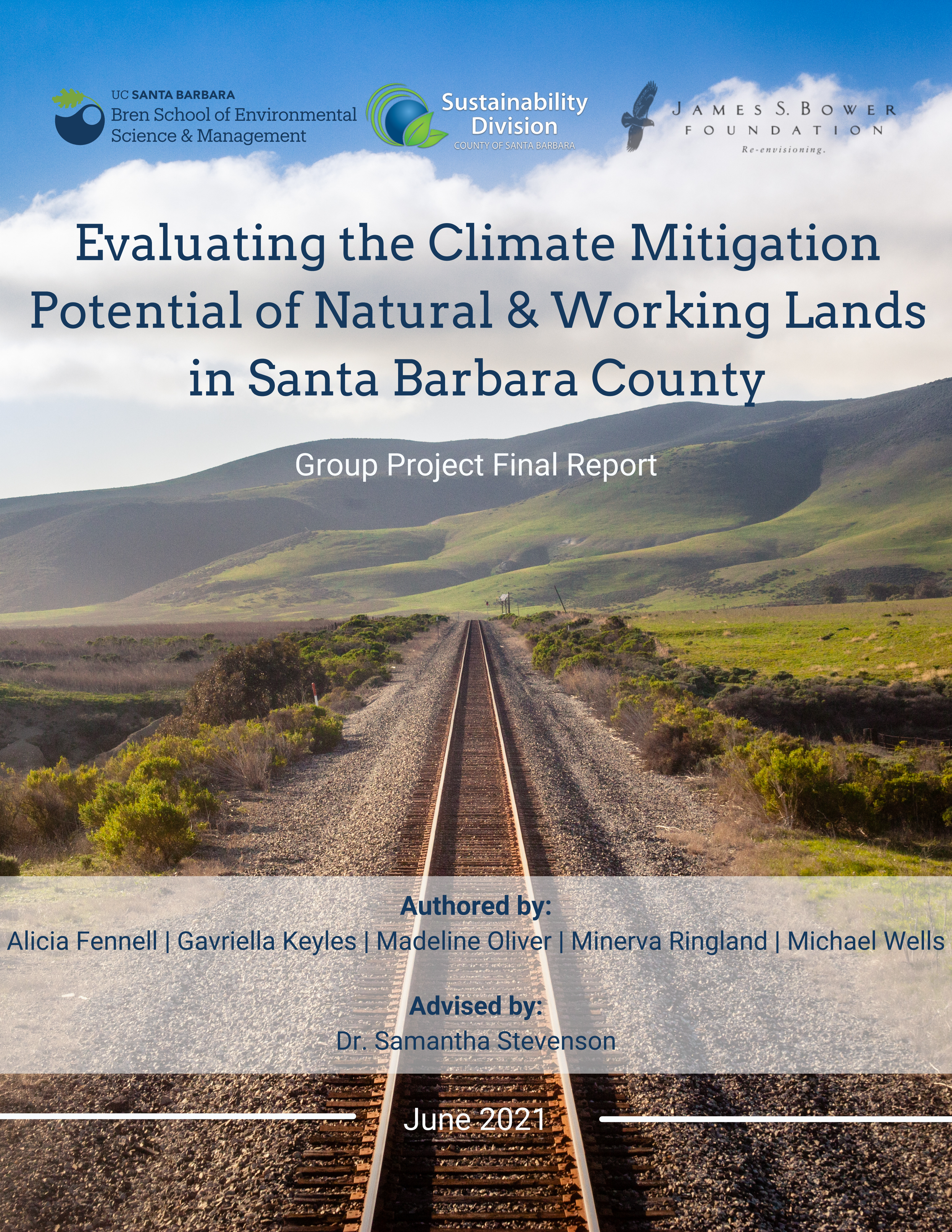

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Sustainability Division
COUNTY OF SANTA BARBARA

JAMES S. BOWER FOUNDATION
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Evaluating the Climate Mitigation Potential of Natural & Working Lands in Santa Barbara County

Group Project Final Report

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Signature Page

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As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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This project centers on the natural and working lands of Santa Barbara County, which are the unceded lands of the Chumash people. While our team did not engage directly with the Indigenous community as we conducted this work, we feel that their input and involvement is critical as the County moves forward to incorporate natural and working lands into climate planning.

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Glossary of Abbreviations

County of Santa Barbara (the County)
U.S. Department of Agriculture (USDA)
California Department of Conservation (DOC)
Greenhouse gas (GHG)
California Air Resources Board (CARB)
Soil organic carbon (SOC)
Assembly Bill 32 (AB-32)
Sustainable Communities Strategies (SCS)
Division of Land Resource Protection (DLRP)
Cachuma Resource Conservation District (CRCD)
Intergovernmental Panel on Climate Change (IPCC)
Climate Action Plan (CAP)
Farmland Mapping & Monitoring Program (FMMP)
Fuel Vegetation Type (FVT)
Existing Vegetation Type (EVT)
Existing Vegetation Cover (EVC)
California Department of Water Resources (CADWR)
USDA Natural Resources Conservation Service (NRCS)
Soil Survey Geographic database (SSURGO)
Community Environmental Council (CEC)
Denitrification-Decomposition (DNDC)
Metric tons of carbon dioxide equivalent ($MTCO_2e$)
Metric tons of carbon (MT C)
Sustainable Groundwater Management Act (SGMA)
Santa Barbara County Association of Governments (SBCAG)
Partners in Restoration (PIR)

Abstract

The state of California is experiencing the physical and economic impacts of greenhouse gas-induced climate change. To respond to this challenge, the County of Santa Barbara adopted a target of reducing emissions 50% below 2007 levels by 2030. Natural and working lands represent an important pathway to mitigating the effects of climate change due to the carbon sequestration potential of the vegetation and soil on these lands. This project quantifies existing carbon stocks on the county's natural and working lands and projects future sequestration that could result from implementing climate-smart land management practices. The majority of stocks are in natural lands, but the county's working lands are more actively managed and represent an opportunity to increase carbon sequestration. We modeled two implementation scenarios of a set of management practices to account for uncertainty in current implementation and future feasibility. Of the practices we evaluated, composting showed the greatest potential for increasing carbon stocks; a high-composting scenario could potentially sequester the equivalent of 14% of the county's projected greenhouse gas emissions in 2030. Based on input from stakeholders, we discuss barriers to implementation and related solutions that the County can pursue to promote and incentivize greater adoption of selected carbon-storing practices.

Executive Summary

Natural and working lands, including rangeland, forests, wetlands, farmland, and more, cover over 85% of Santa Barbara County, and are vital not only to the county's environment, but also to the economy and the well-being of residents (1). Natural and working lands can serve as major carbon sinks, but can become carbon sources, depending on how they are managed. While fire is the largest contributor statewide to greenhouse gas emissions from natural and working lands, urban expansion and resource use are also major contributors (2). In recent years, California has ramped up efforts to address the role of natural and working lands in emitting, storing, and sequestering greenhouse gases in state and local climate action planning. This project assesses the potential of natural and working lands in the county to contribute to the County of Santa Barbara's greenhouse gas emissions reduction goals and the State's carbon neutrality goals.

This project draws on the approach recently demonstrated in Merced County through a collaboration between the Nature Conservancy and the California Department of Conservation, called Resilient Merced (3). The objective is to model how changes in land use and land management impact landscape carbon stocks and land-based emissions. Based on this analysis, we can recommend management strategies that the County of Santa Barbara (the County) could implement to preserve existing carbon sinks and promote carbon sequestration in the future, while also protecting valuable economic and natural resources.

We used available data to estimate the current landscape carbon stock in Santa Barbara County and establish a baseline reference scenario, from which we projected future land use change and resulting carbon stock and emissions to 2030. The future projection was then used to explore how the implementation of different conservation practices on working lands would impact carbon storage and emissions. We used COMET-Planner, a tool developed by the U.S. Department of Agriculture (USDA), to quantify the carbon storage potential per acre of climate-smart management practices including compost application, restoration activities, hedgerow planting, mulching, and reduced till. Forecasted scenarios projected high and low implementation targets of these practices across land types to estimate the expected total carbon sequestration and emissions reduction potential by 2030.

We conducted agricultural community outreach throughout the project to ground our modeling and analysis in the experience of local land managers and stakeholders. The input we gathered informed the scenarios we modeled, as well as policy recommendations that take into account the barriers that these stakeholders suggest are inhibiting greater implementation of conservation practices on county lands.

This work provides a foundation for the County to continue natural and working lands analysis for incorporation into the Climate Action Plan update. Beyond that, based on our analysis alone, we can already highlight key strategies the County can pursue to promote climate-smart practices on working lands, including a permit streamlining process, investment in local technical assistance programs, and investigating funding mechanisms for land managers interested in implementing these practices. Moreover, this project provides tools and a framework for landscape carbon accounting that can be of use to jurisdictions across the state as they work to achieve California’s ambitious climate goals.

Project Objectives

The objectives of this project were to evaluate the carbon storage potential of Santa Barbara County's natural and working lands, as well as how the implementation of a suite of management practices could influence carbon storage. The project originated from a Working Lands and Riparian Corridors grant, which the County received from the state Department of Conservation (DOC) to incorporate natural and working lands into its current Climate Action Plan update.

Developing a land-based carbon inventory allows the County to identify strategies for the optimal management and conservation of these lands, which are vital to the county's economic and environmental health. However, the field is quite new and relatively little guidance exists to direct planners in these efforts. This project builds on pioneering methodology and tools to quantify and predict carbon storage in different land types, and our work provides the County with data necessary to move forward with the natural and working lands component of the Climate Action Plan. More broadly, it serves as an example of how similar processes can be implemented by other jurisdictions throughout the state, ultimately supporting the overarching goals of reducing or avoiding greenhouse gas emissions, and preserving natural resources across the state.

A strategic decision was made to focus the project on working lands, due to the local importance of agriculture and compelling policy implications associated with agricultural land management. The project scope, therefore, includes an estimation of the existing carbon stock and land-based greenhouse gas emissions within the county's working lands and the identification of implementable policies and strategies that support the County's climate mitigation goals.

To achieve the project objectives, we:

1. Calculated a countywide carbon inventory by accounting for carbon stock and emissions associated with Santa Barbara County's natural and working lands
2. Projected land use change and resulting carbon stock and emissions for working lands, using a baseline trend from historical data
3. Engaged the agricultural community to ensure our modeling and recommendations are based in reality
4. Assessed the changes to forecasted stock and emissions from different scenarios modeling adoption of selected climate-smart land management practices
5. Recommended actionable greenhouse gas reduction and management strategies to the County

Significance

Natural and working lands have the capacity to support climate mitigation and adaptation goals due to their ability to sequester carbon, reduce greenhouse gas emissions, and improve an area's ability to withstand climate impacts. A 2017 study found that conservation, restoration, and management activities on California's natural and working lands have the potential to account for up to 17% of California's 2030 greenhouse gas emissions reduction goals (4). In Santa Barbara County, natural and working lands account for approximately 85% of the total land area (1). However, pressure on the value and profitability of natural and working lands will increase as housing demands increase; the countywide population is projected to increase by 23% by 2040 (5). Compounding this threat, Santa Barbara County is already experiencing climate impacts affecting the timing of seasons and temperatures, frequency of wildfire, precipitation, and potential sea-level rise, all of which are expected to worsen with climate change and can reduce the overall health of natural and working lands (6).

This project supports the County of Santa Barbara's greenhouse gas reduction and climate adaptation goals by evaluating the potential of natural and working lands to store and emit greenhouse gases under different land management scenarios. We also support County planning by examining how future land management scenarios could impact this potential. We will provide strategic policy recommendations based on findings from our scenario analysis, engagement of local experts and investigation of best practices.

The climate mitigation strategies we recommend can help farmers, ranchers, and natural land managers respond to both climate change and economic uncertainty. The County will also benefit if it can support landowners in ways that reduce the risk of conversion and the associated greenhouse gas emissions. This project takes an important step towards quantifying the benefits of agricultural practices, which will help the County justify investments to support those efforts in service of state and county climate goals.

Investment in these practices can be further validated by studying the complementary benefits of these conservation practices. For example, carbon farming projects, which employ agricultural practices to capture atmospheric carbon and store it in the soil, have been piloted on grazing lands in the Santa Barbara region and shown to not only sequester carbon, but also improve forage production, soil health, and water retention (7). Complementary benefits like these can be modeled using TerraCount, a new scenario planning tool pioneered by Merced County and The Nature Conservancy. This project has produced valuable carbon storage data that is immediately actionable, but also sets the stage for the County to begin employing TerraCount as the Climate Action Plan update is finalized.

Background

Climate Change and Natural and Working Lands

Policymakers, scientists and citizens alike are working to address anthropogenic climate change, driven by greenhouse gas (GHG) emissions from human activities. Since the start of the industrial revolution around 1850, atmospheric CO_2 concentrations have risen from 280 to more than 400 parts per million (8). This atmospheric carbon loading is increasing global average temperatures, causing wide scale climatic changes worldwide (9). The role of land and soils in producing these GHG emissions is substantial; currently, land use change is estimated to account for about 20% of global carbon emissions (10).

To help meet global GHG emissions reductions goals, policymakers are exploring how proactive land management strategies can not only potentially avoid GHG emissions, but also result in negative emissions—the removal of carbon from the atmosphere—over time. When properly managed, soil can store around three times more carbon than the atmosphere (11). However, fire events, conversion to urban land, and certain activities including many conventional agricultural practices, diminish that storage capacity and can actually release carbon into the atmosphere (12).

Natural and working lands include forests, grassland, rangelands, farms, urban green spaces, and wetlands (2). In California, natural and working lands cover 90% of the state, and as described above, the state has identified natural and working lands as critical to its ambitious climate action goals (13). The California Air Resources Board (CARB) reported that as of 2014, the state's natural and working lands contained an estimated 5.5 billion metric tons of carbon in above and below-ground biomass and soils (2). Beyond storing carbon, natural and working lands provide critical ecosystem services to California: they supply water to California residents, support biodiversity, contribute to clean air and water, and support millions economically. But California's natural and working lands are being degraded and transformed for other uses. Approximately 21,000 acres of farmland and rangeland are converted to urban and built-up land uses each year (14).

In any terrestrial ecosystem, carbon is incorporated into soil and vegetation biomass from carbon dioxide in the air through photosynthesis by plants, including trees, grasses, and crops. Some carbon will eventually enter soil as organic matter dies and is stored as soil organic carbon (SOC) (15). The amount of carbon stored in soils is dependent on climate, soil type and composition, and particularly in the case of agricultural land, management activities taking place. SOC has been depleted through cultivation over time, with some estimates putting global cumulative loss at 30 to 40 megagrams of carbon per hectare of soil (16).

In addition to storing and sequestering carbon, agriculture and agricultural lands can emit GHGs. Synthetic nitrogen fertilizer application emits nitrous oxide. Livestock production and wetland crop systems, such as rice cultivation, emit large quantities of methane. Forest clearing for agriculture can also release enormous amounts of carbon into the atmosphere. Therefore, improving agricultural lands' ability to store carbon while limiting activities that emit GHGs is critical to ensuring agricultural lands act as climate change assets instead of liabilities.

Although SOC storage is uncertain in the face of climate change, certain management practices can be used to restore soils and increase their ability to uptake carbon (17). For example, application of compost to working lands can increase the organic carbon storage of managed soil. Mature compost has been shown to increase SOC more than immature composts, but all long-term compost application experiments increased SOC (18). Reduced tillage is another management practice with the potential to improve SOC, by reducing decomposition and therefore promoting retention of SOC and nitrogen by the soil (16,19). Other management activities that can increase carbon storage and provide other environmental benefits include integrated nutrient management, practicing agroforestry, and diversifying crops (20).

These management activities often lead to complementary benefits beyond improved carbon storage. Compost application for example, when administered in a way that does not encourage growth of non-native species, can also increase crop productivity and quality, while reduced tillage in combination with cover crops can improve water quality (18). These co-benefits amplify the importance of climate-smart management practices, and can make their implementation more attractive to decision makers concerned with air quality, water quality, economics, and biodiversity.

Natural lands vary in their storage and sequestration capacities. Wetlands, for example, can be either a source or a sink of carbon, depending on their age and the surrounding climate (21). Natural wetlands have higher carbon sequestration and lower carbon fluxes than constructed wetlands, so restoration and protection of existing wetlands can improve their carbon storage potential (22). Restored wetlands need years to reach carbon sequestration levels of natural wetlands, so management activities should account for this timeline (22). In forested lands, the largest carbon pool is in aboveground live biomass; protecting forested areas can increase their effectiveness as carbon sinks by allowing the live biomass to sequester more carbon and by avoiding the carbon released through land use change (23). However, forestry carbon mitigation potential is sensitive to analysis assumptions and depends on the forest type and management practices (23).

Natural and Working Lands in Santa Barbara County

The county's natural and working lands provide important ecosystem services—economic, cultural, health and other benefits derived from thriving ecosystems—to residents and visitors (5). Santa Barbara County sits on traditionally Chumash land. Over half of Santa Barbara County's land is protected in National Forest, wilderness, or other designations (5). In the early 1900s, national forests were established inland to protect local watersheds, and in 1936 these became part of the greater Los Padres National Forest, which covers a third of the county. The Santa Ynez Reservation was established in 1901, the San Rafael Wilderness area in 1968, and the Dick Smith Wilderness in 1984 (5). A large portion of protected land is federally managed, including the Los Padres and the federal air force base (5). Only 14,000 acres of the county's land are locally, publicly owned land. The greatest number of public parks and recreational facilities are found in the Santa Barbara area, with 33 sites totalling 1,213 acres. The fragmented nature of land management in the County can pose challenges, especially as this region of the county is subject to the environmental hazards of active faults, severe geologic problems, steep slopes, and flooding (24,25).

From a natural resource perspective, various microclimates, geologic variants, and changing topography make Santa Barbara County a global biodiversity hotspot. For instance, of the 31 vegetation groups found in California, 19 are located within the county (26). Habitat types range from coastal wetlands, grasslands, foothill oak woodlands, savannas, coastal scrub, chaparral, and mixed oak and pine forests. Santa Barbara County is home to over 1,300 plant species, more than 500 bird species, 138 terrestrial and marine mammals and 43 reptiles, 17 amphibians, and over 20 (non-oceanic) fish species.

Agriculture is a fundamental aspect of Santa Barbara County's history, culture and economy (27). Early Chumash inhabitants of these lands engaged in farming, but were not dependent on farming (28). After Spanish conquest and settlement the land was transformed and developed, and conventional agriculture and ranching expanded, becoming a major part of the area's economy. Farming trends vary by local geography within the county due to varying soil and climate conditions, and historical use. The county is divided into northern and southern sections by the Santa Ynez mountains. South County is much more developed than North County, but still features ample agricultural activity with most cut flower operations located in Carpinteria. High value agricultural operations, including avocado and citrus orchards, are prevalent along the coastal terraces below the Santa Ynez Mountains. In most areas within the county, agricultural water rates are lower than urban water rates in order to support this highly valued industry (5).

North County is home to the bulk of the county's strawberry production, which occurs largely in the Santa Maria area. Vineyards are found primarily along the slopes and upland areas in the central and northern parts of the county. Ranching occurs mainly in the inland hills. The Cuyama Valley hosts a range of agricultural activities, including row crops, orchards, and vineyards. In addition to wine grapes and strawberries, broccoli, lettuce and cauliflower are key crops in North County.

Over the years, agricultural activities have shifted in response to the dynamic agricultural economy, which faces constantly changing technology, consumer preferences, and market demands. Current trends in agriculture include increases in organic certification, hoop houses for berry production, and marijuana greenhouses (5). There has also been an increase in mechanization, high-tech growing solutions, and lower-labor crops due in part to labor insecurity, including labor shortages and increasing national attention on migrant labor (5). Many of these shifts are cost prohibitive for smaller, diversified farms.

Rising sea level, increasing rainfall variability, population growth, and land conversion are growing threats to natural and working lands (5), contributing to shifts in production. As shown in Figure 1, between 1950 and 2016 the acreage dedicated to vegetables and vineyards has grown, while field and seed crops have declined. Between 1984 and 2008, roughly 24,000 acres of rangeland were converted to agricultural, commercial and residential uses, while the number of cattle in the county declined from 34,317 in 2012 to 34,317 in 2017 (29). In recent years, drought and the growth of the wine-grape market has led to increased conversion of grazing lands to vineyards.

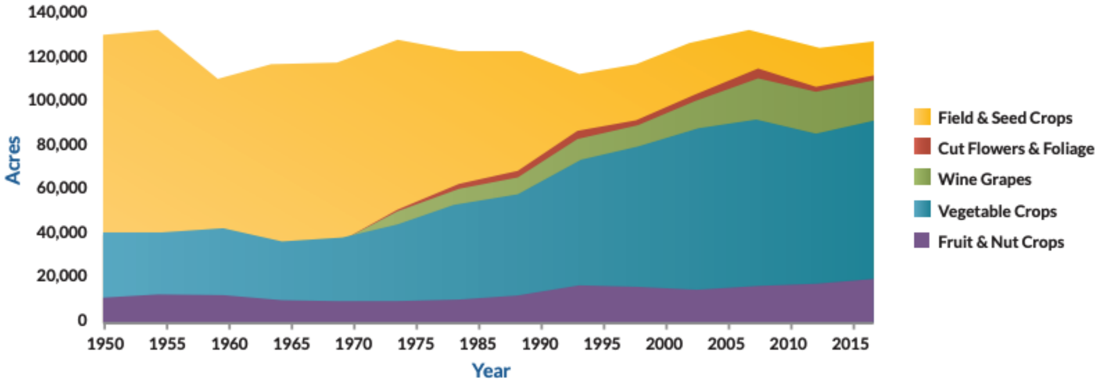

Figure 1. Average Crop Trends Since 1950 in Santa Barbara County (5).

As of 2017, 14% of farms in Santa Barbara County practice cover cropping, a management activity that enhances soil health. 8% of farms practice no till farming and 2% practice reduced till, compared to 15% that use intensive till practices (30). Similar data regarding current implementation levels of other management practices are hard to come by.

Climate Policy Context

California began legally requiring the drastic reduction of GHG emissions with the passing of Assembly Bill 32 (AB-32), the California Global Warming Solutions Act, in 2006 (31). AB-32 requires the California Air Resources Board (CARB) to develop a Scoping Plan, laying out a state strategy for meeting GHG reduction goals and to update the Scoping Plan every five years. Although a “Natural and Working Lands” component was not officially included in an AB-32 Scoping Plan until 2014, a series of regulations and initiatives have set the stage for these lands to become a climate planning priority (31).

In 2008, Senate Bill 375, the Sustainable Communities and Climate Protection Act, required regional metropolitan planning organizations to develop Sustainable Communities Strategies (SCS), which address land use related emissions in order to achieve the GHG emission reduction targets set by CARB (32). A key aspect of SCS was increasing infill development in order to conserve natural resources and farmlands. Years later in 2016, the California state legislature approved Senate Bill 1386, which identified conservation and management of natural and working lands as a key strategy for meeting GHG emissions reduction goals while providing important public benefits (33). The governor also signed Senate Bill 859 in 2016, which called for the development of a state carbon inventory for natural and working lands (34). Consequently, CARB resolved to develop a Natural and Working Lands Climate Change Implementation Plan, to evaluate a range of implementation scenarios and to identify long-term sequestration goals that can be incorporated into future climate policy. A draft implementation plan was released in 2019. Most recently, the governor ordered the plan to include sequestration targets consistent with the state's carbon neutrality goal of 2045 (35).

California serves as an important leader in sustainable land management, in large part due to the historical importance of both agriculture and conservation. The Williamson Act (California Land Conservation Act of 1965) has played a key role in promoting agriculture in Santa Barbara County and preventing the conversion of natural and working lands through tax breaks. The Division of Land Resource Protection (DLRP) within the state DOC also administers several grant programs that protect agricultural operations against urban sprawl (36). In Santa Barbara County, the Cachuma Resource Conservation District (CRCD) is the agency responsible for supporting local sustainability efforts, including water efficiency, fire prevention, and invasive species assistance projects.

In 2018, Californians voted in favor of Proposition 68, or the California Drought, Water, Parks, Climate, Coastal Protection, and Outdoor Access For All Act of 2018 (37). The bill put up for a vote the issuance of $4 billion in bonds to finance programs related to water, parks, climate, and outdoor access. DOC has made $8.5 million of bond funding available for grants in its Working Lands and Riparian Corridors program. This program is intended to fund projects related to "watershed restoration projects and conservation projects on agricultural lands," and is supporting California jurisdictions in investigating land management scenarios and modeling the resulting GHG emissions.

Most recently, in January 2019, CalEPA, CARB and a number of other state agencies released the California 2030 Natural and Working Lands Climate Change Implementation Plan. The plan describes the need to mitigate climate change through conservation and land management; sets a 2030 GHG reduction goal for natural and working lands throughout the state; and provides management activities and potential pathways to achieve these goals (13).

At the international level, the 2019 Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land calls for near-term action to address climate change adaptation and mitigation, by framing land management as risk management (38). The report emphasizes that sustainable land management can be improved by evaluating the effectiveness, co-benefits and risks of emerging response options. Within the United States, the U.S. Climate Alliance, which counts 17 member states representing some of the country's biggest agricultural producers, launched the Natural & Working Lands Challenge (39). These states have pledged to manage natural and working lands in a manner consistent with the goals of the 2015 Paris Agreement.

Climate Planning in Santa Barbara County

Like many local governments throughout the State of California, the County of Santa Barbara approaches climate mitigation through the framework of a Climate Action Plan (CAP). The County adopted its CAP in May 2015 and set a goal of reducing GHG emissions in the unincorporated county to 15% below 2007 levels by 2020 (6). Unfortunately, a recent GHG emissions report showed that emissions were 14% above the 2007 baseline in 2016, and the county was not on track to meet its 2020 target (40). As a result, the County Board of Supervisors doubled down on climate mitigation efforts, setting a target of reducing GHG emissions to 50% below 2007 levels by 2030. To meet this more aggressive target, the County seeks to broaden the scope of the CAP to incorporate the natural and working lands sector.

Acknowledging the pivotal role that strategic management of these lands can play in meeting emissions reduction goals, DOC recently began providing planning grants to support the integration of natural and working lands into local and regional climate action plans, using the Proposition 68 funding described above. Since this is a relatively new field, DOC encourages local jurisdictions to refer to the methodology of a project called Resilient Merced (41). Conducted jointly by Merced County, The Nature Conservancy and DOC, this project piloted the use of a scenario planning tool called TerraCount, which models future emissions scenarios based on projected implementation of conservation activities on natural and working lands. The carbon accounting methods used in this project build on Resilient Merced, and a 2016 predecessor conducted in Sonoma County, the Climate Action Through Conservation Project, which also developed analytic tools for assessing landscape carbon stocks, co-benefits, and the impacts of land management activities and land use changes (42).

In late 2019, the County of Santa Barbara's Sustainability Division was awarded one of DOC's planning grants to incorporate natural and working lands into the CAP update. Other recipients included Mariposa, Sonoma, and San Diego Counties (41). The Sustainability Division worked with members of our team to develop the Carbon Counters group project, determining that Bren students would conduct agricultural community outreach and technical analysis to both inform the new natural and working lands CAP component, and prepare the County to utilize the TerraCount tool. Rather than running the tool as part of our project, we assessed the carbon storage potential of Santa Barbara County's working lands under various land management scenarios using the USDA COMET-Planner tool[1] instead. The County has partnered with Rincon Consultants, Inc. to carry our work forward and complete the NWL component using TerraCount. Working alongside our group to analyze the county's natural lands, the Rincon team also supported us with general project feedback and technical assistance, particularly on geospatial processing using ArcGIS.

Methods

Our technical approach was primarily based on the methodology used by the Resilient Merced pilot project. After processing available datasets and developing a thorough understanding of the steps required to adapt Resilient Merced's approach to Santa Barbara County, it became apparent that the full grant scope would not be feasible given the time and resource constraints of a master's group project. We elected to focus on the following outputs: full landscape land cover classification, full landscape carbon inventory for one year (2016), land cover projections for working lands, and

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[1] The TerraCount tool uses COMET-Planner data in its calculation of the carbon storage and emissions associated with management scenarios.

conservation activities modeling for working lands. For more information on scope, data limitations, and considerations, see Appendix I.

However, to facilitate the continuation of the TerraCount project by the County and Rincon Consultants, we provide technical material including processed GIS shapefiles, compiled datasets, and the code and emissions factors used to calculate carbon and emissions values. We also prepared a preliminary qualitative assessment of co-benefits related to different conservation scenarios. These components can be combined with natural land and urban land analysis to feed into the TerraCount tool.

To contextualize and support the quantitative analysis performed for this project, we conducted an agricultural community outreach campaign to solicit information from stakeholders who are knowledgeable about countywide working lands. These individuals provided invaluable insights on land management practices, including the perceived current implementation of various practices and perceived major barriers to greater implementation of these management practices, which informed the scenarios we chose to model.

Data analysis for this project was conducted using ArcMap 10.8, Microsoft Excel, and R through RStudio version 1.3.1073. Code written in R can be found in Appendices V and VI.

Land Cover Classification

We downloaded LANDFIRE Existing Vegetation Type, Height and Cover (EVT, EVH and EVC); Farmland Mapping & Monitoring Program (FMMP) data; and Cal Ag Pesticide Use Reporting data for Santa Barbara County for three years (2012, 2016, and 2019). For 2019, we used LANDFIRE’s Fuel Vegetation Type (FVT) rather than EVT, EVH, and EVC because of data availability. All datasets are described in further detail below.

The three years used were chosen to maximize projection accuracy while using the best available agricultural spatial data. Santa Barbara County provides annual Cal Ag spatial data only as far back as 2012, limiting our choice of years. Additionally, the team sought to maximize the span of time between the three years to capture the long-term trends in land use change; therefore, 2012 and 2019 were chosen because they were the earliest and most recent years available. 2016 was selected over 2014 because it is more evenly spaced between the start and end years. LANDFIRE data is also available for 2012, 2016 and 2019, which will help with the integration of our results into the TerraCount modeling. This analysis looks back seven years and projects forward eleven years.

LANDFIRE, a USDA program, provides geospatial datasets that describe vegetation regimes across the United States. The Existing Vegetation Type (EVT) dataset contains the primary vegetation type in each 30x30 meter area. This data was used to classify the natural lands in Santa Barbara County into the following land use classifications: forest, shrubland, grassland, developed, agriculture, barren land, riparian/wetland, and water. These classifications were chosen because they align with the broad land cover categories including in the LANDFIRE and help us understand the overall land composition of the jurisdiction.

The Cal Ag Pesticide Use Reporting Program tracks agricultural pesticide use in California. The County provides geospatial data of its pesticide permits and use for each year starting in 2012. These shapefiles display agricultural properties that applied for or used pesticides, and describe the crop types that the pesticides can be used for. Using these datasets, we classified all agricultural properties in Santa Barbara County into the following classifications based on their crop types: annual row crops, greenhouse, orchard, fallow, fodder, managed pasture, and vineyard. These classifications were chosen because they mostly align with the carbon inventory methodology for working lands used by Resilient Merced. We chose to include greenhouse, fallow, and fodder as their own categories (which Merced did not do) to better explore and understand trends over time for different agricultural land classifications.

We decided, in consultation with the County of Santa Barbara's Agricultural Commissioner's Office, that Cal Ag was the most accurate data source for mapping the extent of agricultural properties in each year. Additionally, this data included the specific crop types grown on each parcel of agricultural land, which was necessary for estimating nitrous oxide emissions. Other data sources, such as USDA Cropland Data Layer, California Department of Water Resources (CADWR) Statewide Crop Maps, and FMMP, were reviewed; however, it was determined that they could not be used either because they do not provide data for the years being analyzed (in the case of CADWR) and/or they do not contain detailed information on crop types grown at each location (in the case of FMMP). The USDA Cropland Data Layer, used by Merced County for the Resilient Merced project, was visibly inaccurate compared with satellite data and other sources.

To address some of these concerns, we preprocessed the Cal Ag data to ensure its usefulness and to improve accuracy before reclassifying. After exploring the dataset and corresponding with County data managers, we removed any polygons with blank crop lists, as many of these were duplicates (i.e. these polygons overlapped other polygons representing the same land area, often due to multiple permit applications). We then filtered the data based on the "MostRecAll" attribute to erase entries where "MostRecAll" was "0." We interpreted this attribute as "most recent allocation", but were unable to find metadata on the dataset and were unable to confirm with County and State data managers. This approach assumes that parcels with a "1" in "MostRecAll" represent the most recent allocation of permits, thus filtering out older permits that cause the overlapping polygon issue. We visually compared the edited Cal Ag spatial data to FMMP and CADWR and found only minor discrepancies, affirming the methodology used.

Once we had processed our spatial data, we needed to classify the specific crops found on each polygon as the broader crop categories mentioned above. In Excel, we used the "crop list" attribute that is listed for each parcel to determine the appropriate crop category for the parcels. This was completed by mapping every unique value in "crop list" to a crop category. Lookup functions were used to compile a list of the crop categories that corresponded to each parcel. For parcels with multiple crops listed, the most commonly observed crop category was chosen. In a few rare cases, there were an equal number of observations for two or more crop categories so we deferred to the category that corresponded to the first crop listed in "crop list".

We excluded any polygons that included “rangeland.” After visually comparing the different years with satellite imagery and our own knowledge of the county, we found that Cal Ag’s rangeland data was inconsistent and incomplete. We did model changes in rangeland over time, explained below in the baseline reference scenario section.

For more information on our assumptions and justifications related to data choices and processing, see Appendix II.

Carbon Inventory

The carbon inventory was created by estimating and summing the carbon stock values of aboveground biomass carbon and soil organic carbon across the full county landscape. We also estimated nitrous oxide emissions from fertilizer application and converted them to $MTCO_2e$. This follows the approach outlined in Resilient Merced.

Table 1. Global warming potential unit conversions (3,10,43)

	Metric tons of carbon dioxide equivalent ($MTCO_2e$)
Carbon (C)	3.67
Nitrous oxide (N_2O)	298
Methane (CH_4)	25

The carbon inventory of aboveground carbon in natural lands consisted of inventories of biomass in forestland, shrubland, grassland, and riparian/wetland, which were developed by first estimating the volume of plant material in 30x30 meter pixels using LANDFIRE Existing Vegetation Type (EVT), Existing Vegetation Cover (EVC) and Existing Vegetation Height (EHV). EVT, EVC and EVH are geospatial datasets from the LANDFIRE program that detail the height and cover of vegetation in each 30x30 meter area. The carbon inventory of aboveground carbon in natural lands was calculated based on a methodology created by California Air Resources Board and Battles et al, 2014 (44). Battles et al, 2014 provided volumetric estimates of carbon mass (metric tons per hectare) for every combination of EVT, EVC, and EVH attribute. These values were assigned to each 30x30 meter pixel in Santa Barbara County, converted to 30x30 meter areas, and summed for all natural land in the county. This was done by creating a series of lookup tables in Excel and point layers in ArcMap, and then linking them together using R.

The carbon inventory of aboveground carbon in agricultural lands was developed using estimates of mass of carbon per acre per crop category provided by Resilient Merced: Inventory Methodology (3). The Resilient Merced Project estimated aboveground biomass carbon to be 2 MT C/ha for row crops, 2.9 MT C/ha for grape vineyards, and 3 MT C/ha for irrigated grasslands and fodder crops. For orchards, we used an average of the biomass carbon estimates for a variety of fruit and nut orchard crops, which was 20.7 MT C/ha.

For all land cover classes, soil carbon was estimated by using the USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) organic carbon soil spatial data layer (accessed on Urban Footprint). The data provided values for grams of carbon per square meter of the top 30 centimeters of soils. Soil carbon stocks were estimated in our 2016 inventory by converting the values to metric tons of CO_2 equivalent. Soil carbon data based on vegetation type was not available, and soil carbon stocks can vary widely depending on climate and geological features. The SSURGO dataset is based on soil sampling across geographies, and soil carbon values are assigned to broad polygons that were then broken down into points to match the points containing vegetation information (45).

Nitrous oxide emissions from fertilizer application were estimated for all agricultural lands using estimates of N_2O emissions per hectare (1 hectare = 2.47105 acres) of different crop categories. This process relied on nitrogen application data provided by the County and methodology provided by Resilient Merced (Inventory Methodology). The nitrogen application rates (in pounds per acre) were specified based on the following categories: vegetable crops, field crops, wine grapes, fruits & nuts, berries, and avocados & lemons. Using the Merced inventory methodology (based on IPCC methods), emissions were calculated assuming that 1.75% of all nitrogen inputs are lost as N_2O. This emissions rate includes both synthetic and organic nitrogen additions, such as fertilizer, compost, and mulches; for this reason, no distinctions were made in the estimations of organic and non-organic N_2O emissions. Furthermore, nitrogen application and emissions rates can vary widely on organic agricultural lands, depending on how the crops and soils are managed (46). Further investigation into the nitrogen management of Santa Barbara County organic agriculture was outside the scope of this project. More information on how these methods were selected and applied to calculate nitrous oxide emissions can be found in Appendix II.

After consulting with Dr. John Melack and Dr. Jennifer King at University of California, Santa Barbara, we excluded wetlands from the analysis. Wetlands account for a relatively small portion of the jurisdiction, and emissions from wetlands vary widely based on watershed characteristics (47). Because Santa Barbara County is coastal and has limited inland wetlands, we did not find it appropriate to use Resilient Merced's emissions estimate, which is based on inland freshwater wetland characteristics.

The carbon inventory of urban forestry was completed by our project partner, Rincon Consultants. Rincon's methodology included:

- Defining the area of urban forests using LANDFIRE data and the US Census Bureau's boundaries for urban areas in the unincorporated area;
- Estimating the tree canopy area within the urban areas using the i-Tree Canopy tool; and
- Applying a carbon ratio estimate of CO_2 per acre of tree canopy to calculate the mass of carbon in the urban forests (48).

The calculated urban forestry aboveground carbon stock values were then added to the soil carbon estimates for developed land to finalize the total carbon stock values for the “developed” land category.

Baseline Reference Scenario

This component of the project aimed to create a baseline reference scenario to model what agricultural land cover, carbon stocks, and emissions might look like in 2030 if current land use trends continue with no intervention. The IPCC notes that baseline scenarios, previously referred to as a “business-as-usual” or BAU scenario, “are not intended to be predictions of the future, but rather counterfactual constructions that can serve to highlight the level of emissions that would occur without further policy effort” (49).

The data used for this component includes the processed Cal Ag agricultural land cover data that was created for 2012, 2016, and 2019, and the corresponding carbon stock and N_2O emissions values provided by the Resilient Merced report and by the County. A series of linear regressions was performed using R to project values for 2030. Changes in stocks and emissions correspond to changes in projected acreage by land type and do not reflect changes in management practices.

After analyzing spatial data for natural lands in 2012, 2016, 2019, we decided not to project change for the full Santa Barbara County landscape. We found inaccuracies in pixel attributes (e.g. land visible in satellite imagery miscategorized as an obviously wrong land cover type) and inconsistencies across years (e.g. large swaths of land that appear the same in 2012 and 2016 satellite imagery assigned as grassland in 2012 and shrubland in 2016). The differences can likely be attributed to remote sensing errors in LANDFIRE data and as a result, we determined that we lacked sufficient data to accurately report the changes in land cover in natural lands. Projections based on this data might show the change between reporting errors, not between actual land cover in the county. Therefore, projections for carbon stocks and N_2O emissions on working lands do not represent changes for the full landscape. An increase in agricultural carbon stocks could conceivably result in a net decrease countywide if, for example, land was deforested to allow for agricultural expansion.

Finally, because grazing cattle is a major part of Santa Barbara’s agricultural economy, we wanted to include rangelands in our projections. LANDFIRE does not identify rangelands specifically, and the inclusion of rangelands in Cal Ag data was inconsistent across years and incomplete in all cases. To remedy these inconsistencies, we used acreage figures provided by Santa Barbara County’s annual crop reports. We assumed that rangeland consists largely of what LANDFIRE categorizes as grassland or shrubland. To assign carbon values to rangelands, we took a weighted average of aggregated aboveground and soil carbon contained in what was classified as grassland and shrubland in the 2016 carbon inventory, and multiplied these values by the number of acres of rangeland for each year. The weights were determined by applying the total 2016 acreage calculated for grasslands as a proportion of the total rangeland acreage provided by the 2016 crop report. This weight was applied to grassland, and the remainder to shrubland. These values were then used to make projections to 2030 using the same linear regression technique. In summary, the rangeland category is included in our projections to 2030 and our management scenarios, but not our 2016 carbon inventory, where that same land is categorized as largely shrubland and grassland.

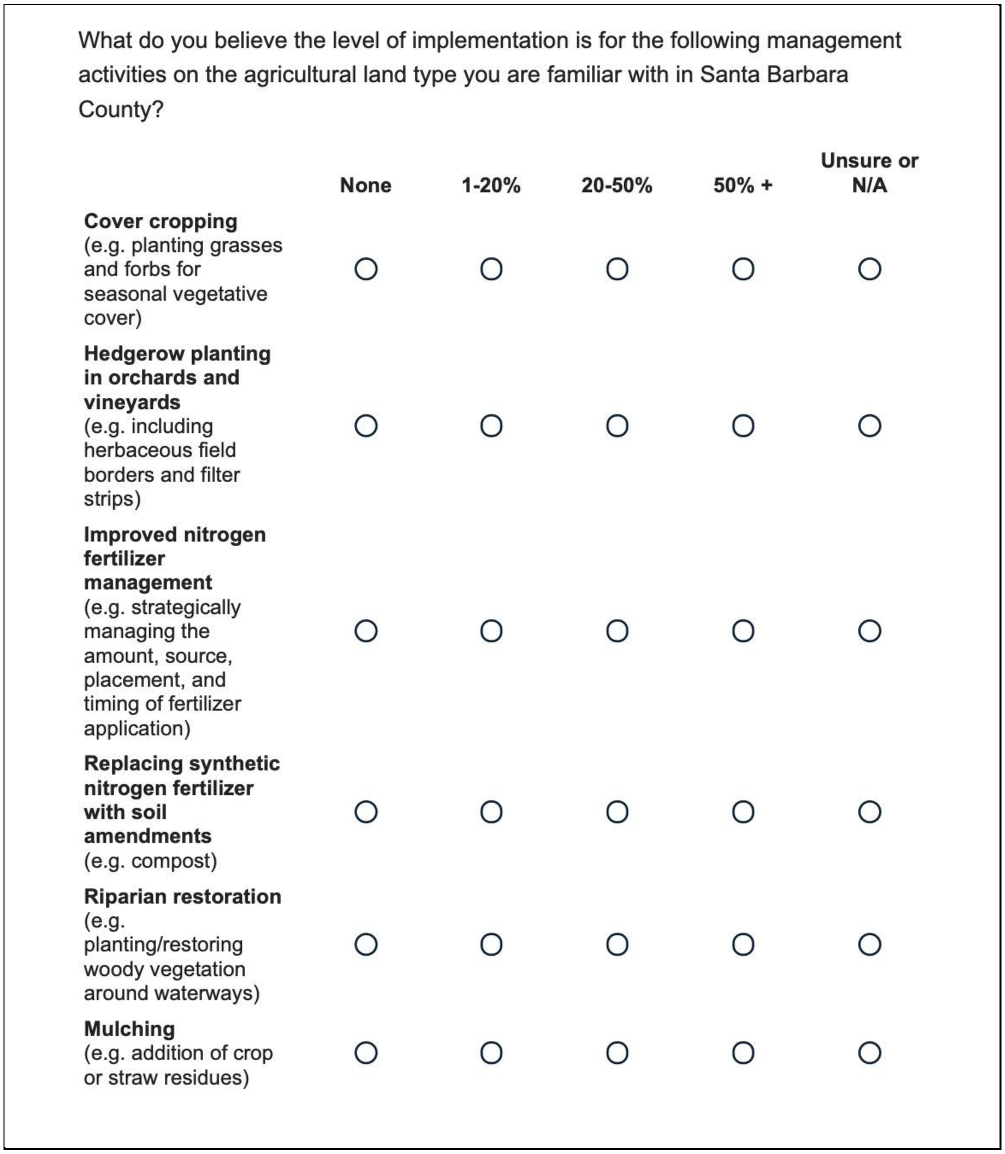
Agricultural Community Engagement

To ensure that our analysis of potential land management scenarios and resulting policy recommendations were tailored to Santa Barbara County, we collaborated with our client to conduct a strategic outreach campaign within the agricultural community. Our first goal was to determine the current level of implementation of a set of management practices, to inform the scenario modeling process. Our second goal was to gather information regarding the barriers to greater implementation of the practices, to inform our recommendations to the County. Our outreach methodology included meetings with individuals, a survey, and facilitated discussions with a relatively small group of individuals who are knowledgeable about countywide management practices.

Survey Design

The pivotal component of our outreach campaign was a survey designed to collect input on current management practice adoption and barriers to greater adoption. We based the questions loosely on the survey distributed by the Resilient Merced project, since the responses lead to inputs for the scenario modeling process. To ensure consistency between our project and the larger TerraCount project, we elected to focus on management practices that are built into the TerraCount tool. These were selected from established NRCS conservation practices, and are thus eligible for certain funding opportunities, but may not represent a comprehensive suite of “climate-smart” activities that land managers can employ (50,51). We nevertheless refer to the practices we studied as “climate-smart” with the intention that future work will expand on included practices, since any activities that sequester carbon or reduce emissions have value.

Although working from Merced’s model, we realized the importance of adapting the survey to fit Santa Barbara County. To do so, we consulted with representatives from the Santa Barbara County Conservation Blueprint, the CRCD and the UC Cooperative Extension (UCCE). We initially considered sending a survey to as many farmers and ranchers as possible. However, these advisors counseled us that this strategy was unlikely to result in meaningful data due to low response rates and response bias. They advised us to make the questionnaire as straightforward, concise, and easy to complete as possible, in order to get a high response rate. Additionally, they recommended we keep the survey anonymous, as some individuals might then be willing to be more forthright in their responses. Since the goal was to first get a very general sense of current implementation of the land management practices, we provided respondents with preset ranges of implementation to select from, in table form (see Figure 2 below). The survey also allowed respondents to provide a freeform response regarding their perceptions of barriers to greater implementation of these activities. For these questions, we were interested in hearing directly from respondents, in their own words, without predisposing them with any cues or example language.



What do you believe the level of implementation is for the following management activities on the agricultural land type you are familiar with in Santa Barbara County?

	None	**1-20%**	**20-50%**	**50% +**	**Unsure or N/A**
Cover cropping (e.g. planting grasses and forbs for seasonal vegetative cover)	○	○	○	○	○
Hedgerow planting in orchards and vineyards (e.g. including herbaceous field borders and filter strips)	○	○	○	○	○
Improved nitrogen fertilizer management (e.g. strategically managing the amount, source, placement, and timing of fertilizer application)	○	○	○	○	○
Replacing synthetic nitrogen fertilizer with soil amendments (e.g. compost)	○	○	○	○	○
Riparian restoration (e.g. planting/restoring woody vegetation around waterways)	○	○	○	○	○
Mulching (e.g. addition of crop or straw residues)	○	○	○	○	○

Figure 2. Survey excerpt: current management practice implementation levels on agricultural lands.

Survey Distribution

The survey was distributed to 34 experts in countywide working lands management practices, and we requested that these individuals forward the survey within their network. After leaving the survey open for two months and occasionally sending follow-up requests for input, we received 15 complete responses to the survey.

Out of 15 respondents, 8 indicated a countywide understanding of land management practices for orchards, 7 for annual row crops, 7 for vineyards, and 13 for rangelands. The specific professional roles and the areas of land management expertise of the 15 survey respondents include:

- Researcher and advisor (livestock)

- Pasture manager (pasture-raised pigs, chickens, cattle grazing)
- USDA-NRCS Rangelands management specialist (cattle grazing)
- Ranch owner/manager (hay farming, cattle grazing)
- Ranch owner (beef breeding cattle)
- Technical assistance provider (ranching)
- Researcher of agricultural production issues (blueberry, citrus, avocado, specialty tree crops)
- Technical provider (vegetables and strawberries)
- Farmer (plant nursery / native plant restoration)
- Vineyard manager (vineyards)
- Farmer (dry farmed wine grapes and olives)
- Resource Conservation District (variety)
- Non-profit/NGO (rangeland, orchards, some row crop strategies)
- Regenerative farm advisor (integrated animal / food / forests, small scale diverse subsistence farming and trees grown for animal fodder, shade, firewood, wind mitigation)

Post-Survey Discussion Groups

To verify our interpretation of the ranges of current implementation and barriers to greater adoption derived from the survey, we facilitated two focus group-style discussions with the SBC Land Stewardship & Carbon Farming Coalition. This subcommittee to the Santa Barbara County Regional Climate Collaborative was convened by the County and the Community Environmental Council (CEC) to discuss land stewardship issues and to advise the Climate Action Plan update process. Many of the committee members happen to be individuals that we had previously engaged or who responded to our survey, which allowed us to more specifically follow up on feedback that was provided in the survey. However, we find it important to note that the overlap could indicate that County stakeholder engagement is limited to this small circle of actively involved individuals.

Our first virtual meeting with the subcommittee took place in January of 2021. We walked through a publicly accessible Google spreadsheet in which we made comments during the meeting, and invited members to edit themselves after the meeting if they still wanted to provide feedback, perhaps more anonymously. We were unable to elicit specific values for current implementation levels of the highlighted management practices, nor estimates of the maximum possible level of implementation. However, a lively discussion of barriers to adoption was sparked. Committee members elaborated on answers that we had flagged for follow-up from the survey, and also volunteered more opinions, anecdotes, and suggestions on obstacles they were aware of.

Our second meeting with the subcommittee took place in March. By that time, we had completed the scenario modeling process and were interested in following up more specifically about the barriers raised in the survey and previous discussion. The County and CEC asked us to focus on regulatory barriers in particular. We first presented our project findings, so that members could respond to the methodology and results. We then presented a set of recommendations we planned to make to the County, based on the barriers highlighted previously. The discussion that ensued supported our prioritization of issues, elaborated on the barriers, and suggested specific implementation strategies and concerns.

Lastly, we relied on email correspondence with several researchers from UCCE, particularly those from the Ventura County and San Luis Obispo County UCCE offices as there is no Santa Barbara County-specific UCCE office. These advisors and specialists were able to provide additional information and local context around our set of climate-smart management practices and corroborate the comments collected in our group discussions.

Scenario Modeling and Analysis

The land management scenario analysis builds on the outputs of the land cover classification, baseline reference scenario, carbon inventory and agricultural community engagement efforts described above. In this phase of the project, we designed scenarios with varying levels of land management activity implementation and modeled their GHG emissions reduction potential using the COMET-Planner tool.

COMET-Planner

COMET-Planner is a widely used, publicly available agricultural carbon accounting tool developed by USDA and Colorado State University. The tool was designed to approximate GHG mitigation potentials of NRCS conservation practices. COMET-Planner calculates the reduced emissions associated with the implementation of each activity over a certain acreage on a given land type. To determine the impacts of adopting NRCS conservation practices on carbon sequestration and GHG emissions, COMET-Planner defines a baseline (BAU) scenario and a conservation implementation scenario. The baseline scenario represents current management practices that are typical of the region at minimal implementation levels (52).

The COMET-Planner tool provides estimates for carbon sequestration and GHG emissions reductions that were calculated from field-based samples used as inputs in process-based computer models, which calculate the estimates at the national scale and then localize them according to regional specific soil and climatic conditions. In 2019, an updated version of the tool was launched, featuring advancements in spatial resolution and regional-specific estimates. Spatial resolution is now at a multi-county region level (40). In January 2020, COMET-Planner created a second version of its updated tool to support the California Department of Food and Agriculture (CDFA) Healthy Soils Program. This version of the tool uses the same general approach and greenhouse gas estimation methods but is modified to account for regionally-specific conditions in each county in California, informed by practice guidelines, extension materials, and expert interviews. For this project, we utilized the updated, Santa Barbara-specific Healthy Soils Program version of the COMET-Planner tool.

COMET-Planner Estimation Methods

COMET-Planner provides estimates of GHG emissions reductions and sequestration on a per acre and per annum basis for each conservation practice. These estimates were developed using a sample-based modeling approach that is aligned with the USDA Methods for Entity-Scale Inventory (53).

The average nitrogen fertilizer rates for major crops used in COMET-Planner were derived from the USDA Economic Research Service. Baseline practices typical of the crops grown in the region were applied to create the baseline scenario (52). COMET-Planner modeled the baseline and conservation scenarios in the COMET-Farm tool to determine the county and regional specific coefficients for each management practice. Methods for direct and indirect soil N_2O follow the U.S. National Greenhouse Gas Inventory methodology (54). Indirect soil N_2O includes emissions from leached and volatilized N.

The emissions reductions and carbon sequestration coefficients for each practice were calculated by using field-based samples under baseline and management scenarios. The data was used to calculate sequestration and emissions estimates for the baseline and management scenarios using process-based computer models. The difference between the estimates for baseline and conservation scenarios were calculated, and then averaged to generate mean sequestration and emissions reduction rates for each management practice. The estimates were localized for regional and county-specific soil and climatic conditions. COMET-Planner also provides a maximum and minimum value for net GHG emissions to demonstrate how estimates vary over a range of soil, weather, and management conditions within each region. Since the carbon stock increases in response to conservation practices are typically limited in duration, the carbon dioxide reductions reported in COMET-Planner should be viewed as average annual values over a 10-year duration (52).

The coefficients for compost application were calculated independently by CARB and included in the COMET-Planner tool. Those values were calculated using a process-based computer simulation model, called the "Denitrification-Decomposition (DNDC)" model, which simulates carbon and nitrogen biogeochemistry. The DNDC simulates the microbial activity that produces CO_2, N_2O, and CH_4 under various environmental conditions, including temperature, pH, crop types, and substrate concentrations in soil. The DNDC model was run for each county in California, using inputs that are specific to their local environmental conditions, and assumed compost was applied to various crop types over a three-year period. The resulting impacts of compost application were calculated as the net change in CO_2, N_2O, and CH_4 between baseline scenarios and the compost application. The values we used in our project are the DNDC results for Santa Barbara County (55).

Scenario Design

Based on feedback from the community engagement process regarding the relative feasibility level of each practice, we developed fourteen land management scenarios (see Table 2). More specifically, we selected seven management practices and created two scenarios for each: high implementation and low implementation. Each scenario consists of a combination of similar land-management activities that can be applied to the applicable land classifications (row crops, orchards, etc.) at various extents of adoption (i.e. number of acres).

Most of the management practices we selected for this analysis were included in both the TerraCount and COMET-Planner tools. We wanted to ensure that the outreach and research we conducted to inform our analysis and recommendations could also be used to inform the County's eventual analysis of the co-benefits of these practices through the TerraCount scenario modeling tool.

The COMET-Planner descriptions, coefficient estimates for reductions in carbon dioxide, nitrous oxide, and methane, and estimated Healthy Soils Program funding per acre for each of our selected management practices are shown in Table 2. Coefficients are reported as metric tonnes of CO_2 equivalent per year, per acre of land over which the management practice is applied.

Table 2. COMET-Planner management practice sets and coefficients.

Land type	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**CH4**	**Total CO_2**	**HSP Payment/acre**
Restoration						
Row Crop	Conservation Cover - Convert Irrigated Cropland to Permanent Unfertilized Grass/Legume Cover-Introduced Species	0.61	0.02	0	0.63	$1703.58
Orchard & vineyard	Conservation Cover - Convert Idle Land near Orchards/Vineyards to Permanent Unfertilized Grass/Legume Cover Pollinator Species	0.6	0	0	0.6	$1703.58
Pastureland & rangeland	Silvopasture - Tree/Shrub Planting on Grazed Grasslands - Establish Trees in Existing Grasses	0.66	0	0	0.66	$235.2
Hedgerow planting						
Crop	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**Total CH4**	**Total CO_2**	**Payment/acre**
Row Crop	Hedgerow Planting - Replace a Strip of Cropland with 1 Row of Woody Plants	8.28	0.13	0	8.41	$10.82
Orchards, & vineyards	Hedgerow Planting - Plant 1 Row of Woody Plants on Border of Orchard or Vineyard	8.2	0	0	8.2	$10.82
Pastureland & Rangeland	Hedgerow Planting - Replace a Strip of Grassland with 1 Row of Woody Plants	8.2	0	0	8.2	$10.82

Land type	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**CH_4**	**Total CO_2**	**HSP Payment/acre**
Reduced Till						
Crop	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**Total CH4**	**Total CO_2**	**Payment/acre**
Row Crop	Reduced Till - Intensive Till to Reduced Till on Irrigated Cropland - Reduced-till	0.09	0.03	0	0.12	$87
Orchards, & Vineyards	Reduced Till - Conventional Till to Reduced Till in Orchard/Vineyard Alleys Reduced-till	0.09	0.03	0	0.12	$87
Pastureland & Rangeland	N/A					
Mulching						
Crop	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**Total CH_4**	**Total CO_2**	**Payment/acre**
Row Crop	Mulching - Add Mulch to Croplands - Natural Materials	0.21	0	0	0.21	$1194.06
Orchards, & Vineyards	Mulching - Add Mulch to Orchard/Vineyards Natural Materials	0.53	-0.19	0	0.34	$1194.06
Pastureland & Rangeland	N/A					
Land type	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**CH_4**	**Total CO_2**	**HSP Payment/acre**

Cover Cropping						
Row Crop	Cover Crop - Add Legume Seasonal Cover Crop to Irrigated Cropland-Multiple Species	0.495	-0.1	0	0.395	$320.10
Row Crop	Cover Crop - Add Legume Seasonal Cover Crop to Irrigated Cropland-One species	0.495	-0.1	0	0.395	$267.60
Orchards & Vineyards	Cover Crop - Add Legume/ Legume Mix Cover Crop to Orchard/Vineyard Alleys- Multiple Species	1.69	-0.05	0	1.64	$320.10
Orchards & Vineyards	Cover Crop - Add Legume/ Legume Mix Cover Crop to Orchard/Vineyard Alleys- One species	1.69	-0.05	0	1.64	$267.60
Compost Application (C:N < or = 11)						
Row crop	Compost Application - Compost (C:N < or = 11) Annual Crops-Compost from certified composting facility or compost produced on-farm	2.23	-0.27	0	1.96	$750
Orchards, Vineyards	Compost Application - Compost (C:N < or = 11) - Compost from certified composting facility or compost produced on-farm	1.69	-0.12	0	1.57	$600
Pastureland and grazing land	Compost Application - Compost (C:N < or = 11) Application to Grazed Grassland-On-farm produced compost or Compost from certified composting facility	1.69	-0.12	0	1.57	$600
Land type	**Practice Definition in COMET-Planner**	**Carbon**	**N_2O**	**CH_4**	**Total CO_2**	**HSP Payment/acre**
Compost Application (C:N > 11)						

Row crop	Compost Application - Compost (C:N > 11) Annual Crops-Compost from certified composting facility or compost produced on-farm	4.41	-0.259	0.01	4.161	$1,200.00
Orchard, vineyards	Compost Application - Compost (C:N > 11) - Compost from certified composting facility or compost produced on-farm	4.51	-0.136	0.1	4.474	$1,200.00
Pastureland and grazing land	Compost Application - Compost (C:N > 11) Application to Grazed Grassland-On-farm produced compost or Compost from certified composting facility	4.4	-0.06	0.006	4.346	$1,200.00

Table 3. Summary of fourteen land management scenarios modeled.

	Low Implementation Scenario					**High Implementation Scenario**				
	2030 Target (additional)				**Acres (additional)**	**2030 Target**				**Acres (additional)**
	Row Crop	Orchard & Vineyard	Pasture	Rangeland	Total	Row Crop	Orchard & Vineyard	Pasture	Rangeland	Total
Restoration	3%	N/A	N/A	0.75%	7,369	6%	N/A	N/A	1.50%	14,738
Hedgerow Planting	3%	3%	3%	0.75%	7,369	6%	6%	6%	1.50%	14,738
Reduced Till	10%	10%	10%	3%	24,563	20%	20%	20%	5%	49,126
Mulching	10%	10%	10%	3%	24,563	20%	20%	20%	5%	49,126
Cover Cropping	10%	10%	N/A	N/A	10,527	20%	20%	N/A	N/A	21,055
Compost (C:N < or = 11)	10%	10%	10%	3%	24,563	20%	20%	5%	5%	49,126
Compost (C:N > 11)	10%	10%	10%	3%	24,563	20%	20%	20%	5%	49,126

Scenario Modeling

We projected the expected future emissions reduction annually up to 2030 for each of our fourteen scenarios using the COMET-Planner emissions reduction values as coefficients for the area of land actively managed.

To forecast total emissions reductions and CO_2 sequestration from the county's working lands from 2021–2030, we modeled incremental implementation over time; for each activity, on each land type, the level of implementation increased linearly year by year, ultimately reaching the target implementation level by 2030. We also incorporated the projected land use change, so that the implementation percentage was applied to the acreage of each land type we expect to exist by 2030.

This model produced an annual measure of carbon sequestration and emissions reductions expected to take place for each year leading up to 2030. This enabled us to not only develop estimates for carbon storage taking place in the year 2030, but also to determine what cumulative emissions reductions and sequestration could be expected in the intervening years.

Results

Land Cover Classification

The reclassification of natural and working lands across the jurisdiction in 2016 produced the land cover acreage shown in Table 4 below. Shrubland, forest, and grassland cover around 82% of the county, and agriculture accounts for another 9% (not including rangelands). The spatial distribution of land cover classifications can be seen below in Figure 3, and the percentage of the county that different land types comprise can be seen in Figure 4.

Table 4. 2016 land cover classifications and associated acreage.

Land Cover Classification	**Acres**
Barren	22,208
Developed	105,836
Fallow	8,028
Fodder	6,844
Forest	292,859
Grassland	239,988
Greenhouse	1,937
Orchard	16,878
Pastureland	2,541
Riparian/Wetland	14,932
Row Crop	80,597
Shrubland	804,518
Vineyard	30,613
Water	4,381
Total	**1,632,162**

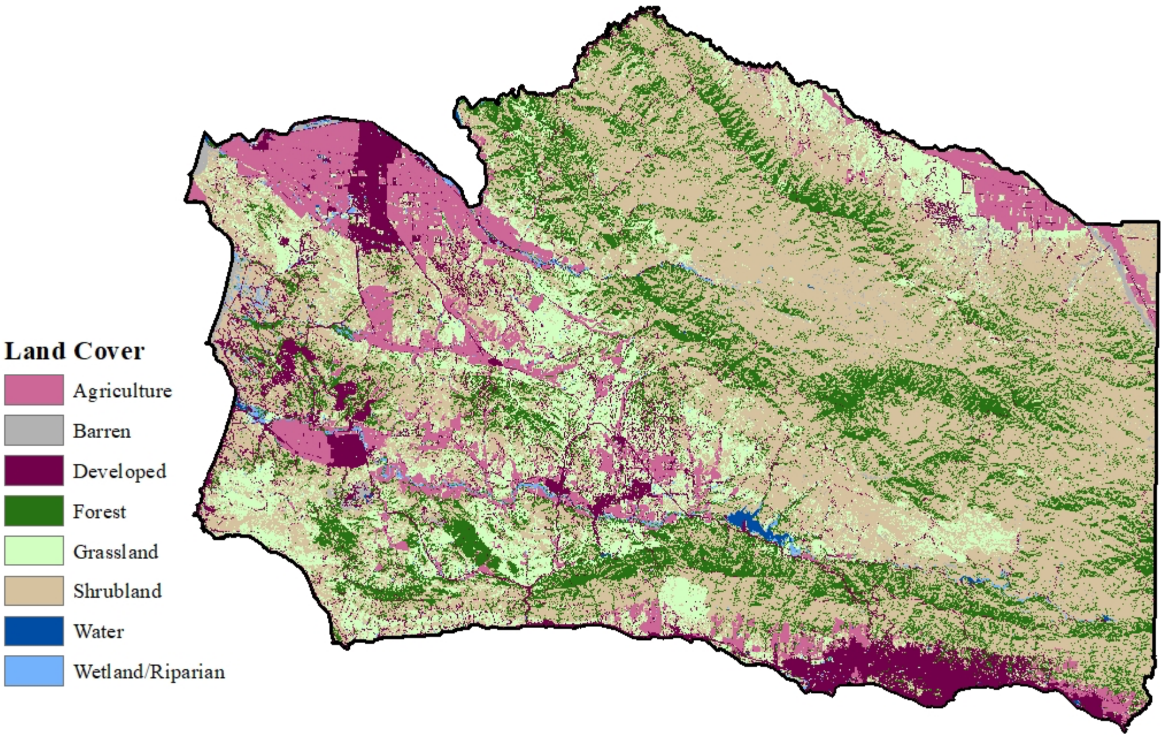


Figure 3. Land cover classifications in 2016 across Santa Barbara County. “Agriculture” is classified with more detail in Figure 5.

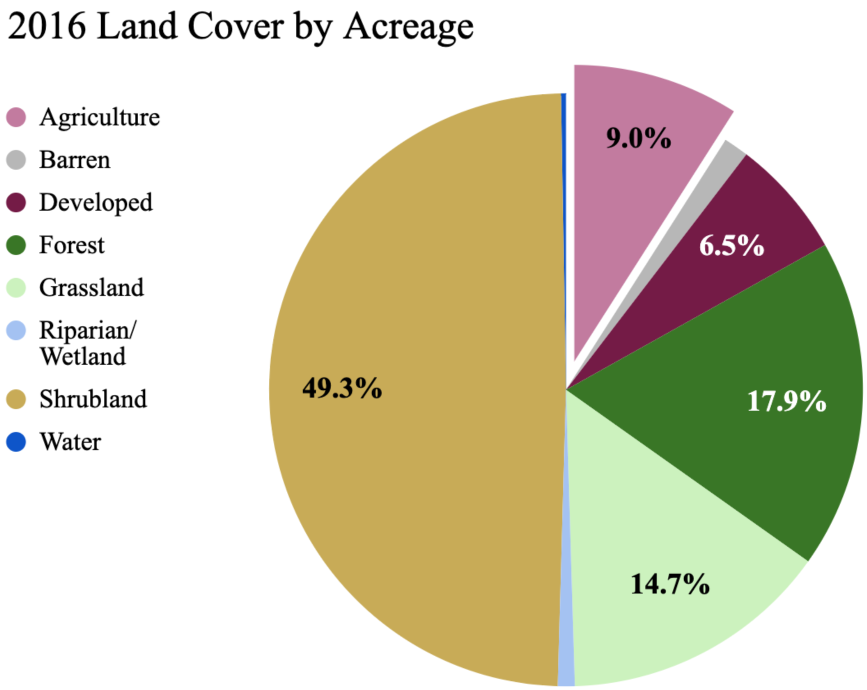


Figure 4. Land cover classification by percent of total acreage in 2016. Agriculture is highlighted since we focus on agricultural management scenarios in the remainder of our analysis.

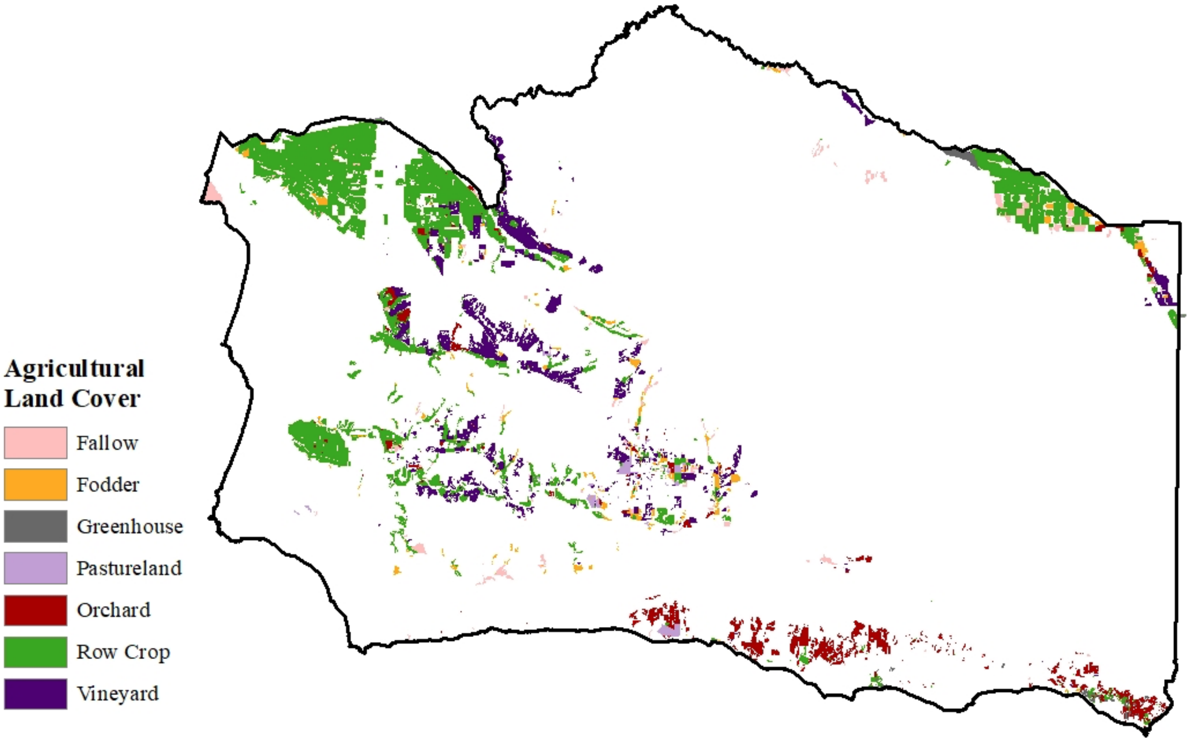


Figure 5. 2016 agricultural land classifications.

Row crops, vineyards, and orchards are the main agricultural crops in the county. Row crops account for 55% of the county's managed cropland, vineyards account for 21%, and orchards account for 11%. Figure 5 includes managed pastureland but does not include "rangeland," which is a combination of grassland and shrubland.

Carbon Inventory

The complete carbon inventory for 2016 includes aboveground carbon stored in biomass and soil organic carbon, both in metric tons of carbon (MT C), as well as nitrous oxide emissions in metric tons of carbon dioxide equivalent (MTCO_2e). Around 49% of the county's carbon stocks exist in shrubland; another 37% is stored in forest and grassland. Aside from unmanaged grazing land (which is a combination of grassland and shrubland), the working land classification with the highest net carbon stock is row crops, which net 1,175,710 MT C. The table and figures below detail the stocks and emissions of each land classification.

Table 5. 2016 land cover classifications and associated carbon stocks and emissions in MT carbon and $MTCO_2e$.

Land Cover Classification	**Total Aboveground Carbon (MT C)**	**Total Soil Carbon (MT C)**	**Total Stocks (MT C)**	**N_2O Emissions ($MTCO_2e$)**
Barren	0	90,077	90,077	0
Developed	3,372,234	1,356,058	4,728,292	0
Fallow	2,293	94,664	96,957	0
Fodder	12,625	107,473	120,098	396
Forest	11,932,601	2,747,504	14,680,105	0
Grassland	676,690	3,543,562	4,220,252	0
Greenhouse	0	19,398	19,398	0
Orchard	136,676	269,417	406,093	3,601
Pastureland	3,116	48,736	51,852	277
Riparian/Wetland	42,546	111,283	153,829	0
Row Crop	62,001	1,113,709	1,175,710	32,871
Shrubland	18,591,734	6,228,164	24,819,898	0
Vineyard	34,147	508,852	542,999	1,816
Water	0	8,469	8,469	0
Total	**34,866,664**	**16,247,367**	**51,114,031**	**38,960**

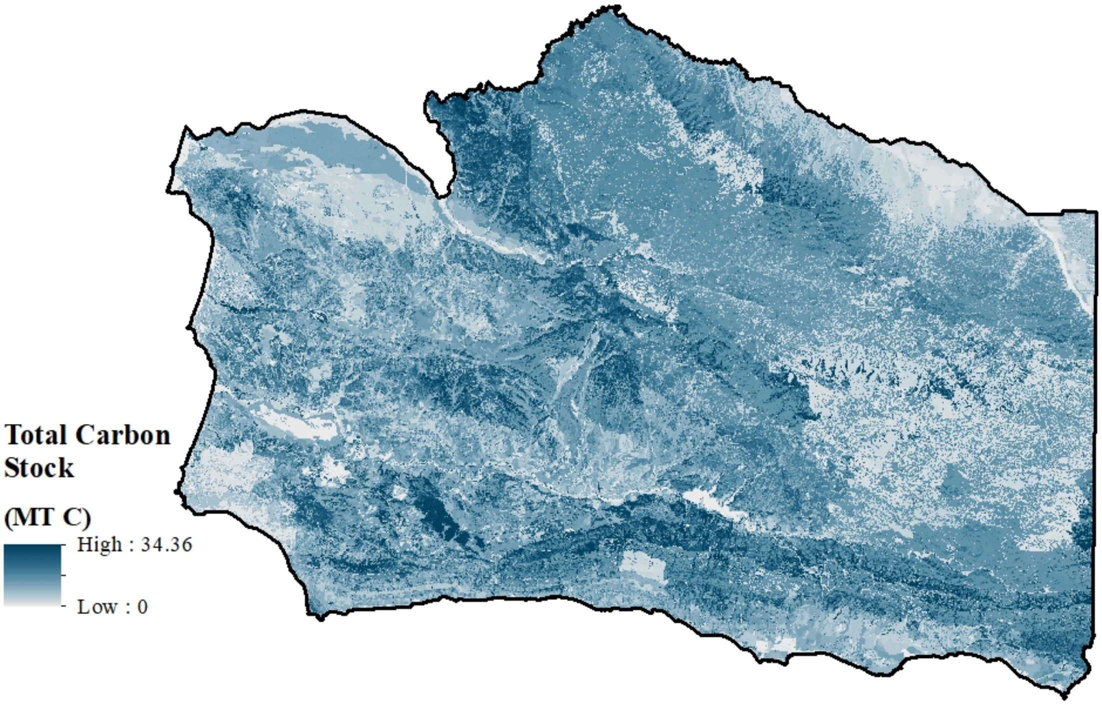


Figure 6. 2016 total carbon stocks in MT C (soil organic carbon plus aboveground biomass carbon) for 30x30 meter areas covering the county. The darker areas indicate higher concentrations of carbon.

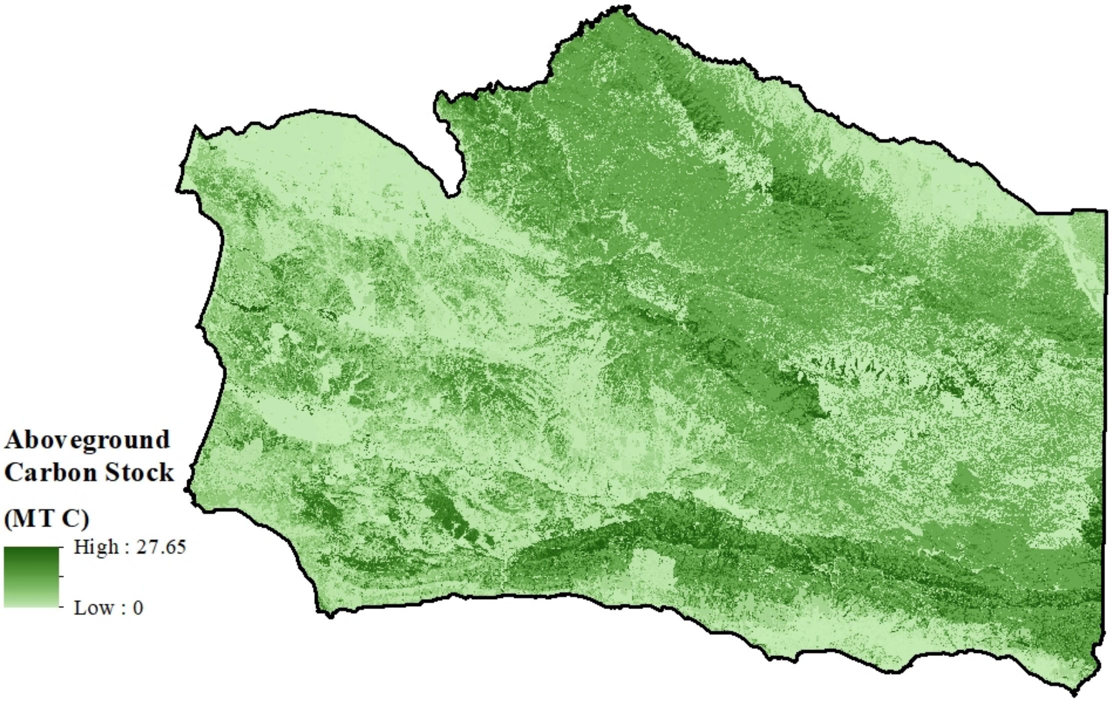


Figure 7. 2016 aboveground carbon stocks in MT C for 30x30 meter areas covering the county. This map does not include urban forestry carbon values, because they are not spatially explicit.

Figure 8. 2016 soil carbon stocks in MT C for 30x30 meter areas covering the county.

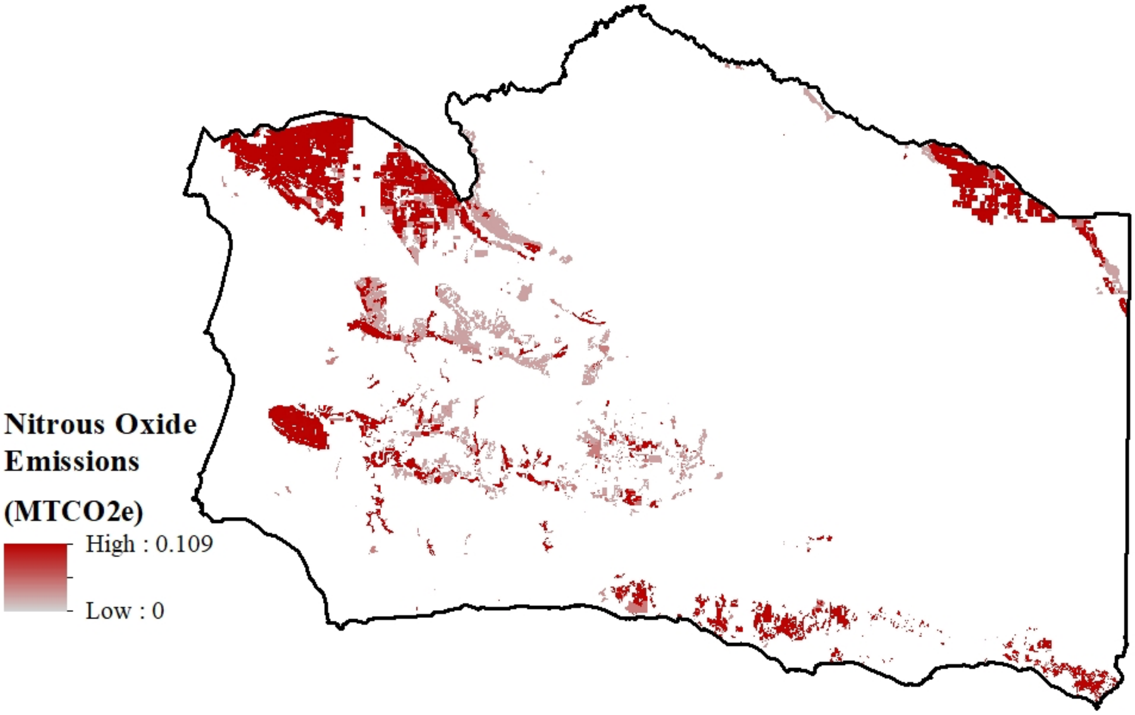


Figure 9. 2016 nitrous oxide emissions in $MTCO_2e$ for 30x30 meter areas covering the county.

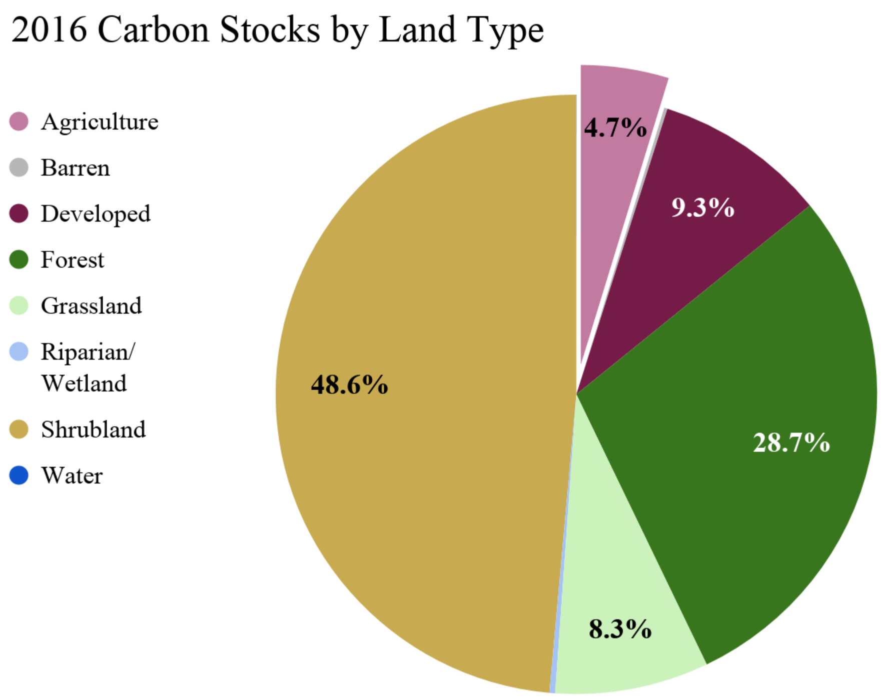


Figure 10. 2016 carbon stocks by land type (soil organic carbon plus aboveground carbon stocks). Shrubland contains almost 50% of the county's total carbon stocks.

Baseline Reference Scenario

Acreage, carbon stocks, and nitrous oxide emissions for each working land cover classification were projected to 2030 and are shown in Figures 11–15. The 2012, 2016 and 2019 values are estimations, calculated using the CalAg spatial datasets as described in the methodology section. The 2030 values are the predicted results from linear regressions performed in RStudio.

This projection provides context for the scenario modeling part of this project; when modeling which land management activities might help sequester carbon, we want to compare our results to what would have happened without changing current management practices. These projections amount to a "business-as-usual" or "baseline" reference scenario. According to this projection, total working lands are projected to decrease slightly from now until 2030. The projections are based on only three data points for the three years as described. Despite limited data, we were able to support the validity of our results by consulting outside experts, qualitatively and quantitatively evaluating historic land use trends in Santa Barbara agriculture, and comparing our results with other projections of agricultural land cover. More information on the implications and assumptions associated with our working lands projections is provided in the discussion section.

Per-acreage rates of carbon storage and emissions are provided in Table 6, and total carbon stocks and emissions for each year (estimated for 2012–2019, projected for 2030) are provided in Tables 7–10. The projected changes in soil carbon stocks or emissions represented in the accompanying graphs are solely the result of projected changes in acreage. These results apply only to agricultural land in Santa Barbara County as defined by the CalAg spatial data we processed, and rangeland numbers from Santa Barbara County crop reports. As a result, the applicability of these results is limited and does not reflect countywide changes in carbon stocks. Please see the discussion section for a more detailed explanation of how these results might be interpreted.

Table 6. Carbon stocks and nitrous oxide emissions per acre by working land cover classification in 2016.

Land Cover Classification	Aboveground Carbon Stocks (MT C/acre)	Soil Carbon Stocks (MT C/acre)	Total Carbon Stocks (MT C/acre)	Nitrous Oxide Emissions ($MTCO_2e$/acre)
Fallow	0.00	12.00	12.00	0.00
Fodder	1.23	16.79	18.01	0.11
Greenhouse	0.00	10.01	10.01	0.00
Orchard	8.38	16.24	24.62	0.20
Pastureland	1.23	19.18	20.40	0.11
Row Crop	0.82	13.92	14.73	0.40
Vineyard	1.17	16.62	17.80	0.06
Rangeland	14.98	10.55	25.54	0.00

Table 7. Estimated carbon stocks and nitrous oxide emissions by working land cover classification in 2012.

Land Cover Classification	**Acres**	**Aboveground Carbon Stocks (MT C)**	**Soil Carbon Stocks (MT C)**	**Total Carbon Stocks (MT C)**	**Nitrous Oxide Emissions ($MTCO_2e$)**
Fallow	1,312	0	18,846	18,846	0
Fodder	2,836	3,478	42,371	45,849	309
Greenhouse	807	0	13,798	13,798	0
Orchard	12,304	103,076	202,871	305,948	2,579
Pastureland	4,010	4,917	65,780	70,698	436
Row Crop	73,620	60,181	1,009,446	1,069,627	28,643
Vineyard	26,640	31,266	435,896	467,162	1,575
Rangeland	584,125	8,751,988	6,165,256	14,917,244	0

Table 8. Estimated carbon stocks and nitrous oxide emissions by working land cover classification in 2016.

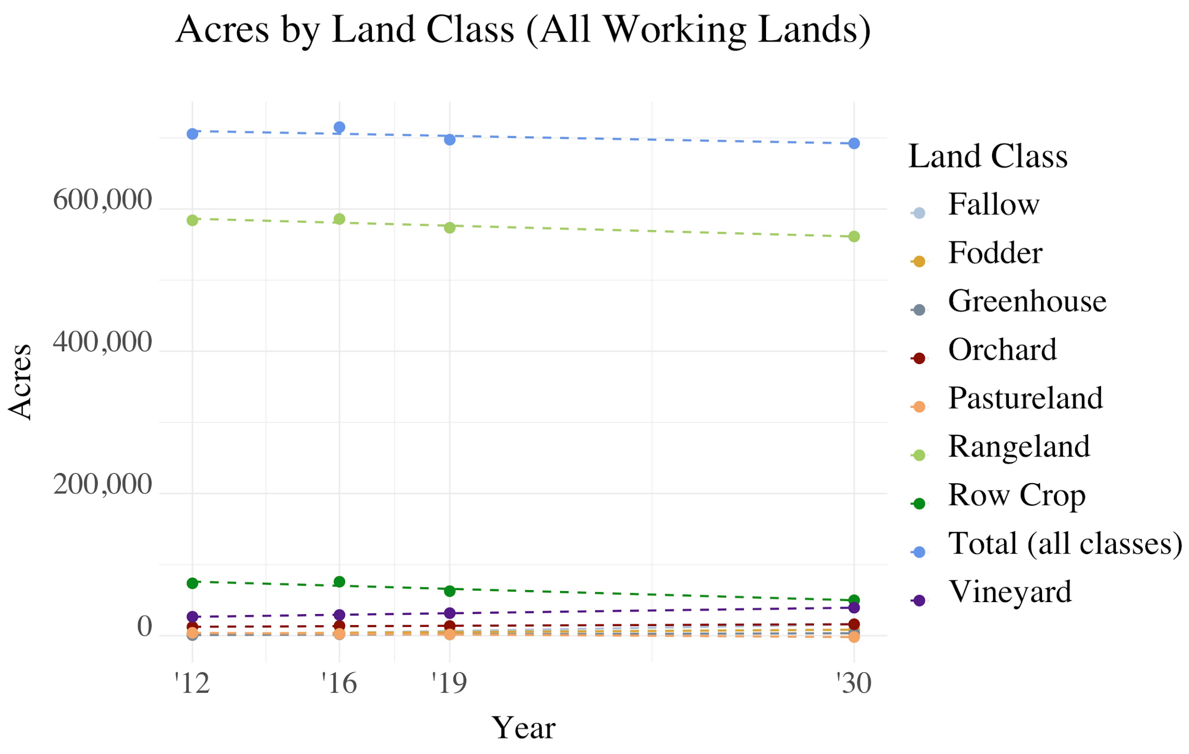
Land Cover Classification	**Acres**	**Aboveground Carbon Stocks (MT C)**	**Soil Carbon Stocks (MT C)**	**Total Carbon Stocks (MT C)**	**Nitrous Oxide Emissions ($MTCO_2e$)**
Fallow	2,360	0	28,314	28,314	0
Fodder	3,641	4,465	61,130	65,595	396
Greenhouse	1,937	0	19,398	19,398	0
Orchard	13,800	115,610	224,186	339,796	2,825
Pastureland	2,541	3,116	48,736	51,852	277
Row Crop	75,847	62,001	1,055,422	1,117,423	30,697
Vineyard	29,096	34,147	483,679	517,827	1,726
Rangeland	586,047	8,780,785	6,185,542	14,966,327	0

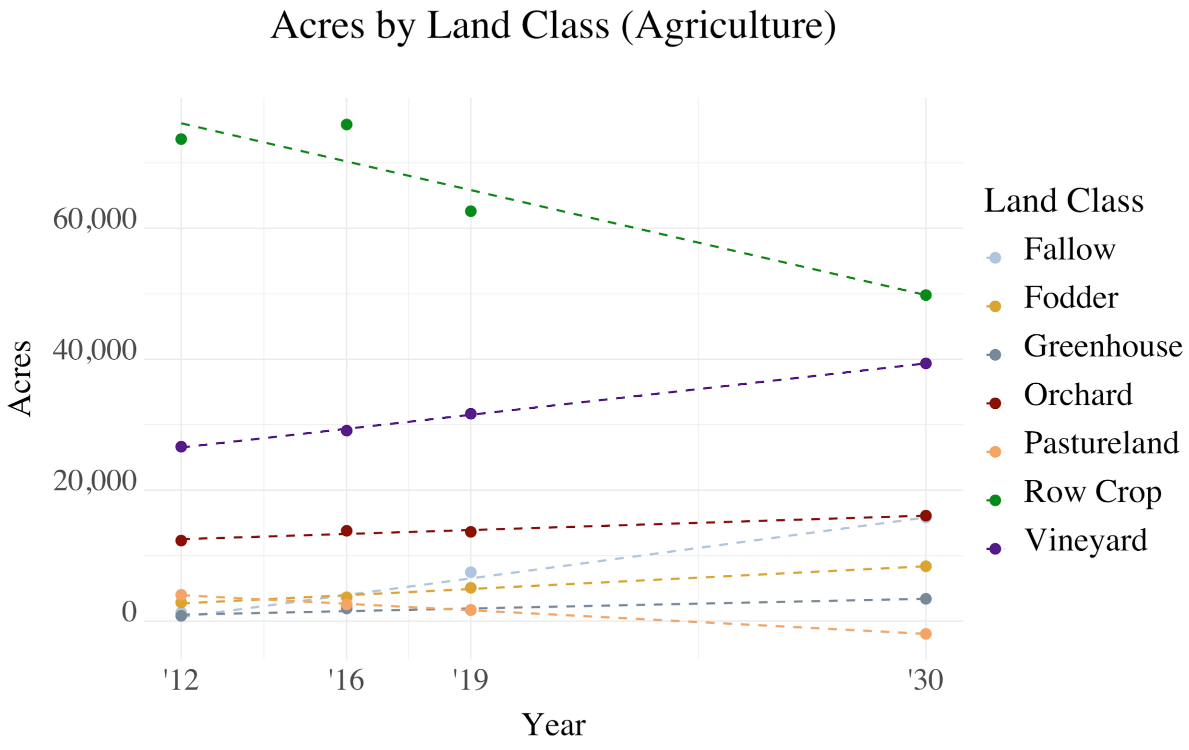
Table 9. Estimated carbon stocks and nitrous oxide emissions by working land cover classification in 2019.

Land Cover Classification	Acres	Aboveground Carbon Stocks (MT C)	Soil Carbon Stocks (MT C)	Total Carbon Stocks (MT C)	Nitrous Oxide Emissions ($MTCO_2e$)
Fallow	7,465	0	93,493	93,493	0
Fodder	5,090	6,242	93,081	99,323	554
Greenhouse	1,692	0	15,572	15,572	0
Orchard	13,634	114,213	228,282	342,495	3,244
Pastureland	1,726	2,116	33,169	35,286	188
Row Crop	62,610	51,181	914,318	965,499	24,136
Vineyard	31,675	37,174	511,507	548,682	1,873
Rangeland	573,678	8,595,459	6,054,991	14,650,451	0

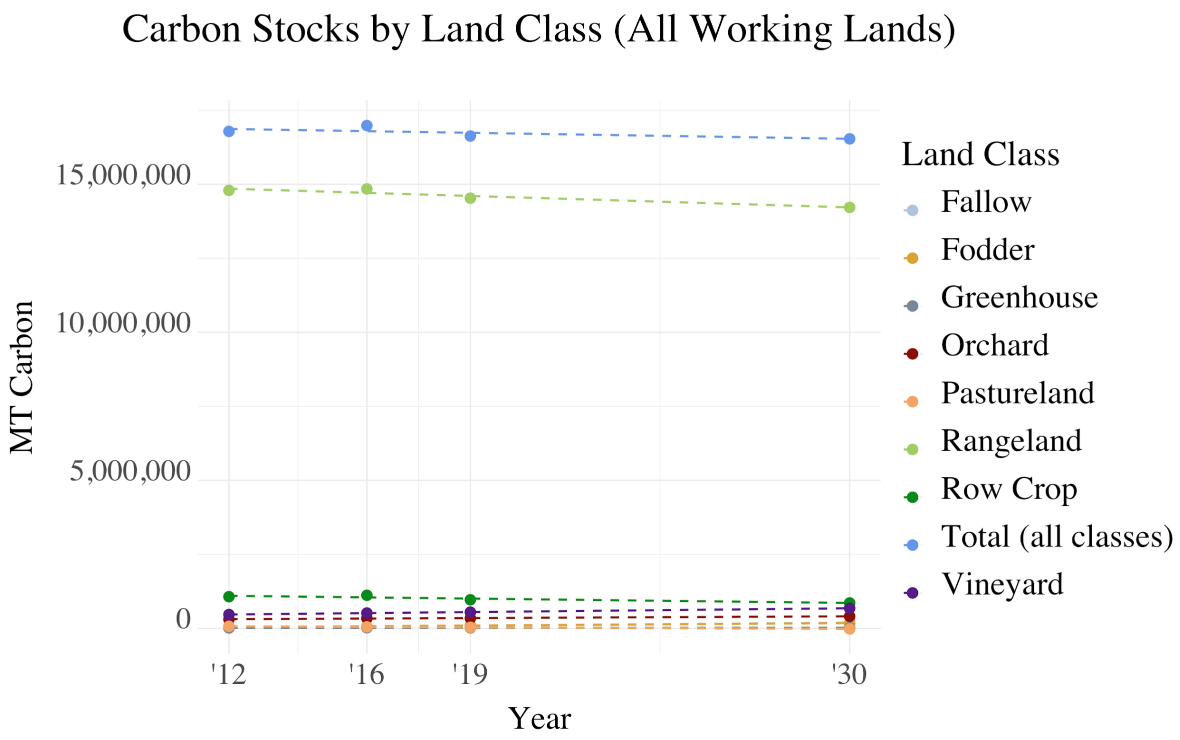
Table 10. Projected carbon stocks and nitrous oxide emissions by working land cover classification in 2030.

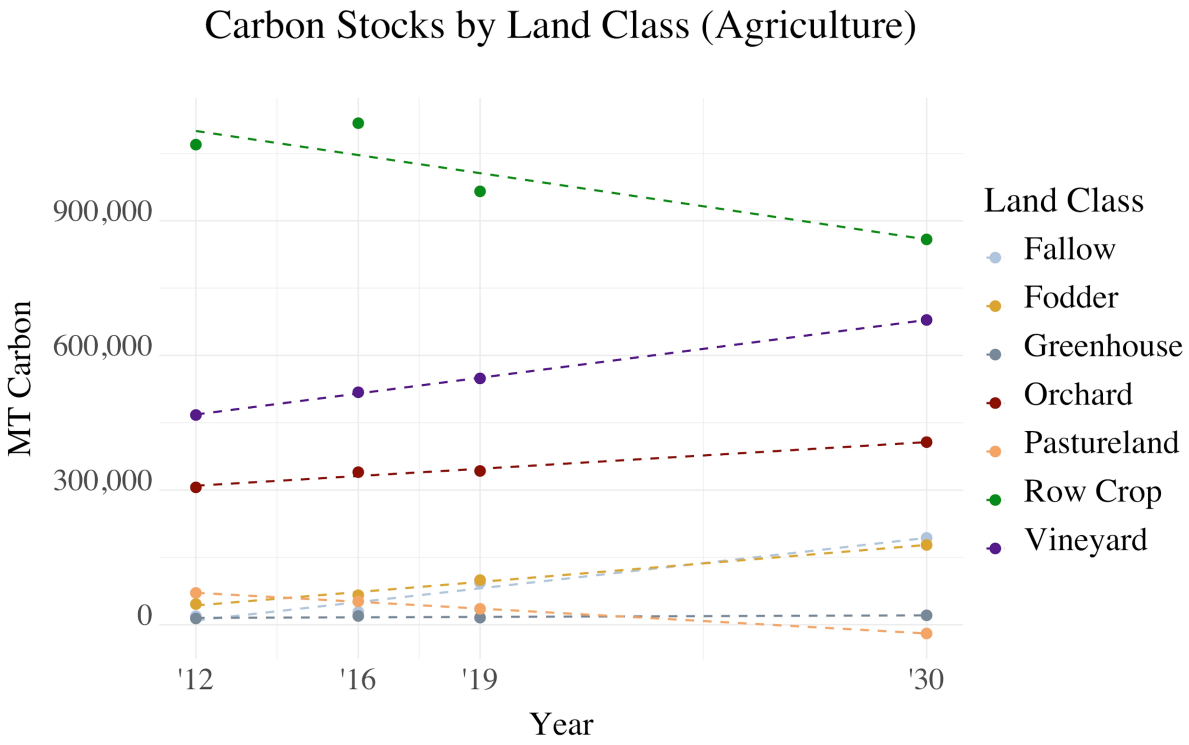
Land Cover Classification	Acres	Aboveground Carbon Stocks (MT C)	Soil Carbon Stocks (MT C)	Total Carbon Stocks (MT C)	Nitrous Oxide Emissions ($MTCO_2e$)
Fallow	15,834	0	193,305	193,305	0
Fodder	8,378	10,273	167,383	177,657	912
Greenhouse	3,412	0	20,777	20,777	0
Orchard	16,111	134,966	271,794	406,760	4,218
Pastureland	0	0	0	0	0
Row Crop	49,798	40,707	817,711	858,418	19,493
Vineyard	39,364	46,199	632,737	678,936	2,331
Rangeland	561,420	8,411,803	5,925,617	14,337,420	0





Figures 11 & 12. Estimated historical (2012–2019) and projected future (2030) acreage by land class. Projections derived from linear regression of observed values. Figure 11 includes all working lands (rangelands and total), while Figure 12 zooms in on just agricultural lands, excluding rangelands.





Figures 13 & 14. Estimated (2012–2019) and projected (2030) carbon stocks by land cover class. Values reflect changes in acreage represented in Figures 11 & 12. Figure 13 includes all working lands (rangelands and total), while Figure 14 zooms in on just agricultural lands, excluding rangelands.

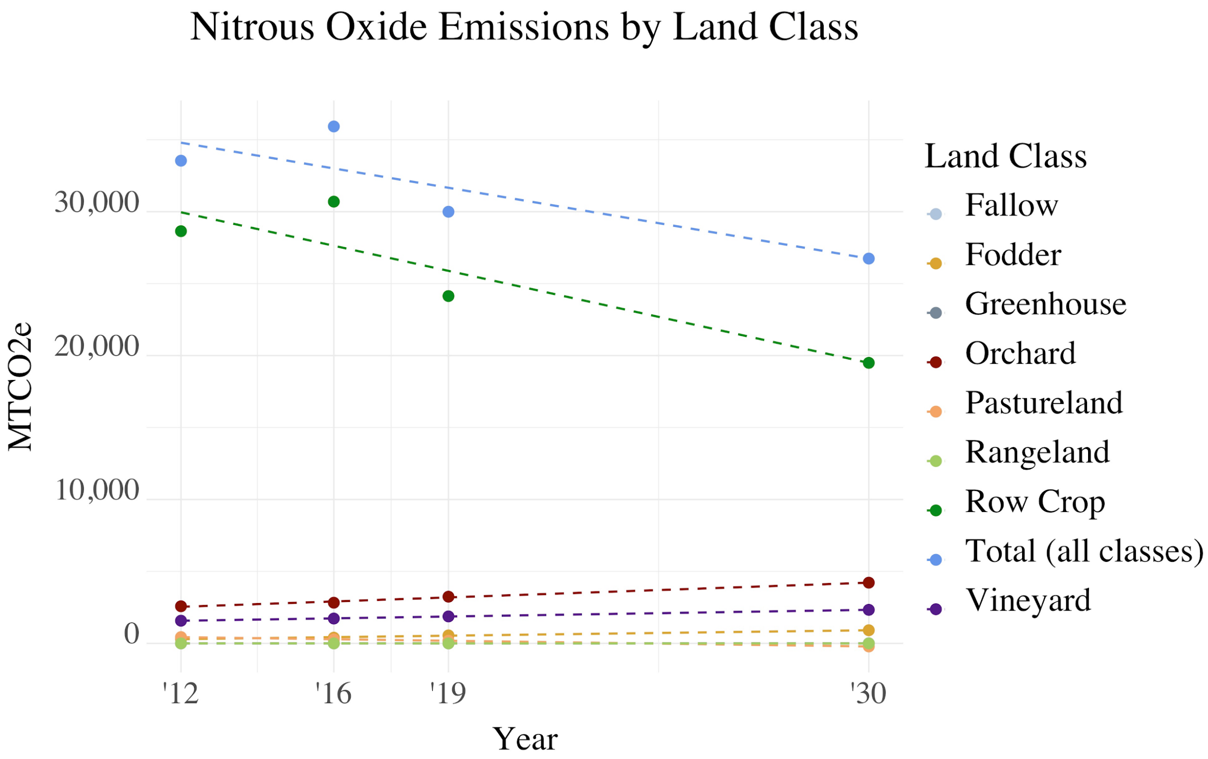


Figure 15. Estimated (2012–2019) and projected (2030) nitrous oxide emissions by land cover class. Values reflect changes in acreage represented in Figures 11 & 12.

Agricultural Community Engagement

Management Practices: Current Level of Implementation

Survey results did not reveal complete consensus on current implementation levels of various land management practices; each activity for each land type exhibited a distribution of responses (see Tables 11 and 12). When given the options of no adoption, 1–20%, 20–50%, or over 50%, most respondents indicated that the current level of implementation of all of the management practices in question on rangelands is between 1–20%. Respondents also largely selected the 1–20% option for management practices that apply to annual row crops, orchards and vineyards. The one exception is for improved nitrogen fertilizer management. Respondents indicated that improved nitrogen fertilizer management is occurring on 20–50% of annual row crops, 20–50% of vineyards and over 50% of orchards.

Table 11. Survey responses: current implementation level of each management practice on agricultural lands (row crops, vineyards, and orchards).

	None		1–20%		20–50%		50%+		Unsure or N/A	
Management practice	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**
Cover cropping	0%	0	16%	6	22%	2	20%	2	0%	0
Hedgerow planting	50%	1	19%	7	11%	1	10%	1	0%	0
Improved nitrogen fertilizer management	0%	0	8%	3	22%	2	40%	4	50%	1
Compost application	0%	0	22%	8	0%	0	10%	1	50%	1
Riparian restoration	50%	1	19%	7	11%	1	10%	1	0%	0
Mulching	0%	0	16%	6	33%	3	10%	1	0%	0
Total	Total	**2**	Total	**37**	Total	**9**	Total	**10**	Total	**2**

Table 12. Survey responses: current implementation level of each management practice on rangelands.

	None		1–20%		20–50%		50%+		Unsure or N/A	
Management practice	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**	**%**	**Count**
Compost application to grassland	50%	3	22%	8	25%	2	0%	0	0%	0
Riparian restoration	17%	1	25%	9	25%	2	50%	1	0%	0
Oak woodland restoration	17%	1	22%	8	38%	3	50%	1	0%	0
Native grassland restoration	17%	1	31%	11	13%	1	0%	0	0%	0
Total	Total	6	Total	36	Total	8	Total	2	Total	0

During the January Santa Barbara County Land Stewardship & Carbon Farming Coalition meeting, we asked the members of the subcommittee to verify our interpretation of the survey results and provide us with a more narrow range wherever possible. The members reaffirmed that the ranges of 1–20% for most practices and 20%+ for improved nitrogen fertilizer management are realistic and valid. However, no one at the meeting volunteered a more granular estimate for any of the practices.

In our correspondence with researchers at the UCCE, we collected additional testimony, summarized in table 13, that supported the estimates used in our scenario modeling.

Table 13. UCCE researchers' feedback on current management practice implementation levels

Management Practice	UCCE Researchers' Insights
Cover cropping	About 6–8% of row crops in the county are organic, and therefore cover crop if not between each cash crop cycle then at least every 2–3 cycles. Of conventional row crops, about 3% of fields get cover cropped. This percentage was much higher when farmers had water allocations but may remain low if the drought continues and there remains limits on groundwater use.
Hedgerow planting	Around 80% of strawberry fields use hedgerow planting to either protect from dust movement using cereals or to harbor insect natural enemies using flower mixes.
Improved nitrogen fertilizer management	Around 20% of producers use UCCE's CropManage platform which is the most efficient and science-based method for managing nitrogen fertilizer application and is available for free through UCCE.
Replacing synthetic nitrogen fertilizer with soil amendments	In many cases soil amendments are less efficient in delivering nutrients and synchronizing supply and demand than nitrogen fertilizer. This, along with their potential to contain chloride salts, can result in environmental damage. Compost is used in 20–25% of fields in modest quantities as pre-plant more for soil physical properties than N source.
Riparian restoration	Growers may not currently be involved in this directly. Some growers mitigate runoff and soil/nutrient losses on slopes when subject to runoff to receiving creeks.
Mulching	Plastic mulch is used on 100% of strawberries, 50% of caneberries and all fresh-market peppers and tomatoes. UCCE worked with some raspberry growers to mulch waterways in/near tunnels and some tried it but it should be noted that it is an added expense. Straw is not used on strawberries for several reasons related to pests and rot.

Management Practices: Perceived Barriers to Greater Implementation

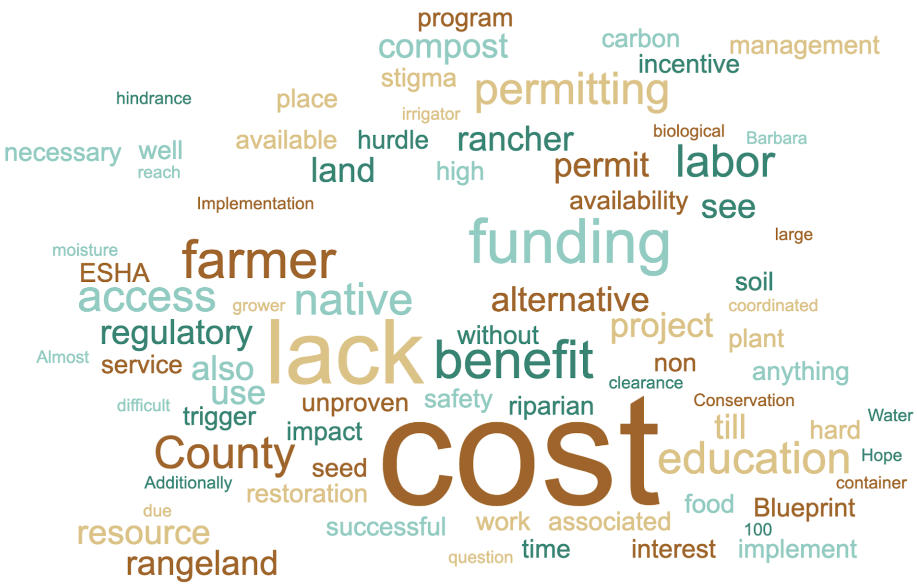


Figure 16. Word Cloud of survey responses regarding barriers to greater implementation

The two primary barriers to greater implementation of the set of management practices were cost and regulatory barriers. Access to resources and information were also identified as important barriers.

All of the management practices require some investment, in the form of labor, equipment, supplies, permits, foregone revenue or other expenditures. The cost of application and transportation is especially burdensome in regards to composting. Without financial incentives, practices that require land to be taken out of production, such as restoration activities or cover cropping, are a “hard sell” for managers especially in North County where much of the cropped land is leased and managers are already spending a lot of money on rent.

Permitting and regulations were cited as a barrier to almost every one of the selected practices. For example, one of our advisors explained that if a producer wishes to make their own compost they are subject to an often overwhelming combination of restrictions and regulations. Permitting and regulations are seen as especially burdensome in the coastal zone where there is a lack of coordination between jurisdictions. Experts indicated that there is inadequate access to technical assistance to help farmers through the permitting and grant application process. Furthermore, even when resources or technical assistance are available, many land managers are not made aware of them.

Our survey responses and group discussions highlighted the fear amongst land managers that adopting practices that improve ecosystem health may create an Environmentally Sensitive Habitat Area and subsequently subject the land owner to burdensome restrictions under the Endangered Species Act. This concern applies to any practice that involves restoration, especially in the coastal zone where there is increased regulation, as noted above.

Food safety concerns were cited as a serious barrier in our survey responses as well as our one-on-one and group discussions with experts and stakeholders. This barrier is primarily relevant to row crops, especially in North County. Food safety concerns may prevent restoration practices within the vicinity of crops as managers are concerned that increased vegetation could bring “critters” into the area which could increase bacterial contamination of their crop. Food safety concerns are also a major barrier to increased compost application on row crops, and several of our advisors noted that access to affordable, high quality compost in the county is limited. However, in a group discussion with the land stewardship subcommittee, one advisor suggested that this concern may not be entirely warranted, and argued that most food illness outbreaks are caused by people not following on-farm food handling protocols rather than the presence of pathogens in farm soil.

While our survey responses and group discussions revealed the actual financial, regulatory and resource related barriers, they also highlighted the role of farmers’ perceptions of environmental issues and the economic cost-benefits of the activities. This finding is supported by a German study by Jantke et al., which found that 65.4% of surveyed farmers were willing to participate in activities to reduce their GHG emissions if it resulted in economic gains, compared to 34.6% who are not willing because they believed the costs would exceed the benefits. Of those that were willing to reduce GHG emissions, 75.6% were motivated by personal beliefs and 68.9% were motivated by public acknowledgement (56).

Table 14. Identified barriers to greater management practice implementation.

Practice	Barriers
Cover Cropping	Cost, foregone income
	Managers do not see a clear benefit to their operation
Hedgerow Planting	Labor costs
	Fear of attracting pests
	Managers do not see a clear benefit to their operation
Compost Application	Access to affordable, high quality compost
	Application cost (resources & labor)
	For tree crops, mulches are preferred over soil amendments to avoid disturbing the root systems
	Permitting: financial & time burden
	Food safety concerns

	Suppliers do not like to make deliveries that are small and/or on steep hill orchards
Restoration Activities	Permitting: financial & time burden
	Managers do not see a clear benefit to their operation
	Fear of creating ESHA & subsequent regulation
	Can be in conflict with the Food Safety Modernization Act, which discourages the creation of habitat where animals find refuge and then forage in fields and groves

Scenario Modeling

We modeled the fourteen scenarios described in our methodology section: high and low implementation of restoration, hedgerow planting, reduced tillage, mulching, cover cropping, composting with C:N ratio > 11, and composting with C:N ratio ≤ 11. Of these fourteen scenarios, we found that high implementation of compost application using compost with a high C:N ratio (> 11) resulted in the largest projected increase in emissions reductions and carbon sequestration compared with business-as-usual. Hedgerow planting and composting with a low C:N ratio (≤11) resulted in the next highest total emissions reductions & sequestration. Table 15 gives an overview of the results by showing the projected emissions reductions and sequestration in the year 2030, and Tables 16–18 break down those values by year and specific impact (sequestration and emissions reductions).

Table 15. Projected emissions reductions and CO_2 sequestration in the year 2030 for each management scenario.

2030 Emissions Reductions & CO_2 Sequestration ($MTCO_2e$)		
	Low Implementation	**High Implementation**
Reduced Till	1,263	2,527
Mulching	2,932	5,864
Restoration	4,719	9,438
Cover Crops	11,065	22,130
Compost (C:N≤11)	40,506	81,011
Hedgerow	60,738	121,477
Compost (C:N>11)	106,539	213,078

Table 16. Projected annual emissions reductions and CO_2 sequestration for each management scenario and year between 2021–2030.

	Total Emissions Reductions & Sequestration from Management Activities ($MTCO_2e$)										
Scenarios	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Cumulative**
Reduced Till - Low	132	263	393	521	648	774	898	1,021	1,143	1,263	7,056
Reduced Till - High	264	526	785	1,042	1,296	1,547	1,796	2,042	2,286	2,527	14,112
Compost (C:N≤11) - Low	4,243	8,437	12,581	16,676	20,745	24,776	28,767	32,719	36,632	40,506	226,082
Compost (C:N≤11) - High	8,487	16,874	25,163	33,351	41,489	49,551	57,534	65,439	73,264	81,011	452,164
Mulching - Low	293	586	879	1,172	1,465	1,758	2,051	2,345	2,638	2,932	16,118
Mulching - High	586	1,171	1,757	2,343	2,930	3,516	4,103	4,690	5,277	5,864	32,236
Cover Crops - Low	1,023	2,065	3,126	4,205	5,302	6,418	7,552	8,704	9,875	11,065	59,336
Cover Crops - High	2,047	4,131	6,252	8,409	10,604	12,835	15,104	17,409	19,751	22,130	118,671
Hedgerow - Low	6,304	12,546	18,727	24,845	30,940	36,991	42,996	48,956	54,870	60,738	337,914
Hedgerow - High	12,608	25,093	37,454	49,691	61,880	73,982	85,993	97,912	109,740	121,477	675,828
Compost (C:N>11) - Low	11,011	21,924	32,739	43,456	54,141	64,760	75,309	85,789	96,199	106,539	591,866
Compost (C:N>11) - High	22,023	43,849	65,478	86,911	108,281	129,519	150,618	171,577	192,397	213,078	1,183,731
Restoration - Low	490	975	1,455	1,931	2,404	2,874	3,341	3,804	4,263	4,719	26,257
Restoration - High	980	1,950	2,911	3,862	4,809	5,749	6,682	7,608	8,526	9,438	52,513

Table 17. Projected annual carbon sequestration in $MTCO_2e$ for each management scenario and year between 2021–2030.

	Carbon Sequestration from Management Activities ($MTCO_2e$)										
Scenarios	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Cumulative**
Reduced Till - Low	99	197	295	391	486	580	674	766	857	947	5,292
Reduced Till - High	198	395	589	781	972	1,160	1,347	1,532	1,714	1,895	10,584
Compost (C:N≤11) - Low	4,643	9,230	13,759	18,232	22,673	27,070	31,422	35,727	39,987	44,200	246,943
Compost (C:N≤11) - High	9,287	18,460	27,519	36,464	45,347	54,141	62,843	71,454	79,973	88,401	493,887
Mulching - Low	383	769	1,158	1,552	1,948	2,349	2,753	3,160	3,571	3,986	21,629
Mulching - High	765	1,537	2,317	3,103	3,897	4,698	5,506	6,321	7,143	7,972	43,258
Cover Crops - Low	1,110	2,237	3,379	4,539	5,715	6,907	8,116	9,341	10,582	11,840	63,765
Cover Crops - High	2,220	4,473	6,759	9,078	11,429	13,814	16,231	18,681	21,165	23,681	127,530
Hedgerow - Low	6,280	12,498	18,657	24,754	30,829	36,861	42,848	48,791	54,690	60,544	336,752
Hedgerow - High	12,559	24,997	37,313	49,508	61,657	73,722	85,697	97,583	109,380	121,088	673,504
Compost (C:N>11) - Low	11,263	22,420	33,472	44,418	55,327	66,162	76,921	87,603	98,208	108,736	604,530
Compost (C:N>11) - High	22,526	44,841	66,944	88,837	110,653	132,324	153,841	175,205	196,416	217,473	1,209,059
Restoration - Low	486	968	1,445	1,917	2,387	2,854	3,318	3,778	4,235	4,689	26,078
Restoration - High	973	1,936	2,889	3,834	4,774	5,709	6,636	7,557	8,471	9,378	52,156

Table 18. Projected annual nitrogen emissions reductions and increases in MTCO$_2$e for each management scenario and year between 2021–2030.

Nitrogen Emissions Reductions from Management Activities (MTCO$_2$e)											
Scenarios	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Cumulative**
Reduced Till - Low	33	66	98	130	162	193	225	255	286	316	1,764
Reduced Till - High	66	132	196	260	324	387	449	511	571	632	3,528
Compost (C:N≤11) - Low	-400	-793	-1,178	-1,556	-1,929	-2,295	-2,655	-3,008	-3,354	-3,695	-20,861
Compost (C:N≤11) - High	-800	-1,585	-2,356	-3,112	-3,857	-4,590	-5,309	-6,015	-6,709	-7,389	-41,722
Mulching - Low	-90	-183	-280	-380	-484	-591	-701	-815	-933	-1,054	-5,511
Mulching - High	-180	-366	-560	-760	-967	-1,182	-1,403	-1,631	-1,866	-2,108	-11,022
Cover Crops - Low	-87	-171	-254	-334	-413	-489	-564	-636	-707	-775	-4,430
Cover Crops - High	-173	-342	-507	-668	-825	-978	-1,128	-1,273	-1,414	-1,551	-8,859
Hedgerow - Low	25	48	70	91	111	130	148	164	180	194	1,162
Hedgerow - High	49	96	140	183	223	260	296	329	360	388	2,324
Compost (C:N>11) - Low	-314	-622	-924	-1,220	-1,512	-1,798	-2,078	-2,353	-2,622	-2,886	-16,329
Compost (C:N>11) - High	-628	-1,244	-1,848	-2,441	-3,023	-3,595	-4,156	-4,706	-5,245	-5,773	-32,659
Restoration - Low	4	7	11	14	17	20	23	25	28	30	179
Restoration - High	8	15	22	28	34	40	46	51	55	60	358

Tables 17 and 18 expand on the values presented in Table 16 to show how different management practices sequester carbon and reduce or increase nitrogen emissions. For example, the composting scenarios sequester substantial amounts of CO_2 each year, but they actually increase nitrogen emissions. Note that Table 18 shows nitrogen emissions *reductions*, so the negative numbers indicate positive emissions. The “Compost (C:N > 11)” scenarios result in methane emissions reductions of 689 and 1,378 $MTCO_2e$ in 2030 for low and high implementation, but no other scenario we modeled impacts methane emissions.

Figures 17 and 18 below show the emissions reductions and sequestration graphically for both the year 2030 and cumulatively between 2021 and 2030.

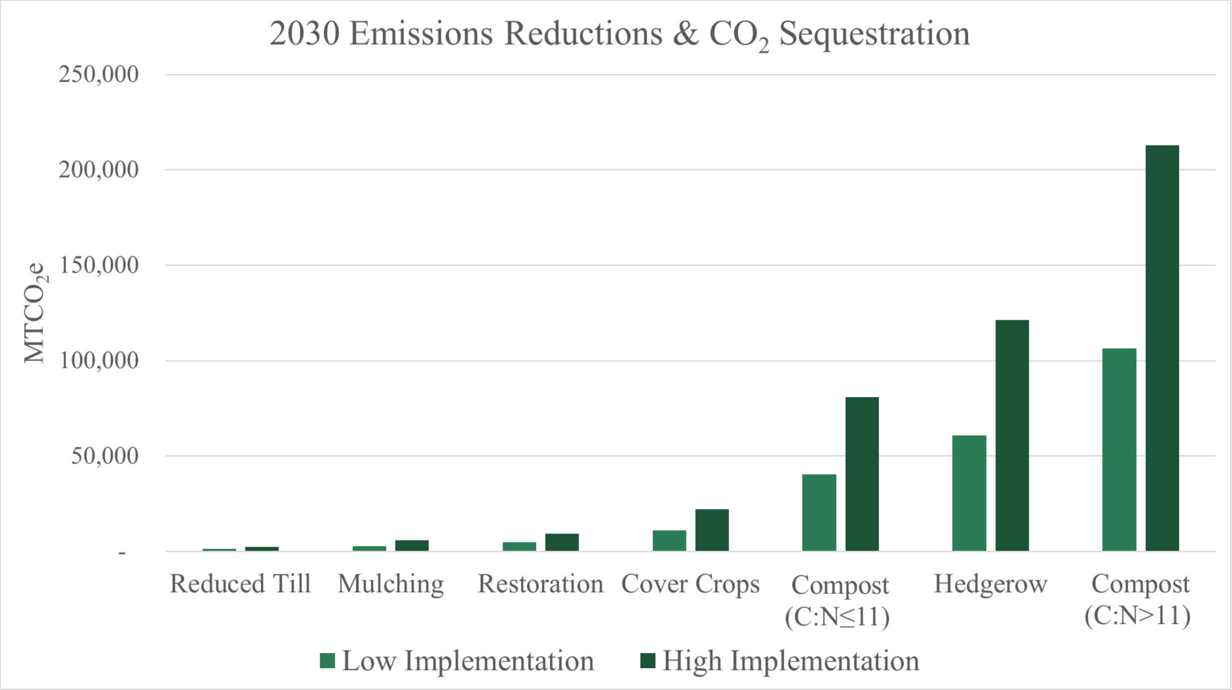


Figure 17. Projected emissions reductions and CO_2 sequestration in 2030 under fourteen management scenarios.

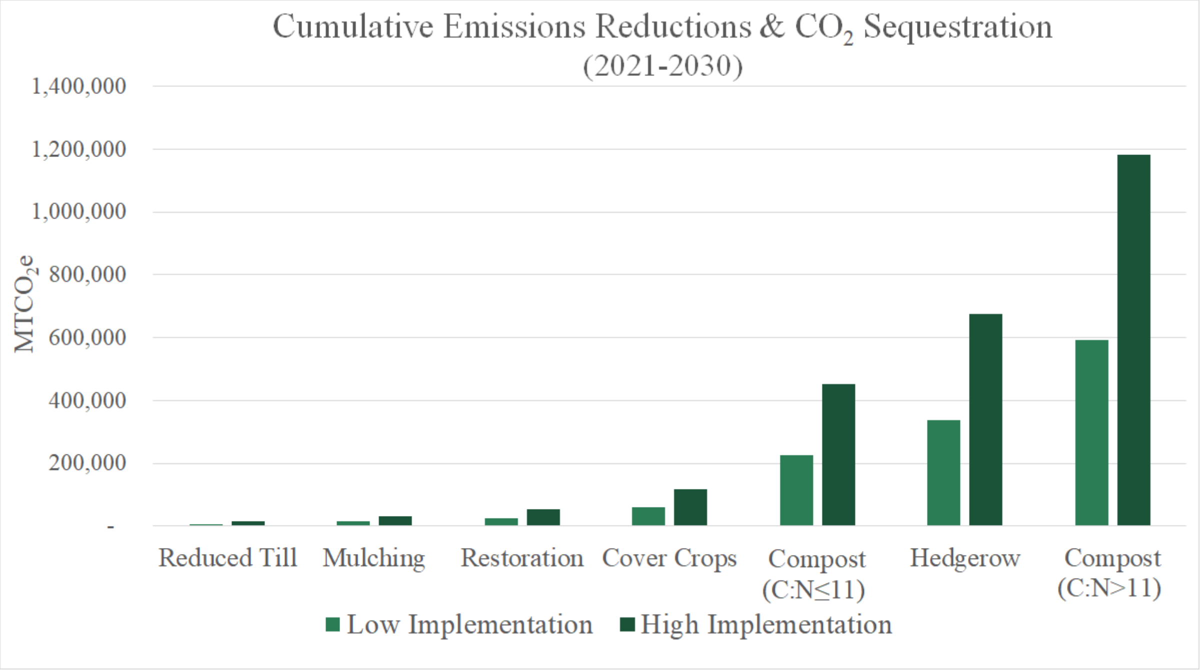


Figure 18. Projected cumulative emissions reductions and CO_2 sequestration between 2021–2030 under fourteen management scenarios.

Both cumulatively and in the year 2030, the two composting scenarios and hedgerow planting are projected to result in the highest emissions reductions and CO_2 sequestration. The cumulative emissions reductions and CO_2 sequestration for the other ten scenarios range from 7–118 thousand metric tons of CO_2e (compared with 226,000 to almost 1.2 million $MTCO_2e$ for the top six scenarios).

These emissions reductions and increased sequestration can also be translated to total carbon stock in working lands. Using our estimated carbon stocks from the baseline regressions, we modeled how these changes in management practices would impact carbon stock. Figures 19 and 20 show carbon stocks on working lands between 2016 and 2030 with no management scenarios (baseline) and low and high implementation levels of the management scenarios we modeled.

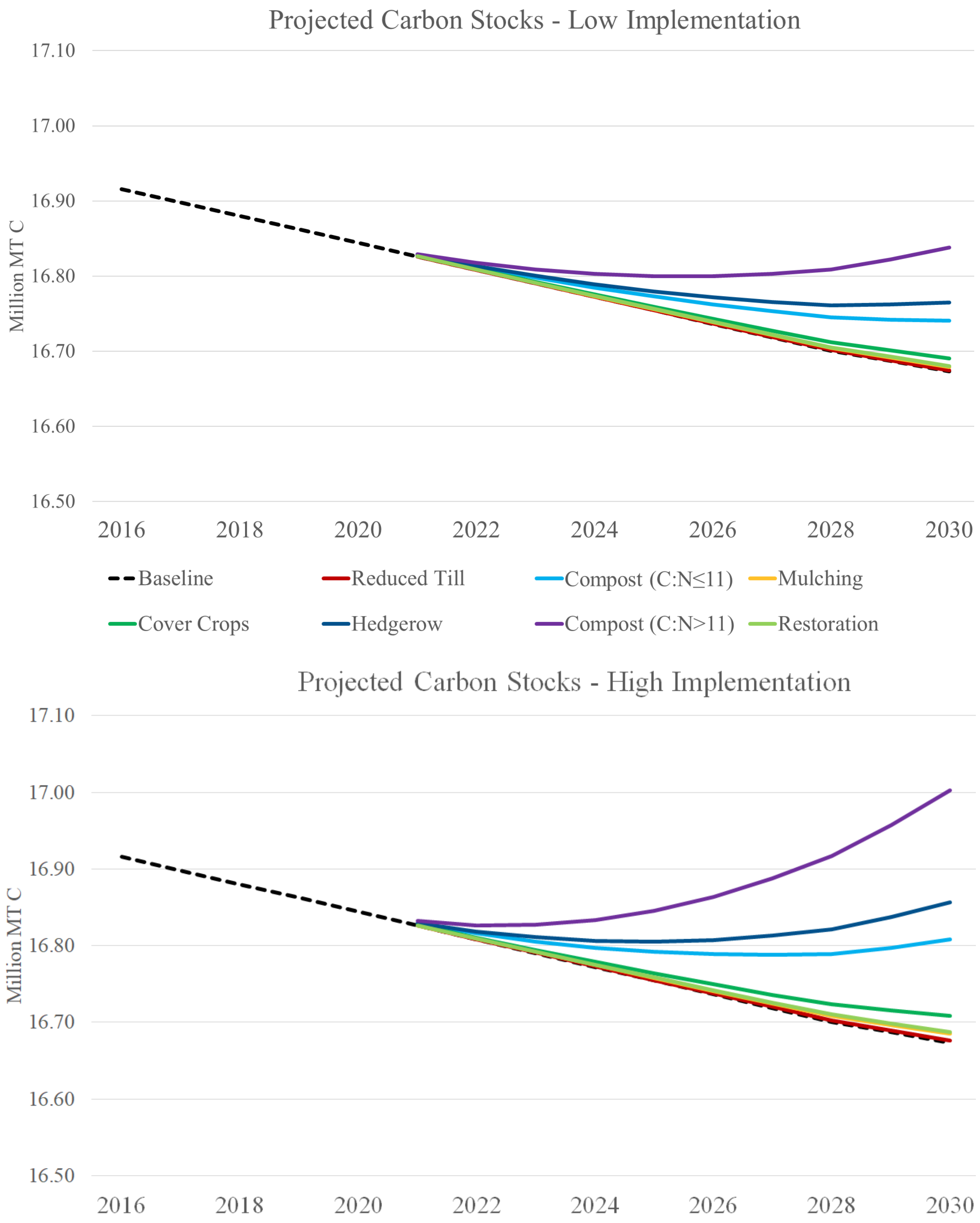


Figure 19. Projected carbon stocks in working lands (in million MT C) under the baseline scenario (in black) and fourteen management scenarios (low and high implementation for seven different practices).

Overall, emissions reductions and CO_2 sequestration values were greatest in the two composting scenarios and hedgerow planting. The other practices all demonstrated positive cumulative emissions reductions and CO_2 sequestration, but to a lesser extent. It should be noted that these scenarios were all modeled separately, and the highest implementation level we modeled was 20%. If these scenarios were to be modeled in tandem or at higher levels, the results would change and we would see higher emissions reductions, CO_2 sequestration, and total carbon stocks. Overall, these results should be interpreted with caution and with an understanding of the assumptions, uncertainties, and nuances involved in the modeling, which we discuss more in the next section.

Discussion

Carbon Inventory

The results from the carbon inventory confirmed our expectation that the majority of the county's carbon stocks lie in natural lands. This is because grasslands, shrublands, and forests occupy the majority of land in the county, and have higher carbon densities on average. We estimated that natural lands store an average of 31 metric tons of carbon per acre, while agricultural lands store an average of 14 metric tons of carbon per acre. These results reinforce the importance of natural lands as critical carbon sinks for both regional and global climate action planning.

Baseline Reference Scenario

The projections to 2030 indicate that in the future, if historical trends continue, agricultural land will slightly decrease in area. Because our future projections for agricultural land cover needed to be crop and crop-type specific, we were limited to using three years of data in constructing our projected 2030 dataset. Using only three data points is problematic because it does not offer the same opportunity to smooth out outliers or detect long-term trends that a larger set of data points would. However, we are comfortable using our projected numbers after cross-checking them with other quantitative and qualitative information.

Cross-referencing reported acreages from Santa Barbara County's crop reports as aggregated by the Santa Barbara County Conservation Blueprint through 2015, agricultural acreage in Santa Barbara County appears to have to increased from the early 1990s into the early 2000s, dipped in the early-mid 2010s and then increased again in the mid-late 2010s (see Figure 1). This aligns with our estimated acreages in 2012 and 2016, alongside USDA NASS Agricultural Census reports for 2012 and 2017 (30,57). Looking further ahead, crop reports for 2016, 2017, 2018 and 2019 do indicate a decline in agricultural acreage going into 2019, our third data point, due to drought, wildfire, mudslides, and other conditions. These sources indicate that our spatial analysis puts our estimated acreages for the three years we used in the right ballpark. Our projections are also consistent with projections calculated for the County of Santa Barbara's 2016 greenhouse gas inventory and forecast by Ascent Environmental, Inc (58). This inventory and forecast used an exponential decline model based on FMMP data for years 1984–2014 (every other year) and projected total agricultural acres in 2030. The 2030 value estimated by Ascent is only slightly less than what our projection produced, and the slope of the downward trend from now to 2030 is similar between the two projections. The County's report estimated 694,000 total acres of agricultural land in 2030, and our projections estimated 692,000 acres (58).

This project included fallow land in historic and future agricultural projections, which were excluded from Ascent's calculations. This potentially accounts for the discrepancy between our findings, and we acknowledge that our projections may slightly overestimate agricultural acreage due to the inclusion of fallow land. We included fallow lands in our projections because these lands can be temporarily fallowed or taken out of production for only a few seasons; additionally, fallow lands do require some management. However, it is likely that lands designated as fallow in our spatial data include some land that is permanently fallowed. Our projections for total agricultural land is likely underestimating the decline in working lands because our projections show fallow land increasing over time.

In addition to comparing our results with other estimates, we contacted researchers at the UCCE and the director of the CRCD to gauge their expectations of future trends in working land use. These individuals anticipate that land will continue to fallow as water resources become more scarce in the future, as a result of the implementation of the Sustainable Groundwater Management Act (SGMA) and of anticipated future drought conditions due to climate change. Some development of agricultural lands may occur, though urbanization on agricultural lands is limited by zoning restrictions and policies like the Williamson Act.

The decline in rangeland reflected in our projections follows historical trends. As noted in the Santa Barbara County Conservation Blueprint report, "Ranching and cattle operations have declined significantly due to economic competition in land uses from rural residential development, cropland expansion, and drought impacts… From 1984 to 2008, ~24,000 acres of rangeland were converted to vineyards, row crops, and commercial and residential development in Santa Barbara County. This represents one of the largest losses of rangeland in any county recorded in California over this time period. An additional 2,800 acres of rangeland have been converted to other urban or intensive agricultural uses since 2008 [as of 2015]" (5).

In terms of carbon stock and emissions, conversion from rangeland to cropland can lead to losses in organic matter and soil carbon. While these losses are less when rangeland is converted to orchards or vineyards due to the high aboveground biomass composition of those crops, there is still a net loss in carbon stock (59). Additionally, the number of cattle on grazing land can vary year to year based on forage availability and drought conditions. Although emissions from livestock were not included in our scope (see Appendix I), a decrease in the number of cattle being grazed in the county would likely represent a decrease in emissions from enteric fermentation. More research is needed to determine the net greenhouse gas impacts from a decrease in rangeland.

It is important to note that the carbon stock projections we present do not necessarily reflect overall carbon stock changes in the county, because we modeled working lands in isolation. Future modeling to feed into the TerraCount tool will combine natural, working, and urban lands to predict how different land types might replace each other, and how overall countywide carbon stocks would change as a result. For example, if agricultural land is being developed into urban land, that could result in a net decrease in carbon, but if agricultural land is being fallowed and allowed to become shrubland, that might result in a net increase in carbon.

The nitrous oxide emissions results follow statewide trends reported by the CARB, which indicate declining use of synthetic fertilizer. At the state level, this is attributable to a reduction in crop acreage, improved nitrogen fertilizer management on farms, and changes in irrigation practices (60).

Improved nitrogen fertilizer management is widespread throughout Santa Barbara County (5), though our trendlines do not incorporate potential improvements in fertilizer use, and are solely based on changes in acreage. This provides a baseline reference for comparison, useful in our scenario modeling. Looking more closely at trends within agricultural land types, we see a decrease specifically in row crop acreage. Row crops are estimated to emit the most N_2O of the crop categories we analyzed (see Table 6), so a decrease in row crop acreage leads to a proportionally greater decrease in nitrous oxide emissions. Nitrous oxide emissions from fertilizer application on agricultural lands can be estimated using various techniques, described in more detail in Appendix II. Our projections match statewide trends in fertilizer emissions, giving us confidence in the usefulness of these results. That being said, it is worth comparing emissions estimation techniques to get a sense of the uncertainty inherent in our projections and others.

We also acknowledge that projecting agricultural land cover to 2030 is difficult and filled with uncertainty. In reality, the amount of working land in commission each year varies based on market trends and other factors. For example, in the mid-2000s, viticulture expanded in Santa Barbara County following a boom from the 2004 film Sideways that drew attention to the region and its wines. Environmental conditions like drought, fire and frost also affect how much land can be worked or harvested (5,50). The baseline scenario we employ is intended to be a simple, straightforward reference that does not take into account possible future conditions that would change the trajectory. Although this lacks nuance, we are confident that our predictions can be useful if the uncertainty involved is documented and understood.

Scenario Modeling

The results of our scenario modeling show potential emissions reductions and CO_2 sequestration of up to 213,078 $MTCO_2e$ in the year 2030 for a single scenario (high implementation of compost (C:N > 11)). This reduction in $MTCO_2e$ is the equivalent of 46,000 fewer cars driven in a year; it can also be compared with the greenhouse gas emissions avoided by running 46 wind turbines for one year (61). As mentioned in the results section, this estimate is for a single scenario at 20% additional implementation; if the County can promote these management practices enough to result in greater implementation and/or a combination of management practices, the emissions reductions and increased sequestration would be even more significant.

However, critical uncertainties, assumptions, and nuances in these calculations should qualify the extent to which these results can be used and relied upon to make policy decisions; the given values should be interpreted with caution and used as a guide for further investigation in consultation with scientists, farmers and ranchers, and other local experts.

First, the accuracy of our results is highly dependent on COMET-Planner's estimates of carbon sequestration and emissions reductions. COMET-Planner estimates that the increase in carbon sequestration from compost application is between 2.8 and 3.0 Mg ha^{-1} $year^{-1}$, depending on the crop type it is applied to. However, a review of global studies have found increases to be anywhere between 0.2 and 4.0 Mg ha^{-1} $year^{-1}$ (62). This range could be attributed to differences in scientific methods, the method of implementation, crop type, and the environmental conditions where the studies took place, all of which make soil carbon notoriously difficult to estimate accurately.

Additionally, it is unknown if and how long the sequestered carbon will remain in an organic form before being released into the atmosphere through decomposition. Most studies measure changes in carbon in the top 30 cm of soil, which is frequently assumed to be the most affected by plant production and agricultural management practices (62). However, soil below 30 cm can hold up to 75% of total soil carbon stocks, and it can be the most resilient to decomposition and have the longest residence time of soil carbon (62). Local environmental conditions and farming practices can influence where and how long sequestered carbon is stored. More studies need to be performed at depths below 30 cm to accurately measure the changes in soil carbon stocks from management practices (62).

In that vein, the COMET-Planner estimates are the average carbon sequestration and emissions reductions over a 10-year period. In this project, the estimates were assumed to be constant each year. It is unclear from COMET-Planner or other studies if the rates of sequestration vary over time and if there are diminishing returns as the carbon stocks become saturated and aboveground vegetation reaches its maximum size. Moreover, carbon sequestration is not necessarily permanent. Carbon stored in soil and vegetation biomass can be released as GHG emissions through disturbance such as tilling and planting for agriculture, erosion, development, and wildfire (63,64).

Due to the potential uncertainties in the carbon sequestration and emissions reduction potential associated with these management practices, the results of this project should not be relied upon as a precise calculation of potential greenhouse gas emissions reductions or changes in carbon storage. However, we believe our scenario modeling can still help prioritize management activities with the highest sequestration potential and inform planning to meet climate goals. We have provided the County and CEC with the tool we developed to model carbon storage and emissions from practice implementation over time, applying COMET-Planner coefficients across land types according to specified implementation levels. This should enable planners to experiment with different adoption levels for various combinations of management practices.

Agricultural Community Engagement

While the County has a direct role to play in preventing land conversion, harnessing the climate mitigation potential of working lands will largely depend on the willingness and ability of land managers to implement climate-smart management practices.

Through our agricultural community engagement, we determined that interest in implementing conservation practices, or at least in securing intertwined economic and environmental sustainability, is high. Since many of these activities are considered agricultural best practices, they are already being employed by some farmers and ranchers, to some extent. However, there are important logistical and structural barriers preventing adoption at higher levels. The recommendations we provide in the next section are intended to address those barriers.

However, we recognize that our findings and recommendations may have been limited by engaging stakeholders with existing ties to the County's political process, rather than attempting to reach every individual farmer and rancher. This may be significant because implementation levels and barriers could vary depending on the size, type and location of a growing or ranching operation. While our data was as representative and accurate as possible given the scope of our project and the general lack of transparency and data collection regarding on-farm management practices, we believe that future efforts to quantify and improve carbon sequestration and emissions reduction on working lands would greatly benefit from engagement and data gathering across all producers in the county.

Next Steps: Expand on Research and Findings

This project provides a foundation from which the County can continue to study, assess, and plan the role that natural and working lands can play in reaching current and future climate goals. As an immediate next step, the County is partnering with Rincon Consultants to use the TerraCount tool to expand upon our analysis, incorporating complementary benefits and producing spatially explicit outputs that model the carbon sequestration potential of land management changes. We have identified several key areas of further study that will address critical data limitations before the CAP update is finalized, in addition to longer-term improvements in data collection.

First, one area that our team was not able to include was the projected impact of urban development on natural and working lands. The Santa Barbara County Association of Governments (SBCAG) has projected further urban development under a business-as-usual scenario, and has also put forth a preferred development scenario out to 2040 (1). Using our spatially explicit carbon inventory, the County can analyze how these urban development scenarios would impact projected emissions, as disturbing land through development releases stored soil carbon as emissions to air.

Another consideration we were not able to investigate is the cost associated with implementing these management practices. Naturally, cost is a major factor in the feasibility of greater implementation and was the most commonly cited barrier in our stakeholder discussions. The COMET-Planner tool allows users to calculate the estimated Healthy Soils Program grant funding they would receive for implementing these practices, but this may not be a reliable proxy for the costs incurred. More certain cost estimates would allow the County to conduct a cost-benefit analysis, weighing financial burden imposed on land managers against benefits incurred by management practices in terms of carbon sequestration, emissions reductions, and complementary benefit value.

Additionally, our team was unable to interface with tribal stakeholders during this project, but feel strongly that it is critical to include traditional knowledge in evaluations of these practices, the concepts of which are rooted in long-standing Chumash ways of land stewardship. Acknowledging that the Indigenous people of Santa Barbara have long-standing knowledge and wisdom about the land of this county and how to manage it effectively, the County has already convened an Equity Advisory and Outreach Committee to counsel the One Climate initiative. We recommend that the County facilitate meetings between the Equity and Land Stewardship Subcommittees to build relationships, recognize and incorporate traditional knowledge and years of experience, meaningfully involve underrepresented communities, and ultimately ensure that overall CAP goals align with the needs and values of all community members.

Finally, in order to better understand realistic pathways to improved carbon sequestration through land management, the modeling inputs and results need to be supported by more detailed and more reliable data. Despite our stakeholder engagement, we relied on very general information about current implementation levels of management practices, which informs the scenario modeling process and also provides a sense of how much future implementation is feasible. The County can prioritize collecting data on what types of management practices are currently being implemented, at what level, and on what types of land. There are also novel methods of emissions quantification being explored by researchers at the UCCE, particularly utilizing a time-adjusted warming potential factor that accounts for the time horizon of expected emissions and allows for better integration with reporting and planning frameworks, that the County should consider employing (65).

To help facilitate data collection, our team has developed a complementary web-based app to both publicly communicate project findings and collect user feedback that will be shared with the County. Listening sessions, focus groups, surveys, and formalized data collection practices can also be useful in furthering the County's understanding of current and potential future land-based carbon sequestration and storage.

Recommendations

The County has the opportunity to play an important role in climate change mitigation through collaborating with state, regional, and local agents to protect existing carbon sinks and incentivize further carbon storing practices. In order to do this, we suggest the following measures be considered for inclusion in the Natural and Working Lands component of the Climate Action Plan:

1. Preserve natural and working lands
2. Create a carbon neutrality and/or carbon sequestration goal
3. Incentivize greater adoption of climate-smart management practices by:
    a. Providing affordable, high quality compost
    b. Removing regulatory and permitting barriers
    c. Facilitating increased farmer-to-farmer networking and resource sharing.
    d. Financing and providing technical support for climate-smart management practices
    e. Supporting carbon farm planning

Preserve Natural and Working Lands

We have projected that the amount of land in agriculture will decline, which is consistent with current trends in groundwater availability and profitability. This pattern, in combination with testimony from land managers about the challenges of keeping land in production, is concerning from both economic and carbon sequestration perspectives. Although this project did not focus on land preservation strategies, our work highlights the importance of preserving both natural and working lands as important reservoirs of carbon, which may be released if the land is converted or not strategically managed.

County zoning currently provides some degree of protection for natural and working lands against urban encroachment. However, land managers can only keep land in active production as long as their operations remain profitable. To prevent any carbon losses that could occur from conversion, the County can investigate mechanisms to support farm and ranch profitability. For example, the Long Range Planning Division is currently proposing an Agricultural Enterprise Ordinance that will expand the allowable uses under existing permits, reducing regulatory burden and ultimately broadening the economic base for farmers and ranchers (66). The current amendment allows mostly small-scale supportive and recreational uses, but subsequent County action could include conservation practices that would promote carbon storage as well. Land conservation strategies were not a focus of stakeholder discussions we facilitated, but could be at future meetings if the County is interested in exploring this avenue further.

Establish a County Neutrality or Sequestration Goal

We found that climate-smart management practices could sequester a meaningful amount of carbon, comparable to a portion of Santa Barbara County's projected emissions in 2030, depending on the combination of management practices and implementation levels. For example, a high composting scenario could potentially sequester the equivalent of 14% of the County's projected greenhouse gas emissions in 2030. Although some management activities, such as reduced tillage, do result in emissions reductions, most of the benefit from these activities lies in increased carbon sequestration. To better incorporate these activities into County climate planning, the County of Santa Barbara can investigate creating a carbon neutrality or carbon sequestration goal to add to the Climate Action Plan update. This kind of policymaking is already taking place at the state level, with CARB studying how natural and working lands can play a role in meeting the carbon neutrality target established by Executive Order B-55-18.

It should be noted that carbon neutrality goals are not meant to replace or offset emissions reductions goals, but instead to build upon emissions reduction strategies and better incorporate carbon sequestration and storage practices into climate action planning. Scientists agree that in order to avoid catastrophic warming and related climate change, the global economy needs to not only reduce emissions but also remove carbon dioxide from the atmosphere and store it over the long term. For this reason, we do not recommend replacing any part of the County's emissions reductions targets with sequestration offsets. Rather, climate-smart management activities and their impacts can build upon the County's established and proposed emissions reductions targets to achieve deeper emissions cuts.

Incentivize Climate-Smart Management Practices

Due to the carbon emissions reduction and sequestration potential of the management practices modeled in this project, as well as the complementary benefits of these practices that have been well documented and acknowledged by the State, we recommend that the County consider adopting policies in their Energy and Climate Action Plan update that aim to increase the implementation level of these management practices (67). In this section, we identify opportunities for the County to increase the implementation of these practices. Similar or equivalent programs are increasingly being recommended and adopted at the state and local levels (13).

Provide Affordable, High Quality Compost

The results from our scenario modeling suggested that compost application offers the greatest carbon sequestration potential, and discussions with local stakeholders suggested that a major barrier to increased compost application is the lack of access to affordable and high-quality compost in the county. Therefore, we recommend that the County explore opportunities for improving local compost supply. A promising option is the newly opened ReSource Center (formerly the Tajiguas Resource Recovery Project), which aims to reclaim compostable material for application and to produce energy. As the facility begins operation, testing and pilot projects could be initiated to address concerns about the quality of material being produced for use on farms and ranches (68). The County could look to Napa County and San Francisco County as examples for developing a local compost program based on best practices.

Remove Regulatory and Permitting Barriers

Discussions with stakeholders and experts, as well as our survey responses, indicate that permitting requirements and regulations are significant barriers to increased implementation of climate-smart management practices. This barrier is especially relevant in coastal zones and for compost application, hedgerow planting, and restoration activities.

Many local jurisdictions in California streamline permitting for restoration activities by adopting a Partners in Restoration (PIR) program. The County has investigated this option in the past but a PIR was not ultimately adopted, much to the dismay of many of the stakeholders we engaged with. It is apparent from our discussion with the agricultural community that revisiting and successfully adopting a PIR would be an important first step in promoting increased implementation of climate-smart management practices.

If the County establishes a carbon farm planning process (discussed in greater detail later in this section), a complementary permit streamlining program for carbon farm plans could reduce permitting burdens. This type of program already exists elsewhere in the state, allowing farmers to develop carbon farm plans for their property with the help of their RCD and other partners. Landowners are then able to adopt practices from a pre-approved list without going through the permitting process, so long as the landowner signs a contract to follow the carbon farm plan.

The County should work with the Land Stewardship & Carbon Farming Coalition and other stakeholders to identify additional solutions for streamlining the permitting process and reducing land managers' concerns related to increased regulation as a result of increased implementation of climate-smart practices, in order to promote carbon sequestration on natural and working lands.

Facilitate Farmer-to-farmer Knowledge Sharing

The importance of farmer-to-farmer resource sharing was a common theme in our expert and stakeholder engagement and is supported by existing literature (69). Peer-to-peer learning and resource sharing, through informal networking or formal workshops and training, is an essential component of promoting a long-term and widespread shift to climate-smart management practices among ranchers and farmers. For this reason, we recommend that the County support existing organizations, such as the CRCD and the White Buffalo Land Trust, who currently conduct this important work.

At the county level, community events and formal or informal groups can improve growers' understanding of climate-smart practices while providing a point of connection for additional technical assistance. On-farm learning activities such as field days allow growers to learn new methods from one another through hands-on activities and demonstrations. On-farm learning also allows conventional producers to see first-hand how alternative, climate-smart management practices have been successful locally, which can be convincing and encouraging. Strong producer networks may also provide a mechanism for equipment sharing to help offset the costs of transitioning to new climate-smart management practices.

Finance Climate-smart Management Practices

Through our stakeholder engagement and expert-informed research, we identified a number of existing programs that provide funding for increasing the implementation of carbon-storing management practices (see Appendix IV). Despite current funding opportunities and resources however, our stakeholders and experts indicated that there remains a need for funding of greater magnitude and that is available more consistently and over a longer term, as well as for more resources to help farmers and ranchers navigate the application process for existing opportunities. The County can address these needs by providing assistance to farmers in identifying and applying for funding, and establishing a natural and working lands carbon finance committee to investigate new funding opportunities such as establishing a local carbon market.

Assist Farmers in Identifying and Applying for Funding

To ensure Santa Barbara farmers capitalize on all available subsidy programs, the County can assist farmers with tracking funding opportunities, assisting them with application processes, and ensuring on-going compliance. The County can also support the CRCD and local NRCS District Office in their current efforts to provide application assistance to growers.

Explore Carbon Market Opportunities

One potential financing mechanism gaining increasing interest in the county and beyond is including natural and working lands in carbon markets. Marin County's Climate Action Plan, published in 2020, is the first in California to address carbon markets in a natural and working lands component. The plan proposes finding potential funding through a locally developed offset market, revolving loan funds, and matching funds that can be used in conjunction with outside funding or state funding. However, the plan notes that while the commercial offset market is a potential source of funding for carbon farming, the current market trades well below the cost to implement many of the practices (69). On a regional level, the Sacramento-San Joaquin Delta Conservancy has established the Delta Carbon program in partnership with California State Agencies, nonprofits, and academic institutions. Through this program, Delta farmers are able to verify the emissions reductions associated with agricultural land use changes. Delta farmers will be able to sell carbon offsets on voluntary markets, and CARB is considering adopting these offsets under the State's Cap-and-Trade compliance market (13).

In our agricultural community engagement, we found that there was more support for a local carbon offset program over joining a large-scale carbon offset market. This is because large-scale carbon offset markets have high verification costs which prevent small farmers from participating whereas a local carbon offset program may be structured and operated in a way to prevent this. This type of local carbon market would be based more on practice rather than outcome and could rely on locally trusted intermediaries such as the CRCD and CEC.

Two main concerns with linking land management practices with offset markets that the County should be aware of are that the sequestration measurements can be inaccurate and the sequestration might not be permanent. These issues could cause discrepancies between the offset credits and the actual long-term removal of atmospheric CO_2. At a countywide or statewide scale, overestimated amounts of sequestration could lead to significant underestimations of the county's and state's net emissions. Because of these uncertainties, it may not be appropriate to finance the land management practices by commoditizing sequestration and selling it to commercial buyers in offset markets. However, the accuracy and permanence concerns could be addressed by applying a discount factor to the credits, or treating the credits as temporary (70,71).

Establish a Natural and Working Lands Carbon Finance Committee

While state, federal and private funding sources for increased implementation of carbon storing management practices, there is a need for additional funding mechanisms and assistance in accessing existing funding. To investigate additional finance mechanisms and funding sources, the County could establish a natural and working lands carbon finance committee. In addition to the development of a local carbon market, potential funding sources may include matching funds and revolving loan funds.

Provide Technical Assistance

The CRCD currently provides some technical assistance to farmers and ranchers interested in adopting climate-smart management practices, but is limited due to resource constraints. The organization would be able to provide more technical assistance to larger numbers of farmers if it had more funding available for this work. The UCCE could also be a resource in these efforts. UCCE has partnered with CDFA to use $1.1 million of California Climate Investments funds to scale-up technical assistance for climate-smart agricultural practices. Providing technical support to farmers by leveraging partnerships with UCCE and the resource conservation districts is a key recommendation in the State’s draft natural and working lands implementation plan (13).

Support Carbon Farm Planning

Managing agricultural and ranch lands to increase carbon sequestration is best accomplished when approached at the farm/ranch level. “Carbon farm planning” is a newly emerging term for this process, which is similar to established NRCS conservation planning but with a focus on increasing the capacity of the farm or ranch to capture and store carbon. The County can support carbon farm planning by encouraging existing efforts by local organizations, such as the recently announced Gaviota District Carbon Management Plan, authored by CRCD and LegacyWorks Group (72). The County could provide essential expertise, such as agroecologists, agronomists, agricultural engineers, conservation planners, biologists and soil scientists to help expand this carbon farm planning process. Additional resources on carbon farm planning are included in Appendix III.

Conclusions

Study Relevance

This project is part of a growing conversation about the critical role that land management plays in mitigating climate change—in Santa Barbara County, in California, and beyond. This project will not only be applicable to this county, but also serves as a blueprint for a simplified version of the natural and working lands carbon accounting projects the State is funding. It is our hope that the results of this project, in particular the stakeholder and expert input we collected about the barriers and solutions to increased use of climate-smart management practices, will further the local, regional, and state conversation around the importance of natural and working lands as a vital tool in the fight against climate change.

Our landscape carbon inventory for Santa Barbara County is one of the first at a jurisdictional level, providing critical context for future decision-making and demonstrating the substantial carbon storage resource that county lands provide. Building upon this information, the County of Santa Barbara can quantify how different decisions can lead to the county's natural and working lands acting as a carbon sink or source. For example, land disturbance, including urban development, emits carbon stored in soils and biomass. Understanding the county's land-based carbon stocks can help decision-makers ensure that planning aligns with stated climate goals and focus on conserving lands with high carbon storage potential.

Beyond carbon accounting, this project quantitatively estimates how agricultural land may shift and change over the next 9 years. The validity of our projections is supported by stakeholder feedback and by comparison with other similar projections. This project also models and quantifies the carbon sequestration potential of a variety of state-supported climate-smart management practices and sheds light on the barriers to implementation that farmers and ranchers face. All together, these deliverables, alongside our accompanying analysis and discussion, will be provided to the County Sustainability Division as an initial step in assessing the role natural and working lands might play in the County's climate action planning. Natural and working lands are a critical, if understudied and underutilized, resource for addressing climate change and greenhouse gas emissions.

Key Takeaways

We have identified two key takeaways from our research and analysis. The first is the need to conserve natural and working lands and keep working lands in production. The second is to support and incentivize farmers and ranchers to implement conservation and climate-smart agricultural practices. While our results emphasize the importance of both, we focus on carbon sequestration in working lands.

From our scenario modeling, it is evident that climate-smart land management practices can substantially increase carbon sequestration and reduce greenhouse gas emissions on natural and working lands. While we did not quantify the additional complementary benefits of climate-smart management practices as part of this project, there is a growing body of research showing how these practices also provide an array of environmental and social benefits locally.

Despite the many global, regional, and on-farm benefits of employing climate-smart management practices, we find that they are still implemented at a fairly low level countywide. This is due to a number of barriers, the primary ones being the financial constraints of land managers, a burdensome regulatory and permitting environment, and a lack of resource and information sharing between various stakeholders. However, our research and community engagement efforts suggest that there are many opportunities for the County to help eliminate these barriers and thereby incentivize greater adoption of climate-smart management practices. In this report, we have provided recommendations for how the County may address these opportunities in its Climate Action Plan update.

To achieve real climate change mitigation, we need to evaluate all possible avenues to reducing emissions and storing carbon. This project takes an important step of integrating working lands, as well as those responsible for managing them, into the public climate action planning process. Our work to holistically and strategically manage these resources also serves as a strong example of how the tools we used can be implemented by other jurisdictions throughout the state, and we look forward to serving as a resource for future efforts.

Appendix I: Scoping & Data Considerations

The methodology used in this project to estimate land-based carbon and GHG emissions is limited by the scope of the project and potential remote sensing errors in the spatial data used. The scope of the carbon accounting in this project does not account for all GHG emissions associated with working lands, described in more detail below.

Data Limitations, Concerns, and Uncertainty

The scope of our project was influenced by data limitations and concerns, some of which we describe below. Much effort was spent comparing and looking for discrepancies between LANDFIRE, Cal Ag, and USDA datasets, and ultimately data accuracy and usefulness shaped the scope of this project. As we expected based on Resilient Merced's experience, great discrepancies were found between datasets. Some of these concerns could have been addressed with more time and resources, and we would recommend that other jurisdictions attempting similar projects try to decrease the uncertainty associated with these datasets whenever possible.

Agricultural Data

As discussed in the methodology section, we reviewed multiple datasets to use for the agricultural land cover data. CADWR Statewide Crop Maps only provided data for 2014 and 2016, which were too close together in time. FFMP did not include data on specific crops grown on parcels, which we needed to better estimate above-ground biomass carbon and nitrous oxide emissions. USDA Cropland Data Layer, the dataset used by Merced County for the pilot project, showed discrepancies when cross-referenced with satellite imagery. These limitations led us to choose Cal Ag Pesticide Use Reporting data; the main concern with this dataset is that it only dates back to 2012 for Santa Barbara County, so we were unable to use a point in time as far back as we would have preferred.

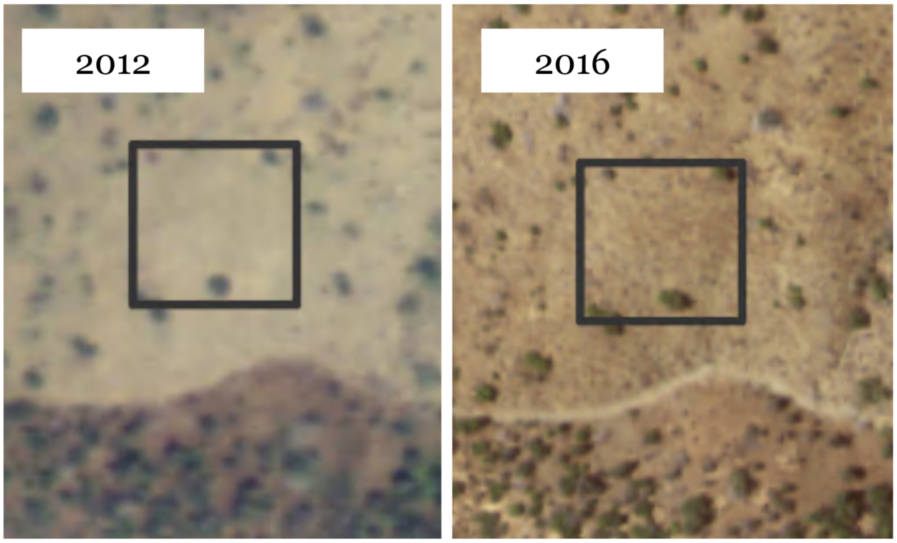
LANDFIRE Data

Data accuracy was one of the main reasons we did not model changes in natural land over time.

A study by Battles et al. that was based on LANDFIRE data estimated the aboveground carbon stock in California to be 850 ± 230 Tg in 2010. This high level of uncertainty was attributed to remote sensing errors in vegetation classifications in LANDFIRE (38). Similarly, the Resilient Merced pilot project team found clear errors and discrepancies in LANDFIRE data, which led them to perform custom classifications on almost all of the land categories explored. Of the twelve general land cover classes reported, only barren, forest, and shrubland were used directly from LANDFIRE with no customization (3).

As expected based on Merced's experience, our team found inaccuracies in the LANDFIRE data. The biggest discrepancy we found was the change in classification between 2012 and 2016 in grassland

and shrubland; in 2012, the majority of Santa Barbara County's natural lands was classified as grassland, and in 2016, much of that area shifted to shrubland (see Figure 22). After speaking with advisors and visually comparing satellite imagery from the two years, we feel confident that the change in classification is due to changes in remote sensing or reporting from LANDFIRE and not because of actual vegetation shifts. As seen in Figure 20 below, land cover looks almost identical between 2012 and 2016, but the change in LANDFIRE classification would represent a considerable change in the reported carbon stock value. Using the vegetarian type, height, and cover values from LANDFIRE, the same pixel of land would store 6.97 MT/ha of carbon in 2012 and 73.18 MT/ ha of carbon in 2016.



*Black square demonstrates the same geographic area for comparison

Figure 20. Satellite imagery of the same spot of land in Santa Barbara County in 2012 and 2016.

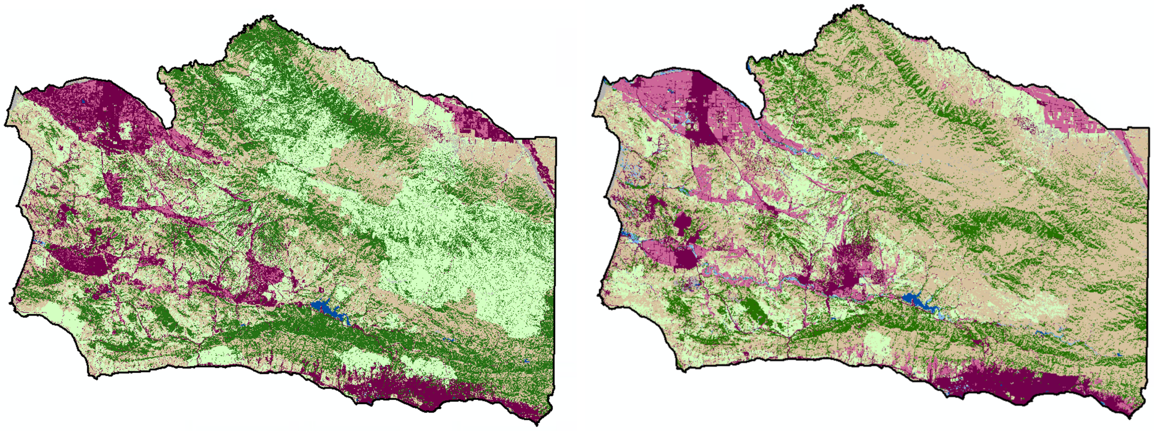


Figure 21. Santa Barbara County reclassified into broad land categories using LANDFIRE for 2012 (left) and 2016 (right).

LANDFIRE data also showed discrepancies in forest, developed, agriculture, and riparian/wetland areas between 2012 and 2016, some of which can be seen in Figure 21.

The Resilient Merced project addressed most of these inaccuracies by using machine learning, expert engagement, and other methods to customize these classifications. Our project team did not have the time or expertise to pursue custom classification, and we felt that it would be inappropriate to model natural lands using the unaltered LANDFIRE data. For these reasons, we used the LANDFIRE data only to estimate the countywide carbon inventory for a single year (2016), and we only modeled future changes in working lands using Cal Ag data.

Other Emissions

This project does not include all emissions related to land and land use. There are important emissions sources that were outside the scope of this project, some of which are discussed briefly below.

Wildfire

This project focuses on the historical and projected ability of lands in Santa Barbara to store and emit carbon and greenhouse gases. On short time scales, the largest source of emissions from land is wildfire, which can make lands net carbon sources. Therefore, protecting land from wildfire can be an important emissions reduction strategy, for example in areas with large swaths of old-growth forest. In Santa Barbara County, however, the impact of wildfire on emissions over time is less clear, since the majority of natural land in the County is made up of fire-adapted chaparral (5). Fire-adapted ecosystems with relatively consistent fire intervals can be considered carbon neutral when examined over long periods of time and at scale (73), because fire spurs new growth of biomass and the accumulation of biomass in soils, counterbalancing emissions from combustion and decomposition (73). At the same time, calculating post-fire biomass is difficult because some burned material is not fully combusted, becoming dead biomass which still stores carbon, though in a less stable form than live biomass (2). There is also no guarantee that restored natural lands will regrow to their pre-fire state without additional land management interventions (73).

The complexity of carbon dynamics related to fire, particularly in fire adapted ecosystems like in Santa Barbara County, places these considerations outside the scope of this project. However, it will be important for the County to further investigate how fire management and preparedness can help support climate goals, as well as protecting both public and private lands from damage. CRCD is currently working in partnership with Conservation Biology Institute, LegacyWorks, and Sharyn Main Consulting on a Regional Priority Plan to address wildfire risk through a community planning tool that will be published through the Santa Barbara County Conservation Blueprint (74). The County can draw upon this resource, as well as the state's Fire Hazard Planning Technical Advisory, to inform its planning for wildfire (75).

Livestock

Because we focused on estimating land-based agricultural emissions, we considered methane emissions from livestock to be beyond our project scope. However, the County included emissions from enteric fermentation and manure management in its 2016 GHG Inventory Update and Forecast (prepared by Ascent Environmental). This report estimated that enteric fermentation accounted for emissions of 2,300 MT CH_4 per year, equivalent to 57,509 $MTCO_2e$ per year (58). It also estimated that manure management emits 22,928 $MTCO_2e$ per year. These estimates were calculated based on assumptions used in California's 2015 GHG Inventory, prepared by CARB. To compare these livestock-based emissions with nitrous oxide emissions from fertilizer, the same report estimated 135,666 $MTCO_2e$ emitted per year from nitrogen fertilizer application.

Emissions from enteric fermentation are influenced by a variety of factors, such as daily gross energy intake, body weight, percent of the livestock population that is pregnant, and type of livestock (76). The Inventory Report used emission factors of 76 and 95 kg CH_4 per head of cattle per year for beef and dairy cattle. The US EPA reports emission factors of 100 and 146 kg CH_4 per head per year for beef and dairy cattle in California (76), which would bring the Santa Barbara County's enteric fermentation emissions to 75,844 $MTCO_2e$ per year. Because there are many assumptions and uncertainties in estimating emissions from livestock and nitrous oxide, it is difficult to directly compare the two emission sources. However, these two categories are the main contributors to agricultural emissions, so it would be wise to consider emissions from livestock in future County planning.

Beyond the uncertainties related to emissions factors, the number of livestock in the county is highly sensitive to environmental conditions; for example, many cattle are sold during a drought, and the number of cattle produced each year is dependent on the amount of forage produced (personal correspondence with UCCE).

Other Agricultural Emissions

Our project does not account for indirect emissions that result from management activities, such as changes in the total vehicle miles traveled or shifts in urban or economic development as a result of the management activities (1). It is also important to note that this project does not consider the GHG emissions associated with agricultural equipment, which are not accounted for in other inventories either. Santa Barbara County's 2016 GHG inventory included only fertilizer and livestock emissions under agriculture. To close this gap, the County can look to Napa County's CAP, in which policies are targeted at reducing emissions from agricultural equipment, as farm equipment other than irrigation pumps accounted for 60% of the Napa County's agricultural emissions in 2014 (77).

Appendix II: Assumptions & Justifications

Although we attempted to verify and ground-truth our data sources, and select models with the greatest levels of certainty, there are several key assumptions and sources of uncertainty that are important to highlight. In this section, we make explicit the assumptions built into our project, justify our choices, and discuss how different assumptions might change the results of our analysis.

Land Cover Data

As discussed in the methodology section, the Cal Ag data contained overlapping polygons. To process this data, we assumed that the "MostRecAll" attribute refers to "most recent allocation," and we assumed that a value of "1" means that a given polygon has active and recent permits; we filtered out values of "0" and any polygons that contained blank crop lists. Comparing our resulting spatial data to satellite imagery justified our choices, because we found only minor discrepancies, but if different assumptions were used, the resulting acreage for each crop type could shift.

Further, we understand that the crops listed for each polygon are the crops that a parcel is allowed to grow with a given permit. Therefore, it is possible that not all crops listed are grown in a given year. Because we aggregated crops into crop categories to analyze acreage and nitrous oxide emissions, we assume that the patterns represented in our modeling match the actual landscape. For example, if a given polygon listed "bell pepper, strawberry, lettuce, onion," then that area was designated as "row crops." Even if bell peppers were not actually grown that year, the crop category would still be accurate. Also, our approach of assigning a broader crop category to a given polygon assumes that each crop listed is grown on the same amount of land; for example, if a polygon listed "bell pepper, strawberry, lettuce, lemon," we would assign that as "row crops," assuming that lemons make up a minority of the land. Again, if different assumptions were used, the amount of land associated with each crop category would change.

The main assumption we made with LANDFIRE data is that the carbon stocks we estimated are in the general range of what actually exists. Our concerns and limitations surrounding LANDFIRE are discussed above in Appendix I.

Nitrous Oxide Emissions

Though much of our technical methodology for the carbon inventory was based on the approach outlined in the Resilient Merced report, nitrous oxide emissions associated with fertilizer application to agricultural soils was more complex and required further exploration. The Resilient Merced team used an application-rates approach, meaning they identified through spatial analysis how many acres of different crops are grown in the area of study. Then, using published average fertilization rates, calculated an estimated total usage in pounds of nitrogen per acre. An emissions factor of .01 g/g N_2O/N was applied to estimate nitrous oxide emissions associated with fertilizer use. The estimates we calculated using this methodology diverged from the estimates provided to the County by consultants as part of the 2016 greenhouse gas emissions estimates. Upon further investigation, we found it more appropriate to use a .0175 g/g emissions factor, in line with the calculations provided by the consulting group, but our methodology still diverges. Our estimated total nitrogen fertilizer application amount still relies on application rates, provided to the County by another consulting group as part of the 2007 greenhouse gas emissions inventory, providing the basis for fertilizer emissions for that report. These rates are county specific. The 2016 greenhouse gas inventory utilized data published by CDFA which reports how much fertilizer is purchased in each county in California each year (78). In that inventory, the .0175 g/g factor was multiplied by the tonnage of nitrogen fertilizer purchased in Santa Barbara County in 2016. This resulted in an estimated 135,666 MT CO_2e from fertilizer emissions in 2016, compared with our estimate of 38,960 MT MT CO_2e in 2016. The difference in methodology explains the divergence, though our team decided not to use tonnage to estimate the fertilizer usage. Our decision to continue using the application-rates approach can be attributed to the following:

- While using tonnage estimates from CDFA are appropriate at the state level, they can be problematic at the jurisdictional level. As Rosenstock et al. write in *California Agriculture*, "While fertilizer sales data are reported to CDFA at the county level, the precision of these data is problematic. County fertilizer data portray a geographic distribution of sales unlikely to match actual use for most counties. This is due to the method of data collection, which neglects fertilizer transported from one county to another. For example, more than 20% of total statewide nitrogen sales were reported to have taken place in San Joaquin County. It is entirely possible that this value can be attributed to the large quantity of ammonia delivered to the Port of Stockton and redistributed from there. County-level sales data may be an appropriate proxy for nitrogen applications in counties where one does not suspect significant transport of nitrogen into or out of the county, but it is not possible to be certain with the current data collection system" (79).
- Statewide trends reported by the California Air Resources Board point to declining use of synthetic fertilizer use, due in part to a reduction in crop acreage, improved nitrogen fertilizer management on farms, and changes in irrigation practices (60). In Santa Barbara County, overall crop acreage has remained relatively stable and according to our own expert elicitation data, improved nitrogen fertilizer management is widespread throughout the county (5). This would lead us to expect a more moderate increase in nitrous oxide emissions leading up to 2016, as opposed to the 127% increase estimated between 2007 and 2016 in the County's 2016 inventory report.

Overall, there is a great deal of uncertainty in calculating nitrous oxide emissions numbers, and as such it is appropriate to report both estimates.

Appendix III: Existing Funding and Resources

The County may use the information in this section to improve their ability to connect land managers to resources. The USDA's Natural Resource Conservation Service, a major source of federal funding, provides a full list of NRCS incentive and assistance programs on their website (80).

Table 19. Existing programs and resources for increasing the adoption of climate-smart management practices.

Program/Resource	Description
California Healthy Soils Program	The Healthy Soils Program (HSP) is a state-administered program to promote healthy soils on California's farmands and ranchlands. There are two components: the HSP Incentives Program and the HSP Demonstration Projects. The HSP Incentives Program provides financial assistance for the implementation of conservation management practices. The program is funded by California's cap and trade proceeds and grants are administered on an annual cycle. The HSP is currently funding a carbon farming demonstration project at Chamberlain Ranch in Santa Barbara County. The project includes on-the-ground implementation of soil-building practices such as mulch and compost application. The project research team estimates 270,000 acres in the county could support at least one carbon farming practice (5). Scaling the pilot project would require funding for training, outreach, and improved local compost supply and distribution systems. The project team has also identified the need to modify local permitting in order to allow for the long-term success of carbon farming in the county.
Environmental Quality Incentives Program (EQIP)	EQIP is a voluntary conservation program administered by the Natural Resources Conservation Service (NRCS) that provides financial and technical assistance to agricultural producers to address natural resource concerns and improve environmental resources such as water quality, air quality, ground and surface water conservation, soil health, reduced soil erosion and sedimentation, improved wildlife habitat, drought mitigation and more (81). Historically underserved participants are eligible for advance payments to help offset costs of purchasing materials or contracting through EQIP. The 2018 Farm Bill expanded EQIP eligibility to include State, irrigation district, ground water management district, acequia or similar entities. The 2018 Farm Bill

	also required that 10% of program funding be targeted towards source water protection. Popular practices implemented through EQIP include cover cropping, nutrient management, mulching, crop residue management (no-till), windbreaks, and prescribed grazing. California producers received over $120,000 through EQIP in 2018 and over $116,000 in 2019.
Conservation Innovation Grants (CIG)	Under CIG, Environmental Quality Incentives Program (EQIP) funds are awarded to competitive applications from non-governmental organizations, tribes, or individuals to stimulate the development and adoption of innovative conservation approaches and technologies on agricultural lands. Through CIG, the USDA NRCS awarded $640,000 in 2020 to six applicants in California (82).
Conservation Stewardship Program (CSP)	The Conservation Stewardship Program is an NRCS program that helps farmers and ranchers by providing technical assistance for developing conservation plans tailored to their operation (83).
Sustainable Agricultural Land Conservation (SALC) Program	SALC uses cap-and-trade program revenue (CCI) to promote smart growth by protecting strategic agricultural lands. Eligible project types include Agricultural Conservation Planning Grants, which regional scope organizations can apply for, as well as Agricultural Conservation Acquisitions which local jurisdictions, nonprofits, RCDs, open-space authorities, and tribal governments can apply for. Landowners can't directly apply for SALC funding but can work in partnership.
Marin Carbon Project and the Carbon Cycle Institute	Marin Carbon Project and the CA NRCS have produced guidance documents for writing carbon farm plans. The Carbon Cycle Institute also provides free resources on their website. As carbon farm planning is evolving, templates are emerging from RCD collaboratives. Resources we recommend: https://www.marincarbonproject.org/carbon-farming/carbon-farm-plans https://www.carboncycle.org/wp-content/uploads/2016/12/CarbonFarmPlanning-CARCD.pdf http://www.carboncycle.org/wp-content/uploads/2018/02/carbon-farm-planning-step-by-step.pdf https://www.marincarbonproject.org/document.doc?id=107
Programmatic Safe Harbor Agreements	One of the major barriers to increased restoration activities identified in our outreach is the concern that these activities could lead to the creation of habitat that is protected under the Endangered Species Act. The federal Safe Harbor Agreement (SHA) program was designed to

	incentivize and expedite implementation of conservation activities over large geographic areas by shielding landowners from liability if a protected species is accidentally “taken” as part of the agricultural practice. SHA is implemented by the U.S. Fish and Wildlife Service and NMFS under Section 10(1)(a) of the Endangered Species Act. California’s Safe Harbor Agreement Program Act (SB 448) updated the Fish and Game Code to include a parallel process to the federal program. Three agreements are currently in place in California.
Voluntary Local Program (VLP)	The VLP, created by Senate Bill 231 (Costa 1997), requires the California Department of Fish and Wildlife (CDFW) in cooperation with the California Department of Food and Agriculture, to adopt regulations to create locally designed voluntary programs for routine and ongoing agricultural activities that encourage habitat conservation on farms and ranches. One of the major barriers to greater implementation of restoration practices on the County’s natural and working lands is the fear of creating habitat that could lead to regulation under CESA. The VLP incentivizes farmers and ranchers to employ wildlife-friendly practices by providing an exemption from some prohibitions in CESA. Incidental Take Permits and State Safe Harbor Agreements are considered too expensive and time consuming to create, approve, and administer. In contrast, VLP has shown to be easy to administer and simple for landowners to enroll in (84). However, the first VLP wasn’t created until 15 years after the bill passed and today only two VLP’s exist in the state (in Alameda and Contra Costa counties).
USDA Community Compost and Food Waste Reduction (CCFWR)	The USDA Community Compost and Food Waste Reduction (CCFWR) program provides grants for local government pilot projects (85). The program funds projects led by local governments that 1) generate compost; 2) increase access to compost for agricultural producers; 3) reduce reliance on, and limit the use of fertilizer; 4) improve soil quality; 5) encourage waste management and permaculture business development; 6) increase rainwater absorption; 7) reduce municipal food waste; 8) divert food waste from landfills. USDA’s Natural Resources Conservation Service provides assistance for conservation related activities.

Appendix IV: TerraCount: Lessons Learned & Recommendations

The original scope of our project involved running the TerraCount tool as part of the Department of Conservation local and regional planning grant. While we ultimately determined that this was not feasible based on our time and resources, we did include in our scope a number of objectives that will prepare the County to run TerraCount at a later date. We also believe that over the course of our project, we gained knowledge that would be useful to the County of Santa Barbara and any other county hoping to run TerraCount.

Many of the data limitations that we experienced and previously described would also apply to other projects that use TerraCount. Notably, the limited availability of accurate spatial data for natural lands is a serious impediment to the completion of a TerraCount project in a timely and cost-effective manner. The Merced project, which was a TerraCount pilot project, planned on using LANDFIRE spatial data, but LANDFIRE's inaccuracies led them to create a custom spatial dataset from satellite imagery and machine learning algorithms. It is unlikely that Merced's workaround solution can be repeated by other counties that have limited funding and time to complete the project. For widespread use of the TerraCount tool that produces accurate and actionable results, DOC should consider creating a statewide spatial dataset of natural lands that is more accurate than LANDFIRE, perhaps using the same methodology as the Merced project. If a more accurate natural lands spatial dataset already exists, it would be helpful for DOC to provide related documentation and education for TerraCount users.

Another concern about the TerraCount tool and recommended methodology is the reliance on spatial data from only two years. As with any statistical analysis, it is unlikely that just two data points will yield accurate results. Short-term variations in land-use, spatial data inaccuracies, or other factors that produce outlier data could skew the baseline trends that TerraCount relies on for comparison with the impacts of management practices. In this project, we identified this weakness in the methodology and sought to improve upon it by using three years of data, instead of just two years. Despite this, using more years of data would likely improve the accuracy of our results. We recommend that the TerraCount methodology suggests using a minimum of three years or more if time and budgets permit.

Finally, more guidance and documentation on data sources and best practices provided by DOC would help future TerraCount users. Our group had trouble accessing the soil types and climate zones maps that Merced relied on for soil carbon estimates, and once we found them, we realized the data had been customized to Merced County. Documentation on which data sources and processes are replicable with public data and which are Merced-specific would be useful for future projects.

Appendix V: Carbon Inventory Code

Prepared in R Studio, this code was used to prepare the full landscape carbon inventory, as well as the working lands inventories used in the baseline reference scenario code (see supplemental materials). For all data citations and detailed explanation of methods, please refer to the Methodology section of the report.

Code setup

```r
# Attach packages
library(tidyverse)
library(tidyr)
library(here)
library(janitor)
library(plotly)
library(kableExtra)
library(effsize)
library(broom)
library(formattable)
library(purrr)

# read in data. file descriptions above each file.

# carbon value table from CARB
carbon_vals <- read.csv(here::here("files", "luts", "lut_lf_carb.csv"),
encoding = "UTF-8")

# existing vegetation cover (LANDFIRE) look up table
evc_lut <- read.csv(here::here("files", "luts", "lut_evc.csv"), encoding =
"UTF-8") %>%
  clean_names() %>%
  rename(classnames_evc = x_u_feff_classnames)

# existing vegetation height (LANDFIRE) look up table
evh_lut <- read.csv(here::here("files", "luts", "lut_evh.csv"), encoding =
"UTF-8") %>%
  clean_names() %>%
  rename(classnames_evh = x_u_feff_classnames)

# existing vegetation type (LANDFIRE) look up table
evt_lut <- read.csv(here::here("files", "luts", "lut_evt.csv"), encoding =
"UTF-8") %>%
  clean_names() %>%
  rename(classnames_evt = x_u_feff_evt_name)

# nitrogen look up table (2007 SB County GHG inventory)
lut_n <-  read.csv(here::here("files", "luts", "lut_n.csv"), encoding =
```

```
"UTF-8") %>%
  clean_names() %>%
  rename(nitrogen_cat = x_u_feff_nitrogen)

# 2016 evc/evh/evt for 2016, assigned to points for each 30x30m pixel in
the county (our pre-processed data)
lf_evc_16 <- read_csv(here::here("files", "natlands", "LF_2016_EVC.csv"))

lf_evh_16 <- read_csv(here::here("files",  "natlands", "LF_2016_EVH.csv"))

lf_evt_16 <- read_csv(here::here("files",  "natlands", "LF_2016_EVT.csv"))

# read in nitrogen categories to apply to LANDFIRE data where appropriate
lf_reclass_n <- read.csv(here::here("files", "luts",
"lf_reclass_nitrogen.csv"), encoding = "UTF-8") %>%
  clean_names() %>%
  rename(classnames_evt = x_u_feff_evt) %>%
  rename(lf_n_category = n_category)

# read in soil data - unit = gC / m^2

soil <- read_csv(here::here("files", "soil", "ssurgo.csv")) %>%
  dplyr::select(pointid, soc0_30)
```

2016 full landscape inventory

```
###############################################################
# Natural lands
###############################################################

# Data cleaning and merging

carbon_vals <- carbon_vals %>%
  clean_names("snake") %>%
  filter(!is.na(w_total_mt_cha)) %>%
  rename(total_mt = w_total_mt_cha) %>%
  rename(grouped = x_u_feff_lf_key)

# combine all three (EVC, EVH, EVT) landfire data frames for 2016, and
clean
precombin_df <- merge(lf_evc_16, lf_evh_16, by = "OBJECTID")

# combine all together, and create "grouped" variable to later match with
carbon values
combined_lf_df <- merge(precombin_df, lf_evt_16, by = "OBJECTID") %>%
  dplyr::select(OBJECTID, pointid, CLASSNAMES.x, CLASSNAMES.y, EVT_NAME,
```

```
Reclass_16) %>%
  clean_names("snake") %>%
  rename(classnames_evc = classnames_x) %>%
  rename(classnames_evh = classnames_y) %>%
  rename(classnames_evt = evt_name) %>%
  left_join(evh_lut, by = "classnames_evh") %>%
  left_join(evc_lut, by = "classnames_evc") %>%
  left_join(evt_lut, by = "classnames_evt") %>%
  mutate(grouped = paste(evt_group, evh_group, evc_group, sep = "")) %>%
  left_join(lf_reclass_n, by = "classnames_evt") %>%
  dplyr::select(-reclass_16) %>%
  rename(reclass_16 = reclass_category)

###############################################################
# Add agricultural lands
###############################################################

# read in ag data

ag_2016_raw <- read.csv(here::here("files", "ag", "ag_2016.csv"), encoding
= "UTF-8", na.strings=c(""," ", "NoData", "NA"))

# clean 2016 ag data and make appropriate changes to nitrogen values and
classifications (some of these may be outdated/irrelevant, but this does
not affect the results)
# designate which points will rely on CalAg data, and which on LANDFIRE.
This effectively overlays the CalAg data onto the LANDFIRE data

ag_2016 <- ag_2016_raw %>%
  dplyr::select(!c(organic, crop_list)) %>%
  rename(nitrogen = nitrogren_) %>%
  clean_names("snake") %>%
  rename(pointid = objectid) %>%
  mutate(ag_class = as.character(ag_class)) %>%
  mutate(nitrogen = as.character(nitrogen)) %>%
  mutate(nitrogen = ifelse(ag_class == "Barren / Fallow" | ag_class ==
"Greenhouse", 0, nitrogen)) %>%
  mutate(ag_class = ifelse(ag_class == "Irrigated Pasture",  "Fodder",
as.character(ag_class))) %>%
  mutate(ag_class = ifelse(ag_class == "Barren / Fallow",  "Fallow",
as.character(ag_class))) %>%
  mutate(nitrogen = ifelse(ag_class == "Pastureland", "Field Crops",
nitrogen)) %>%
  mutate(source = ifelse(is.na(ag_class), "landfire", "calag"))

# merge natural lands with ag, replace grouped name with ag classification
where appropriate, clean data
```

```
combined_ag_natland <- merge(combined_lf_df, ag_2016, by = "pointid") %>%
  mutate(ag_class = as.character(ag_class)) %>%
  mutate(lf_n_category = as.character(lf_n_category)) %>%
  mutate(grouped = ifelse(is.na(ag_class), grouped, ag_class)) %>%
  mutate(reclass_cat = ifelse(is.na(ag_class), as.character(reclass_16),
as.character(ag_class))) %>%
  mutate(reclass_cat = as.character(reclass_cat)) %>%
  mutate(reclass_cat = ifelse(reclass_cat == "Barren / Fallow",  "Fallow",
as.character(reclass_cat))) %>%
  dplyr::select(evt_group, pointid, reclass_cat, grouped, nitrogen,
lf_n_category, source) %>%
  rename(nitrogen_cat = nitrogen) %>%
  mutate(reclass_cat = ifelse(reclass_cat == "Wetland",
"Riparian/Wetland", as.character(reclass_cat))) %>%
  mutate(reclass_cat = ifelse(reclass_cat == "Irrigated Pasture",
"Fodder", as.character(reclass_cat))) %>%
  mutate(nitrogen_cat = ifelse(source == "calag",
as.character(nitrogen_cat), as.character(lf_n_category)))

# create simplified file to use in GIS mapping
reclass_map_file <- combined_ag_natland %>%
  dplyr::select(pointid, reclass_cat)

# calculate stored carbon and nitrous oxide emissions for each pixel (900
sq m)

ag_natland_carbon_n_16 <- combined_ag_natland %>%
  left_join(carbon_vals, by = "grouped") %>%
  mutate(mt_900 = (total_mt*.09)) %>% # MT carbon per hectare multiplied
by .09 to get metric tons of carbon per pixel (900 sq m)
  left_join(lut_n, by = "nitrogen_cat") %>%
  mutate(lbs_n_pixel = (n_rate_lbs_acre*.222395)) %>% # nitrogen
application rate (pounds per acre) multiplied by .222395 to get pounds of
N applied per per pixel
  mutate(emit_n_lbs_pix = (lbs_n_pixel * .0175)) %>% # 1.75% of nitrogen
escapes at N2O emissions
  dplyr::select(!c(n_rate_lbs_acre, lbs_n_pixel)) %>%
  mutate(stock_abvgc_mtco2e_pixel = (mt_900*1)) %>%  # multiply metric
tons of carbon by 3.67 to get MT of CO2 equivalent # Decided to report as
MT instead, replace 3.67 value w 1 to not break rest of code
  mutate(emit_no_mtco2e_pix = emit_n_lbs_pix*298*0.000453592) # multiply
pounds to N2O emissions by 298 to convert to pounds CO2e, then by
0.000453592 to get metric tonnes

# combine aboveground carbon and nitrogen data with soil data
```

```r
all_c_n_soil <- merge(ag_natland_carbon_n_16, soil, by = "pointid") %>%
  mutate(soil900 = (soc0_30*900)) %>% #per m^2 to per 900 m^2
  mutate(soilMT = (soil900/1000000)) %>%  # grams to metric tons of
organic carbon
  mutate(stock_soilc_mtco2e_pix = soilMT*1) # convert to CO2e # Decided to
report as MT instead, replace 3.67 value w 1 to not break rest of code

# make into a table, does not yet include urban forestry

all_clean_16_no_tree <- all_c_n_soil %>%
  dplyr::select(pointid, reclass_cat, stock_abvgc_mtco2e_pixel,
stock_soilc_mtco2e_pix, emit_no_mtco2e_pix, source) %>%
  mutate(emit_no_mtco2e_pix = replace_na(emit_no_mtco2e_pix, 0))

# calculate acreages per landclass category

all_acreages_16 <- all_clean_16_no_tree %>%
  group_by(reclass_cat) %>%
  summarize(pixels = n()) %>%
  mutate(sqmeter = pixels*900) %>%
  mutate(acreage = sqmeter/4047) %>%
  dplyr::select(! c(pixels, sqmeter)) %>%
  adorn_totals()

#create a summary (preliminary inventory without urban forestry)
ci_summary_cat_16 <- all_clean_16_no_tree %>%
  dplyr::select(!source) %>%
  group_by(reclass_cat) %>%
  summarise_all(.funs = c(sum="sum"), na.rm = TRUE) %>%
  mutate(net = (stock_soilc_mtco2e_pix_sum +
stock_abvgc_mtco2e_pixel_sum)) %>%
  merge(all_acreages_16, by = "reclass_cat") %>%
  dplyr::select(!pointid_sum)

################################################################
# Add in urban forestry
################################################################

# CO2e stored/urban tree canopy (metric tons/acre) converted to MT C

tree_num <- 114.8730627/3.67

# Assign # of acres of developed land as object for calculations
# If making changes, double check this cell reference is correct (should
reference "developed")

urban_acres <- all_acreages_16[2, 2]
```

```
# create a row that matches ci_summary_cat_16 (preliminary inventory) to
add data with rbind

tree_row <-data.frame("Urban Forestry (Aboveground Only)",
tree_num*urban_acres, 0, 0, tree_num*urban_acres, 0)
names(tree_row)<-c("reclass_cat", "stock_abvgc_mtco2e_pixel_sum",
"stock_soilc_mtco2e_pix_sum", "emit_no_mtco2e_pix_sum", "net", "acreage")

# add urban forestry row to inventory

ci_summary_cat_16 <- rbind(ci_summary_cat_16, tree_row) %>%
  mutate(reclass_cat = ifelse(reclass_cat == "Urban Forestry (Aboveground
Only)", "Developed", reclass_cat)) %>%
  group_by(reclass_cat) %>%
  summarise_all(sum) %>%
  adorn_totals()

# rename columns

colnames(ci_summary_cat_16) = c("Landcover Classification", "Total
Aboveground Carbon (MT C)", "Total Soil Carbon (MT C)", "Total NO
Emissions (MT CO2e)", "Total Stocks (MT C)", "Acres")

# final landscape inventory
ci_summary_cat_16

##  Landcover Classification Total Aboveground Carbon (MT C)
##                    Barren                           0.000
##                 Developed                     3372234.090
##                   Fallow                        2293.470
##                    Fodder                       12624.849
##                    Forest                    11932600.874
##                 Grassland                      676689.881
##                Greenhouse                           0.000
##                   Orchard                      136676.009
##               Pastureland                        3115.975
##          Riparian/Wetland                       42546.252
##                  Row Crop                       62001.362
##                 Shrubland                    18591734.128
##                  Vineyard                       34147.413
##                     Water                           0.000
##                     Total                    34866664.304
##  Total Soil Carbon (MT C) Total NO Emissions (MT CO2e) Total Stocks (MT
C)
##                 90077.412                       0.0000
90077.412
```

```
##                1356058.392                            0.0000
4728292.483
##                  94663.749                            0.0000
96957.219
##                 107472.848                          396.2391
120097.697
##                2747504.041                            0.0000
14680104.915
##                3543562.388                            0.0000
4220252.268
##                  19398.360                            0.0000
19398.360
##                 269416.907                         3600.7312
406092.916
##                  48735.973                          276.5252
51851.948
##                 111282.989                            0.0000
153829.241
##                1113708.673                        32871.0189
1175710.036
##                6228164.288                            0.0000
24819898.416
##                 508851.928                         1815.7271
542999.341
##                   8469.227                            0.0000
8469.227
##               16247367.175                        38960.2416
51114031.479
##         Acres
##     22207.784
##    105836.175
##      8027.502
##      6844.403
##    292859.155
##    239987.991
##      1937.213
##     16878.280
##      2541.216
##     14932.394
##     80597.480
##    804518.162
##     30613.121
##      4381.468
##   1632162.342
```

The next section essentially repeats the process above, using a loop, but excludes LANDFIRE data to create inventories from the CalAg data for 2012, 2016, and 2019. These will be used to create the baseline reference scenario

```
################################################################
# Process dataframes to use in baseline projections
################################################################

# read in ag 2012 and 2019,and re-read in 2016 data

ag_2019_raw <- read.csv(here::here("files", "ag", "ag_2019.csv"), encoding
= "UTF-8", na.strings=c(""," ", "NoData", "NA"))

ag_2019 <- ag_2019_raw %>%
  dplyr::select(!c(organic, crop_list)) %>%
  rename(nitrogen = nitrogren_) %>%
  clean_names("snake") %>%
  mutate(ag_class = as.character(ag_class)) %>%
  mutate(nitrogen = as.character(nitrogen)) %>%
  mutate(nitrogen = ifelse(ag_class == "Barren / Fallow" | ag_class ==
"Greenhouse", 0, nitrogen)) %>%
  mutate(ag_class = ifelse(ag_class == "Irrigated Pasture",  "Fodder",
as.character(ag_class))) %>%
  mutate(ag_class = ifelse(ag_class == "Barren / Fallow",  "Fallow",
as.character(ag_class))) %>%
  rename(pointid = objectid) %>%
  mutate(source = ifelse(is.na(ag_class), "landfire", "calag"))

ag_2012_raw <- read.csv(here::here("files", "ag", "ag_2012.csv"), encoding
= "UTF-8", na.strings=c(""," ", "NoData", "NA"))

ag_2012 <- ag_2012_raw %>%
  dplyr::select(!c(organic, crop_list)) %>%
  rename(nitrogen = nitrogren_) %>%
  clean_names("snake") %>%
  rename(pointid = objectid) %>%
  mutate(ag_class = as.character(ag_class)) %>%
  mutate(nitrogen = as.character(nitrogen)) %>%
  mutate(nitrogen = ifelse(ag_class == "Barren / Fallow" | ag_class ==
"Greenhouse", 0, nitrogen)) %>%
  mutate(ag_class = ifelse(ag_class == "Irrigated Pasture",  "Fodder",
as.character(ag_class))) %>%
  mutate(ag_class = ifelse(ag_class == "Barren / Fallow",  "Fallow",
as.character(ag_class))) %>%
  mutate(nitrogen = ifelse(ag_class == "Pastureland", "Field Crops",
nitrogen)) %>%
  mutate(source = ifelse(is.na(ag_class), "landfire", "calag"))
```

```r
ag_2016_update <- ag_2016_raw %>%
  dplyr::select(!c(organic, crop_list)) %>%
  rename(nitrogen = nitrogren_) %>%
  clean_names("snake") %>%
  rename(pointid = objectid) %>%
  mutate(ag_class = as.character(ag_class)) %>%
  mutate(nitrogen = as.character(nitrogen)) %>%
  mutate(nitrogen = ifelse(ag_class == "Barren / Fallow" | ag_class ==
"Greenhouse", 0, nitrogen)) %>%
  mutate(ag_class = ifelse(ag_class == "Irrigated Pasture",  "Fodder",
as.character(ag_class))) %>%
  mutate(ag_class = ifelse(ag_class == "Barren / Fallow",  "Fallow",
as.character(ag_class))) %>%
  mutate(nitrogen = ifelse(ag_class == "Pastureland", "Field Crops",
nitrogen)) %>%
  mutate(source = ifelse(is.na(ag_class), "landfire", "calag"))

# put files into a list

ag_files_list <- list(ag_2012, ag_2016_update, ag_2019)

# first, merge with LANDFIRE data so as to not break any of the above code

fx_merge <- function(ag) {

  merge(combined_lf_df, ag, by = "pointid") %>%
  mutate(ag_class = as.character(ag_class)) %>%
  mutate(grouped = ifelse(is.na(ag_class), grouped, ag_class)) %>%
  mutate(reclass_cat = ifelse(is.na(ag_class), reclass_16, ag_class)) %>%
  dplyr::select(evt_group, pointid, reclass_cat, grouped, nitrogen,
source) %>%
  rename(nitrogen_cat = nitrogen) %>%
  filter(source == "calag")

}

results <- lapply(ag_files_list, fx_merge) %>%
  setNames(c(2012, 2016, 2019))

# make into data frames

fx_df <- function(result){
  df_name <- data.frame(result)
}

dfs <- lapply(results, fx_df) %>%
```

```r
  setNames(c(2012, 2016, 2019))

# calculate stored carbon and nitrous oxide emissions for each pixel (900
sq m)

fx_ghg_calc <- function(dfs) {

dfs %>%
  left_join(carbon_vals, by = "grouped") %>%
  mutate(mt_900 = (total_mt*.09)) %>% # MT carbon per hectare multiplied
by .09 to get metric tons of carbon per pixel (900 sq m)
  left_join(lut_n, by = "nitrogen_cat") %>%
  mutate(lbs_n_pixel = (n_rate_lbs_acre*.222395)) %>% # nitrogen
application rate (pounds per acre) multiplied by .222395 to get pounds of
N applied per per pixel
  mutate(emit_n_lbs_pix = (lbs_n_pixel * .0175)) %>% # 1% of nitrogen
escapes at NO emissions
  dplyr::select(!c(n_rate_lbs_acre, lbs_n_pixel)) %>%
  mutate(stock_abvgc_mtco2e_pixel = (mt_900*1)) %>%  # multiply metric
tons of carbon by 3.67 to get MT of CO2 equivalent # Decided to report as
MT instead, replace 3.67 value w 1 to not break rest of code
  mutate(emit_no_mtco2e_pix = emit_n_lbs_pix*298*0.000453592) # multiply
pounds to NO emissions by 298 to convert to pounds CO2e, then by
0.000453592 to get metric tonnes

}

ghgs <- lapply(dfs, fx_ghg_calc) %>%
  setNames(c(2012, 2016, 2019))

ghg_dfs <- lapply(ghgs, fx_df) %>%
  setNames(c(2012, 2016, 2019))

# add soil

fx_soil <- function(ghg_dfs) {

ghg_dfs %>%
  merge(soil, by = "pointid") %>%
  mutate(soil900 = (soc0_30*900)) %>% #per m^2 to per 900 m^2
  mutate(soilMT = (soil900/1000000)) %>%  # grams to metric tons of
organic carbon
  mutate(stock_soilc_mtco2e_pix = soilMT*1) # convert to CO2e #Decided to
report as MT instead, replace 3.67 value w 1 to not break rest of code
}

soil_results <- lapply(ghg_dfs, fx_soil) %>%
```

```
  setNames(c(2012, 2016, 2019))

soil_results_dfs <- lapply(soil_results, fx_df) %>%
  setNames(c(2012, 2016, 2019))

# name these just to preview
combined_2012_df <- soil_results_dfs[[1]]
combined_2016_df <- soil_results_dfs[[2]]
combined_2019_df <- soil_results_dfs[[3]]

# clean up results and summarize values
fx_all_clean <- function(df) {
df %>%
  dplyr::select(reclass_cat, stock_abvgc_mtco2e_pixel,
stock_soilc_mtco2e_pix, emit_no_mtco2e_pix) %>%
  group_by(reclass_cat) %>%
    summarise_all(.funs = c(sum="sum"), na.rm = TRUE) %>%
    adorn_totals()
}

summaries <- lapply(soil_results_dfs, fx_all_clean) %>%
  setNames(c(2012, 2016, 2019))

summaries_dfs <- lapply(summaries, fx_df) %>%
  setNames(c(2012, 2016, 2019))

names <- names(summaries_dfs)

res_list <- vector("list", length = length(names)) %>%
  setNames(names)

# lastly, make some tables

for(i in names){

loop_total_table <- soil_results_dfs[[i]] %>%
  group_by(reclass_cat) %>%
  summarize(pixels = n()) %>%
  mutate(sqmeter = pixels*900) %>%
  mutate(acreage = sqmeter/4047) %>%
  merge(summaries_dfs[[i]], by = "reclass_cat") %>%
  filter(reclass_cat %in% c("Fallow", "Fodder", "Orchard", "Row Crop",
"Pastureland", "Vineyard", "Greenhouse")) %>%
  mutate(net = (stock_soilc_mtco2e_pix_sum +
stock_abvgc_mtco2e_pixel_sum)) %>%
  adorn_totals() %>%
  mutate(year = i)
```

```
res_list[[i]] <- loop_total_table

  }

total_tables <- lapply(res_list, fx_df) %>%
  setNames(c(2012, 2016, 2019))

# and name them as objects

ag_acreage_12 <- total_tables[[1]]
ag_acreage_16 <- total_tables[[2]]
ag_acreage_19 <- total_tables[[3]]
```

Appendix VI: Baseline Reference Scenario Code

Prepared in R Studio, this code was used to prepare the baseline reference scenarios as described in the methodology and results sections of the final report. Plots are excluded from this document.

Code Setup

```r
# Attach packages
library(tidyverse)
library(tidyr)
library(here)
library(janitor)
library(plotly)
library(kableExtra)
library(effsize)
library(stargazer)
library(broom)
library(plotly)

# Read in data files and clean up, created in carbon inventory script.
These files contain # of acres of each ag class according to calag
(excludes landfire).

ag_12 <- read_csv(here::here("results", "ag_final_12.csv")) %>%
  dplyr::select(! c(pixels, sqmeter))
ag_16 <- read_csv(here::here("results", "ag_final_16.csv")) %>%
  dplyr::select(! c(pixels, sqmeter))
ag_19 <- read_csv(here::here("results", "ag_final_19.csv")) %>%
  dplyr::select(! c(pixels, sqmeter))

# change column names
colnames <- c("class", "acres","abvgc", "soilc", "noemit", "net", "year")
colnames(ag_12) = colnames
colnames(ag_16) = colnames
colnames(ag_19) = colnames

#Add in rangeland values from cal ag

# First, use carbon inventory to get average carbon values per acre
inventory <- read_csv(here("results", "inventory_16.csv")) %>%
  clean_names

# crop report #s https://countyofsb.org/agcomm/cropReportArchive.sbc

range_acre_19 <- 573678
range_acre_12 <- 584125
range_acre_16 <- 586047
```

```r
# assign total # of grassland acres from carbon inventory, then subtract
from rangeland acreage to get shrubland weight
range_grass <- 239987.991
range_shrub <- range_acre_16 - range_grass
range_weights <- c(range_grass, range_shrub)

# get average aboveground and soil carbon storage per acre of grassland
and shrubland
shrub_grass <- inventory %>%
  filter(landcover_classification %in% c("Grassland","Shrubland")) %>%
  mutate(soil_avg = total_soil_carbon_mt_c/acres) %>%
  mutate(abvg_avg = total_aboveground_carbon_mt_c/acres)

# calculate average aboveground and soil carbon for rangeland
avg_soil_rangel <- weighted.mean(shrub_grass$soil_avg, range_weights)
avg_abvg_rangel <- weighted.mean(shrub_grass$abvg_avg, range_weights)

# prepare rows to add to ag inventories
range_data <- data.frame(class = "Rangeland", "acres" = c(range_acre_12,
range_acre_16, range_acre_19), "abvgc" = 0, "soilc" = 0, "noemit" = 0,
"net" = 0, "year" = c(2012, 2016, 2019)) %>%
  mutate(abvgc = avg_abvg_rangel*acres) %>%
  mutate(soilc = avg_soil_rangel*acres) %>%
  mutate(net = abvgc+soilc)

# make combined dataframe to make calculations easier

all_ag_df <- rbind(ag_12, ag_16) %>%
  rbind(ag_19) %>%
  rbind(range_data) %>%
  filter(class != "Total")

# calculate per acre storage and nitrous oxide emissions
best_at <- all_ag_df %>%
  filter(year == 2016) %>%
  mutate(best_abvg = (abvgc/acres)) %>%
  mutate(best_soil = (soilc/acres)) %>%
  mutate(best_overall = ((abvgc+soilc)/acres)) %>%
  mutate(worst_n2o = (noemit/acres))

# wide format dataframe
all_ag_df_wide <- all_ag_df %>%
  pivot_wider(names_from = class,
              values_from = c(acres, abvgc, soilc, noemit, net)) %>%
  clean_names()
```

Run linear regressions

```
## First, we'll make a data frame of years out to 2030

predict_df_30_acres <- data.frame(year = c(2012, 2016, 2019, 2030))

# Next we will build models to fit a linear regression to each crop
category along with total ag acreage

select_ag <- all_ag_df_wide %>%
  dplyr::select(2:41)

ag_names <- colnames(select_ag)

res_list_plots <- vector("list", length = length(ag_names)) %>%
  setNames(ag_names)

# first, linear regressions

fx_lm <- function(name) {

  lm_loop <- lm(all_ag_df_wide[[name]] ~ year, data = all_ag_df_wide)

}

all_lms <- lapply(ag_names, fx_lm) %>%
  setNames(ag_names)

all_lms[[1]] # cool

##
## Call:
## lm(formula = all_ag_df_wide[[name]] ~ year, data = all_ag_df_wide)
##
## Coefficients:
## (Intercept)         year
##  -1700970.1        845.7

# Now we will use these models to predict acreage (total and per crop
type) in 2030

fx_predict <- function(lm) {

  predict_run_loop <- predict(lm, newdata = predict_df_30_acres)
  predict_df_loop <- data.frame(predict_df_30_acres, predict_run_loop)
  predict_df_loop <- predict_df_loop

}
```

```
looped_predict_dfs <- lapply(all_lms, fx_predict) %>%
  setNames(ag_names)

looped_predict_dfs[[1]] # great

##   year predict_run_loop
## 1 2012         611.5671
## 2 2016        3994.4333
## 3 2019        6531.5830
## 4 2030       15834.4650

# These plots compare real data to the regression

for (name in ag_names) {
  plot <- print(ggplot() +
  geom_point(data = all_ag_df_wide, aes(x = year, y =
all_ag_df_wide[[name]])) +
  geom_line(data = looped_predict_dfs[[name]], aes(x = year, y =
predict_run_loop)) +
  theme_minimal() +
  labs(x = "year",
       y = paste(name)))

}
```

Clean and prepare results for use

```
#create big dataframe of all predicted values

#first, change column names
for(name in ag_names){

  colnames(looped_predict_dfs[[name]]) <- c("year", name)

}

# merge dataframes, common column = year
all_predict_df<- looped_predict_dfs %>%
  reduce(full_join, by = "year")

# make this dataframe tidy
tidy_predict_df <- all_predict_df %>%
  pivot_longer(!year,
               names_to = c("variable", "land_class"),
               names_sep = "_",
               values_to = "value")
```

```
# add totals
totals_predict <- tidy_predict_df %>%
  group_by(variable, year) %>%
  summarise(value = sum(value)) %>%
  mutate(land_class = "total_allclasses") %>%
  relocate(year, variable, land_class, value)

# put it together
final_predict_df <- bind_rows(tidy_predict_df, totals_predict)

# do the same for observed values

tidy_observed <- all_ag_df %>%
  pivot_longer(cols = 2:6,
               names_to = "variable",
               values_to = "value") %>%
  rename(land_class = class) %>%
  relocate(year, variable, land_class, value)

totals_observed <- tidy_observed %>%
  group_by(variable, year) %>%
  summarise(value = sum(value)) %>%
  mutate(land_class = "total_allclasses") %>%
  relocate(year, variable, land_class, value)

final_observed_df <- bind_rows(tidy_observed, totals_observed)
```

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