to Estimate Existing Carbon Stock in the Unincorporated County** describes the data, sources, and methodology used to estimate existing carbon stock.

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[1] Available at: https://www.sandag.org/-/media/SANDAG/Documents/PDF/projects-and-programs/environment/climate-resilience-and-adaptation/holistic-adaptation-planning/carbon-storage-and-sequestration-study-san-diego-county-2022-03-01.pdf

1 OVERVIEW OF CARBON STOCK AND SEQUESTRATION

The natural carbon cycle involves the exchange of carbon between the atmosphere and the Earth (land and ocean). As part of the carbon cycle, fire, plant respiration and decomposition are balanced by plant growth and other processes that take place over decades or centuries. When in balance, these biogenic CO_2 emissions from fire and other sources are balanced by CO_2 sequestration in natural and working lands and waters, resulting in relatively minimal change in the total concentration of atmospheric CO_2 that drives climate change. Emissions from fossil-fuel combustion and other anthropogenic activities have accumulated in the atmosphere at an unprecedented pace and contributed to putting the natural carbon cycle out of balance, thereby increasing the greenhouse effect, and causing anthropogenic climate change. This imbalance in Earth's carbon cycle also contributes to a feedback loop for, among other things, natural and working lands in which increasing atmospheric concentrations of emissions result in warmer temperatures, extreme heat events, droughts, and wildfires, which in turn release additional emissions into the atmosphere. In addition to limiting emissions from fossil fuel combustion and other human activities, managing natural and working lands to increase CO2 sequestration is critical to efforts to achieve carbon neutrality, which means balancing all sources of GHG emissions with carbon sinks.

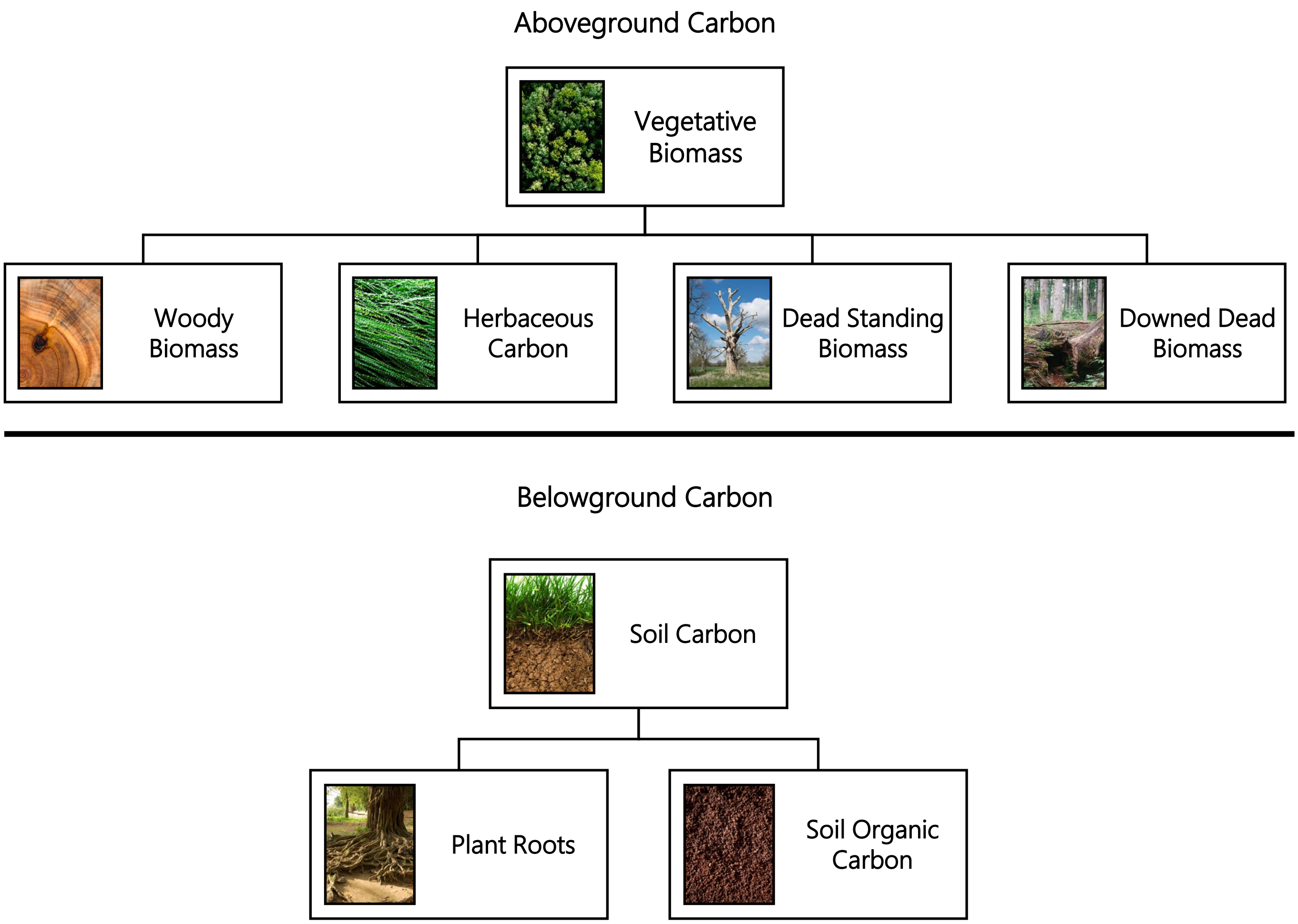
The carbon stock estimates reported in this memo represent the amount of carbon stored in natural lands (e.g., forests, wetlands, grasslands), working lands (e.g., cropland), and other land cover types in 2016. In addition, to estimate carbon stock (amount of carbon) in the unincorporated county, both aboveground and belowground carbon pools (systems that can hold or release carbon) were assessed. The types and sources of carbon that are evaluated in this memo are described below and depicted in Figure 1. References in the remainder of this memo to amounts of carbon stored in land cover types found in the unincorporated county include both aboveground and belowground carbon unless stated otherwise.

1.1 ABOVEGROUND CARBON

Aboveground carbon is the amount of carbon stored within vegetative biomass that is above the soil. Vegetation uses photosynthesis to take carbon dioxide out of the atmosphere and incorporate the carbon into biomass. Aboveground carbon includes woody biomass in trunks, branches, and shoots as well as herbaceous carbon in leaves, flowers, fruiting bodies, and grasses. Additionally, aboveground carbon includes the carbon in leaf litter, dead standing biomass, and downed dead biomass. Approximately 45-50 percent of the dry biomass weight of the vegetation is equivalent to its carbon stock (McGroddy et al. 2004; Schlesinger 1991).

1.2 BELOWGROUND CARBON

Belowground carbon is the carbon stored within plant roots and soil. Plant root carbon stock is estimated the same way as aboveground carbon: estimating biomass by using the dry weight of the materials and converting the biomass to carbon. In soil, carbon is primarily stored as soil organic matter (SOM). SOM is a mixture of carbon compounds consisting of decomposing plant and animal tissue, carbon associated with soil minerals, and microbes. Within SOM, approximately 58 percent is soil organic carbon (SOC), which represents the distinct carbon pool in the soil (Lal 2004). Overall, soil carbon (i.e., organic, and inorganic carbon) constitutes approximately 75 percent of the carbon in terrestrial environments, which is three times the amount stored in living plants and animals. Soils represent a massive sink potential for carbon dioxide from the atmosphere, although soil carbon can either be stored in the soil for millennia or can be quickly released back into the environment due to decomposition. Decomposition of organic matter in the soil by microbial activity can release carbon dioxide as a byproduct, causing the soil to also be a source of atmospheric carbon. The length of time that carbon is stored in soils can be affected by a variety of environmental factors such as vegetation type, climatic conditions, and soil properties such as texture and type. Further, management practices (anthropogenic factors) can affect a soil's potential to be either a source or a sink of carbon. For example, sustainable farming practices such as reduced tillage, cover cropping, and crop rotation can be used to increase soil carbon compared to conventional practices (Ecological Society of America 2000).



Source: Ascent 2023

Figure 1 Aboveground and Belowground Carbon Sources included in Carbon Stock Estimates for the Unincorporated County

1.3 KEY TERMS

The following key terms are used throughout this technical memorandum:

- Carbon Pool: A system which has the capacity to accumulate or release carbon, considered to be a reservoir. Examples include vegetation biomass, soils, and dead and downed vegetation (IPCC 2000).
- Carbon Sequestration: The process of increasing the carbon content of a carbon pool other than the atmosphere (IPCC 2000).
- Carbon Stock: The absolute quantity of carbon (above and/or belowground) held within a pool at a specified time (IPCC 2000).
- Carbon Dioxide Equivalent (CO_2e). The amount of carbon dioxide emissions that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs (IPCC 2018). In addition to carbon dioxide, CO_2e includes the global warming effects of gases such as methane and nitrous oxide, if those gases are present in emissions. It is a standard unit of measure for carbon inventories. All the carbon stock and sequestration data and figures in this memo use CO_2e as the unit of measurement.

- **Sequestration rate:** The rate at which a carbon pool absorbs or releases carbon into the atmosphere, expressed in terms of metric tons of carbon-equivalent per acre per year (MT CO_2e/acre/year). A positive sequestration rate indicates that the carbon pool is absorbing carbon from the atmosphere, and a negative rate indicates that the carbon pool is releasing carbon into the atmosphere.
- **Soil Carbon:** Includes inorganic and organic carbon within soil, constituting 75 percent of terrestrial carbon (Ecological Society of America 2000).
- **Soil Organic Carbon:** The amount of carbon within the organic compounds of soil. Soil organic carbon accounts for 58 percent of soil organic matter (Ecological Society of America 2000).
- **Soil Organic Matter:** A mixture of carbon compounds consisting of decomposing plant and animal tissue and carbon associated with soil minerals and microbes (Ecological Society of America 2000).
- **Natural Lands:** Lands consisting of forests, grasslands, deserts, freshwater and riparian systems, wetlands, coastal and estuarine areas, watersheds, wildlands, or wildlife habitats, or lands used for recreational purposes such as parks, urban and community forests, greenbelts, trails, and other similar open-space lands. For purposes of this paragraph, "parks" includes, but is not limited to, areas that provide public green space (California Public Resources Code (PRC) 9001.5).
- **Working Lands:** Lands used for farming, grazing, or the production of forest products (PRC 9001.5).

2 SUMMARY OF ESTIMATED EXISTING CARBON STOCK IN THE UNINCORPORATED COUNTY

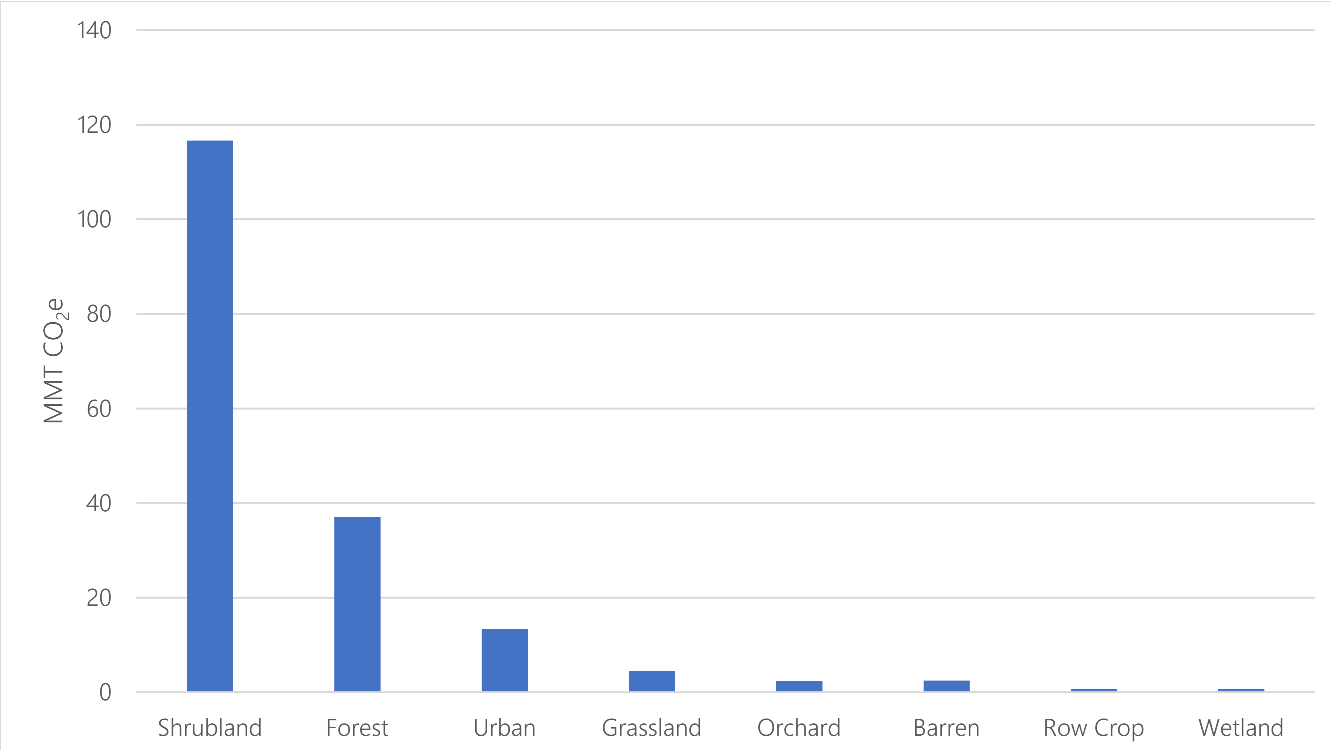
Total carbon stock in the unincorporated county was approximately 178 million metric tons (MMT) of carbon dioxide equivalent (CO_2e) as of 2016.[2] As shown in Table 1 and Figure 2, the majority (87 percent) of this carbon is stored in shrublands and forests, with the rest being stored in urban (developed) areas,[3] grasslands, orchards, barren lands, row crops, and wetlands. Table 1 also shows the average metric tons of carbon stock per acre by landcover type, which highlights that forest and shrublands are the landcover types with the highest stock per acre. These data were taken from SANDAG (2022) using the methods discussed in Section 3.

Table 1 Unincorporated San Diego County Carbon Stock by Land Cover Type in 2016 (MMT CO_2e)

Land Cover Type	MMT CO_2e	Acres	Carbon Stock Rate (MT CO_2e/ acre)
Shrubland	117	1,134,822	102.8
Forest	37	158,638	233.7
Urban	13	235,680	56.9
Grassland	4	68,044	66.0
Orchard	2	33,866	69.7
Barren	2	344,858	7.2
Row Crop	1	14,573	47.6
Wetland	1	14,457	48.4
Total	**178**	**2,004,938**	**88.7**

Notes: CO_2e = carbon dioxide equivalent; MMT = million metric tons.
Source: Ascent 2023.

[2] 2016 is the most recent year for which these data are available and was used as a proxy for 2019, which is the baseline year for the CAP.
[3] See SANDAG (2022: 33): "Urban forests come in many different shapes and sizes and can include urban parks, street trees, landscaped boulevards, gardens, coastal promenades, greenways, and wetlands. Urban trees and their urban canopy cover provide a multitude of benefits, including storing carbon."



Notes: CO_2e = carbon dioxide equivalent; MMT = million metric tons.

Source: Ascent 2023

Figure 2 Unincorporated San Diego County Carbon Stock by Land Cover Type in 2016 (MMT CO_2e)

3 METHODS TO ESTIMATE EXISTING CARBON STOCK IN THE UNINCORPORATED COUNTY

This section describes the data and methods used to estimate existing carbon stock in the unincorporated county by utilizing SANDAG's *Carbon Storage and Sequestration Study for San Diego County*. The data referenced in Sections 3.1 and 3.2 were summarized using a script in the Python computer programming language to calculate total carbon stock by land cover type for the unincorporated county in 2016 (Refer to Appendix A).

3.1 VEGETATIVE CARBON

As discussed in the *Carbon Storage and Sequestration Study for San Diego County*, the 2016 carbon inventory for all of San Diego County (incorporated cities and the unincorporated county) was completed by SANDAG using the US Geological Survey's LANDFIRE raster dataset, which is collected using satellite imagery, to assess the land cover types within the county. LANDFIRE data has a 900 square meter resolution, dividing the San Diego region into a grid of 900 square meter cells. Each cell includes data about the land cover. Specifically, the LANDFIRE data has metric tons of carbon stock for land cover classification types (EVT), vegetation cover classes (EVC), and vegetation height (EVH). EVT is the complexes of plant communities classified through ecological systems classification, EVC is the vertically projected percent cover of the live canopy for a specific area, and EVH is the average height of the dominant vegetation (LANDFIRE, n.d.). These three datasets were intersected to create a layer with a unique combination of EVT, EVC, and EVH in each 900 square meter cell for the entire county.

SANDAG then aggregated EVT provided by LANDFIRE and assigned each EVT to one of the 11 land cover classes: barren, forest, grassland, irrigated pasture, orchard, row crop, shrubland, urban, vineyard, water, and wetland. Additionally, agricultural mapping from LANDFIRE was augmented with the vector data from California Department of Water Resources' statewide crop (DWR 2023a) and land use mapping data (DWR 2023b). The California Department of Water Resources (DWR) uses aerial photography, digital satellite imagery, and new analytical tools to make remote sensing land use surveys possible at a field scale comparable to DWR historical field surveys. The DWR data was then further verified with County of San Diego crop reporting statistics (County of San Diego 2001; County of San Diego 2016).

Metric tons of carbon stock for non-soil carbon were assigned to each unique combination of the EVT-EVC-EHV layers to represent a more holistic carbon density estimation. For the baseline year of 2016, 769 unique combinations were found and assigned a carbon density value. Then they were aggregated for summary purposes into the 11 broad land cover classes (shown in Table 1). Carbon densities (i.e., weight of carbon per unit of soil volume) were found using international, national, state, and local literature and assigned to non-soil and soil carbon pools (SANDAG 2022). The 2001 and 2016 metric tons of carbon stock and correlated land cover types were created by SANDAG in a raster dataset with a resolution of 900 square meters. The dataset was then used to calculate the carbon stock inventories by clipping the spatial data to only include the unincorporated county out of the entire San Diego region. [4] For this analysis, the raster data was first converted into point data, with each point representing a 900 square meter cell. Each point included a carbon stock value for 2001 and 2016, as well as a land cover type classification.

3.2 SOIL CARBON

The US Department of Agriculture's Natural Resource Conservation Service for San Diego County's regional soil survey, maintained and distributed by the San Diego Geographic Information Source (SanGIS), was used by SANDAG to create estimated metric tons of soil carbon stock. Consistent with the US Environmental Protection Agency's GHG inventory methods, specific soil types were grouped into soil classes based on their soil properties and climate zone, including mineral soils, sandy soils, clay soils, volcanic soils, and organic soils (IPCC 2006). Carbon content within the soils of the unincorporated county was included in the raster dataset created by SANDAG. These soil carbon values were incorporated in the total carbon per cell and used in this analysis to determine overall carbon stock and carbon stock per land cover type.

3.3 SEQUESTRATION RATES

The proceeding section describes how the 2001 and 2016 data was used to estimate the rate of change in the quantity of carbon in a carbon pool, or sequestration rates, to understand carbon storage potential of different land cover types when improved land management practices are applied.

Total carbon stock by land cover type for the unincorporated county in 2001 and 2016 was summarized. Overall, the carbon stock declined from approximately 191 MMT CO_2e in 2001 to 178 MMT CO_2e in 2016, or 7 percent, as shown in Figure 3.[5] According to the SANDAG Carbon Storage and Sequestration Study (2022: 14), this is likely due to a combination of disturbance, drought-related tree mortality, and wildfires, which can release carbon from the soil and vegetation. Additionally, the types of land cover changed in many places between 2001 and 2016—for example, some natural lands with the shrubland cover type in 2001 converted to the urban land cover type (e.g., residential development) by 2016, which would have changed the land's ability to sequester carbon. Alternatively, some lands changed from one natural land cover type to another between 2001 and 2016, for example from forest to grassland, which also would have changed the amount of carbon stored in the soil and/or vegetation.

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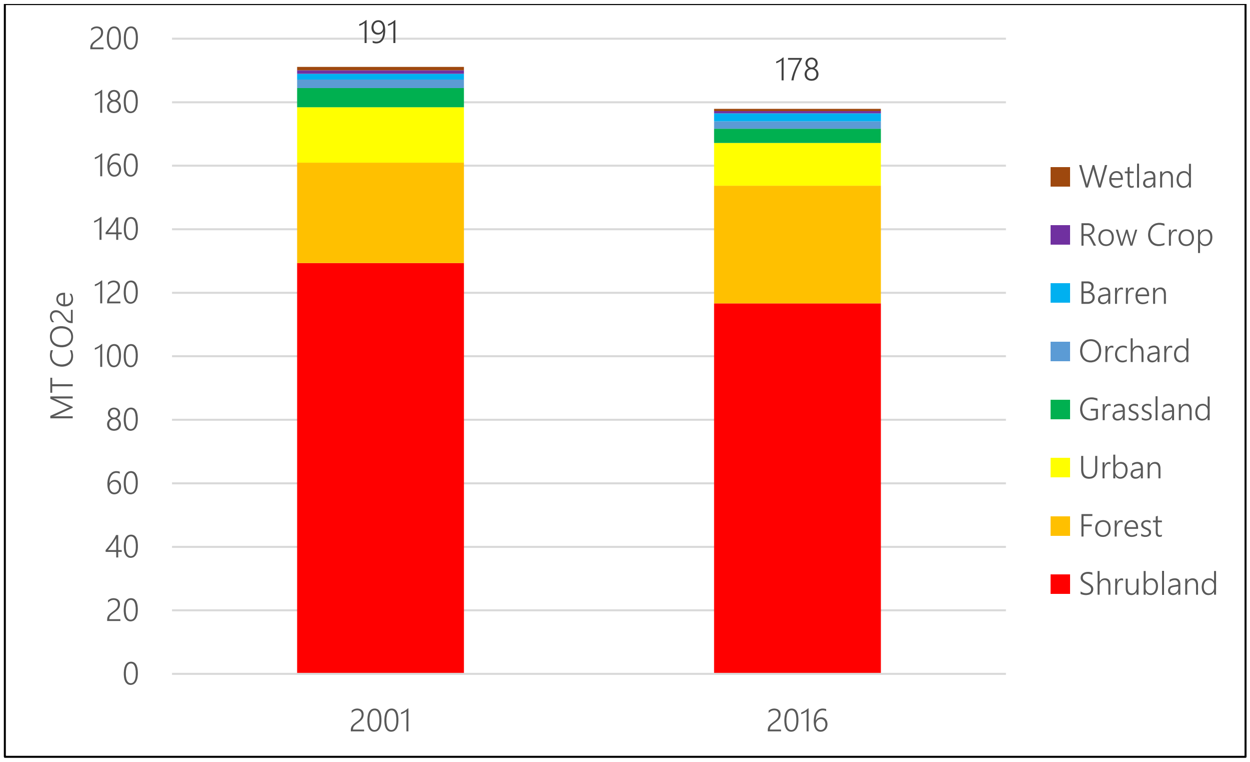
4 Military lands and Tribal lands located within the boundaries of the unincorporated county were excluded from this analysis.

5 Sequestration and storage rates for water, irrigated pasture, and vineyards are not shown separately in the results below. Together, these land cover types represent less than one half of one percent of total area, and thus do not materially affect the results. Their sequestration rates are anomalous and likely due to lack of data.



Notes: CO_2e = carbon dioxide equivalent; MMT = million metric tons.
Source: Ascent 2023.

Figure 3 Unincorporated San Diego County Carbon Stock in 2001 and 2016 (MMT CO_2e)

Wildfires alter the landscape by destroying vegetation and depositing ash, and therefore affect the land's ability to sequester carbon. To account for this, separate sequestration rates were calculated for lands that had been burned, and lands that had not burned. The following steps were taken to perform this calculation. First, carbon stock in 2001 and 2016 was split into lands that had been burned since 1980, and lands that had not been burned since 1980, using the CAL FIRE Historical Perimeters Dataset (CAL FIRE 2023). The change in total carbon stock over the 15-year period from 2001 to 2016 was calculated separately for each subgroup of burned and not burned lands, and then divided by 15 (the number of years between 2001 and 2016) to calculate annual sequestration rates. Table 3 and Figure 4 below shows the results of this calculation.

The calculation of sequestration rates only used lands which did not change land cover type from 2001 to 2016 (i.e., a subset of the data shown above—approximately 1.5 million acres out of a total of 2 million in the unincorporated county, or 75 percent). For example, if a given acre was shrubland in both 2001 and 2016, it would be included in the calculation of sequestration rates; if that acre were converted to urban land, that acre would be excluded. The purpose of this step was to estimate a sequestration rate for each land cover type that, where feasible, excludes the effects of human disturbance, land management practices, or development. All these human activities could cause the land type to change.[6] Carbon gains or losses from these activities should not be included in a calculation of the sequestration rate because they do not reflect the natural carbon cycle as described in Section 1.

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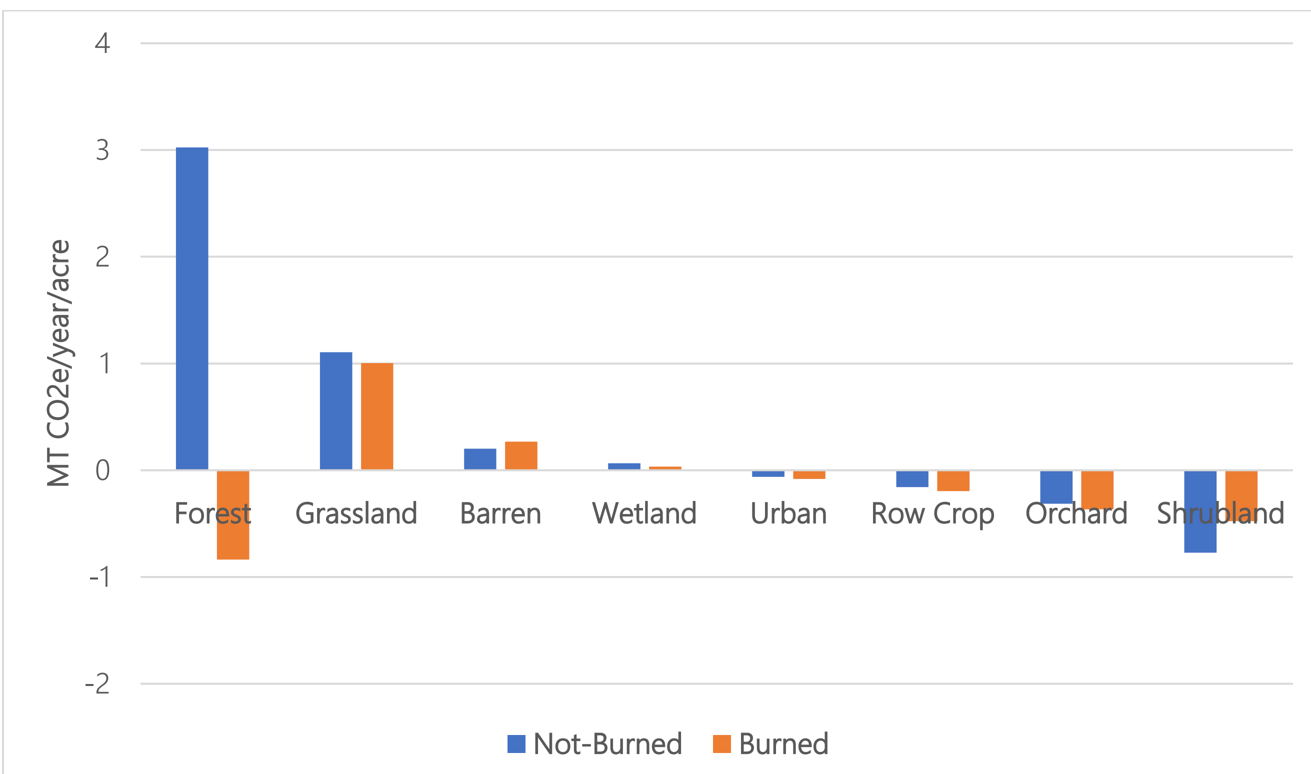
[6] Detailed data indicating the reason that land cover changed from one type to another in the unincorporated county between 2001 and 2016 were not available and could be due to multiple factors. SANDAG (2022: 14) describes four of those factors. First, "the loss of forest and shrublands to fire, including the major fires of 2003 and 2007, and the subsequent conversion of those areas to other, less-dense vegetation types and younger age classes." Second, "the conversion of higher-carbon-density vegetation types to lower-carbon-density vegetation types as a result of drought, pests/disease, invasive species, and climate change." Third, "land use changes resulting in the conversion of higher-carbon-density natural lands to lower-carbon density urban and barren lands." Fourth, "land use changes resulting in the conversion of higher-carbon-density agricultural lands to lower-carbon density urban and barren lands."

Table 3 Sequestration Rates by Land Cover Type and Burned / Not Burned Status (Excludes Areas Where Land Cover Type Changed Between 2001 and 2016)

2016 Land Cover Type	Total Acres			Sequestration Rates (MT CO_2e/acre/year)			Percent of land that has burned since 1980
	All Lands	Burned	Not Burned	All Lands	Burned	Not Burned	
Shrubland	867,379	437,709	429,670	-0.62	-0.48	-0.77	50%
Barren	322,781	4,177	318,603	0.20	0.27	0.20	1%
Urban	155,971	35,422	120,549	-0.07	-0.08	-0.06	23%
Forest	96,658	59,951	36,708	0.63	-0.84	3.02	62%
Grassland	33,293	12,589	20,705	1.07	1.00	1.11	38%
Orchard	23,912	4,122	19,790	-0.32	-0.37	-0.31	17%
Row Crop	2,960	171	2,789	-0.16	-0.19	-0.16	6%
Wetland	902	263	639	0.06	0.03	0.07	29%
Total	1,503,857	554,404	949,453	-0.26	-0.45	-0.16	37%

Source: Ascent 2023.



Source: Ascent 2023.

Figure 4 Sequestration Rates by Land Cover Type in Unincorporated San Diego County

The sequestration rates show two patterns. First, in general, not burned lands generally sequester carbon at a higher rate than burned lands, with not burned forests and grasslands sequestering carbon at the highest rates.[7] This is likely due to the presence of vegetation that removes carbon dioxide from the air and stores it as carbon in soil and biomass. However, some land cover types are more resilient than others to the effects of wildfires. For example, grasslands' sequestration rate decreases only slightly from having been burned, as opposed to forests which suffer a drastically reduced rate of sequestration. This is because grasslands tend to store more of the carbon belowground, where wildfires cannot affect it, whereas forests store more carbon in aboveground woody biomass such as trees (Kerlin 2018).

Second, many land cover types have negative sequestration rates. Urban, shrubland, orchard, and row crops are all land cover types with negative sequestration rates between 2001 and 2016. A negative sequestration rate means that a land cover type is a source of emissions instead of a sink; this can be due to soil disturbances (especially in urban environments and agricultural areas such as vineyards and orchards), wildfires, methane emissions from decomposing biomass, or drought. In the case of shrublands, vegetation density and height declined from 2001 to 2016[8], which contributed to the reduction in carbon stock over time (and thus negative sequestration rate).

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7 Shrublands and barren lands are notable exceptions. In the case of shrublands, these lands have dry soil and sparse vegetation, and thus have the overall lowest sequestration rates of any land cover type included in this analysis. Wildfires produce ash which creates more fertile soil and later plant growth, so wildfires may increase the sequestration rate for shrublands over time. Additionally, shrublands likely store most of their carbon below ground, so fires do not deplete shrubland carbon stock as much as they affect carbon pools with greater aboveground carbon storage, such as forests. In the case of barren lands, the sequestration rate results are likely an anomaly due to small sample size—only 1 percent have burned since 1980.

8 See SANDAG (2022: 12-13): "Average carbon densities in the forest and shrubland vegetation types also decreased over this period, which is indicative of a shift to vegetation that is less dense, potentially due to drought or mortality, and with less height, potentially due to type conversion, disturbance, or mortality."

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