JANUARY 2016

CONSERVING LANDSCAPES, PROTECTING THE CLIMATE

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SONOMA COUNTY AGRICULTURAL PRESERVATION AND OPEN SPACE DISTRICT

The Nature Conservancy

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Sonoma County Agricultural Preservation and Open Space District

Introduction

Conserving and improving the management of natural and working landscapes reduces net greenhouse gas emissions and delivers multiple other benefits. A healthy forest, for instance, sequesters carbon while also storing and filtering water, providing habitat for wildlife, and building resilience to climate change.

Developing or poorly managing such landscapes imperils these benefits. Such practices can release greenhouse gases to the atmosphere, reduce or eliminate water and habitat benefits, and limit the potential for the land to sequester carbon in the future and adapt to a warming climate.

The Climate Action Through Conservation (CATC) project provides a way for local governments, land managers, and planners to understand the links between climate benefits and conservation values and incorporate that knowledge into decisions about land use and land management.

This report presents the result: a new set of free analytic tools for quantifying landscape carbon sequestration, assessing the multiple other benefits that landscapes provide, and evaluating how future land-management activities and land-use changes may affect these benefits.

County-level management of landscape carbon

Land-use decisions on California's private lands are made predominantly at the local government level—from zoning designations and regional development "blueprints" to the establishment of urban growth boundaries and locally driven conservation initiatives. For this reason, many of the steps to realize the potential climate benefits of the state's landscapes must also be taken at the local government level. In addition, local communities are in the best position to design climate programs that address local needs and concerns.

Counties around California are developing climate action plans. Land-use planning is an important component of these plans. However, local governments typically do not have the tools to perform the analyses needed to guide long-term, sustainable management of landscape carbon. These analyses include:

- Landscape carbon inventories and baseline projection: How much carbon is sequestered in the county's landscapes currently? How has that amount changed in recent decades? If current trends continue, what will it be in 2030 and 2050?
- Conservation value assessments: What is the current status of key conservation values—agricultural productivity, habitat, water resources, and the potential for carbon sequestration—and how may these values be affected by land-use changes or interventions to sequester carbon?
- Alternative scenario evaluations: How might changes in land use or land management influence landscape carbon sequestration in the future?

The CATC project provides a new set of tools (see figure below) that enable counties to answer many of these questions and inform land use decisions accordingly. This report describes the tools and shows how they are being applied to a pilot program in Sonoma County, conducted by the California Chapter of The Nature Conservancy in partnership with the Sonoma County Agricultural Preservation and Open Space District (SCAPOSD).

A jurisdictional carbon accounting framework

The CATC tools are designed to evaluate carbon sequestration at the county scale, an example of what is known as a "jurisdictional" approach to carbon accounting. Jurisdictional accounting operates at the level of political jurisdictions, such as a county, a collection of counties, or a state[1]. It is characterized by its large scale compared with "activity"-level carbon accounting. Activity-level accounting assesses the amount of the carbon sequestered by discrete parcels of land, typically where land managers are undertaking activities designed to increase carbon sequestration. Such parcels can be any size, but are typically on the scale of dozens to thousands of acres—that is, significantly smaller than Sonoma County, the jurisdiction evaluated in this report, which covers roughly 1 million acres.

Jurisdictional and activity-level accounting systems are complementary. The jurisdictional approach has several benefits in the CATC context:

- It is comprehensive: Activity-level carbon accounting, by definition, focuses on carbon-sequestration changes within the boundaries of certain parcels. But what happens outside those boundaries matters too. For instance, a change in land management designed to increase carbon sequestration on one parcel might prompt-land use changes elsewhere in the region that reduce carbon sequestration. The CATC approach integrates landscape carbon changes across the entire county, including activity as well as non-activity areas.

1. See Appendix A for a more detailed discussion.

The CATC tools support a county-level jurisdictional carbon accounting framework

Components of a jurisdictional carbon accounting framework			
Tools developed by the CATC project			
Jurisdictional carbon inventory and baseline projection	Conservation values assessment	Scenario analysis: the Conservation Carbon Accounting Tool (C-CAT)	Monitoring and reporting
Estimates countywide landscape carbon for 1990, 2010, 2030, and 2050. Provides basis for estimating and monitoring greenhouse gas (GHG) reductions	Evaluates land in the county based on 11 conservation metrics, such as habitat value and water yield. Provides multi-benefit context for GHG reductions	Models how changes in land use and land management affect carbon sequestration and conservation values. Forecasts county-wide GHG reduction potential (compared to baseline)	Provides for ongoing data collection and analysis and standardized reporting of GHG reductions achieved

- It can reduce the burden of administering individual activities, and provides a "backstop" for activity-level accounting: In some cases, such as for regulatory compliance or to meet the needs of investors, landscape carbon activities require highly accurate—and costly—ground-level monitoring and verification. But in other cases, assessments based on satellite data provide sufficient accuracy at far lower cost. In addition, the spatially explicit, jurisdiction-level data generated by the CATC approach can be useful in verifying estimates of the benefits of carbon projects estimated by ground-level accounting methods.
- It is spatially explicit: For land-use planning at a jurisdictional scale, a spatial approach is essential for evaluating greenhouse gas baselines and setting climate goals that incorporate multiple conservation values. Spatial analyses can identify areas where management or policy changes may have the greatest carbon sequestration benefit. Such analyses can also indicate where carbon and other values are aligned and where there are trade-offs—that is, they can help to distinguish locations where land management for carbon sequestration is likely to increase one or more other conservation values, such as water quality, from locations where carbon-oriented land management might negatively impact another conservation value, such as terrestrial habitat. Thus, a spatial approach allows for strategic landscape planning that optimizes multiple benefits, including a net increase in carbon sequestration, and drives more efficient use of planning resources and conservation funds.

The state policy context: Many opportunities

State climate policy is generating new funding and other incentives for land management and conservation to increase net carbon sequestration on natural and working lands. The 2014 update of the state Scoping Plan, the blueprint for reducing California's net greenhouse gas emissions, envisions funding and other support for such activities on forests, rangelands, and wetlands. New funds from the state's cap-and-trade program are being invested as well.[2]

Local governments have an important—but as yet underdeveloped—role to play in developing and implementing strategies that capitalize on the potential for landscape-based climate benefits that also meet other conservation and societal goals. In particular, there is a need for tools to engage local actors and demonstrate to policymakers and other stakeholders that landscape carbon represents a good investment of the funds available for climate change mitigation.

Sonoma County

Sonoma County has been a national leader in coordinated climate action at the local government level. All 10 of the county's local governments—the county government and nine city governments—have committed to long-term greenhouse gas reductions that are more aggressive than those required under Assembly Bill 32, the California Global Warming Solutions Act of 2006. In 2009, the Regional Climate Protection Authority (RCPA) was created to help each jurisdiction reach its goal under the Climate Action 2020 program,[3] which will be integrated into the county's general plan, the document that guides growth, development, and land use throughout the county.

SCAPOSD, a partner agency in the CATC project, is a special district created in 1990 and charged with protecting the county's natural areas as well as working farms and ranches. It is funded by a voter-approved quarter-cent sales tax. Since its creation, SCAPOSD and its partners have protected more than 106,000 acres in the county, predominantly via conservation easements.

The agency's mission and activities have strong links with landscape carbon sequestration. SCAPOSD chose to work with TNC on this project for several reasons: to document and quantify the role of conservation and land management in meeting the county's climate goals; to ensure that conservation programs are integrated effectively in Climate Action 2020; to help the county attract funding for climate-oriented conservation programs and policies; and to document for local voters the climate benefits and improvements to conservation values that Sonoma County programs generate.

2. California Air Resources Board, "Cap-and-Trade Auction Proceeds Triennial Investment Plan," 2015, http://www.arb.ca.gov/cc/capandtrade/auctionproceeds/investmentplan.htm.

3. See http://www.sctainfo.org/climate_action_2020.htm.

Outreach

A central goal of the CATC project is to produce tools that will be of practical use to policymakers and state agencies, as well as others working in land management, climate change mitigation and adaptation, and land-use policy. To that end, the project team conducted eight workshops in Sacramento and elsewhere in the state in 2014 and 2015 (Tables 1a and 1b). This report and the design of the CATC tools reflect the feedback gathered at the meetings.

Table 1a: CATC outreach meetings

- Southern California Workshop, Los Angeles, hosted by the Southern California Association of Governments
- Placer County/Sierra Foothills Workshop
- California Environmental Protection Agency, California Air Resources Board
- California Department of Conservation
- California Office of Planning and Research
- California Local Government Commission
- California Legislature
- Alliance of Regional Collaboratives for Climate Adaptation (Sacramento practitioners workshop)

Table 1b: Outreach meeting participants: Organizations represented at CATC workshops

350 Sacramento
AECOM
Ascent Environmental, Inc.
Asian Pacific Policy & Planning Council
Breathe California
California Coastal Conservancy
California Department of Fish and Wildlife
California Department of Parks & Recreation
California Department of Water Resources
California Natural Resources Agency
California Special Districts Association
City of Folsom
City of Sacramento
City of Sacramento Office of Emergency Services
Climate Resolve
Coachella Valley Association of Governments
Congresswoman Doris Matsui
Cool Davis
Dogwood Springs Forestry
Four Twenty Seven, Inc.
ICF International
Little Hoover Commission
Local Government Commission
Los Angeles County
Los Angeles County Department of Parks and Recreation
Los Angeles County Planning Department
Natural Resources Defense Council
Nature Commission
Newport Bay Naturalists and Friends
Orange County Transportation Authority
Palos Verdes Peninsula Land Conservancy
Placer County
Placer County Air Pollution Control District
Placer County Land Trust
Placer County Planning Department
Puente Hills Habitat Authority
Rangeland Conservation Trust
Rincon Consultants
Riverside County Transportation Commission
Sacramento Area Council of Governments
Sacramento County
Sacramento County Department of Waste Management and Recycling
Sacramento County DHHS, Division of Public Health
Sacramento Metropolitan Air Quality Management District
Sacramento Municipal Utility District
Sacramento Tree Foundation
Santa Barbara Council of Governments
Sierra Business Council
Southern California Association of Governments
Starr Ranch Sanctuary
Tehama Resource Conservation District
The Nature Conservancy
Townsend Public Affairs
UC Davis
UC Davis Policy Institute for Energy, Environment, and the Economy
US Fish and Wildlife Service
Valley Vision
Ventura County
Ventura Hillsides Conservancy
Yolo Energy Watch
Yuba-Sutter Habitat Conservation Plan

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The project: Methods and findings

The CATC project focuses on four broad landscape types: forests, grasslands, shrublands, and urban forests. The framework described below provides a methodology for jurisdictional landscape carbon accounting and enables estimates of greenhouse gas reductions that may be achieved through management, restoration, and conservation activities. The framework can be modified in the future to include updated science and other landscape types, such as wetlands, that may sequester significant amounts of carbon.

The methodology is designed to be transparent and replicable. All methods are described in this report and the technical appendices; data sources are cited and shared freely; and, where possible, the methodology uses data sets generated by programs (generally federal government programs) with stable funding, which increases the likelihood that comparable data will be collected in the future. In addition, the framework is designed to be consistent with other major efforts to quantify stocks and changes in landscape carbon. For instance, in key respects the CATC inventory methods are consistent with those used recently by the California Air Resources Board for state-level landscape carbon accounting.[4]

The project uses metric tons of carbon dioxide equivalent, or tCO_2e, as the basic unit of greenhouse gas accounting. For comparison, one tCO_2e is emitted by, for instance, burning 112 gallons of gasoline in a car. An average acre of redwood forest in Sonoma County contains roughly 528 tCO_2e, including the carbon in trees, roots, down wood, litter, and soil. In 2013, the most recent year for which figures are available, California's statewide greenhouse gas emissions totaled 459 million tCO_2e.

The project's four main analytic components—jurisdictional carbon inventory and baseline projection; conservation values assessment; scenario analysis tool (the Conservation Carbon Accounting Tool, or C-CAT); and economic impact assessment—are described below, with additional detail provided in the technical appendices.

4. P. Gonzalez, J. J. Battles, B. M. Collins, T. Robards, and D. S. Saah, "Aboveground Live Carbon Stock Changes of California Wildland Ecosystems, 2001–2010," *Forest Ecology and Management* 348 (2015): 68–77, doi.org/10.1016/j.foreco.2015.03.040.

CARBON INVENTORY AND BASELINE PROJECTION

Jurisdictional carbon inventory

The carbon inventory is an estimate of landscape carbon sequestration for a county. Based on transparent and publicly available data, the CATC project developed county-scale carbon inventories with a focus on four land-cover types: forests, grasslands, shrublands, and urban forests. It also tracks soil carbon sequestration for agricultural and urban lands. The carbon inventory serves as the basis for developing the county's jurisdictional carbon baseline projection.

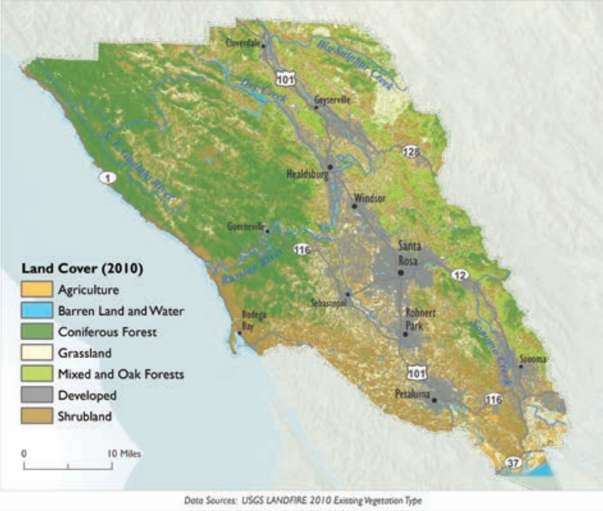
The overall goal of the inventory methodology is to be accurate to plus or minus 20% at a 90% confidence level. Confidence intervals are evaluated where possible.

All land in the county is mapped into a land-cover class (Figure 1) based on data from the LANDFIRE program, a long-term, satellite-based land-cover mapping program supported by the U.S. Department of the Interior, the U.S. Department of Agriculture, and the U.S. Forest Service.[5] LANDFIRE distinguishes six general land-cover categories—forest, shrubland, grassland, urban forest, agriculture, and non-vegetated land and water—as well as dozens of subcategories, such as coastal redwood forest and mixed evergreen forest. These subcategories are then further characterized by the density and size of vegetation—trees or shrubs—detected by the imagery used in the project.

The LANDFIRE data cover the entire county at a resolution of 30 meters—so each "pixel" on the land-cover map of the county generated from the LANDFIRE information is a 30-meter-by-30-meter square.

Carbon is sequestered in multiple places in landscapes—in the trunks, branches, and roots of living trees, in dead wood and litter on the ground, in the soil, in shrubby vegetation, and so on. Table 2 indicates which carbon pools are quantified for each general land-cover type in the CATC framework. For each pool, a different method is used to translate the LANDFIRE land-cover information for each pixel into a figure for the mass of carbon in that pixel. The mass of carbon in each pool and in every pixel in the county can then be added together to generate a figure for the total mass of carbon sequestered in the county's landscapes. The methods used to convert the LANDFIRE data into a carbon mass figure for each pool are detailed in Appendix B.

Figure 1: LANDFIRE land-cover classes for Sonoma County show the major land-cover types assessed in the CATC project.



The inventories conducted for this project reflect the carbon sequestered in the Sonoma County landscape at two points in time, 1990 and 2010. For detailed methods for those two inventories, please see Appendix B.

The data sets used for the Sonoma County analysis—LANDFIRE, the Forest Inventory and Analysis program of the U.S. Forest Service; the Carbon Online Estimator (COLE), and the SSURGO database maintained by the Natural Resources Conservation Service—are available for nearly every county in California.[6] Data collection is likely to be replicated at regular intervals, making it possible to repeat this inventory in the future using the same methods.

5. LANDFIRE, Existing Vegetation Type, Cover and Height Layers, LANDFIRE 1.2, U.S. Department of the Interior, Geological Survey, 2010, www.landfire.gov.

6. See www.websoilsurvey.nrcs.usda.gov/DataAvailability/SoilDataAvailabilityMap.pdf and www.ncasi2.org/COLE.

Table 2: Carbon sequestration assessment boundaries addressed in the inventory framework.

Description	Included or Excluded? by Land Cover Class		Explanation
Standing live and dead carbon (carbon in all portions of living trees)	Urban forests	Yes	Changes in standing live and dead carbon stocks are important direct effects of changed management practices in forested landscapes.
	Grasslands	No	
	Shrublands	No	
	Forests	Yes	
Soil carbon	Urban forests	Yes	Land-use conversion and changed agriculture practices may have significant direct effects on soil carbon.
	Grasslands	Yes	
	Shrublands	Yes	
	Forests	Yes	
Down woody debris	Urban forests	No	Down woody debris may constitute a substantial direct source of emissions when forests are converted to other land uses.
	Grasslands	No	
	Shrublands	No	
	Forests	Yes	
Litter and duff	Urban forests	No	Litter and duff may constitute a substantial source of emissions when forests are converted to other land uses.
	Grasslands	No	
	Shrublands	No	
	Forests	Yes	
Shrubs	Urban forests	No	Shrubs can be a source of emissions when they are converted to other land uses.
	Grasslands	No	
	Shrublands	Yes	
	Forests	Yes	
Harvested wood products	Urban forests	No	Strategies to improve forest management may have positive or negative effects on carbon sequestered in long-term wood products.
	Grasslands	No	
	Shrublands	No	
	Forests	Yes	
Harvested wood products in landfills	Urban forests	No	Strategies to improve forest management may have positive or negative effects on carbon sequestered in long-term wood products in landfills.
	Grasslands	No	
	Shrublands	No	
	Forests	Yes	

Jurisdictional carbon baseline projection

The jurisdictional carbon baseline serves as a reference case, sometimes referred to as "business as usual," against which future changes in carbon sequestration can be compared. It assumes that the carbon sequestration trends in the county observed between 1990 and 2010 will continue. An increase in carbon sequestration relative to the baseline projection may be considered a reduction in greenhouse gas emissions, while a decrease relative to the baseline may be considered an increase in emissions. A similar approach to baseline projection is being used in multiple countries around the world.[7]

The 1990 and 2010 carbon inventories are the basis for the baseline projection. For each land-cover type, or carbon pool, at the resolution of cover class, size class, and density class (see Appendix B), the 1990-2010 rate of change is extrapolated linearly into the future. Baseline projection figures are reported for 2030 and 2050, consistent with the timing of major statewide greenhouse gas reduction targets established by California. In cases where the linear extrapolation for a given carbon pool falls below zero (as is the case for a number of pools that declined from 1990 to 2010) it is assigned a value of zero, rather than a negative number. Doing so avoids the nonsensical result of some carbon pools containing less than zero carbon, but it inflates the countywide baseline projection by placing a floor on the declines in some carbon pools that would otherwise offset gains in other pools.

The baseline projection may need to be adjusted if future emissions (reductions in carbon) from natural disturbances, such as catastrophic wildfire, exceed emissions from natural disturbances in the 1990-2010 baseline reference period. The baseline projection should be revised periodically as updated land-cover data become available. Each update of the county carbon inventory will provide new information that will adjust the historical trend, refining the baseline projection. Please see Appendix A for a discussion of these issues.

The baseline approach is inherently uncertain. Sources of uncertainty include: possible errors in the 1990 and 2010 inventories that establish the baseline trend; unanticipated future changes in land cover, such as might arise from a major change in land-use policy or from catastrophic wildfires; and the unknown but potentially large effects of climate changes on vegetation communities. In addition, as the baseline projection is extended further out in time, there is less certainty. Consequently, the 2030-2050 projection reported below should be seen as an illustration of the scale of potential changes in landscape carbon sequestration.

Results: Jurisdictional carbon inventory and baseline projection

The results of the carbon inventory show that Sonoma County's natural and working landscapes are making a positive, and large, contribution to meeting California's climate goals (Tables 3a and 3b and Figure 2, following page). From 1990 to 2010, carbon sequestration in the county increased more than 15 million tCO_2e, an average of over 750,000 tCO_2e per year. For comparison, annual anthropogenic emissions from all sources were most recently estimated at 3.7 million tCO_2e, based on data from 2010.[8]

Increased carbon sequestration in the county's forests is the major driver of this positive trend. Forest cover expanded by more than 20,000 acres from 1990 to 2010, as shrublands transitioned to forest. In addition, the LANDFIRE data show that forests, on average, registered net growth over that period, with the average carbon content of each acre of forest increasing from 414 tCO_2e in 1990 to 443 tCO_2e in 2010. This observation points to the need for management practices that promote healthy forests and minimize the risk of carbon loss (or emissions) due to catastrophic wildfire or conversion to other uses.

The baseline carbon projection suggests that, based on recent trends, carbon sequestration in the county will increase by roughly 21 million tons between 2010 and 2030, and by a similar amount between 2030 and 2050. These 20-year increases are greater than the 1990-2010 increase due to changes in land-cover classifications in the LANDFIRE data and to the issue, discussed above, of carbon pools that would fall below zero if extrapolated linearly. As stated above, the baseline projection includes uncertainty and reflects an objective approach to a "business as usual" baseline based on climate policy precedent in other international frameworks.

7. Notably in programs designed to reduce net greenhouse gas emissions by preserving forests under the United Nations Framework Convention on Climate Change. These efforts are known as Reduced Emissions from Deforestation and Degradation, or REDD, programs.

8. See: Draft Countywide Emissions by Sector for 2010. Sonoma County Regional Climate Protection Authority. Available at: http://www.sctainfo.org/pdf/Draft_GHG_Inventory_Countywide.pdf

Table 3a: Measured and projected changes in landscape carbon sequestration (millions of tCO_2e) and land cover (acres) in Sonoma County, 1990-2050.

Millions of tCO_2e		**Forest**	**Grassland**	**Shrubland**	**Other** *(urban forest, agricultural land, roads, and barren land)*	**Total**
Inventory	1990	161.3	11.7	35.6	6.4	**215.1**
	2010	181.9	10.8	31.4	6.2	**230.4**
Baseline extrapolation	2030	206.4	11.1	27.7	6.4	**251.6**
	2050	231.4	11.2	23.4	6.4	**272.3**

Acres		**Forest**	**Grassland**	**Shrubland**	**Other** *(urban forest, agricultural land, roads, and barren land)*	**Total**
Inventory	1990	389,439	138,183	332,591	156,566	**1,016,781**
	2010	410,524	136,888	293,161	176,207	**1,016,781**
Baseline extrapolation	2030	438,321	140,185	257,823	180,451	**1,016,781**
	2050	477,482	141,032	216,726	181,541	**1,016,781**

Figure 2: Sonoma County carbon inventory and baseline projection results, 1990-2050.

Table 3b: Urban forest carbon inventory and baseline projection, 2010-2050.

Due to changes in LANDFIRE land-cover classifications between 1990 and 2010, it was not possible to develop a reliable estimate for the carbon stored in the county's urban forests in 1990. We report here our finding for 2010, along with the baseline projection for 2030 and 2050 developed using methods described in Appendix B.

Millions of tCO_2e		**Urban forest**
Inventory	2010	2.7
Baseline projection	2030	2.8
	2050	2.8

Acres		**Urban forest**
Inventory	2010	100,882
Baseline projection	2030	103,312
	2050	103,936

CONSERVATION VALUES ASSESSMENT

This component of the project evaluates all land in Sonoma County according to four broad conservation themes—agriculture, terrestrial biodiversity, water, and climate—which are in turn based on an evaluation of 11 conservation metrics (Table 4). The result is a series of maps and spatial data that can be used to illuminate the variety of co-benefits and trade-offs of alternative land conservation and land-use scenarios.

The conservation values assessment represents multiple conservation themes spatially and prioritizes them according to transparent criteria. The framework can help to inform decisions today, and can be adapted as new questions emerge and new information becomes available.

In combination with the carbon inventory and the C-CAT tool, the conservation values assessment can help to identify locations where efforts to sequester carbon are aligned with conservation priorities, as well as where they are not. That is, the tools can provide an indication of where land-management activities designed to increase carbon sequestration are likely to preserve or enhance conservation values. By the same token, the tools can suggest where carbon sequestration activities may have an undesired impact on conservation values.

Appendix C describes the assumptions, data sources, processing steps, and classification decision rules for each theme in the assessment. This information is intended to serve as an initial step toward a comprehensive vision for integrated conservation in the county.

The assessment does not provide information at sufficient resolution to replace conservation planning for specific projects such as riparian restoration or land acquisition. However, it does provide important larger-scale context for such strategies, for instance by providing initial assessments of co-benefits. As such, it can help to provide a basis for partnerships and programs leading to positive multi-benefit conservation outcomes.

Data from the assessment are incorporated into the C-CAT tool in two ways. First, the tool can be configured to exclude areas with high conservation value (generally defined as lands that rank in the top 20% for a given conservation value) from vineyard or residential development. Second, for each scenario run, the tool reports on the conservation values of the land affected by rural or vineyard development, providing a summary of the various effects on conservation values caused by the modeled land-use changes.

Table 4: Metrics evaluated in the conservation values assessment. The maps on the following pages show the results of the assessment for each metric.

Category	Conservation value
Agriculture	Agricultural land
Terrestrial biodiversity An aggregate terrestrial biodiversity value was calculated by weighting each of the seven terrestrial habitat values as follows: • Landscape condition (3) • Floodplain habitat (2) • Forest structure (2) • Restricted habitats (1) • Linkages (1) • Rare species density (1) • Serpentine soils (0.5)	Landscape condition (fragmentation)
	Floodplain habitat
	Forest structure
	Restricted habitats
	Linkages between habitat areas
	Density of rare species
	Serpentine soils
Water	Water yield
	Headwater stream quality
Climate	Carbon storage

Figure 3: Combining data on seven habitat and biodiversity metrics—according to the weighting shown in Table 4—generates a map of aggregate terrestrial biodiversity value. See Appendix C for additional details.

Landscape condition (fragmentation)
Lands with low fragmentation tend to have higher habitat value. We combined spatial data on the location and size of roads and anthropogenic land cover (cultivated and developed land) to develop a map of habitat fragmentation in the county.

Floodplain habitat
Floodplains provide important habitat for terrestrial and aquatic species and also provide numerous ecosystem services. We identified floodplain areas based on Federal Emergency Management Agency 100-year floodplain maps and SSURGO map units that indicated some occurrence of flooding. Lands in those categories that were not cultivated or developed were considered to be floodplain habitat.

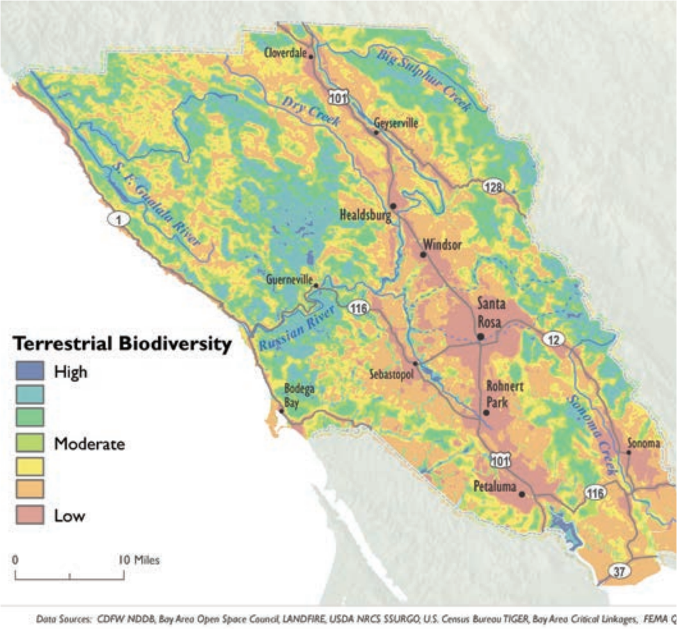
Forest structure
Structurally complex forests provide important and increasingly rare habitat for many species. We modeled the location of such stands using LANDFIRE tree size and canopy cover.

Restricted habitats
The Bay Area Open Space Council's Conservation Lands Network (CLN) program has collected spatial data on rare habitats, including vernal pool complexes, old-growth forests, and rare plant communities.

Linkages between habitat areas
The Bay Area Critical Linkages project has generated spatial data on important landscapes for wildlife linkages, such as riparian corridors, for a range of key species.

Density of rare species
The California Natural Diversity Database (NDDB) records occurrences of rare species in the county. We summarized occurrence density, weighting each occurrence by its global rarity.

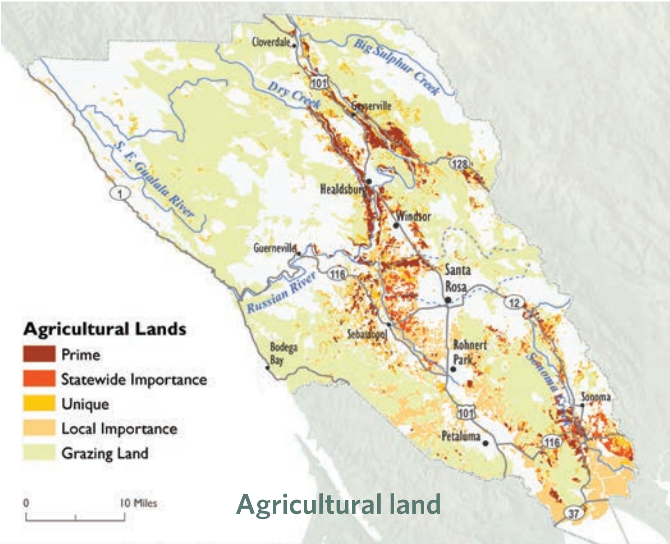
Serpentine soils
These soils are particularly suitable for certain rare plants. NRCS soil survey data (SSURGO) identify the locations where they occur.



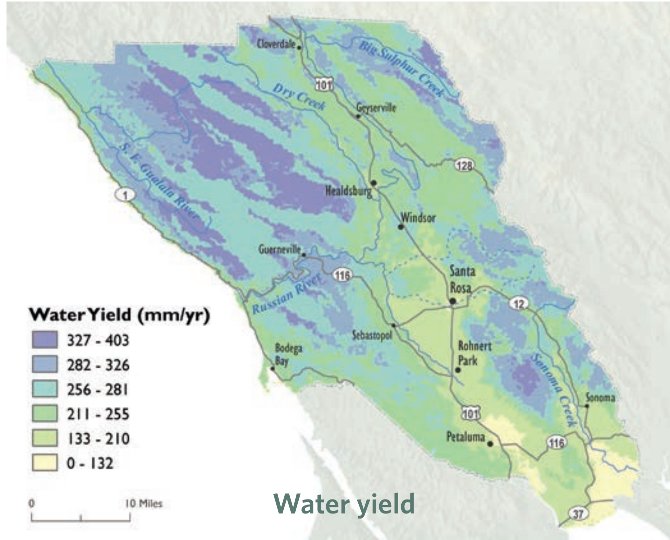
Aggregate terrestrial biodiversity value
The seven criteria used to assess terrestrial biodiversity value differ qualitatively from one another. Some values are place-based and may be somewhat ephemeral (vegetation communities or species occurrences) compared with others that may provide benefits over large areas (e.g. linkages). To calculate an aggregate conservation value, we summed these criteria using a weighting (see Table 4) assigned based on expert opinions about each component's relative importance to ecological integrity. This approach is not meant to be prescriptive, and both the criteria themselves and the weighting method could be adjusted based on stakeholder input.

As the map shows, because of the high weight assigned to landscape intactness, many areas at the edge of developed areas and cultivated agricultural lands show up as low to moderate value. This is partly due to the scale of the input data that we used for this analysis. Finer-scale data on habitats and species occurrences may be available, but they have not been compiled for a large enough portion of the county to be used here. Please see Appendix C for a complete description of the methods and data sources for terrestrial biodiversity value.

Figure 4: Data on up to five metrics—aggregate terrestrial biodiversity value (Figure 3), agricultural land, water yield, headwater stream quality, and carbon storage—can be integrated to generate a combined conservation value index (Figure 5, following page).



Data Sources: CA Department of Conservation- Farmland Mapping and Monitoring Program 2010



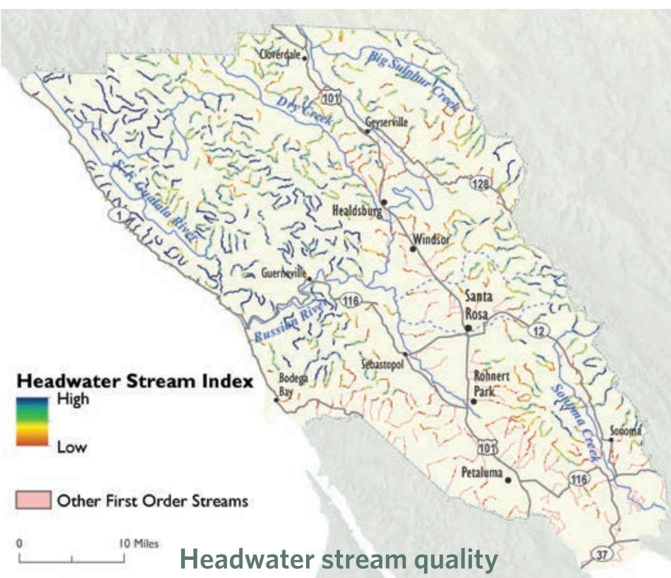
Data Sources: USGS Basin Characterization Model Avg Annual Recharge and Runoff (1981 -2010)

Agricultural land

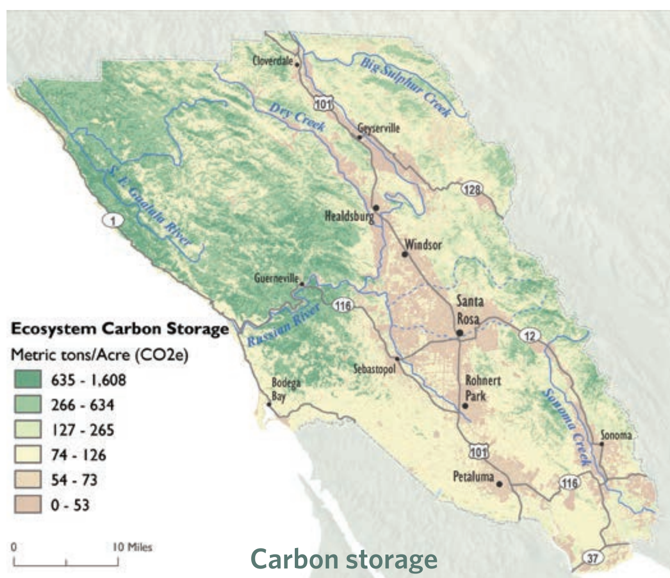
GIS data published by the state Farmland Mapping and Monitoring Program are used to map land in five categories: Prime Farmland (29,939 acres), Farmland of Statewide Importance (17,192 acres), Unique Farmland (32,924 acres), Farmland of Local Importance (80,195 acres), and Grazing Land (417,773 acres).

Water yield (recharge and runoff)

The Basin Characterization Model developed by USGS researchers plots the average annual groundwater recharge and average annual runoff for all county land for 1981-2010 on a 270-meter grid. Water yield is calculated as the sum of groundwater recharge and runoff.



Data Sources: USGS LANDFIRE 2010 vegetation, USGS NHD



Data Sources: USGS LANDFIRE vegetation data, FIA inventory, Carbon Online Estimator, USFS shrub photoseries, NRCS SSURGO for soil

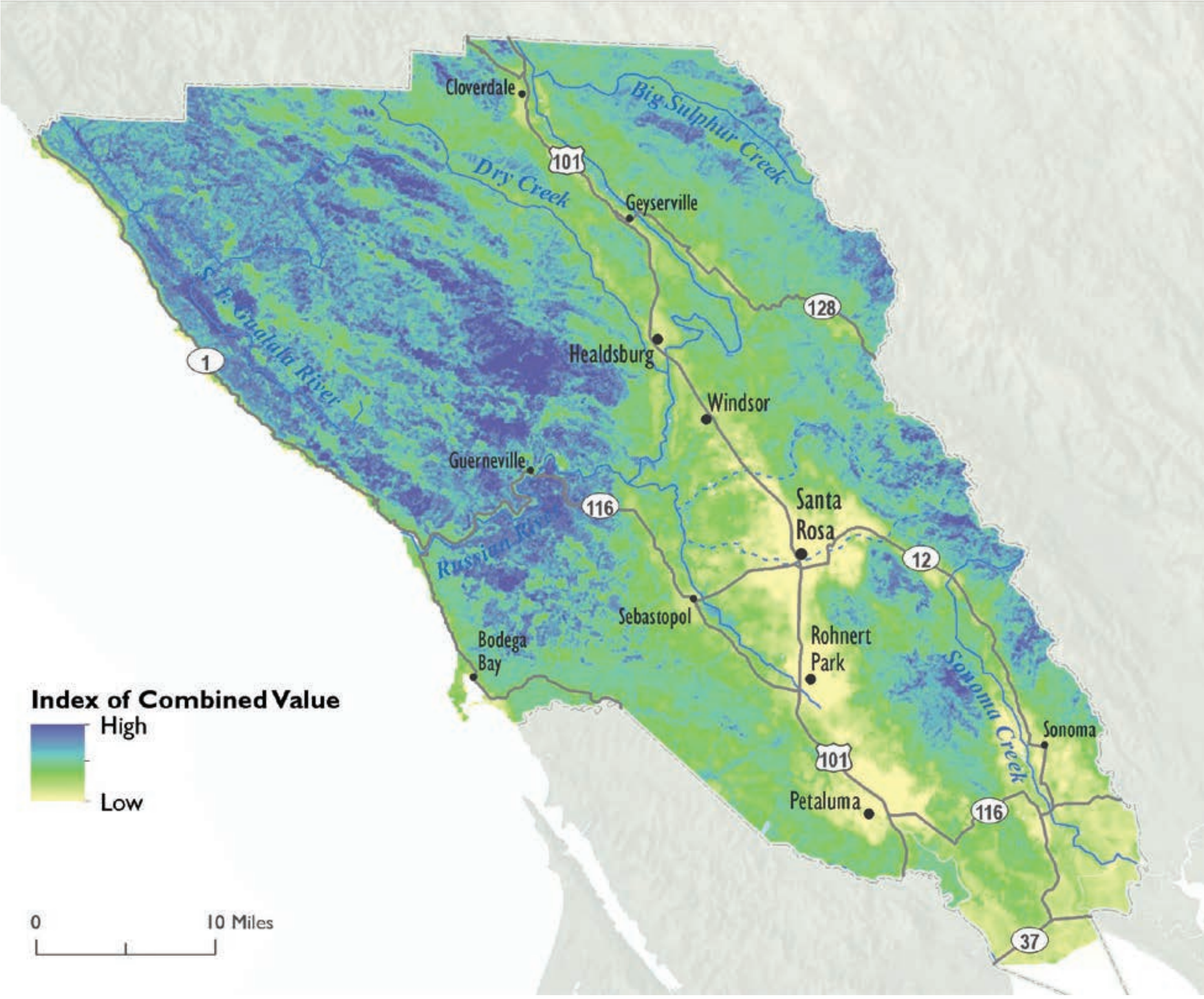
Headwater stream quality

Forests and riparian vegetation provide water filtration and temperature regulation services in watersheds. We mapped forest cover within 100 meters of headwater (first order) streams—those that flow year-round and do not have tributaries.

Carbon storage

The methods used to develop the countywide carbon inventory also generate spatial data on the carbon sequestered in any given 30-meter-by-30-meter square in the county.

Figure 5: Combined conservation value. Combining three of the metrics shown on the previous page yields an integrated analysis of multiple conservation values.



This integrated analysis shows one approach to generating an analysis of multiple ecosystem services and habitat values.

To generate this map, we normalized the carbon storage, aggregate terrestrial biodiversity conservation value, and water yield data on a 0-to-1 scale and summed the data for each pixel. It does not incorporate the agricultural land and headwater stream quality data. Using this approach, areas in the western part of the county with dense forest and significant water yield have the highest scores.

Depending on the decision being considered, the weighting method could be adjusted to incorporate a different mix of metrics and give more or less weight to certain values. Because many of these values are correlated spatially, this map should be interpreted as a general representation of the relative variation of these different conservation values.

C-CAT: THE CONSERVATION CARBON ACCOUNTING TOOL

C-CAT is a GIS model that can be run for a county or other jurisdiction. It estimates how changes in land use, land management, and land cover affect landscape carbon sequestration and conservation values over time, and helps to identify areas where conservation goals are aligned with emissions reduction potential. The tool was developed for Sonoma County, but with region-specific inputs and scenarios, it could be applied to counties elsewhere in California and the United States.

Planners can use the tool to run scenarios for the entire county or for any defined sub-area within the county. Because the tool is highly configurable, it can be used to model the effects of a wide range of land-use policies, conservation and land-management strategies, and restoration programs.

The tool runs in ESRI's ArcMap software. It can be downloaded and run on any computer with ArcGIS Advanced (ArcInfo) version 10.2.2 or later with the Spatial Analyst extension. The link and full operating instructions are provided in Appendix D. The code for the tool is open source, and users are welcome to edit it or add modules.

To run C-CAT, the user first specifies the assumptions that define a scenario—how much land can be developed, which lands will be excluded from development, which lands are most likely to be developed, which forest activities will be performed and on how many acres, and so on (Figure 6 and Table 5).

Once these constraints and instructions have been entered, the tool is ready to run.

Using algorithms described in Appendix D, the tool "grows" vineyards—the predominant type of new agricultural development in Sonoma County—and residential developments over a 20-year scenario period (2010 to 2030). The tool chooses locations for vineyards and residential developments intelligently, based on analyses of historical development patterns,[9] specifications for vineyard plot size and shape, and other constraints.

9. D.A. Newburn, P. Berck, and A. Merenlender. "Habitat and open space at risk of land-use conversion: targeting strategies for land conservation," *American Journal of Agricultural Economics*, 88, no. 1 (2006): 28-42.

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In vegetated areas that are not developed and had seen an increase in carbon sequestration during the baseline period, the tool "grows" landscape carbon at a rate consistent with the changes observed through analysis of the LANDFIRE data from 1990 and 2010. In forestland that is developed, the tool records the carbon value associated with the new land-cover type. A pixel converted from forest to vineyard, for instance, will have a negative carbon change for the 2010–2030 period, reflecting the loss of carbon from that land unit.

In the current version of C-CAT, all vineyard and rural residential conversions occur in the model between 2010 and 2030; there is no "second round" of conversion between 2030 and 2050. However, the tool can model the 2030–2050 period with respect to changes in landscape carbon due to vegetation growth and landscape treatments.

When the tool completes a run, it generates a figure for the total changes in landscape carbon from 2010 to 2030 and from 2030 to 2050, a map of the developed land in the county, and a summary of the impacts of the development on four conservation values—agricultural land, aggregate terrestrial biodiversity value, water yield, and headwater stream quality.

Figure 6: Built-in and user-specified inputs control how the C-CAT "grows" vineyards and rural residential developments, which in turn determines overall impacts on landscape carbon and conservation values.

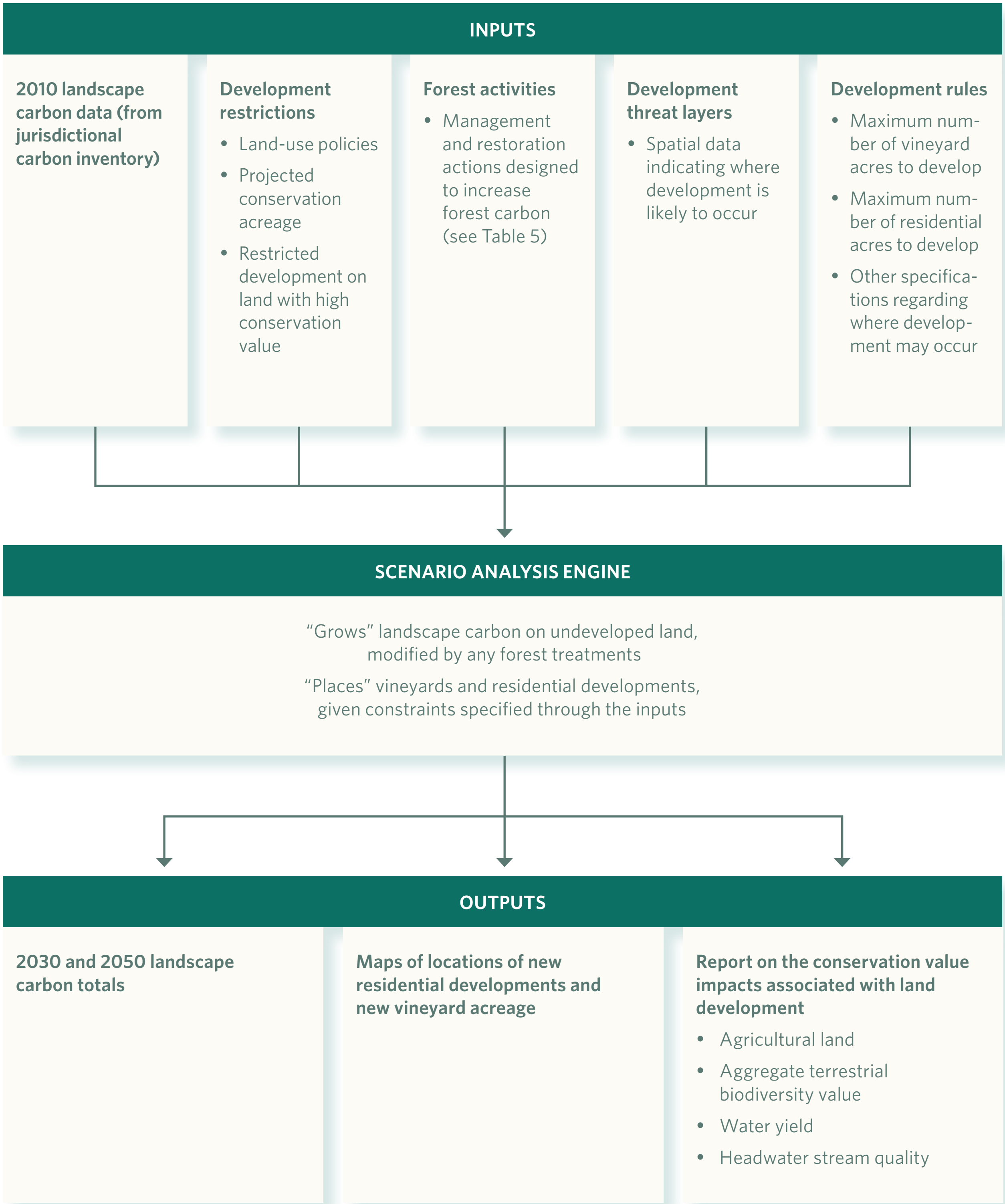

Table 5: The C-CAT Tool can be configured to model a range of land-use policies, land-management activities, and conservation actions.

Category	Variable	Description
Land-use policies	Restrictions on development	Laws and policies limit or prohibit development in certain areas. The model does not allow development on lands within a specified distance of a stream (default is 500 feet), areas of very steep slope (default excludes lands with slope of 55% or greater), Timber Production Zones, land protected by easements, and lands owned by public agencies or conservation organizations.
Converted acreage cap	Vineyard acreage cap	The user can define the maximum amount of acreage that can be converted to vineyards in a 20-year period. The default is 25,000 acres, similar to rates of development observed between 1990 and 2010.
	Residential acreage cap	The user can define the maximum amount of residential development. The default value is 7,500 acres over 20 years, similar to rates observed from 1990 to 2010.
Land conservation	New acres conserved	The user can choose the amount of land conserved over 20 years (beyond existing conserved land). The user can upload data that represents acquisition priorities to incorporate that factor in a scenario. For the countywide scenario presented here, we used data of priority conservation areas defined by SCAPOSD. For reference, from 1990 to 2010, public agencies and conservation groups protected about 80,000 acres in Sonoma County.
Forest activities *These options model the effects of several types of management activities expected to deliver long-term carbon benefits while also increasing conservation values. Additional activity scenarios could be developed and added to the tool.*	Conifer forest management activity	To model the positive effects on tree growth of "thinning from below" silviculture, pixels in parcels zoned for timber production and with certain combinations of size and density according to LANDFIRE data are "grown" one size class between 2010 and 2030. See Appendix D for details.
	Valley oak restoration	Non-forested areas of potential valley oak habitat are allowed to "grow" some forest cover between 2010 and 2030. Forest is grown in a randomly selected percentage of non-forested pixels in these areas.
	Riparian restoration activity	Non-forested areas of potential riparian forest habitat are allowed to "grow" some forest cover between 2010 and 2030. Forest is grown in a randomly selected percentage of non-forested pixels in these areas.

continued on next page

Table 5 continued

Category	Variable	Description
Conservation Values *Lands in each of these categories may be either excluded from development or allowed to develop*	Agricultural land	Areas designated by the state Farmland Mapping and Monitoring Program (FMMP) as Prime Farmland, Farmland of Statewide Importance, Farmland of Local Importance, or Unique Farmland.
	Aggregate terrestrial biodiversity value	The top 20% of lands in terms of habitat quality, as determined by a weighted analysis of seven characteristics: landscape intactness (lack of fragmentation); presence of floodplain habitat; forest structure; rare vegetation communities; linkages between habitat areas; density of rare species; and serpentine soils (which tend to support rare plant species).
	Water yield	The top 20% of lands for average annual water yield, calculated as the sum of water runoff and groundwater recharge.
	Headwater stream quality	Lands within 100 meters of first-order streams (meaning streams that have no tributaries) in areas that are among the top 20% for tree canopy cover. Such lands contribute to headwater stream quality.
	Multi-benefit areas	Lands that fall within the top 20% of a multi-benefit conservation value ranking, calculated as a composite of the five conservation values above.
Other development rules *These options give additional flexibility in specifying where residential or vineyard development can occur*	Other development rules	The user determines whether each of the following restrictions will be turned on or off for the scenario run: Develop unthreatened rural residential areas: New rural residential development either will or will not be modeled in areas with no identified development threat. Develop unthreatened vineyard: New vineyards either will or will not be allowed in areas with no identified development threat. Develop in “no units allowed” areas: The model either will or will not override the “no units allowed” restriction specified in county parcel data. Develop TPZ: The model either will or will not allow vineyard and rural residential development in designated timber production zones (TPZs).

This report presents the results of four runs of C-CAT. Two scenarios evaluate the benefits of conserving Buckeye Forest, a property in Sonoma County that was slated for development. The other two runs compare a countywide baseline scenario with a scenario that includes both extensive forest management activities and accelerated residential and agricultural development.

Buckeye Forest and Preservation Ranch scenarios

Buckeye Forest covers roughly 19,000 acres in northwestern Sonoma County (Figure 8). The site was slated for residential and vineyard development—with the area to be called "Preservation Ranch"—as well as timber production. Instead, the property was purchased by a collection of conservation organizations. Preserving the forest minimized residential development, eliminated the prospect of vineyard development, and provided for sustainable forest management to encourage the growth of large trees.

To understand the differences in carbon sequestration between the two projects, we ran two scenarios on the parcel. The two scenarios start in 2010 with the same amount of carbon; inputs for the two scenarios were identical except for the following differences:

- In the **Preservation Ranch Scenario (Development Scenario)**, pixels in 60 pre-selected estate areas are converted to a carbon value associated with residential development, and all pixels within the proposed vineyard boundaries (totaling 2,408 acres) are converted to a carbon value associated with vineyards.
- In the **Buckeye Forest Scenario (Conservation Scenario)**, pixels in seven pre-selected rural residential areas are converted to a carbon value associated with rural residential development.

Running the tool shows that by 2030, Preservation Ranch would have roughly 1.0 million tCO_2e less landscape carbon than Buckeye Forest (Figure 7). The conversion of forest to vineyard results in an initial loss of carbon. The difference increases over time. While the trees in Buckeye Forest continue to grow and sequester carbon, the vineyards in the Preservation Ranch scenario are assumed to contain a fixed amount of carbon that does not increase with time. Several factors are important to remember when interpreting

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these results. We did not model the alternative forestry activities of the different scenarios. Also, because we didn't estimate the amount of carbon stored in harvested wood products, we have likely overestimated the amount of GHG reductions by as much as 30%.

The C-CAT tool also determines the conservation value of the land converted to residential or vineyard uses in the two scenarios. As Figure 9 shows, the Preservation Ranch scenario has a much greater impact on lands rated at the highest level of importance for water yield.

Figure 7: C-CAT results comparing the Preservation Ranch and Buckeye Forest scenarios indicate that conserving Buckeye Forest would increase net carbon sequestration by roughly 1 million tCO_2e. Preservation Ranch Plan vs. Buckeye Forest Conservation Scenario.

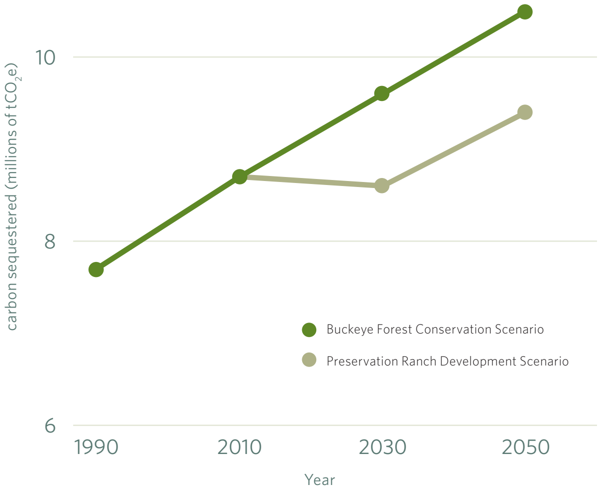


Figure 8: Protecting Buckeye Forest from development is expected to increase landscape carbon sequestration by 1.0 million tCO_2e over 20 years, while also preserving a variety of valuable ecosystem services. Note: while the maps below show the alternative forestry activities under each scenario, the effects of those activities on carbon sequestration were not modeled. The difference in projected carbon sequestration between the two scenarios is due only to the differences in vineyard and residential land conversion.

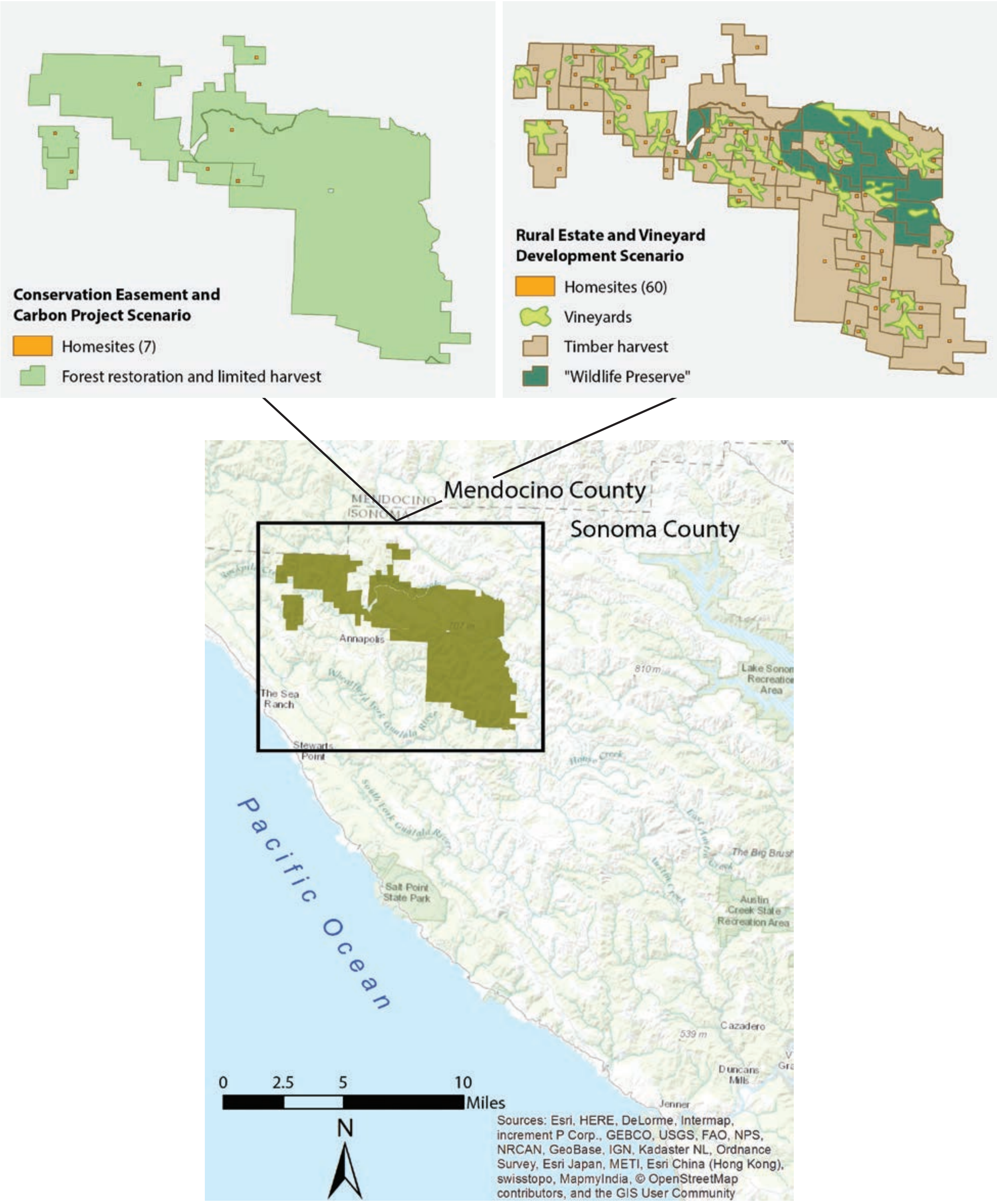
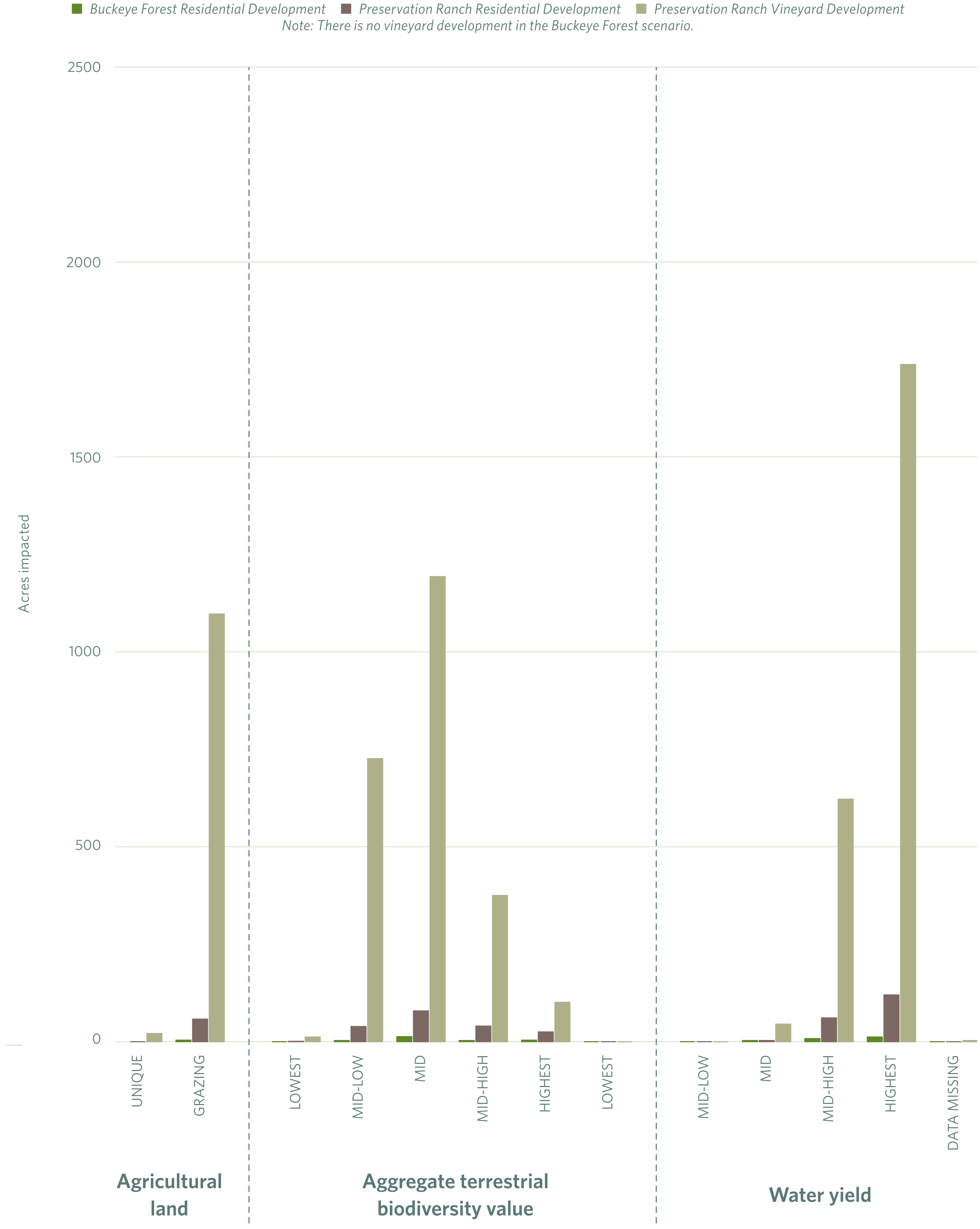


Figure 9: Outcomes for conservation values under two scenarios: Preservation Ranch and Buckeye Forest (acreage impacts for each conservation value due to residential or vineyard development). The three conservation values, and the data sources used to evaluate them, are explained on pages 13 and 18. No land with notable headwater stream quality was impacted by development in this scenario.



Countywide scenario

The countywide scenario presented in this section illustrates three capabilities of C-CAT:

1) spatially explicit modeling of conservation areas (areas where residential and vineyard development is not allowed);

2) quantification of the carbon sequestration effects of improved forest management and oak and riparian restoration activities; and

3) quantification of the net carbon emissions that result from vineyard and residential land development.

The scenario models the conservation of 120,000 acres in the county (beyond what is protected as of 2010). It enacts the three types of improved forest management activities that C-CAT models: 26,890 acres of valley oak restoration, 11,505 acres of riparian restoration, and improved conifer forest management on 6,292 acres in 2030 and 12,559 acres in 2050. In addition, it models 20,000 acres of vineyard development and 5,000 acres of low density rural residential development beyond baseline levels (due to constraints in the current version of C-CAT, all of this development is modeled as occurring between 2010 and 2030; no additional development above baseline levels occurs from 2030 to 2050).

The model was run with this collection of inputs and the results for 2030 and 2050 were compared with the results from the baseline scenario (Tables 6a and 6b). This comparison shows the magnitude of greenhouse gas emissions at stake in long-term decisions about land use, management, and conservation.

The tool estimates that the net carbon sequestration impact of the forest management activities would total 5.0 million tCO2e over 20 years and 9.1 million tCO2e over 40 years. Improved conifer management has the largest impact over the 40-year period, (4.2 million tCO2e) followed by valley oak restoration (3.2 million tCO2e) and riparian forest restoration (1.7 million tCO2e).

The additional residential and vineyard development modeled in this scenario drives substantial carbon emissions. In the 2010-2030 period, this development results in emissions of 4.5 million tCO2e, nearly equaling the additional carbon sequestration generated by the improved forest management activities. In 2030-2050, no additional land is developed. However, compared to the baseline, there are ongoing net emissions associated with the developed land because development removed trees and shrubs that would have continued to grow and sequester carbon. C-CAT estimates the ongoing emissions associated with this lost carbon sequestration opportunity to be 0.3 million tCO2e in 2030-2050.

The impact of the rural residential and vineyard conversions on three of the conservation values is shown in Figure 10.

Tables 6a and 6b: Results from the countywide C-CAT scenario run show how the tool models the carbon sequestration effects of improved forest management activities and increased residential and vineyard development.

Table 6a: Carbon stocks under baseline and alternative (more conservation, widespread improved forest management activities, more development) scenarios, 2010-2050.

(all figures in millions of tCO_2e)			Baseline: Without additional conversion and treatments		Alternative Scenario: Includes land conversion and treatments	
	1990	2010	2030	2050	2030	2050
Areas with no additional treatments or land-use conversion	202.9	218.0	238.5	258.7	238.5	258.7
Valley oak restoration areas	1.8	1.6	1.5	1.4	3.9	4.6
Riparian restoration areas	1.1	1.0	0.9	0.8	1.7	2.5
Improved conifer management areas	4.8	5.0	5.6	6.0	7.4	10.2
Areas converted in C-CAT to residential development or vineyard	4.5	4.8	5.1	5.4	0.6	0.6
Total	215.1	230.4	251.6	272.3	252.1	276.6

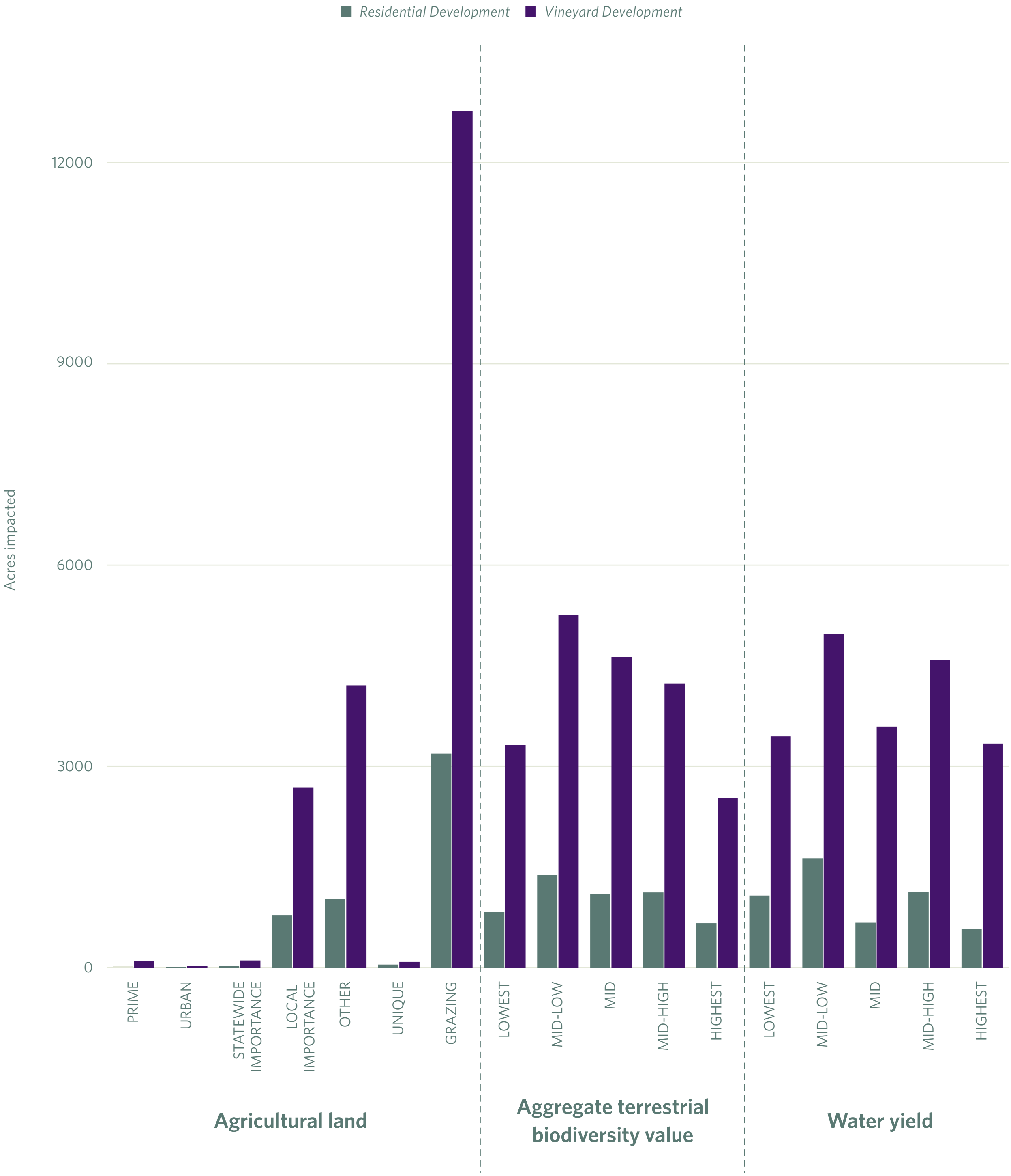
Table 6b: Carbon sequestered (positive numbers) or emitted (negative numbers) due to treatments and land conversion, 2010-2050. The figures in this table represent the difference between the baseline and alternative scenarios.

(all figures in millions of tCO_2e)	2010–2030 changes due to conversion and treatments	2030–2050 changes due to conversion and treatments	2010–2050 changes due to conversion and treatments
Areas with no additional treatments or land-use conversion	0	0	0
Valley oak restoration areas	2.4	0.8	3.2
Riparian restoration areas	0.8	0.9	1.7
Improved conifer management areas	1.8	2.4	4.2
Areas converted in C-CAT to residential development or vineyard	-4.5	-0.3[10]	-4.8
Total	0.5	3.8	4.3

10. In the current version of the C-CAT model, all land-cover conversion in the scenario occurs between 2010 and 2030; there is no additional conversion in the 2030–2050 period. See Appendix D for more details.

The conservation value results from this scenario show the likely numbers of acres impacted by 2030 due to the residential and vineyard development in this scenario (Figure 10). Due to a lack of precise historical data on land use in the county, it is not possible to generate comparable figures for a baseline scenario.

Figure 10: Acreage of land, by conservation value, impacted by the additional 25,000 acres of development modeled in the C-CAT alternative scenario described on page 22.



Economic impact assessment

Economists use a variety of methods to assess the value of conserving natural landscapes. For the CATC project, we use the social cost of carbon, which estimates the long-term economic cost attributable to greenhouse gas emissions. This approach fits with the ethic of conservation that guides the work of TNC and SCAPOSD: taking action to avoid harm to natural systems, keeping in mind the interests of future generations.

The social cost of carbon is typically expressed as the marginal increase in long-term, climate-change-related economic damages associated with the emission of one additional tCO_2e in a given year.

The models used to estimate future economic damages account for impacts such as changes in net agricultural productivity, increased risks to human health, property damages from increased flood risk, certain damages associated with sea level rise, and changes in energy system costs including reduced costs for heating and increased costs for air conditioning.[11] They generally do not account for less-certain but potentially large impacts such as the cost and disruption of human migrations due to sea level rise and major changes in climate; the models also do not quantify some impacts that are difficult to monetize, such as extinctions.

Hundreds of published studies have calculated the social cost of carbon. While the estimates vary widely, reviews of the literature have consistently found the median value of published studies to be well above the current market price of carbon.[12] In this report, we use the U.S. Environmental Protection Agency's figure for the social cost of carbon: $38.42 per tCO_2e for emissions in 2013 (adjusted to 2015 dollars), based on a discount rate of 3%. A discount rate of 3% is typically used in estimates of the long-term value of infrastructure projects and in cost-benefit analyses of policies meant to protect the environment. A higher discount rate results in a lower social cost of carbon figure, and vice versa.

Calculating the economic impact of reducing greenhouse gas emissions using the social cost of carbon methodology is straightforward. For example, in the Buckeye Forest example modeled with C-CAT above, the avoided social cost associated with reducing net emissions by 1 million tCO_2e over 20 years can be calculated in 2015 dollars as 1,000,000 x $38.42 = $38.4 million. Even after only 20 years, this figure substantially exceeds the costs of conserving the land: an initial cost of $24.5 million in 2013 (the year in which the project was approved), or $25.1 million in 2015 dollars, and ongoing management costs in the range of $300,000 to $400,000 annually.

In addition to this avoided cost to society, preventing development on Buckeye Forest preserves key ecosystem services, which provide significant direct value to the county and its residents. These include:

Water yield and water quality: Given the same precipitation and underlying geology, healthy, intact natural landscapes are better able to sustain water delivery through the dry season than disturbed landscapes. As documented through the conservation values assessment, Buckeye Forest's water yield values are some of the highest in the county, making its protection from intensive land uses important for fish and human communities. Conserving the land also has water quality benefits: avoiding sediment and nutrient (nitrogen and phosphorus) loading from rural residential roads, septic tanks, construction, and heavy timber harvest helps to keep stream waters clean. This preserves critical habitat and spawning areas for steelhead, coho salmon, and other aquatic species, while also helping to avoid costly investments in filtration equipment for downstream municipal water supply systems.

Biodiversity: Buckeye Forest includes a rich mix of habitats: coastal redwood and Douglas-fir forest with its associated mixed hardwoods and sugar pine, native true oak stands and woodlands, montane hardwood-conifer forest, chaparral, grasslands, intact riparian corridors, springs, seeps, and wetlands. In addition, Buckeye

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11. U.S. Environmental Protection Agency, "The Social Cost of Carbon" (webpage), 2015, www.epa.gov/climatechange/EPAactivities/economics/scc.html.
12. See, e.g., https://ideas.repec.org/p/cdl/agrebk/qt8wk3t1c8.html for a discussion of the ranges of estimates. See also R. S. J. Tol, "The Social Cost of Carbon," *Annual Review of Resource Economics* 3, no. 1 (2011): 419–43. For comparison, the price of a 1 tCO2e allowance in the most recent auction for California's cap-and-trade system was $12.52.

Forest contains multiple rare grassy openings within the forested landscape. Such meadows have a particularly high conservation value because they provide habitat for a number of rare and endemic species and contribute to landscape level biodiversity.[13]

A 2006 report[14] on the property identified 84 species of birds, mammals, reptiles, and amphibians, including 11 special status animal and plant species. The acreage also contains more than 20 miles of Class I (where fish are always or seasonally present) and II (where fish are not present, but aquatic non-fish vertebrates and/or aquatic benthic macroinvertebrates exist) streams. Protection of Buckeye Forest preserves critical habitat and spawning areas for steelhead, coho salmon and other aquatic species.

13. C. A. Copenheaver, S. A. Predmore, and D. N. Askamit, "Conversion of Rare Grassy Openings to Forest: Have These Areas Lost Their Conservation Value?" *Natural Areas Journal* 29, no. 2 (2009): 133–39.
14. P. Town, "Wildlife Habitat Resources Report for Preservation Ranch," February 10, 2006.

The Buckeye Forest conservation project reduced the number of possible homesites from 60 down to 7, which equates to reduced human and vehicle traffic, which is likely to reduce the number and extent of non-native invasive species that displace native habitat and degrade biological diversity and integrity.

Forest Products: The Buckeye Forest conservation easement allows for economically and ecologically sustainable forest management, including long-term harvest of valuable forest products. A forest management plan is required for the conservation easement and must be approved by the Sonoma County Agricultural Preservation and Open Space District.

Ongoing Carbon Sequestration Potential: Preserving natural landscapes maintains their ability to sequester carbon in the future.

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Policy relevance

The CATC framework and tool can support several existing state climate initiatives and help to ensure that California's natural and working landscapes contribute to meeting the state's climate goals. Specifically, they can:

- *Provide analytical support for investments in landscapes from the Greenhouse Gas Reduction Fund.* Proceeds from the auction of emission allowances under California's cap-and-trade program are deposited in the Greenhouse Gas Reduction Fund, which in turn is used to support a variety of emissions-reduction projects, now called "California Climate Investments." In the 2014-2015 fiscal year, about 8% of the proceeds were used to fund projects to reduce emissions on natural and working lands. The expansion of funding for such programs has been constrained, in part, by difficulties associated with projecting and tracking changes in landscape carbon, including cost, complexity, and a lack of standard methods. The CATC framework provides a set of open-source and transparent methods and tools, usable by agencies as well as landowners, that can help to address these obstacles.

- *Help to integrate landscapes into the implementation of Sustainable Communities Strategies.* Senate Bill 375, the Sustainable Communities and Climate Protection Act of 2008, requires planners to consider the relationships between land use and emissions, with an emphasis on transportation-related emissions. Integrating natural and working lands into these analyses, as the CATC tool kit enables, would help to identify strategies that account for, and optimize, potential greenhouse gas reductions from landscapes and foster regional planning that accounts for the multiple benefits of conservation. In addition, it would demonstrate the synergies and multiple public benefits that can be achieved by coordinating transportation and conservation planning.

- *Facilitate landscape carbon accounting toward meeting statewide GHG reduction goals.* Executive orders issued by Gov. Jerry Brown and former Gov. Arnold Schwarzenegger have set aggressive targets for reducing statewide emissions—to 40% below 1990 levels by 2030 and 80% below 1990 levels by 2050.[15] Gov. Brown also has called for tapping the potential emissions reductions offered by the state's natural and working landscapes.[16] The CATC framework can be used to evaluate the emissions reduction potential at the regional and county level, and then to support the development of county and regional-level plans to develop that potential, consistent with conservation and other public values. Because the CATC carbon inventory methodology is consistent with that used by the state Air Resources Board for state-level estimates, such local and regional planning efforts will dovetail with statewide programs.

- *Help incorporate GHG accounting into state land conservation policies.* The demand for quantifiable reductions in carbon emissions creates the potential to monetize such reductions to help fund conservation activities. Given the uncertainty of long-term state funding for important conservation programs such as those under the Williamson Act, developing new funding streams based on greenhouse gas benefits could become important. The CATC framework could provide the basis for quantifying landscape carbon benefits in such cases and tracking them over time.

- *Account for emissions mitigation pursuant to the California Environmental Quality Act.* State law requires the mitigation of greenhouse gas emissions associated with many new infrastructure and other construction projects. Mitigation measures can include land-management actions designed to reduce emissions or sequester carbon in the landscape, but there is not currently a statewide standard for calculating the carbon benefits of such projects. Adopting the CATC framework would provide a transparent, low-cost methodology that aligns with statewide accounting methods.

15. Executive Order B-30-15, available at www.gov.ca.gov/news.php?id=18938.
16. Governor's inaugural address, January 5, 2015, available at www.gov.ca.gov/news.php?id=18828.

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Conclusions

The Climate Action Through Conservation project makes explicit the link between landscape carbon sequestration and the multiple other benefits of land conservation. These multiple benefits—highly valued by local communities—include climate adaptation, water quality and supply, biodiversity, and agricultural viability.

This report presents a transparent, replicable, and broadly applicable spatial framework for assessing changes in landscape carbon sequestration and conservation values over time. While we have focused on county-scale analyses in this report, the framework could also be applied to multi-county regions as well as to sub-county areas (as in the Buckeye Forest example above).

We hope that future projects will adapt and apply these tools to new geographies. We plan to partner with other organizations to extend the framework presented here to include modeling of the carbon sequestration impacts of agricultural land-management practices and wetland restoration. As this framework is applied in new geographies, future refinements could include new activities and incorporation of alternative risk factors, including those from catastrophic wildfire.

APPENDIX A

An Accounting Framework for Achieving GHG Reductions and Conservation Benefits: A Jurisdictional Approach

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Introduction

This appendix provides an overview of the CATC carbon accounting framework. It outlines a scaled quantification approach to estimating, monitoring, and reporting greenhouse gas (GHG) emissions and carbon sequestration (landscape GHG emissions reductions) for a county. The current framework focuses on four land-cover types: forests, grasslands, shrubs, and urban forests. It provides a general framework for GHG accounting and enables estimates of reductions that may be achieved through management, restoration, and conservation activities. The framework is adaptable and can be modified over time to include updated science and other land-cover types that can produce GHG reductions, such as wetlands and agricultural lands.

Approach and components

Under the United Nations Framework Convention on Climate Change, five key principles should be considered when developing a GHG accounting framework. They include: (1) transparency, (2) completeness, (3) consistency, (4) comparability, and (5) accuracy. This framework is designed to meet all five of these standards.

The framework includes a detailed jurisdictional carbon inventory (Appendix B); a method and guidance to establish a carbon sequestration baseline and demonstrate additionality[1]; a co-benefits analysis (the Conservation Values Assessment—Appendix C); a scenario analysis tool (the Conservation Carbon

1. Additionality in this case refers to the determination of whether a land-management or land-use activity, policy, or decision has the effect of increasing carbon sequestration (that is, reducing net GHG emissions) above a baseline level.

Accounting Tool, C-CAT—Appendix D); and guidance for monitoring, reporting, and verifying carbon sequestration and emissions over time.

- Carbon inventory: A carbon inventory is calculated for biological land cover classes with transparent and publicly available data (based primarily on satellite data from the LANDFIRE program) at the jurisdiction scale. Inventories are developed for current conditions (2010 data) as well as for historical conditions (1990 data) and address the suite of land cover types within the jurisdiction. The carbon inventory methodology, and the inventories themselves, establish a basis to develop jurisdictional baselines and monitoring changes in stocks in the future. Appendix B provides further detail.

- Carbon baseline projection: A linear trend line is developed based on the current and historical (2010 and 1990) carbon inventories for each land cover type. The trend line is projected into the future (to 2030 and 2050) as a reference against which future carbon inventories can be evaluated. Since each land cover type is projected independently, drivers of change can be inferred and explicitly addressed with management activities to change the course of future emissions. The reference line of carbon stocks establishes the basis for determination of benefits from activities that provide GHG reductions and is the main focus of GHG monitoring within the accounting framework.

- Conservation values assessment: A spatially explicit analysis is conducted to assess the conservation values—habitat and biodiversity, water yield, food production, carbon sequestration and climate resilience—associated with lands in the county. The conservation analysis highlights important areas for conservation and provides a basis for achieving co-benefits beyond climate mitigation goals. See Appendix C.

- Scenario analysis: The C-CAT tool (Appendix D) models the carbon sequestration effects of land cover changes and land-management activities. It is spatially explicit, meaning that activities and land-cover changes are modeled as occurring at particular locations; this feature allows for a detailed evaluation of the conservation values affected by the change. It also enables the development of strategies that sequester carbon while also addressing other important environmental, social, and conservation goals.

- Monitoring and reporting: The framework includes guidance for ongoing monitoring and reporting GHG reductions and emissions at the jurisdictional scale. Monitoring and reporting at the activity scale will be developed for each activity. Periodic and/or random activity monitoring ensures effective ongoing implementation and assesses co-benefits.

- Registration of jurisdictional and activity data: A registry should be developed to track both jurisdictional and activity data. Jurisdictional data to be tracked should include inventories (which will be periodically updated), a reference level projection and estimates of jurisdictional reductions. Activity level data in the registry should include the type of management activity implemented, the location of the activity (including the name of the entities involved), the co-benefits sought as part of the activity, and the estimated reductions associated with the activity.

GHG accounting scales: jurisdictional and nested activities

This framework operates at two scales: the county (jurisdiction) scale and the "activity" scale. Both scales have guidelines for accountability and reporting of CO_2e reductions (Fig. A1).

Jurisdictional accounting refers to GHG accounting that occurs within a political jurisdiction, such as a municipality, county, or state.

Activities, by contrast, are defined as discrete actions to enhance existing carbon pools (i.e., sequester more carbon) or prevent land cover classes from being converted (i.e., reduce GHG emissions) over time and space.

Jurisdictional Accounting

Carbon is held in various places in natural landscapes, such as soils, litter, above-ground and below-ground trees, etc. These are referred to as carbon pools. The jurisdictional carbon inventory accounts for the sum total of all covered carbon pools (see Table A1) throughout the jurisdiction's boundaries.

The jurisdictional accounting framework provides a mechanism by which activity-scale actions to reduce emissions are reconciled at the jurisdictional level. Jurisdictional-scale accounting transfers the responsibility of a detailed and statistically accurate inventory to the larger, jurisdictional scale, which may encompass many activities within a broad area.

The jurisdictional accounting system builds upon data sets that are statistically sound and likely to be replicated in the future. The forest inventory (see Appendix B), for example, is calculated from the U.S. Forest Service's Forest Inventory and Analysis (FIA) program. The forest inventory estimated from FIA data uses the same LANDFIRE stratification process developed for the Air Resources Board to geographically represent the forest inventory at a higher spatial resolution. All data sets used are accessible throughout California and likely to be replicated in the future, forming a strong platform for assessing the longevity of carbon sequestration as well as co-benefits.

This jurisdictional approach is similar (though not identical) to GHG accounting approaches undertaken in a number of international jurisdictions seeking to reduce GHG emissions from deforestation and forest degradation and enhance carbon sequestration (REDD+)[2].

A key reason for the use of jurisdictional accounting is that land-use decisions on California's private lands are made predominantly at the local government level—from zoning designations and regional development "blueprints" to the establishment of urban growth boundaries and locally driven conservation initiatives. For this reason, many of the steps to realize the potential for the state's landscapes to reduce net GHG emissions must also be taken at the local government level. In addition, local communities are in the best position to design climate programs that address local needs and concerns.

In certain cases, it may be appropriate for this framework to be expanded to groups of counties or, in the case of federal lands, discrete management units.

Another important benefit of jurisdictional accounting is that it helps to identify carbon "leakage" from activities.

2. REDD+ refers to reducing emissions from deforestation and forest degradation and includes both the conservation and enhancement of forest carbon stocks.

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Leakage occurs when an activity on a given land parcel results in carbon sequestration on that parcel but drives an increase in GHG emissions elsewhere. By quantifying carbon across a broad area, the jurisdictional approach captures both the direct effect of an activity within that activity's boundaries as well as other indirect effects (positive or negative) outside the boundaries.

"Nested" activity accounting

Nested activities are land-management or land-use actions that occur within the county at a smaller scale than the jurisdictional level (e.g., on a single parcel of land). Many such activities can provide or support GHG reductions, including:

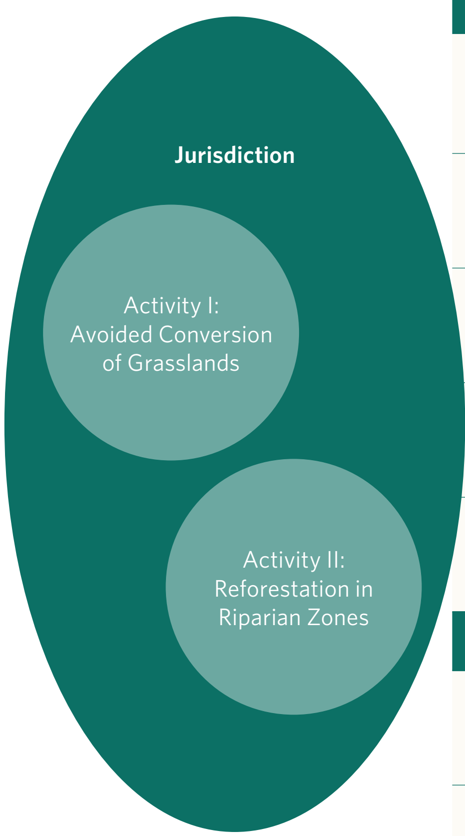
- The avoided conversion of natural land cover types to intensive agriculture or housing; preventing such conversion avoids the immediate release of greenhouse gases associated with land clearing and disturbance, and retains the landscape's ability to sequester carbon in the future.
- Forest management activities designed to accelerate the rate of sequestration and increase carbon stocks in natural and urban forest ecosystems.
- Forest management and restoration activities designed to reduce the risk of catastrophic wildfire and its associated GHG emissions.
- Reforestation in areas that have been converted from forests to other uses or are understocked and identified as environmentally appropriate for being managed under forest cover.

Certain activities provide immediate net GHG emission reductions (e.g., avoided conversion of grasslands or forests) while others provide reductions over a long time horizon (e.g., reforestation). Other activities, such as management for reduced wildfire risk, may cause net emissions in the near term, before producing carbon sequestration over the long term. As the science continues to develop for identifying carbon sequestration benefits associated with changes in management within agricultural systems, those activities might also be included. The list of activities that support carbon sequestration can continue to be developed over time as the data and understanding of carbon accounting for certain activities and land types evolve.

Emissions reductions should be estimated for each activity prior to its implementation over a defined period of time. In this framework, the monitoring of activities is focused more on ensuring that the stated actions defined for each activity are being implemented, rather than on quantifying carbon sequestration outcomes. The determination of net GHG emissions reductions is estimated at the jurisdictional scale. The jurisdictional inventory serves as an accounting "backstop" for activities: the total of GHG emissions reductions from individual activities within the jurisdiction must be consistent with the results of the jurisdictional inventory.

Separately, we recognize that countywide GHG emission reductions will be affected by activities and policies that occur outside the scope of formal nested activities. We anticipate, for instance, that some formal activities will have a "trickle up" effect, prompting other beneficial activities outside the boundaries of the formal activities.

Figure A1. The jurisdictional and activity-level carbon accounting systems are complementary.



Jurisdiction-level GHG accounting	
Baseline	A trend line of carbon stocks in covered pools for the jurisdiction, which serves as a reference line for identifying greenhouse gas reductions.
Quantification	Methods for estimating carbon inventories are defined at the jurisdiction level with a goal of heightened certainty.
Additionally	Carbon stocks in excess of baseline trend are identified as additional greenhouse gas reductions.
Verification	Inventories are developed with transparent and publicly available data.
Monitoring and reporting	Estimates of carbon inventories are periodically updated to track GHG reductions achieved over time at jurisdictional scale.
Activity-level accounting	
Eligibility	Eligible activities and requirements to be described by the program.
Monitoring and reporting	Focus on ensuring stated actions to achieve greenhouse gas reductions occur.

Greenhouse gas assessment boundaries

The GHG assessment boundaries refer to the carbon pools—the physical sites in the environment where carbon is stored—that are included in the Accounting Framework at the jurisdiction scale by land cover class.

In general, carbon pools are included if they are likely to be influenced as a direct effect of land-use or -management activities. The general land cover classes and associated carbon pools included for monitoring are displayed in Table A1. The methodologies for monitoring the covered pools are described in Appendix B.

Table A1. GHG assessment boundaries addressed in the accounting framework by land-cover class.

ID	Description	Type	Included or excluded? By land cover class		Justification/Explanation
Direct Effects					
1	Standing live and dead carbon (carbon in all portions of living trees)	Reservoir	Urban forests	Yes	Changes in standing live and dead carbon stocks are important direct effects of changed management practices in forested landscapes.
			Grasslands	No	
			Shrublands	No	
			Forests	Yes	
2	Soil carbon	Reservoir	Urban forests	Yes	Land use conversion and changed agriculture practices may have significant direct effects on soil carbon
			Grasslands	Yes	
			Shrublands	Yes	
			Forests	Yes	
3	Downed woody debris	Reservoir	Urban forests	No	Downed woody debris may constitute a substantial direct source of emissions when forests are converted to other land uses.
			Grasslands	No	
			Shrublands	No	
			Forests	Yes	
4	Litter and duff	Reservoir	Urban forests	No	Litter and duff may constitute a substantial source of emissions when forests are converted to other land uses.
			Grasslands	No	
			Shrublands	No	
			Forests	Yes	
5	Shrubs	Reservoir	Urban forests	No	Shrubs are especially important in shrublands and are a source when they are converted to other land uses.
			Grasslands	No	
			Shrublands	Yes	
			Forests	Yes	

Continued on next page

Table A1 continued

ID	Description	Type	Included or excluded? By land cover class		Justification/Explanation
Direct Effects					
6	Harvested wood products	Reservoir	Urban forests	No	Strategies to improve forest management may have positive or negative effects on carbon stored in long-term wood products.
			Grasslands	No	
			Shrublands	No	
			Forests	Yes	
7	Harvested wood products in landfills	Reservoir	Urban forests	No	Strategies to improve forest management may have positive or negative effects on carbon stored in long term wood products in landfills.
			Grasslands	No	
			Shrublands	No	
			Forests	Yes	
8	Other management-related emissions, including emissions associated with site preparation, mobile and stationary emissions associated with management activities	Source	Urban forests	No	These emissions are not likely to deviate substantially from reference-level emissions.
			Grasslands	No	
			Shrublands	No	
			Forests	No	
Indirect Effects					
9	Combustion emissions from production, transportation, and disposal of alternative materials to forest products	Source	Excluded for all land cover classes		Changes in forest-product production may cause consumers of these products to increase or decrease their consumption of substitute materials (such as alternative building materials, including cement or steel). In many cases, alternative materials will have higher combustion GHG emissions associated with their production, transportation, and/or disposal than wood products. These activities are included in California's emissions reporting and are therefore excluded.
10	Biological emissions from clearing of existing land cover classes outside of changes in management activities Biological emissions/removals from changes in management practices outside of changes in management activities	Source	Monitoring included within all participating jurisdictions for all activities Monitoring excluded beyond all participating jurisdictions for all activities		California is monitoring landscape carbon throughout the state. Additionally, leakage effects will be monitored by participating jurisdictions, which will only recognize jurisdiction benefits if leakage is held in check.

Jurisdictional baseline projection

The baseline projection represents the anticipated changes in countywide carbon sequestration under a "business as usual" scenario. In this framework, the baseline serves as a reference line against which future carbon sequestration and GHG emissions can be measured.

The baseline is determined from the trend established by the 1990 and 2010 carbon inventories. This 20-year time frame is called the baseline reference period. This approach to the development of baseline is based on similar approaches that are under consideration with programs considering REDD initiatives[3]. The calculated baseline is projected for 20 years and 40 years, to 2030 and 2050. These years are relevant for policy purposes, as they are key deadlines identified in California's climate change programs.

It is possible that a linear increase in carbon sequestration based on an extrapolation from the baseline reference period is not sustainable due to excessive levels of carbon stocking (as in overly dense forests) that are at a high level of risk to disturbance factors, such as wildfire and pests. Other than recommendations for baseline adjustments, described below, this report does not propose how an assessment of such risks would be conducted. In the event that a credible approach to analyzing this risk at the jurisdiction level is developed, the baseline trajectory may be modified accordingly.

Adjustments to the Baseline

A review of the baseline should occur at the 20-year midpoint (that is, in 2020) to determine if it is appropriate for the baseline to continue on the same trajectory. The causal factors that influenced the carbon stocks in the baseline reference period (1990 to 2010) may have changed or the jurisdiction may have achieved a level of carbon stocking that is not considered resilient

3. The Verified Carbon Standard, 2014. Jurisdictional and Nested REDD+ (JNR) Requirements, available at http://www.v-c-s.org/sites/v-c-s.org/files/Jurisdictional%20and%20Nested%20REDD%2B%20Requirements%2C%20v3.2.pdf. See also Meridian Institute. 2011. "Guidelines for REDD+ Reference Levels: Principles and Recommendations" Prepared for the Government of Norway, by Arild Anglesen, Doug Boucher, Sandra Brown, Valerie Merckx, Charlotte Streck, and Daniel Zarin. Available at www.REDD-OAR.org.

to ecological perturbations, as described above. Baselines may need to be adjusted in cases where emissions associated with natural disturbances in the GHG reduction period exceed emissions associated with natural disturbances during the baseline reference period between 1990 and 2010. This is described in further detail below.

Any adjustments to the GHG baseline should be considered carefully, as they will affect calculations of GHG reductions.

Additionality and GHG reductions

Additionality, in the context of this framework, is the net carbon benefit achieved through the suite of management activities and policies within the jurisdiction. It is calculated in periodic jurisdictional inventory updates as the sum of all carbon pools minus the baseline trajectory of carbon pools. This net increase in carbon sequestration relative to the baseline represents overall GHG emissions reductions achieved at the jurisdictional scale.

Permanence of carbon sequestration

The "permanence" of carbon sequestration refers to the duration that an additional tCO_2e is stored and kept out of the atmosphere. In this accounting framework, permanent sequestration is defined as lasting at least 100 years, consistent with California's forest offset protocols.[4]

A reversal of carbon sequestration may occur due to human activities, such as conversion of natural land cover classes to intensive agriculture or housing. Reversals can also occur as the result of natural disturbances like wildfire, disease, or pests, which in the context of this accounting framework are part of the baseline reference period. Natural disturbances are stochastic in nature and it is likely that disturbance events will vary between the reference period and the baseline projection periods. If estimated carbon losses associated with natural disturbances exceed the estimated carbon losses that occur during the baseline reference period, the baseline will be adjusted to compensate for the excess emissions.

4. California Air Resources Board, 2014. Compliance Offset Protocol, U.S. Forest Projects. http://www.arb.ca.gov/regact/2014/capandtrade14/ctusforestprojectsprotocol.pdf.

Individual activities have varying capacity to generate permanent carbon sequestration. It is not always feasible to establish monitoring and reporting protocols at the activity scale for a 100-year period. Incentives could be tailored to encourage permanent reductions at the activity scale, or programs and/or jurisdictions implementing this framework could choose to apply different time frames for activities, so long as the collection of information on activities and reductions is managed to enable documentation of permanent reductions at the jurisdiction scale.

Leakage

While jurisdictional accounting helps to account for and minimize leakage associated with activities to reduce emissions, some leakage outside of the jurisdiction may still occur. Leakage will be completely monitored within the state once all jurisdictions implement a similar program. Certain activities are more prone to leakage than others. Reducing timber harvest in one place may result in increased harvest in other places, for example. Leakage from avoiding conversion to semi-rural housing may be minimized through policies that encourage infill. Each activity implemented within a jurisdiction should address leakage and, where the risk of leakage is high, aim to implement actions to address it. In cases where leakage outside of a jurisdiction is identified, the amount of that leakage (in tCO_2e) could be subtracted from the jurisdiction's overall carbon inventory. This places the local jurisdiction in an active and vital role to resolve further losses of carbon stocks.

Monitoring and reporting

The monitoring and reporting process helps to ensure that the program is meeting its goals of sequestering carbon and achieving the desired environmental and social outcomes. It is envisioned that monitoring and reporting would be conducted differently at the jurisdictional scale than at the activity scale. The administration of monitoring and reporting is described below.

Jurisdictional Monitoring

At the jurisdiction scale, monitoring is the ongoing process of periodically updating the inventory estimates of carbon stocks and comparing the estimates with

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previously reported data and the baseline projection. The data (see Appendix B) used to develop the reports should be updated over five- to ten-year intervals. However, monitoring intervals are often constrained by external programs and their update cycles. Much of the information used to compile inventory estimates for this framework is based on federal programs, such as the Forest Inventory and Analysis (FIA) program and LANDFIRE (a spatially explicit land cover tool).

Monitoring reports may be submitted to the program annually. These reports would provide a description of additional activities implemented over the course of the previous year and their anticipated effects on jurisdictional carbon inventories. The effects of other impacts on previously reported carbon inventories, such as forest growth, effects of natural disturbances, or converted areas can be described and estimated on an annual basis. These reports can be "trued up" as the data used to estimate the inventories are updated and become publically available. Where no updates have been performed, the monitoring report should note that no updates have occurred and indicate that the figures reported are estimates.

Nested Activity Monitoring

To ensure programmatic efficiencies, monitoring at the activity scale should focus on ensuring that the planned activities are implemented. The documentation of the activity should describe the site of the activity and address the anticipated benefits of the activity, including benefits related to biodiversity, water supply and quality, safety, and employment. The activity documentation should also specify the estimated emissions reductions that will be calculated according to methodological guidance developed by the program for each activity. The program might include a random sampling approach to effectiveness monitoring to determine if the methodological guidance and estimated activity benefits are being achieved as intended. Ongoing annual reports may be recommended depending on the activity type.

Administration of accounting framework and incentives

It is anticipated that a state agency, local government ,and/or registry would be responsible for the management and oversight of a database to track various elements within the accounting framework. It is envisioned that the agency would maintain jurisdictional inventory summaries, baseline estimates, and reductions achieved. These data would be published online in a transparent manner. Activity data would be included. Geographic locations of the activities would be available for public oversight, as would be descriptions of the activity type, the environmental and social goals and objectives sought as part of the activity, and any activity-level data and analysis.

Funding or policy incentives for activities may be distributed by various state agencies overseeing specific programmatic areas. Policies and incentives for activities may come from other sources as well. Jurisdictions will seek or develop incentives for activities that best match the priorities that have been established to achieve their environmental and social goals.

APPENDIX B

A Trajectory of Carbon Inventory Estimates in Natural Landscapes of Sonoma County, 1990-2050

Table of Contents

Sonoma County Agricultural Preservation and Open Space District

Introduction

The inventory methodology is designed to quantify and monitor carbon in the major biological sinks, sources, and reservoirs described below for each participating jurisdiction in California. The inventory methodology is designed to capture estimates at the county scale. Fluctuations in soil inventory due to improved agricultural management, for example, are not part of this inventory design.

Carbon inventories are presented in this section in metric tons of carbon dioxide equivalent (tCO_2e). Greenhouse gases other than CO_2 are not included in this inventory methodology at this time.

For standardized reporting, all estimates of forest carbon stocks must be provided in terms of tCO_2e on a project and a per-acre basis. Unless otherwise required in the referenced biomass equations, the following conversion formulae are used:

Base Unit	Conversion		Final Unit
Biomass	.5 x biomass	=	Carbon
Carbon	3.67 x carbon	=	CO_2e
Tons	0.90718474 x tons	=	Metric tons (MT)
Hectares	0.404686 x hectares	=	Acres

The biological inventory is developed to represent inventory estimates of CO_2e for years 1990 and 2010.

The purpose of developing the inventory estimates at two points in time is to establish a trend that can be projected into the future as a reference level, or baseline. The biological inventory is an important structural element for programs looking to prioritize policy initiatives aimed at reducing CO_2e emissions or increasing carbon inventories (that is, increasing carbon sequestration). The biological inventory provides visibility into causal elements of change to carbon inventories and is also a tool to monitor the progress of policy initiatives over time.

The goal of the inventory methodology is to develop accurate estimates at the jurisdiction level. The overall target for statistical accuracy at the jurisdiction scale is +/- 20% at a 90% confidence level. Wherever possible, the development of the inventory methodology should include data that lend themselves to confidence testing. Where such information are not available, the best data possible must be used with the recognition there will be improvements in the future.

The inventory methodology described in this document is designed to be transparent and replicable. The methodology uses publicly available data and data sources that are likely to be updated in the future. This will enable the inventory to be replicated in other jurisdictions within California and elsewhere.

Stratification of jurisdictions into land-cover classes

An important component of the inventory methodology and future monitoring is the division, or stratification, of the land cover into unique classes. Stratification enables inventory estimates from field sampling to be derived with greater resolution. It also leads to a clearer understanding of where carbon exists across the landscape and what drives change within a given land-cover stratum. Furthermore, it enables the estimates associated with the land-cover classes to be presented in graphical format, such as with maps.

The stratification system utilized with this inventory methodology is LANDFIRE[1]. LANDFIRE (also known as Landscape Fire and Resource Management Planning Tools) was developed through an interagency and partnership program that focuses on vegetation, fire, and a fuel characteristics mapping program. LANDFIRE is sponsored by the United States Department of the Interior (DOI) and the United States Department of Agriculture, Forest Service. LANDFIRE produces a comprehensive, consistent, scientifically credible suite of spatial data layers for the entire United States.

The earliest date for which LANDFIRE data was available was 1998, which presented a challenge in terms of estimating vegetative conditions in 1990. In order to estimate 1990 conditions in terms of LANDFIRE vegetation strata, an analysis of changed vegetation between 1990 and 1998 was conducted. Where landscapes had been modified from natural landscapes to agriculture or other converted landscapes, LANDFIRE classes for the converted areas were estimated using a nearest-neighbor analysis, where proximate natural LANDFIRE classes were used to inform the decision.

LANDFIRE data can be accessed throughout California and are likely to be updated in the future. Additionally, the state of California is using LANDFIRE data to develop its emissions accounting system for biological inventories.

The land cover classes addressed in this methodology through the use of LANDFIRE data include:

1. Forests
2. Grasslands
3. Shrublands
4. Barren lands and water
5. Agriculture
6. Urban

1. LANDFIRE, Landscape Fire and Resource Management Planning Tools, is a shared program between the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior, providing landscape scale geo-spatial products to support cross-boundary planning, management, and operations.

Carbon sinks, sources, and reservoirs

The availability of data to develop carbon inventories varies by land cover class. Table 1 provides a comprehensive list of carbon sinks, sources, and reservoirs (collectively referred to as pools) to be included or excluded in quantification of county carbon inventory, baseline trend, and benefits from conservation and land use scenarios and actions. Reasons for excluding a given pool include: a de minimis contribution to the overall carbon inventory, a limited ability to influence the pool through focused activities, or the pool's being outside the scope of the methodology.

Table B1. CO_2e assessment boundaries in Sonoma County inventory methodology.

Land cover classes	Forests	Grasslands	Shrublands	Agriculture	Urban	Barren lands and water
Carbon pools						
Soils	Included	Included	Included	Included	Included	Included
Standing live and dead wood (trees)	Included	Excluded	Excluded	Excluded	Included	Excluded
Litter and duff	Included	Excluded	Excluded	Excluded	Excluded	Excluded
Lying dead wood	Included	Excluded	Excluded	Excluded	Excluded	Excluded
Harvested wood products and landfill	Included	Excluded	Excluded	Excluded	Excluded	Excluded
Shrubs/crops	Excluded	Excluded	Included	Excluded	Excluded	Excluded
Grasses	Excluded	Included	Excluded	Excluded	Excluded	Excluded
Carbon pool included with land cover class	Included					
Carbon pool excluded with land cover class	Excluded					

Included Excluded

Both the acreage and the carbon inventories were estimated at two points in time: 1990 and 2010. This process enabled a trajectory of both land cover area and carbon inventories associated with these land covers to be projected into the future. 2030 and 2050 estimates of land cover acres and carbon inventories by carbon pool are developed, serving as a benchmark against which explicit management activities can be evaluated.

Sonoma County Agricultural Preservation and Open Space District

Inventory methodology: Standing live and dead trees: Above and below ground

Jurisdiction-level inventory estimates are derived using U.S. Forest Service Forest Inventory and Assessment (FIA)[2] data from plots within the jurisdiction. Permanent FIA plots exist throughout forested areas in most of the United States. The plots have been in place for many years and are periodically monitored to update the conditions found on the plots. The location of the plots is confidential and known only to FIA personnel and contractors, landowners who have plots within their ownership, and a few privileged researchers. The plots are intended to be subjected to background perturbations, including wildfire and insect disturbances, as well as management events. Therefore, FIA plots provide a sound basis to portray conditions across forested landscapes. Each FIA plot has an attribute called "Field Type Code" which is used to assign the plot to a forest vegetation group, or stratum.

An inventory analysis was conducted for Sonoma County by Tom Gaman of East West Forestry Associates, Inc.[3] Plot data were retrieved from an FIA data portal[4]. All plots used to develop the 2010 estimate have been re-measured since 2001. While the inventory estimate is intended to reflect conditions as of 2010, no effort has been made to "grow" or update the plots from their date of measurement. Similarly, the plots used to develop the 1990 estimate were based on plot measurements that were as close to 1990 as possible. No effort was made to modify the plot data for the few years' worth of growth. The arguments for not attempting to modify the plot data focus largely on the fact

2. The Forest Inventory and Analysis (FIA) research program has been in existence since mandated by Congress in 1928. FIA's primary objective is to determine the extent, condition, volume, growth, and depletion of timber on the Nation's forest land. Before 1999, all inventories were conducted on a periodic basis. The passage of the 1998 Farm Bill requires FIA to collect data annually on plots within each State.

3. For further information, see Gaman, T. 2013. Sonoma County Forest and Woodland Carbon Inventory 2.0. The Nature Conservancy – San Francisco. Unpublished.

4. (http://www.fia.fs.fed.us/).

that the extent of growth within the short time period is within the measurement error of sampling. Also, for the short time period, more uncertainty would have been added to the tree measurements in any attempt to project them forward.

Carbon estimates were calculated for each plot by calculating the biomass for each tree record using the same regional biomass equations used by FIA in calculating biomass and carbon estimates for the US Forest Service. These equations are available on the Climate Action Reserve's website[5]. The equations use diameter at breast height (DBH), total tree height, and species-specific wood densities to estimate volume and biomass. Carbon in each tree is converted to CO_2e using the conversion multipliers described previously. The estimates for each plot were calculated on a per-acre basis, meaning the estimates can be expanded to provide estimates to larger spatial landscape units that have similar forest vegetation characteristics.

The spatial distribution of Sonoma County's forests was analyzed using both LANDFIRE and CALVEG[6]. Sonoma County's forest vegetation was generalized into two forest types—conifer/mixed conifer and hardwood—and acres of each type were determined. The FIA plots were linked to one of the forest types based on the 'Forest Type' field mentioned above. The conifer plots (30 plots) included redwood and Douglas-fir forest types. The hardwood plots (39 plots) included mixed hardwood and woodland forest types. The per-acre estimates were expanded to the areas represented by each of the two forest vegetation classes. The combined (both conifer and hardwood strata) mean estimate of carbon was 41.6 metric tons C per acre on 514,021 acres for a sum of 21,407,668 metric tons C.

The standard error of the mean estimate of above-ground standing live and dead trees was 4.0, or 9.6%, within the level of confidence desired for the project.

5. (http://www.climateactionreserve.org/how/protocols/forest/biomass-equations/)

6. The CALVEG ("Classification and Assessment with Landsat of Visible Ecological Groupings") system was initiated in January 1978 by the Region 5 Ecology Group of the U.S. Forest Service with headquarters in San Francisco. The Calveg team's mission was to classify California existing vegetation communities for use in statewide resource planning considerations.

Had the standard error exceeded +/- 10%, we would have considered adding additional FIA plots from adjacent jurisdictions for the same broad land cover classes from LANDFIRE to increase the confidence in the estimate.

The inventory estimate for conifers and hardwoods was apportioned to LANDFIRE strata based on an inventory analysis conducted by the California Air Resources Board (ARB). The ARB methodology includes a process that estimated LANDFIRE classes further refined into size and density classes. Each stratum in the ARB methodology is populated with an estimate for above-ground carbon in standing live and dead trees. The ARB estimate used FIA plot data that extended beyond the jurisdiction (Sonoma County) to the entire range of the forest type.

Each ARB stratum estimate was calculated as a percentage of the sub-population (conifer/mixed conifer or hardwood). The percentage was subsequently applied to the inventory estimate based on data unique to Sonoma County. The goal of this step is to produce an inventory estimate that is equivalent to the estimate derived for the jurisdiction, but distributed to more resolute forest strata that include the range of size and density variation found in the forest type.

Estimating the below-ground proportion of standing live and dead trees

Below-ground CO_2e associated with live and dead trees was estimated at 24% of the above-ground CO_2e based on a general analysis of the relationship of root to shoot ratios from use of the Cairns equation[7]. This value was applied to the estimate of the above-ground CO_2e for each LANDFIRE stratum with associated trees. These estimates are displayed in Table 2 (CO_2e in Standing Live and Dead Carbon Estimates in Forested Land Cover Types).

7. Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A. 1997. Root Biomass Allocation in the world's upland forests. Oecologia.

Table B2. Standing live and dead carbon estimates in forested land cover classes.

STANDING LIVE AND DEAD CARBON POOLS

Forest type	Acres	tCO_2e /acre	Total tCO_2e
Coniferous forest			
California Montane Jeffrey Pine (Ponderosa Pine) Woodland	1,229	159	194,802
Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	1	77	52
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	32,980	255	8,396,858
Mediterranean California Mesic Mixed Conifer Forest and Woodland	130	265	34,559
Mediterranean California Mixed Evergreen Forest	13,403	331	4,432,624
Pinus sabiniana Woodland Alliance	2,239	164	366,304
Total	**49,982**	**269**	**13,425,198**
Mixed forest			
California Montane Riparian Systems	7,060	131	922,754
Total	**7,060**	**131**	**922,754**
Oak woodland			
California Coastal Live Oak Woodland and Savanna	5,283	65	345,589
California Lower Montane Blue Oak Forest and Woodland	3,254	99	321,479
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	48,086	108	5,202,761
Mediterranean California Lower Montane Black Oak- Conifer Forest and Woodland	18,212	161	2,928,279
Mediterranean California Mixed Oak Woodland	5,509	60	331,596
North Pacific Oak Woodland	25,787	104	2,690,617
Quercus garryana Woodland Alliance	95	48	4,566
Total	**106,227**	**111**	**11,824,888**
Redwood forest			
California Coastal Redwood Forest	246,809	292	71,971,736
Total	**246,809**	**292**	**71,971,736**
Grand Total	**410,524**	**239**	**98,144,576**

Inventory methodology: Soil carbon

Estimates of soil CO_2e were calculated by intersecting spatial data from a national soils inventory developed by the Natural Resources Conservation Service (NRCS)[8] referred to as SSURGO data, with the LANDFIRE strata that includes land cover, size, and density attributes. The publicly available soil survey contains estimates of soil carbon for each soil class in the survey. The soil carbon inventory estimates were determined by using the values provided for soil organic matter values and soil bulk density values at a depth of 0-30cm available in the SSURGO database for Sonoma County.

The soil organic carbon estimates were calculated as described in "Quantification Guidance for Use with Forest Carbon Projects" from the quantification guidance associated with the Climate Action Reserve's Forest Carbon Protocol, Version 3.3[9]. Soil organic carbon was calculated in metric tons per acre for each polygon from LANDFIRE. Overlaying these soil values with the LANDFIRE strata enabled the calculation of soil carbon values for each stratum, using a weighted average. These values were converted to CO_2e for each LANDFIRE stratum.

The resolution of soil carbon estimates in the NRCS data is broad and does not account for soil carbon associated with landscapes that have been heavily modified through management activities, such as with agriculture and urban development. VandenBygaart et al. (2003)[10] indicate losses of soil carbon associated with conversion of natural land cover types to agriculture or urban use with widely varying estimates of losses. For soils associated with urban, barren, and agricultural land cover types, soil estimates were adjusted to 30% of the NRCS estimates to reflect the decline in soil carbon as the result of enhanced decomposition associated with conversion. Soil carbon was quantified for all LANDFIRE cover classes in Sonoma County. The soil carbon estimates calculated for each land cover class remained constant for historical and projected estimates. Estimates of soil carbon are summarized in Table 3 (Soil CO_2e estimates by Land Cover Class).

8. (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/),
9. file:///C:/Users/john/Downloads/FPP_Quantification_Guidance_1.21.14%20(7).pdf

10. VandenBygaart et al. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can. J. Soil Sci. 83:363-380.

Table B3. Soil CO_2e estimates by land cover class for 2010.

Land cover class	Acres	Per acre	Total
Agriculture and urban	119,175	52	6,197,099
Barren land and water	14,411	4	55,458
Forest	410,524	87	35,526,086
Grassland	136,888	78	10,717,736
Roads	42,621	70	2,979,815
Shrubland	293,161	73	21,260,247
Grand total	**1,016,781**	**75**	**76,736,441**

Inventory methodology: Shrub, lying dead wood, and litter and duff CO_2e associated with forested LANDFIRE cover classes

Estimates of CO_2e in shrubs, lying dead wood, and litter and duff were calculated for forested LANDFIRE cover classes using a tool called the Carbon Online Estimator (COLE) developed by the National Council for Air and Stream Improvement, Incorporated (NCASI) (http://www.ncasi2.org/) and the US Forest Service. COLE relies on FIA data to generate estimates. COLE provides the estimates for litter, duff, lying dead wood, and shrubs (not including the shrub land cover class) forest ecosystems. COLE is an online tool that enables users to query the most recent US Forest Service FIA data available. Queries can be conducted at a variety of spatial scales, including county-scale data. In this analysis, a query was conducted for Sonoma County plots. The inventory estimates from COLE (litter, lying dead wood, and shrubs) are not available for different points in time. Therefore, the inventory values for litter, lying dead wood, and shrubs were held constant for each of the reporting periods.

The data from COLE are reported in tons of carbon per hectare. The reported values were converted to metric tons of CO_2e per acre to be consistent with other reported inventory units. COLE reporting provides estimates by a Forest Type value from FIA data. These data were associated with generalized cover classes from LANDFIRE. Table B4 displays the generalized cover classes associated with LANDFIRE cover classes and the associated data from the COLE report for litter, lying dead wood, and shrubs.

Table B4. Generalized cover classes from LANDFIRE and forest type associations used from the COLE report.

Generalized cover classes	COLE reporting data used	LANDFIRE cover classes	Litter/duff tCO_2e acre	Lying dead wood CO_2e mg/acre	Shrubs tCO_2e /acre
Hardwood Forests	Black Oak	California Montane Riparian Systems	43	6	6
		Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	43	6	6
		California Lower Montane Blue Oak Forest and Woodland	43	6	6
		California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	43	6	6
		California Lower Montane Foothill Pine Woodland and Savanna	43	6	6
		California Coastal Live Oak Woodland and Savanna	43	6	6
		Mediterranean California Lower Montane Black Oak Forest and Woodland	43	6	6
		Quercus garryana Woodland Alliance	43	6	6
		Mediterranean California Mixed Oak Woodland	43	6	6
		North Pacific Oak Woodland	43	6	6
Coniferous Forests	Douglas-fir	Mediterranean California Lower Montane Conifer Forest and Woodland	55	27	24
		Mediterranean California Mesic Mixed Conifer Forest and Woodland	55	27	24
		Mediterranean California Mixed Evergreen Forest	55	27	24
		Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	55	27	24
		California Montane Jeffrey Pine (Ponderosa Pine) Woodland	55	27	24
		Mediterranean California Red Fir Forest	55	27	24
		Pinus sabiniana Woodland Alliance	55	27	24
		Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	55	27	24
Redwood	Redwood	California Coastal Redwood Forest	94	49	6

The individual carbon pools quantified for the forest sector were summed to generate a CO_2e estimate for each LANDFIRE forest class, by size and density for both 1990 and 2010. Tables B5 and B6 display the LANDFIRE forest class (summarized by forest class) estimates for historic and projected acres and historic and project total CO_2e.

Table B5. Historic and projected acres by LANDFIRE forest class.

LANDFIRE forest classes	Acres by year			
	1990	2010	2030	2050
California Coastal Live Oak Woodland and Savanna	3,238	5,440	7,643	9,867
California Coastal Redwood Forest	238,888	242,790	246,692	251,165
California Lower Montane Blue Oak Forest and Woodland	-	3,175	-	-
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	43,577	47,458	51,320	58,629
California Montane Jeffrey Pine(-Ponderosa Pine) Woodland	1,207	1,246	1,284	1,326
California Montane Riparian Systems	4,374	6,902	9,429	11,983
Developed Ruderal Evergreen Forest	-	105	-	-
Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	-	0	-	-
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	32,602	33,204	33,800	34,477
Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	18,205	18,167	18,125	18,127
Mediterranean California Mesic Mixed Conifer Forest and Woodland	151	214	275	338
Mediterranean California Mixed Evergreen Forest	13,072	13,628	14,175	15,996
Mediterranean California Mixed Oak Woodland	4,257	5,878	7,498	9,143
Mediterranean California Red Fir Forest	-	0	-	-
North Pacific Oak Woodland	26,921	25,499	24,083	22,743
Pinus sabiniana Woodland Alliance	2,511	2,400	2,363	2,331
Quercus garryana Woodland Alliance	131	100	63	35
Ruderal Deciduous Forest	-	22	-	-
Ruderal Mixed Forest	-	303	-	-
Grand Total	**389,134**	**406,531**	**416,751**	**436,159**

Table B6. Historic and projected CO_2e tons by LANDFIRE forest class.

LANDFIRE forest classes	tCO$_2$e			
	1990	2010	2030	2050
California Coastal Live Oak Woodland and Savanna	679,496	942,914	1,189,601	1,436,287
California Coastal Redwood Forest	116,129,364	127,305,040	144,447,438	161,589,836
California Lower Montane Blue Oak Forest and Woodland	-	662,088	-	-
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	10,058,782	10,334,071	11,072,237	12,448,210
California Montane Jeffrey Pine(-Ponderosa Pine) Woodland	386,075	427,302	491,889	556,528
California Montane Riparian Systems	1,364,589	1,690,030	2,141,260	2,592,490
Developed Ruderal Evergreen Forest	-	6,652	-	-
Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	-	98	-	-
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	12,835,950	14,140,704	16,027,199	17,915,034
Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	5,736,735	5,720,447	6,021,379	6,322,542
Mediterranean California Mesic Mixed Conifer Forest and Woodland	56,733	95,605	148,524	201,555
Mediterranean California Mixed Evergreen Forest	5,986,954	7,060,232	8,559,665	10,430,870
Mediterranean California Mixed Oak Woodland	851,578	1,050,406	1,290,900	1,531,999
Mediterranean California Red Fir Forest	-	124	-	-
North Pacific Oak Woodland	6,366,682	5,801,499	5,538,698	5,281,039
Pinus sabiniana Woodland Alliance	729,190	775,804	861,765	947,877
Quercus garryana Woodland Alliance	21,604	15,925	10,050	5,897
Ruderal Deciduous Forest	-	1,283	-	-
Ruderal Mixed Forest	-	14,753	-	-
Grand Total	**161,203,731**	**76,044,975**	**197,800,606**	**221,260,166**

The estimates of tCO_2e in all included forest carbon pools and forest acres, historic and projected, are presented graphically by generalized forest types in Figures B1 and B2.

Figure B1. Historical and projected tCO_2e by generalized forest type.

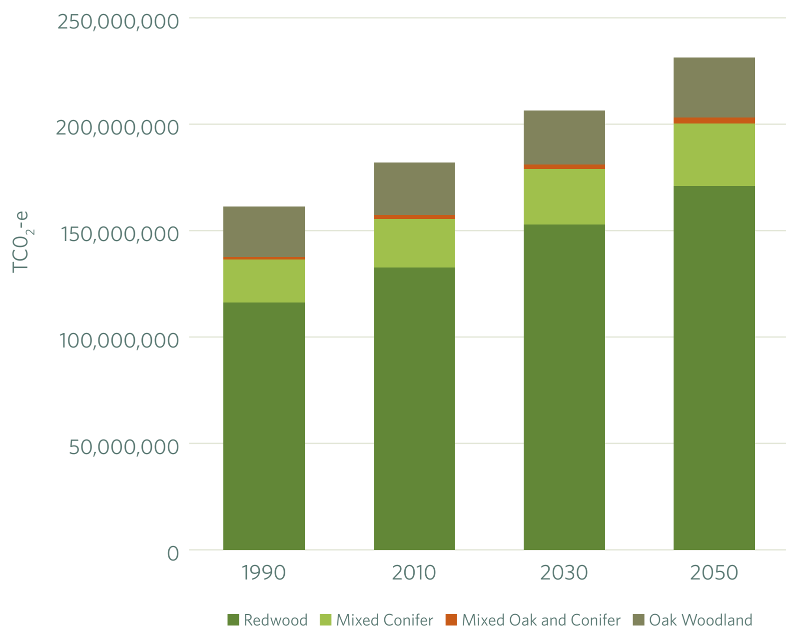
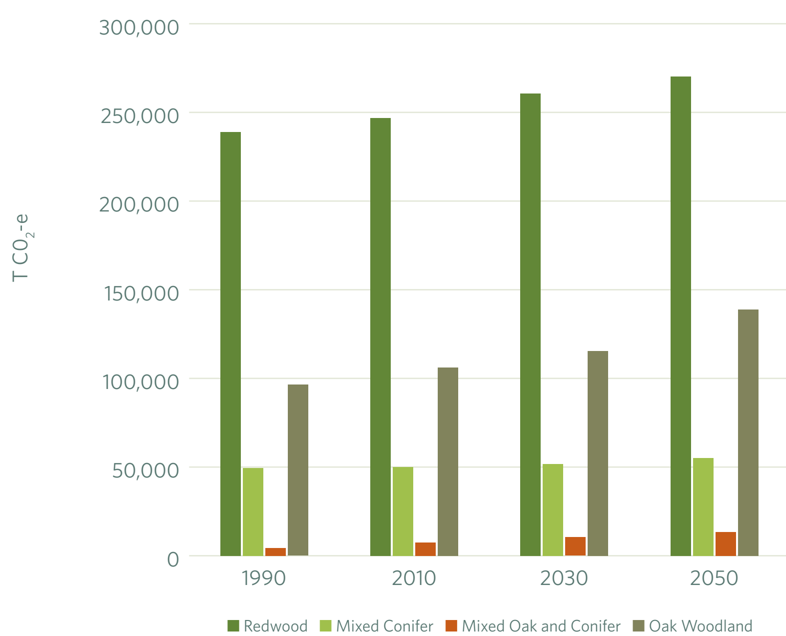


Figure B2. Historic and projected acres by generalized forest type.



Inventory methodology: CO_2e associated with shrubs in LANDFIRE cover classes dominated by shrub cover classes

Shrubland land cover is approximately 30% of Sonoma County's overall land cover, based on LANDFIRE stratification. Besides CO_2e associated with soils, CO_2e associated with shrub, mainly chaparral, provides a substantial contribution to the overall CO_2e storage in this land cover type. CO_2e storage associated with shrubs was estimated for each LANDFIRE stratum dominated by shrubs by comparing LANDFIRE strata (species, size, and density) with similar species compositions, vegetation height, and density found in the Digital Photo Series published by the Pacific Northwest Research Station of the US Forest Service[11]. The website provides links to a photo series that displays the vegetation, identifies the species composition in the photo, and provides estimates of the biomass associated with the vegetation type. The estimates are provided in biomass tons per acre, which were converted to tCO_2e per acre.

Table B7 displays the total CO_2e estimates associated with LANDFIRE strata historically, and projected into the future in Sonoma County. The change in values from between time frames is due to the change in associated acres (Table B8) for each LANDFIRE shrub class.

11. (http://depts.washington.edu/nwfire/dps/).

Table B7. LANDFIRE shrub-dominated strata in Sonoma County with estimates of CO_2e/acre associated with above-ground biomass in shrub cover classes.

LANDFIRE forest classes	Total tCO_2e			
	1990	2010	2030	2050
California Maritime Chaparral	109	359	675	991
California Mesic Chaparral	18,690,708	15,953,979	14,019,698	12,085,416
California Montane Woodland and Chaparral	6,242,314	5,350,855	4,731,217	4,111,580
California Xeric Serpentine Chaparral	74,713	67,355	63,571	59,787
Klamath-Siskiyou Xeromorphic Serpentine Savanna and Chaparral	831,666	765,640	1,597,306	2,428,972
Mediterranean California Sparsely Vegetated Systems	-	170,086	-	-
Northern and Central California Dry-Mesic Chaparral	9,431,102	7,758,167	6,456,545	5,154,923
Northern California Coastal Scrub	318,980	338,952	374,186	409,420
Undeveloped Ruderal Shrubland	-	150	150	150
Grand Total	**35,589,592**	**30,405,542**	**27,243,348**	**24,251,239**

Table B8. LANDFIRE shrub-dominated strata in Sonoma County with estimates of acres associated with above-ground biomass in shrub cover classes.

LANDFIRE shrub forest classes	Acres			
	1990	2010	2030	2050
California Maritime Chaparral	3	3	4	4
California Mesic Chaparral	174,574	152,596	130,617	108,886
California Montane Woodland and Chaparral	57,650	50,693	43,735	36,861
California Xeric Serpentine Chaparral	799	753	707	662
Klamath-Siskiyou Xeromorphic Serpentine Savanna and Chaparral	8,156	7,477	15,633	23,843
Mediterranean California Sparsely Vegetated Systems	-	2,206	-	-
Northern and Central California Dry-Mesic Chaparral	88,327	73,974	59,621	45,371
Northern California Coastal Scrub	2,965	2,890	2,814	2,745
Undeveloped Ruderal Shrubland	-	132	132	132
Grand Total	**332,476**	**290,723**	**253,263**	**218,504**

Certain LANDFIRE strata in urban areas indicate the presence of shrubs based on the description of the cover class and presence of size and density attributes for shrubs. These strata were assigned 19 tCO_2e/acre as their descriptions best matched chaparral cover types that are small in height and medium in density.

Estimates of CO_2e for shrubs in shrub-dominated land cover types are summarized in Tables B7 and B8.

Inventory methodology: CO_2e in harvested wood products and landfills

When trees are harvested, carbon may remain sequestered for long periods of time in harvested wood products and in landfills before they decompose and release the carbon stored in them to the atmosphere. The State of California Board of Equalization[12] publishes annual timber harvest records by county that have been reported for timber harvest tax purposes. The harvest volume, reported in board feet log volume, must undergo several conversions to estimate the amount of carbon sequestered over a 100-year time period in both harvested wood products and in landfills.

12. http://www.boe.ca.gov/proptaxes/timbertax.htm

The data conversions required to estimate the tCO_2e sequestered in long-term wood products are shown in Table B9.

Table B9. Data conversions used to convert harvested logs into estimated tCO_2e sequestered.

Data unit in	Conversion	Data unit out
Log volume in thousand board feet (scribner long volume)	145	Log volume in cubic feet
Log volume in cubic feet	.0283	Log volume in cubic meters
Log volume in cubic meters	.675	Sawtimber in cubic meters. Conversion is a measure of mill efficiency.
Sawtimber in cubic meters	.3990	Sawtimber biomass. Conversion is the specific gravity in softwoods.
Sawtimber biomass.	.5	Sawtimber carbon
Sawtimber carbon	3.67	Sawtimber CO_2e
Sawtimber CO_2e	.76	Sawtimber remaining long-term (100 years) in wood products and/or in landfill.

*All conversion units based on guidance from Climate Action Reserve from Harvested Wood Products Calculation Worksheet guidance (http://www.climateactionreserve.org/how/protocols/forest/).

The trend for harvested wood products developed from 1990 to 2010 would indicate there would soon be no harvest in Sonoma County. As a practical adjustment, we will maintain the volume of harvested wood products at the 2010 level out to 2050. Monitoring of harvested wood products will be achieved through periodic analysis of reported data from the State Board of Equalization. Table B10 displays the harvest data from Sonoma County.

Table B10. Board foot timber harvest in Sonoma County, 1990–2010.

Year	Board feet harvest	CO_2e sequestered metric tons
1990	34,658*	53,449
1991	33,042*	50,957
1992	31,456*	48,511
1993	29,546	45,566
1994	28,042	43,246
1995	26,330	40,606
1996	36,698	56,595
1997	31,739	48,948
1998	20,509	31,629
1999	30,918	47,682
2000	24,157	37,255

Year	Board Feet Harvest	CO_2e sequestered metric tons
2001	9,559	14,742
2002	9,671	14,915
2003	15,698	24,209
2004	14,136	21,800
2005	8,953	13,807
2006	11,196	17,266
2007	10,646	16,418
2008	11,835	18,252
2009	1,288	1,986
2010	8,902	13,729

* Data were not available for these years. They were estimated from linear interpolation.

Inventory methodology: CO_2e associated with grasslands in LANDFIRE cover classes

Grasslands comprise nearly 15% of Sonoma County's land cover according to LANDFIRE stratification. CO_2e in soils associated with grasslands was described within the soils section. The contribution of CO_2e by the above-ground grasses has not been a focus of inventory sampling and no data were available to estimate the CO_2e associated with grasses. We assumed an estimate of of 1 tCO_2e/acre in above-ground grass as a placeholder until better data can be developed. The different LANDFIRE cover classes dominated by grass are shown in Table B11.

Table B11. LANDFIRE cover classes dominated by grass vegetation.

LANDFIRE forest classes	tCO2e			
	1990	2010	2030	2050
California Annual Grassland	4,436,134	4,592,832	4,979,459	5,366,086
California Mesic Serpentine Grassland	1,166	1,321	1,529	1,737
California Northern Coastal Grassland	25,568	18,945	14,122	9,298
Herbaceous Semi-wet	1,321	-	399,544	799,087
Herbaceous Wetlands	693,287	-	-	-
Introduced Upland Vegetation-Perennial Grassland and Forbland	206,959	291,619	-	-
North Pacific Montane Grassland	4,404,033	4,181,665	4,165,052	4,148,439
Pacific Coastal Marsh Systems	2,004,726	1,626,687	1,360,858	1,095,030
Ruderal Grassland	-	88,226	-	-
Undeveloped Ruderal Deciduous Forest	-	-	-	-
Undeveloped Ruderal Evergreen Forest	-	1,170	-	-
Grand Total	**11,773,194**	**10,802,465**	**10,920,564**	**11,419,677**

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Inventory methodology: Urban forest inventory estimates

The estimate of CO_2e in urban forests was based on two levels of sampling. First, the area within a defined "urban area" that has tree canopy is estimated. Second, random ground plots are visited within the urban area. Trees and canopy cover are measured to develop a ratio estimator of CO_2e to canopy area. The ratio estimator can be expanded to desired areas of canopy cover within the urban area, which could include the entire urban area or discrete areas of urban canopy to derive an estimate of CO_2e within the defined area.

The sampling approach included the following steps, each of which is described in greater detail in this section:

1. Define the extent of the urban forest area.
2. Estimate the tree canopy area within the urban area.
3. Select random points with tree canopy for ground-based sampling of tree data to develop an estimate of the relationship between CO_2e and canopy cover.
4. Expand the CO_2e estimate to desired areas of urban forest canopy.

Defining the urban forest area

The United States Census Bureau[13] provides a spatial definition of the urban area. 2010 data were downloaded and used as the basis for urban area sampling. The map below displays the urban area, as defined by the US Census Bureau for the southern portion of Sonoma County (Figure B3).

Estimating the tree canopy area within the urban area

The United States Forest Service has developed an online tool that efficiently estimates the canopy area within a defined spatial extent. The tool is called i-Tree Canopy[14] and is publicly available. The i-Tree Canopy tool assigns sequential random points within the spatial extent identified by the analyst, which in this case is the urban area. The points are intersected on a high-resolution aerial photo, which allows the user to label analyst-defined cover classes immediately under the point. The cover classes included in this sample effort were:

- Tree canopy
- Non-tree, non-plantable
- Non-tree, plantable
- Building
- Road

13. https://www.census.gov/geo/maps-data/maps/2010ua.html
14. http://www.itreetools.org/canopy/

Analysts continue to apply sample points until a sufficient level of confidence is achieved in the estimate of tree canopy cover. In this case, the sampling goal was +/- 5% at one standard error. Figure B4 shows the trend of the estimate of canopy cover and sampling error relative to the increasing sampling intensity.

The sampling effort resulted in a mean estimate of 26.1% canopy cover area within the urban forest area. It was also estimated that an additional 27.8% of the urban area could support tree canopy. This figure indicates the potential to expand urban tree planting areas, although must be taken with caution as there are many social and environmental reasons why this would be impractical.

Select random points with tree canopy for ground-based sampling of tree data to develop an estimate of the relationship between CO_2e and canopy cover.

Approximately 260 points (of 1,000 points) from the i-Tree Canopy survey intersected with tree canopies. 120 points of the 260 points were randomly selected for field sampling. Tree data collected from the fixed area field points included tree species, Diameter at Breast Height (DBH), and total height. Canopy area measurements were also recorded within the fixed area. The tree data wer analyzed using biomass and

Figure B3. Urban area within the southern portion of Sonoma County from U.S. Census Bureau data.

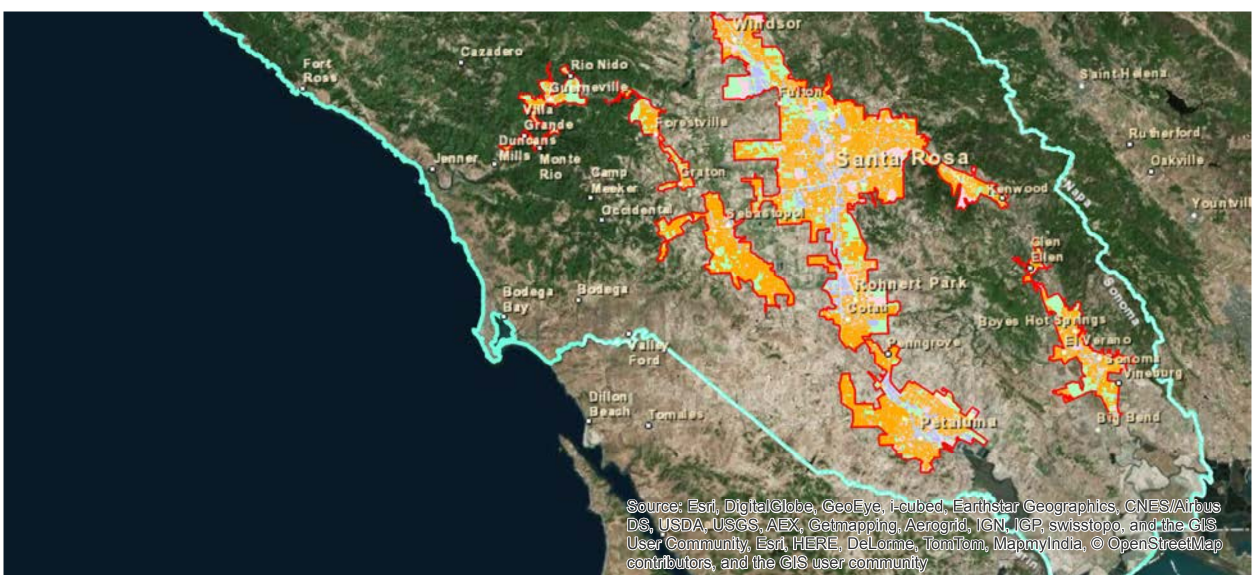
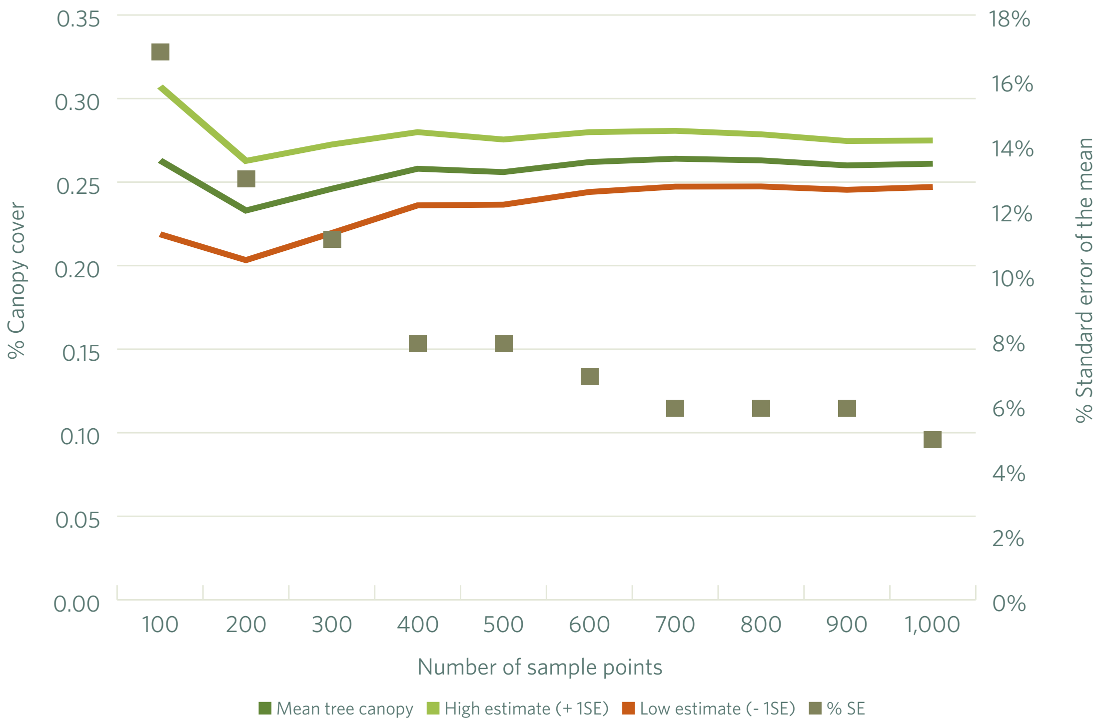


Figure B4. Trends of percent canopy cover and sampling error associated with increasing levels of sampling intensity.



density equations Greg McPherson of Pacific Southwest Research Station has collated from published sources. The list of equations is published (forthcoming) on the Climate Action Reserve's Urban Forest webpage.[15]

The ratio estimate was calculated to be 41.69 kilograms CO_2e per square meter of canopy area, or 1.25 kilograms CO_2e per 30-meter pixel that is 100% in tree canopy. The LIDAR data provided a proportional value for each pixel to which the ratio estimator was applied to calculate the CO_2e associated with the urban LANDFIRE cover classes.

Expand the CO_2e estimate to desired areas of urban forest canopy

The initial intent of the inventory design was to expand the CO_2e/canopy area ratio to the entire urban area using the canopy area estimate in the entire urban area as a multiplier. This would have completely replaced the above-ground standing live and dead tree estimate for the urban area. It was determined that the LANDFIRE data within much of the urban area provided the ability to perform better spatial analysis that would have occurred had we assigned one estimate to the entire urban area, or even within urban classes within the urban area.

Instead, LIDAR data were intersected with those LANDFIRE cover classes that were determined to be highly urbanized and likely to be improved through application of the estimation process described in this section. Table B12 displays the LANDFIRE cover classes that met the urban classification. Each 30-meter LIDAR pixel has a measurement of the portion of the pixel that is in tree canopy, which enabled an estimate of canopy area to be determined for each of the LANDFIRE cover classes.

15. http://www.climateactionreserve.org/how/protocols/urban-forest/

Table B12. LANDFIRE cover classes designated as urban.

LANDFIRE cover classes	
2010 Classes	High-Intensity Urban
	Low-Intensity Urban
	Medium Intensity Urban
	Western Cool Temperate Urban Deciduous Forest
	Western Cool Temperate Urban Evergreen Forest
	Western Cool Temperate Urban Herbaceous
	Western Cool Temperate Urban Mixed Forest
	Western Cool Temperate Urban Shrubland
	Western Warm Temperate Urban Deciduous Forest
	Western Warm Temperate Urban Evergreen Forest
	Western Warm Temperate Urban Herbaceous
	Western Warm Temperate Urban Mixed Forest
	Western Warm Temperate Urban Shrubland
2009 Classes	Developed/High-Intensity
	Developed/Medium Intensity
	Developed/Upland Deciduous Forest
	Developed/Upland Evergreen Forest
	Developed/Upland Herbaceous

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The 2010 estimate of CO_2e is 2,699,131 tCO_2e on 100,882 acres of area designated as urban forests. Of the CO_2e estimate, approximately 10% of the COe is in urban trees, with the balance in soils. The estimate of acres and CO_2e in urban forests is expected to increase by approximately 3% by 2050.

LANDFIRE modified its classification rules for the 2010 LANDFIRE classification, which created a challenge in reconciling certain 2010 land cover classes with earlier classifications. The greatest challenge existed with agriculture and urban classifications. The 2010 estimate of urban area was considered more reasonable than the 1990 estimate as a base. We applied an adjustment to the 1990 estimate of urban land cover based on professional judgment. Otherwise the change in the estimate of urban land between the two dates would have been far from reasonable. We anticipate the future releases of LANDFIRE data allow for improved reconciliation between LANDFIRE cover classes as drastic changes in how LANDFIRE classifies cover classes is not anticipated.

Summary

Carbon inventories are expected to increase in Sonoma County. Most of the increase will take place within redwood and Douglas-fir forests where per-acre values of CO_2e increase substantially and there is some increase in the area they will cover. Shrublands are projected to decline, due to forest expansion as well as conversion to agriculture. Figure B5 displays the projection of CO2e by cover class and harvested wood products out to 2050. Figure B6 displays the projection of acres by cover class out to 2050.

Figure B5. Projection of CO_2e by cover class to 2050.

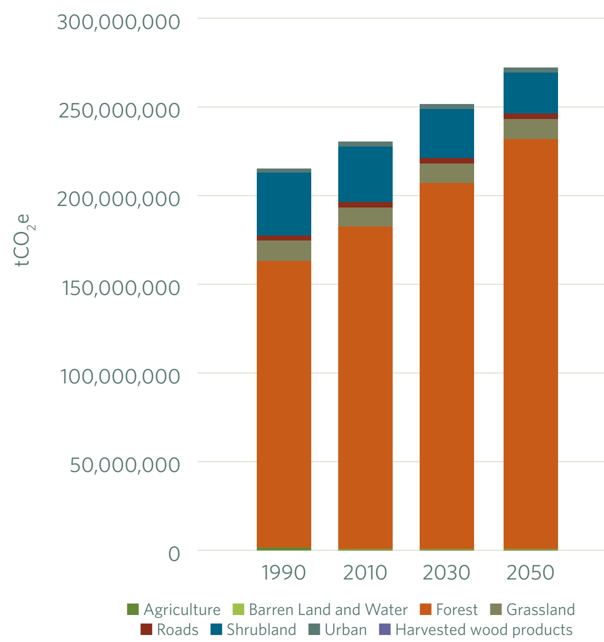
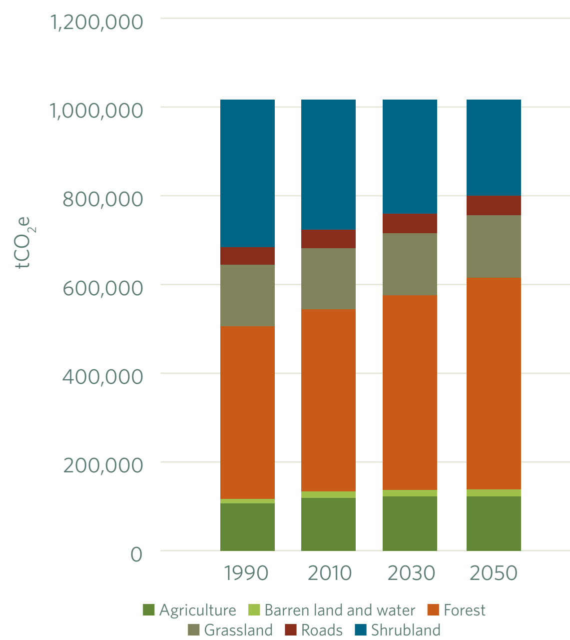


Figure B6. Projection of acres by cover class to 2050.



APPENDIX C

Sonoma County Conservation Values Assessment

Table of contents


Sonoma County Agricultural Preservation and Open Space District

Introduction

The Sonoma County Conservation Values Assessment ("assessment") is an integrated approach to mapping the relative conservation value of multiple themes (such as agriculture, biodiversity, and water resources). These conservation value layers can be used to assess the co-benefits and tradeoffs of alternative conservation management and land-use scenarios. Stakeholders throughout the county have different priorities, so it is only through an integrated approach that conservation values can be aligned to meet collective social, economic, and ecological goals. This assessment is a key component of the Climate Action Through Conservation project.

This assessment is an example of a "regional greenprint" in which multiple themes, such as agricultural productivity, habitat conservation value, and water resources, are represented using spatial data and prioritized using transparent criteria. Regional greenprints can have many drivers or key questions—such as how energy development can co-exist with species protection, or how a landscape can sustain agricultural productivity while providing high-quality water for urban residents. The framework of a regional greenprint is meant to support decisions related to multiple potential drivers and scenarios, and be adapted as new questions emerge or data become better. In other words, the structure provides an ability to answer questions related to the impact or benefit of a variety of policies or land use and conservation actions and, as such, lead to more informed and accountable decision-making for how land and water resources are managed.

In this assessment, we assembled spatial data for multiple themes within the county, including agricultural productivity, terrestrial habitat, water-related

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ecosystem services (supply and quality), ecosystem carbon storage, and climate change resilience. This document describes the assumptions, data sources, and processing steps and presents the results of the assessment. We consider this information an initial step toward a broader strategy for integrated conservation and land use decision-making in the county.

The approach that we have taken is not meant to replace conservation planning for specific implementation strategies such as riparian restoration or land acquisition. The amount of data resources and analytical depth needed to accurately prioritize those types of investments is beyond the scope of this effort. Yet, this assessment presents contextual information for finer-scale strategy implementation, and an initial accounting of co-benefits associated with those strategies. As such, it can be a basis for forging unconventional partnerships and leveraging funding across themes, providing exposure for positive multi-benefit conservation outcomes.

Conservation values

Agricultural Productivity

Agriculture supports open-space preservation by providing an economically stable land use alternative to urban uses. Working landscapes provide numerous public benefits such as healthy, locally produced food, open and scenic landscapes, and a robust local economy. Sonoma County's roughly 160,000 acres of cultivated lands and 417,000 acres of pasture and rangeland support a wide range of row and field crops and livestock and poultry products, notably high-quality wine grapes and organic dairy products. The gross value of the raw agricultural commodities in Sonoma County is valued at approximately $900,000,000 per year[1], placing it in the top 20 counties in California in agriculture production. In Sonoma County, as in many places, urban and industrial development has occurred disproportionately along major transportation corridors in lowland areas where row, crop agricultural productivity is highest. For instance, this important land base has been affected by a nearly 30% increase in urban development since 1984[2]. Similar impacts have reduced the extent of livestock grazing rangelands in the county, although these areas have been subject to lower-density, rural "ranchette"-style subdivision rather than urban or industrial development. Low-density subdivisions may reduce land lots to below agriculturally viable sizes and in other ways reduce overall suitability of a region for livestock operations. Protecting productive soils and large lots from subdivision and development through conservation easements supports agricultural productivity and thus helps to maintain the community benefits agriculture provides.

This theme focuses on lands that are currently used for agricultural production of all forms—both row-crop and other "intensive" farmland types as well as rangelands that are potentially used for livestock grazing, or "extensive" agriculture. The approach described below does not prioritize one form of agriculture over the other (e.g., intensive over extensive). Agricultural resources we identified as conservation priorities for this study include all remaining farmland on the Santa Rosa Plain and other alluvial valley floors, economically important vineyards and orchards, and the large swaths of productive grasslands located throughout the county that produce forage for livestock grazing.

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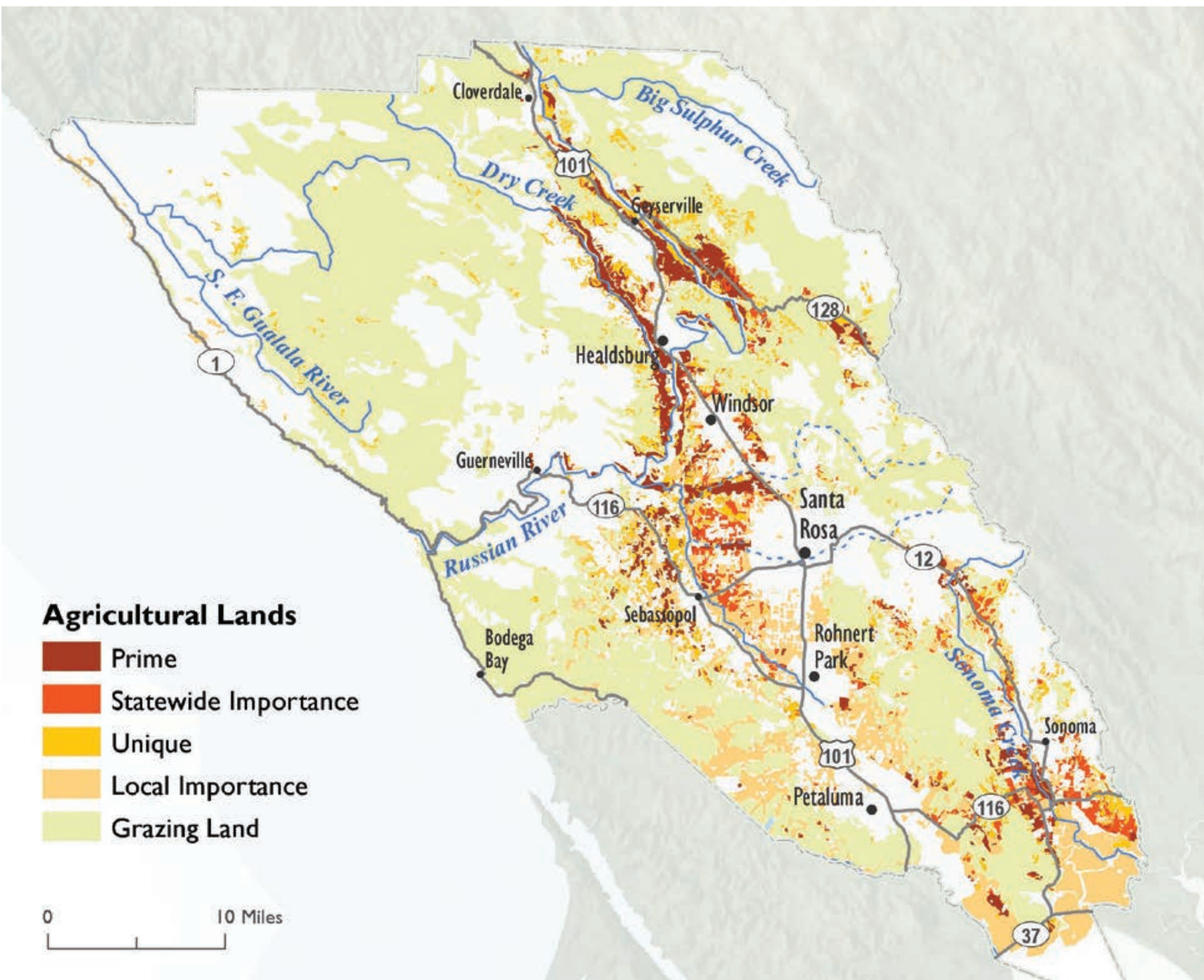
We distinguish between intensive and extensive agriculture in the modeling framework in order to accurately assess impacts resulting from conversion. For example, there may be differences in water resources needed between intensive and extensive agriculture, and the degree to which land is converted from a "natural" state is much higher for intensive crop types. Furthermore, a distinction is made because of differences in the economic value of crops produced, the much smaller land base for intensive agriculture, and the higher likelihood of farmland loss to other developed uses given historic patterns of conversion. While we have not explicitly factored in the threat of conversion at this point in the analysis, historical patterns of conversion have disproportionately affected land used for intensive crops. Distinguishing between intensive and extensive agriculture rather than treating both as a single class gives the ability to address these differences in relative impacts of conversion and threat.

For the spatial data analysis, we used GIS data published by the California Department of Conservation's Farmland Mapping and Monitoring Program (FMMP)[2]. The FMMP maps active farmland and suitable livestock grazing land for most counties in California using high-resolution aerial photography and input from local government officials. We used the most current FMMP edition at the time of our analysis, which was based on aerial photography taken in 2010. Farmland is categorized into four classes in FMMP: Prime Farmland, Farmland of Statewide Importance, Unique Farmland, and Farmland of Local Importance. Grazing land is its own category (Figure C1). Prime Farmland and

Farmland of Statewide Importance are distinguished for their ability to sustain long-term agricultural production based on soil characteristics, slope, and ability to store soil moisture. In Sonoma County, these farmland types are found in the shallow alluvial valleys and support many of the county's iconic orchards and wine appellations. Unique Farmland contains soils of lesser quality on steeper slopes but support some of the state's most high-value crops. Indeed, many of Sonoma County's most famous hillside vineyards (e.g., Kunde, Kendall Jackson, and Gallo) are designated Unique Farmland. Farmland of Local Importance is farmland deemed important to the local agricultural economy. In Sonoma County, Farmland of Local Importance mostly comprises hay production in Sonoma Valley and west of Petaluma that is critically important to the county's livestock industries. Full descriptions and mapping criteria for each class can be found here: http://www.conservation.ca.gov/dlrp/fmmp. The data are updated every two years.

For the purposes of this assessment, all existing agricultural land is considered high value. Assessment of relative value across agricultural land types requires a mix of physical and economic analyses that are beyond the scope of this assessment. Thus, we make the simple distinction between agricultural land (i.e., cultivated and rangeland) and non-agriculturally valuable land (e.g., poor soils, forests). Figure C1 shows the geographic distribution of agricultural land by FMMP class.

Figure C1. Agricultural lands in Sonoma County.



Data Sources: CA Department of Conservation—Farmland Mapping and Monitoring Program 2010

Terrestrial biodiversity

Sonoma County has a diverse collection of habitats from coastal scrub to redwood forest to hot, dry oak woodlands and grasslands. This vegetation and habitat diversity is due primarily to the highly variable physical and climatic conditions characteristic of this area. We prioritized terrestrial habitats in a way that represents different aspects of conservation value. For example, an area of land may be important for what is in it (e.g. as habitat for rare or vulnerable species), or where it is in the landscape (e.g. between two protected areas or near freshwater). Both of these factors may be a driving factor in a conservation prioritization, based on the objectives of a conservation strategy. To represent the different scales of information and levels of biological organization (species, community, landscape type) that are important to consider in conservation planning, we collected data for both more general "coarse filter" elements such as vegetation communities and "fine filter" elements such as locations of rare, endemic species and communities.[3]

A key assumption in this approach is that the relative level of disturbance from roads, croplands, and development infrastructure, including homes, commercial, and industrial areas, is a key factor in the long-term viability of ecosystems and at-risk species.[4] Areas with a large proportion of converted habitat or extensive fragmenting features such as roads, homes, or office parks have lower habitat value for most species than large, intact wildland areas. Yet several biodiverse habitats and unique species in coastal California can thrive within a more developed matrix and need to be prioritized as well. These include habitats such as vernal pools, seasonal wetlands, riparian areas, and some rare plant concentrations. The approach described here prioritizes areas where these features are found within a less developed matrix of land uses, while recognizing the high value of these habitats in any landscape context. In other words, we prioritize areas that provide benefits to ecosystems at both broad scales (such as landscape intactness) and fine scales (presence of unique communities or endemic species). In addition to these factors, we also incorporated the results from the Bay Area Critical Linkages project that identified priority areas for maintaining habitat connectivity at regional scales for a complementary set of focal species.[5] Preventing fragmentation of habitat is a critical factor in maintaining healthy populations of wildlife, especially wide-ranging species.[6]

Below we describe the categories of data used to characterize relative terrestrial biodiversity conservation value. Our final layer—aggregate terrestrial biodiversity conservation value—is a weighted summation of the seven conservation value elements described below. This approach is based on relatively simple algorithms and fundamental assumptions of conservation biology. This design provides a plausible starting point for future refinement and engagement by a range of stakeholders.

Landscape intactness

Similar to other landscape assessments of conservation value, a key element to help set priorities is the degree to which land is intact or, conversely, fragmented.[7] We developed an intactness surface for the county using two inputs: road density (weighted by class of road) and anthropogenic land cover (cultivated croplands and developed lands).

We assigned a weighting to the roads data to reflect their relative influence as a movement barrier for wildlife. Specifically, our assumption is that larger roads have more traffic and are physically wider and more difficult for wildlife to traverse. We assigned a weight of 10 to U.S. and state highways, a value of 5 to secondary roads (major arterials), and a value of 1 to city streets and local roads.[8] This means that for a given length of road, a highway is modeled to have ten times the fragmenting influence of a local road. We sampled the road density with a 1-kilometer search radius in a circle around each 100-meter cell to create a surface of weighted road density. To classify land cover, we used the General class level of our classification of LANDFIRE land cover types (Appendix 1B). We assigned a weight to the land cover classes based on their relative disturbance of existing habitat. We assigned developed (residential, industrial, commercial) land classes a weight of 5: barren, water, and agricultural classes a value of 1: and all other natural and semi-natural lands[1] a value of 0. These weightings are meant to represent the relative resistance to move-

1 Semi-natural lands are defined by the National Vegetation Classification Standard as vegetation that has been shaped by both anthropogenic disturbances and ecological processes (e.g. reclaimed cropland or rangeland).

ment that these land covers represent to wildlife. We smoothed this layer to account for the proximity effects of disturbance using a 1-kilometer search radius around each 100-meter cell. We scaled the road density surface into five equal area (quintile) classes with values scaled from 1 (roadless) to 5 (highest density). The road density and land cover disturbance grids were added together, and rescaled so that the lowest fragmentation values have a value of 1 and highest values are 0. This was done so that the landscape condition grid could be combined with the other terrestrial habitat conservation value inputs.

Rare, endemic, and threatened species and habitats

We used several composite data sets to represent areas that support rare, unique, and endemic plants and wildlife. These include:

1. **Serpentine soils:** Due to the high suitability of serpentine soil for many rare plants, we used the NRCS soil survey[9] to identify areas where the parent material of the dominant component included any serpentine-derived bedrock (Figure C2). These polygons were classified as binary (1 for present, 0 for absent) and the layer was smoothed using a 500-meter search radius.
2. **Restricted habitats:** We used a compilation of data developed as part of the Conservation Lands Network (CLN) planning by the Bay Area Open Space Council to represent rare plants, vernal pool complexes, and old growth forests (Figure C2).[10] The "rarity" value assigned by the CLN process was used to assign weightings to the different communities, with the most rare, getting a value of 2, and more common types getting a value of 1. The same smoothing function was applied as with serpentine and the final output was scaled from 0-1, low to high.
3. **Density of rare element occurrences:** The California Natural Diversity Database (NDDB) records observed occurrences of rare plants, animals, and other communities that are rare globally or within California.[11] We weighted the number of times an occurrence is counted in the density surface based on the Global (G) or State (S) Rank assigned by NatureServe and California Department of Fish and Wildlife. These are assigned based on the estimated number of individuals that exist within the state or the world (Table C1). Because the database maintains many historical records or occurrences that may be of lower quality, it is important to filter the data. We filtered the occurrences and removed extirpated, older, lower-quality, and less precisely mapped occurrences that have not been extirpated. We then summarized the density of point occurrences (using the weights based on G/S ranks) to develop a continuous surface of values. Because observational data is incompletely sampled and is easily misinterpreted, we used the data conservatively in this analysis. This layer was scaled 0-1, low to high. See Figure C2 for the full range of values.

Table C1. Global (G) or State (S) Rank weighting scheme.

Class	Weight
G1 or S1	10
G2 or S2	5
G3—G5 or S3—S4	2

Wildlife linkages

We used modeled wildlife linkages developed as part of the Bay Area Critical Linkages project as a factor in setting the relative conservation value levels for biodiversity conservation. Both riparian corridors and landscape linkages were included in the analysis (Figure C2). There are a range of focal species included in the linkages assessment and the network represents the union of all the individual focal species linkages.[5]

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Forest structure

Structurally complex forests provide important and increasingly rare habitat for many species in the forested parts of California.[12] We prioritized stands with larger tree sizes and a more closed canopy as a proxy for late seral forests in the county. We applied ordinal weights to each combination of the tree size and canopy cover reclassification of the LANDFIRE data, as shown in Table C2. We smoothed the grid using a 500-meter search radius for each of the 30-meter cells. While older stands of oaks may have more open canopies than younger stands, we applied the same classification to both hardwoods and conifer forests in the county. Figure C2 shows the distribution of values for forest structure across the county.

Table C2. Weightings applied to tree size and canopy cover for forest structure.

	Cover			
Size	1	2	3	4
1	0.1	0.1	0.1	0.1
2	0.1	0.25	0.25	0.25
3	0.25	0.75	0.75	1
4	0.75	0.75	1	1

Floodplain habitat

Floodplains provide important habitat for terrestrial and aquatic species and communities and provide numerous ecosystem services. We selected all FEMA Q3 100-year floodplain and all SSURGO soil survey map units that have any flood frequency (Rare, Occasional, Frequent).[9,13] We removed all cultivated and developed land within the extent of these two layers using the 2010 Farmland Mapping and Monitoring Program (FMMP) classification for developed land, and prime, statewide, or unique important farmland to create a layer of non-cultivated, non-developed floodplain habitat. A binary raster was created from this final polygon layer with a value of 0 representing non-floodplain habitat and 1 representing floodplain habitat.

Aggregate terrestrial biodiversity conservation value

The multiple criteria that we assembled for terrestrial biodiversity value span a wide range of conservation values, across a broad range of space and time. Some values are place-based and may be somewhat ephemeral (vegetation communities or species occurrences) compared to others that may provide benefits over large areas (e.g. linkages). To reflect the aggregate habitat conservation value, we summed these criteria using a weighting assigned based on expert assignment of relative importance to ecological integrity. Both the criteria themselves as well as the weights can be adjusted based on stakeholder input and this approach is not meant to be prescriptive. For each criterion ***j*** we multiplied the criterion value ***v*** by the weight ***w***, and summed to get habitat value.

$$Hab_{sum} = \sum_{j=1}^{n} w_j v_j$$

The weights used for each input are shown in Table C3.

Table C3. Weights used for combined terrestrial biodiversity combined layer.

Factor	Weight
Landscape intactness	3
Floodplain habitat	2
Forest structure	2
Rare vegetation communities	1
Linkages	1
Species density surface	1
Serpentine soil	.5

Figure C2. Inputs used to classify terrestrial biodiversity conservation value. These data are combinations of fine-filter and coarse-filter criteria. For forest structure, areas in darker green are indicative of late seral forests and have higher weighting.

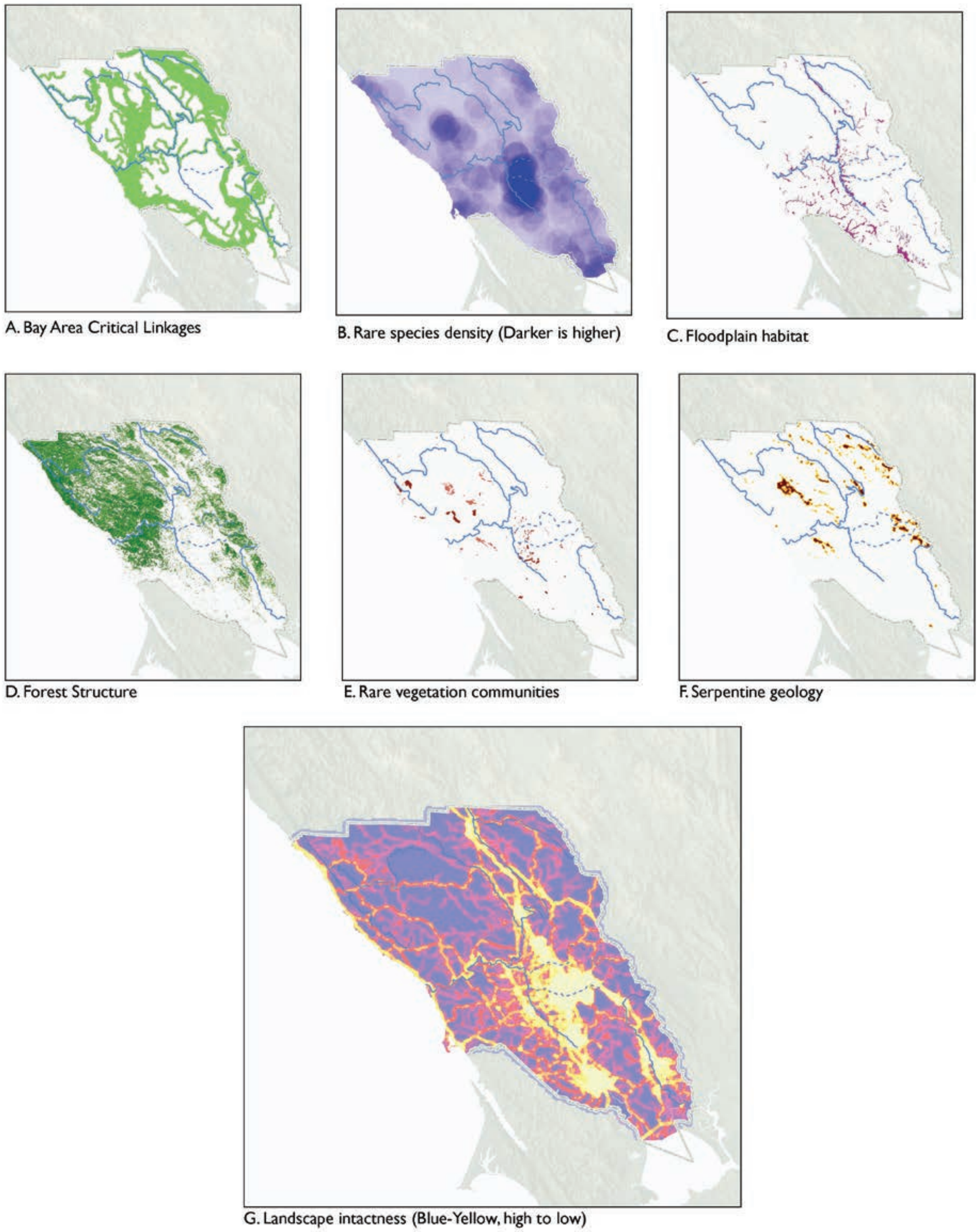
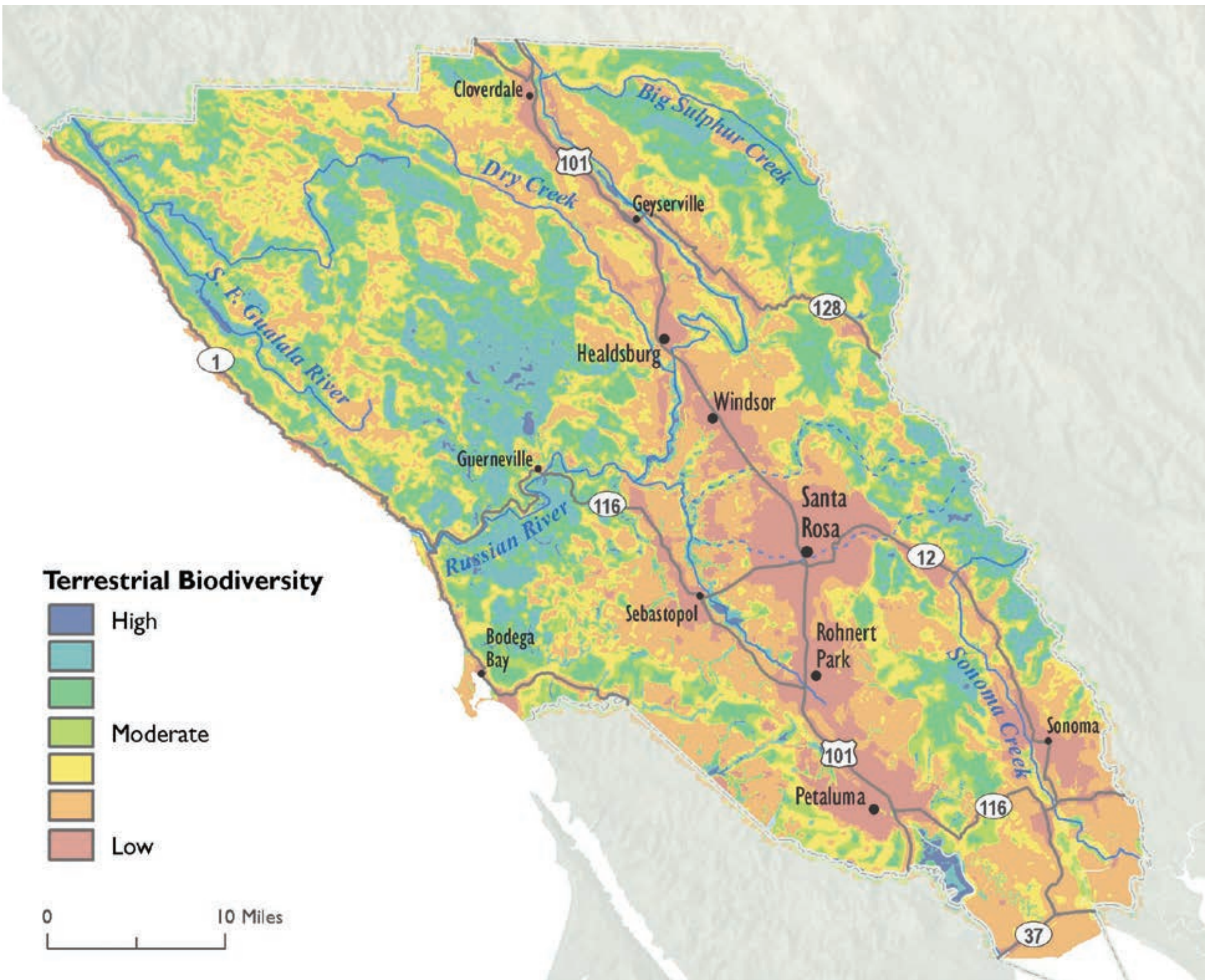


Figure C3 shows aggregate terrestrial biodiversity conservation value as defined above. Because of the higher weighting for the landscape intactness, many lands at the edge of developed areas and cultivated agricultural lands show up as low to moderate value. This is partly due to the scale of the input data that we used for this analysis. Finer-scale data on habitats and species occurrences may be available, but were not compiled for a large enough portion of the county to be used here.

Figure C3. Terrestrial biodiversity relative conservation value.



Data Sources: CDFW NDDB, Bay Area Open Space Council,LANDFIRE, USDA NRCS SSURGO, U.S. Census Bureau TIGER, Bay Area Critical Linkages, FEMA Q3

Water-related ecosystem services

Rainwater capture and filtration by natural lands is an important process in Sonoma County. For instance, the Russian River provides clean drinking water for over 600,000 people in the region without the need for an expensive treatment plant. The river's relatively intact watersheds and deep alluvial gravels capture and naturally filter rainwater. Tributaries of the Russian and other rivers and creeks in the county deliver water that is used for agriculture and rural residences. Native vegetation, particularly along headwater streams, is an important component of the natural water capture, filtration, and delivery processes.[14] We present below methods to assess water-related ecosystem services via two factors: water yield and headwater stream water quality.

Water yield

An important ecosystem service related to water supply is water yield, or the total amount of rainfall and other precipitation that comes from a given area after accounting for losses from evapotranspiration. Precipitation that is not lost via evapotranspiration moves as surface runoff into streams or into aquifers via subsurface infiltration. It is considered an important conservation concern because, in addition to all wildlife, human communities rely on these water supplies for drinking water, agricultural irrigation, and power generation.

Water yield varies throughout the landscape. It is affected by precipitation patterns, soil and geologic conditions, location of aquifers, terrain (e.g., slope), and vegetation cover. In Sonoma County, the above factors lead to particular areas generating more water yield than others. For example, the mountainous regions of the county tend to yield more water than the large river valleys. For the purpose of including a water supply benefit in this conservation assessment, we considered areas that yield the greatest amount of water to be higher priorities for conservation in order to preserve the ecosystem benefits they deliver to ecosystems and human communities.

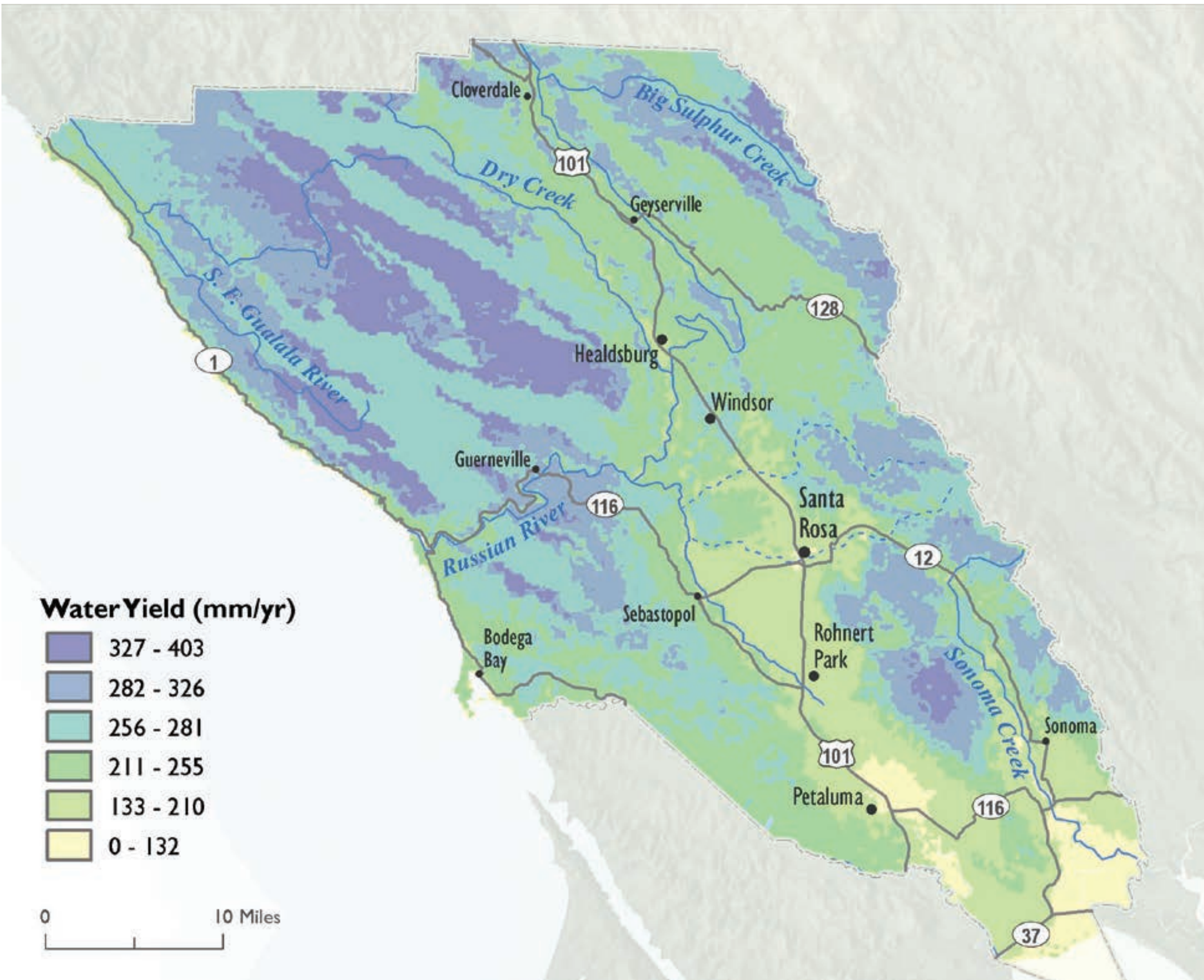
Water yield of a given location is represented in water balance models as the difference between total precipitation and evapotranspiration. As discussed above, an area yields the remaining precipitation as either surface water runoff or groundwater recharge. Therefore, water yield for a region can be estimated by adding runoff and recharge values at all locations in the region. This type of calculation is made possible in Sonoma County through the data developed for the California Basin Characterization Model,[15] which produced maps of runoff and recharge estimates for the whole county, from 1981-2010 average annual rates (Figure C4).

Headwater stream water quality

A key ecosystem service provided by intact watersheds is the delivery of clean water for downstream agricultural, residential, commercial, and industrial uses. Filtration of sediment and pollutants from surface water runoff by roots and biomass in vegetation provides benefits to water users and ecosystems downstream, possibly to the degree that it can offset expensive water treatment plants.[16] Shading from vegetation also keeps water cool, providing habitat for salmonids and other species. This filtration and temperature modulation happens at multiple spatial and temporal scales, yet headwater streams are recognized as a key hydrologic feature in which maintenance of water quality is critical.[14]

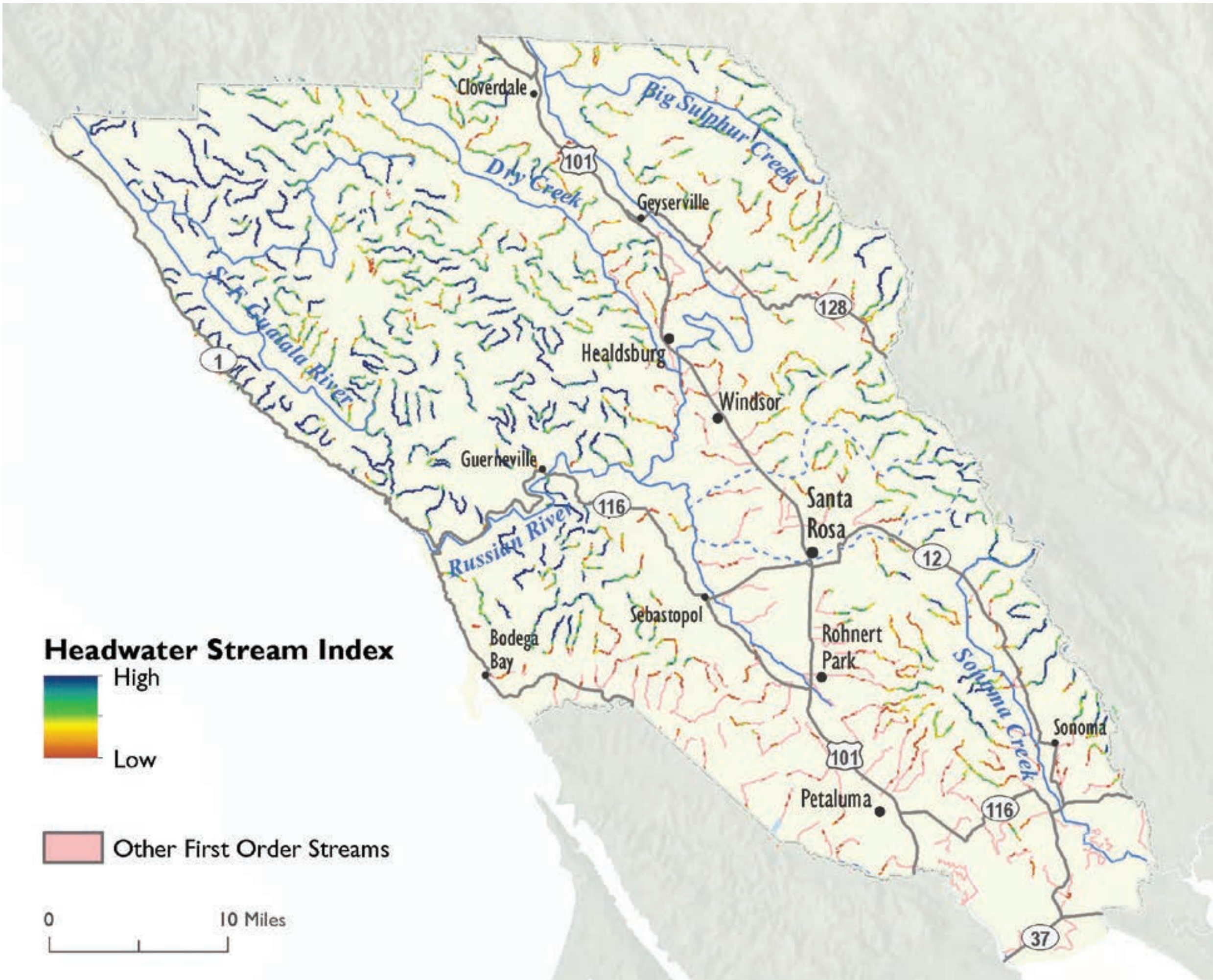
Given the role of forests and streamside vegetation in providing these benefits, we developed a headwater water quality index based on the amount of forests and woodlands within a 100-meter buffer of first-order streams mapped by the National Hydrography Dataset (NHD).[17] We selected hardwood forest and woodlands, riparian vegetation, and conifer forests from the LANDFIRE 2010 Existing Vegetation Type dat aset used for the carbon inventory and summarized the combined proportion of these beneficial cover types in a 300-meter-radius circle around each cell in the 100-meter buffer raster. This layer of woodland, riparian, and forest cover was then selected for the area within a 100-meter buffer on first-order streams (Figure C5).

Figure C4. Water yield is the sum of runoff and recharge data for each 270-meter pixel in the Basin Characterization Model data. While not all water is captured for economic uses, this can be considered the basis of a water supply ecosystem service that benefits agricultural and developed land-use water uses.



Data Sources: USGS Basin Characterization Model Avg Annual Recharge and Runoff (1981–2010)

Figure C5. Headwater stream index. Because of the importance of vegetated first-order streams in downstream water quality, we summarized the proportion of a 100-meter buffer on these streams that have forest, woodland, or riparian streamside vegetation as a proxy for water quality ecosystem service benefits.



Data Sources: USGS LANDFIRE 2010 vegetation, USGS NHD

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Ecosystem carbon storage

One of the primary goals of the Climate Action Through Conservation project is to provide tools to account for the climate benefit of alternative land use and conservation scenarios. These benefits are provided by either the avoided emissions from habitat conversion of land, changes in management practices to reduce emissions from fire, or the increased sequestration of CO_2 in vegetation and soil through conservation and restoration actions. To create these tools, we used public domain plot data for Sonoma County (Forest Inventory and Analysis, or FIA) to assemble a county-level above-ground forest and woodland inventory. We have allocated the county-level inventory to mapped vegetation classes using estimates provided through the statewide forest and rangeland stock change assessment commissioned by California Air Resources Board.[18] For detailed methods on the forest and woodland inventory and other information related to carbon in other pools and ecosystem types, please see the inventory methods document, Appendix B.

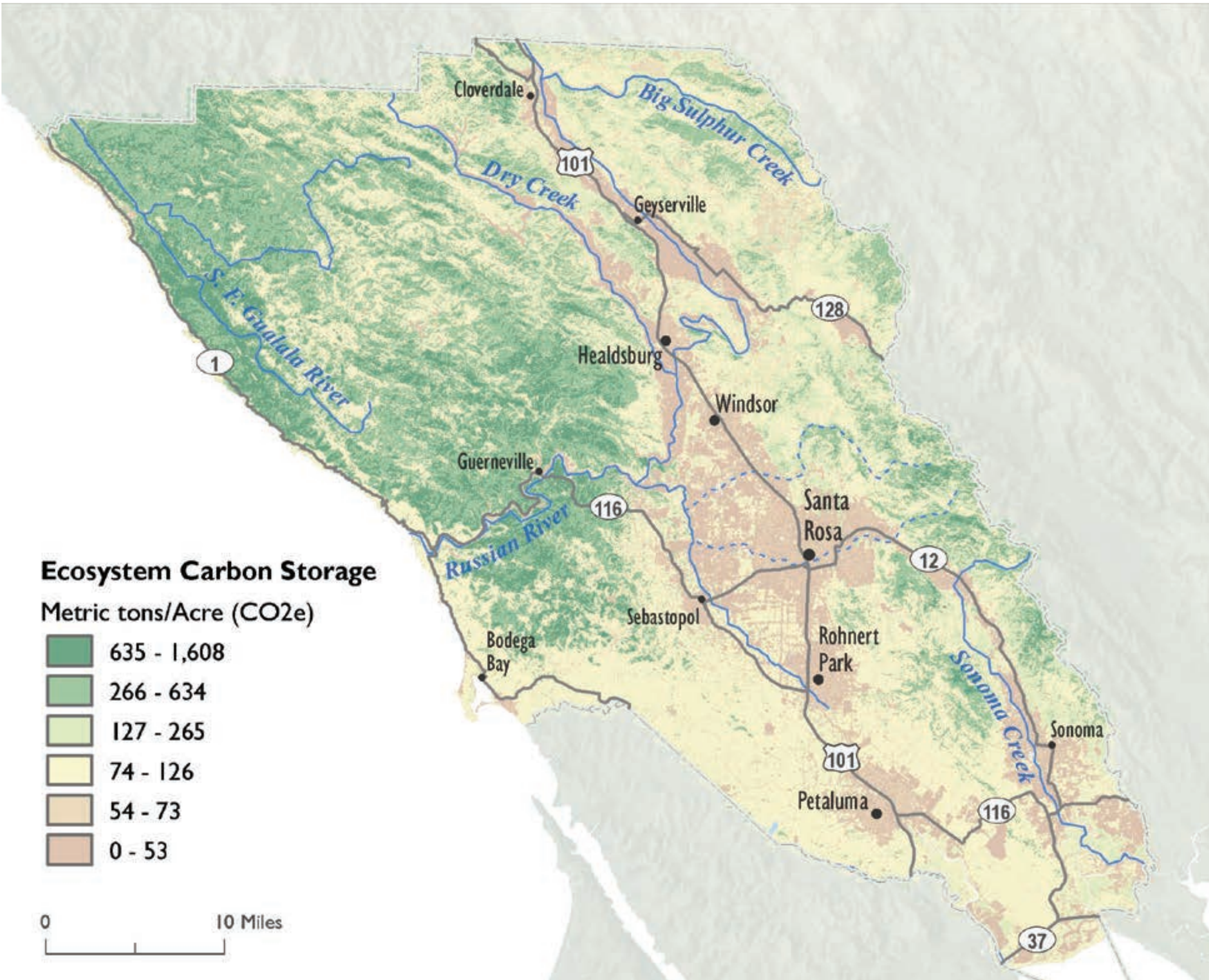
There were 69 plots from 2001 to 2010 from the FIA program that we used to conduct the 2010 above-ground inventory. The plots were divided into two primary strata—one for mixed evergreen and conifer forest types, and for hardwood forest and woodland types. Summary statistics for each stratum are shown in Table C4.

Table C4. Summary statistics for forest and woodland inventory using 2001-2010 FIA data.

Summary statistics (Metric ton /acre carbon)	Mixed evergreen and conifers	Hardwoods
Mean	62.8	24.5
Standard Error	8.2	3
Median	46.1	20.9
Standard Deviation	49.9	16.9
Sample Variance	2489.8	285.3
Range	244	79.6
Min	1.9	4.7
Max	245.9	84.3
Count	37	32
Confidence Level (90%)	13.5	4.9
CI (90%) sampling error	22%	20%

We used the LANDFIRE 2010 existing vegetation type, land-cover, and height data as strata for the carbon stock inventory, using the proportional allocation of the stock into strata from the Battles et al. study as a way of allocating our two carbon classes. For soil carbon, we used the NRCS SSURGO inventory and analyzed it using methods described in the inventory document. Figure C6 shows the total above- and below-ground carbon storage (2010) for the pools that we measured in the inventory.

Figure C6. Ecosystem carbon storage for above- and below-ground carbon storage. See Appendices A and B for the full inventory methodology.



Data Sources: USGS LANDFIRE vegetation data, FIA inventory, Carbon Online Estimator, USFS shrub photoseries, NRCS SSURGO for soil

Climate change resilience

Sonoma County Resilience

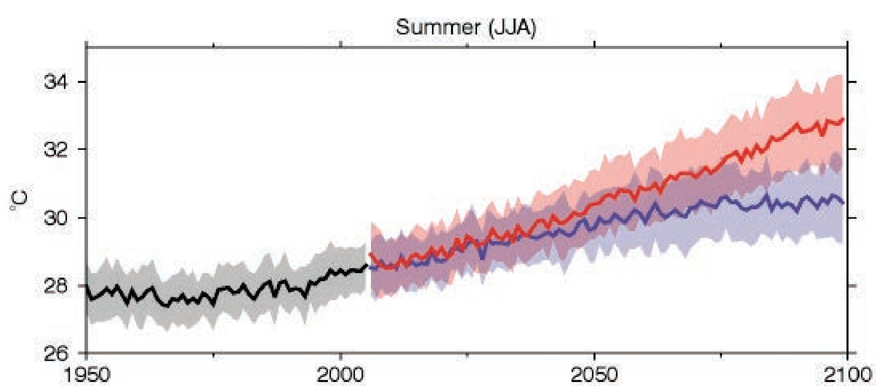
In the coming century, Sonoma County is likely to experience increases in maximum summer temperature (between 2.7 and 4.1 degrees Celsius, 4.9 and 7.4 degrees Fahrenheit), increases in water stress in plants, and decreases in soil moisture (Figures C7-C9 show climate projections for Sonoma County).[19] The combination of these changes will likely mean that natural communities will increasingly experience stress due to moisture limitations. Plant and animal species will be more resilient to these climatic changes if they are able to access areas less stressed by moisture limitations.

Climatic water deficit (CWD) is a measure of the evaporative demand that exceeds soil moisture and is calculated as potential evapotranspiration minus actual evapotranspiration.[15] CWD has been shown to be a key determinant in plant distributions in the Bay Area. Although CWD may increase in general in the coming century, the pattern and distribution of CWD diversity is not expected to change significantly. Therefore, areas with relatively lower climatic water deficit may continue to have relatively lower species turnover and therefore will likely be important areas for biodiversity in the future.

Changes in distribution are likely to occur in plants and animals to adjust to the changed conditions. Landscapes that are unfragmented and that facilitate local movement better enable species to redistribute to access areas with more suitable climatic conditions. We assume that this ability to access a range of habitat conditions confers resilience to species in those regions. Areas with high local permeability may also serve as a resource for neighboring species and communities. We measured the degree to which the landscape facilitates local (3-kilometer) movement by assessing the degree of landscape conversion, the location of transportation and energy infrastructure, and housing density. Specifically, for each cell, we quantified the proportion of the 3-kilometer neighborhood that is accessible to that area based on resistance-weighted movement outward from the focal area. We treat permeability here as a generalized representation of resistance to movement and not specific to any species groups. So, while permeability in fragmented areas is lower in general, there are still movement options at fine scales through agricultural or developed areas, especially through riparian areas.

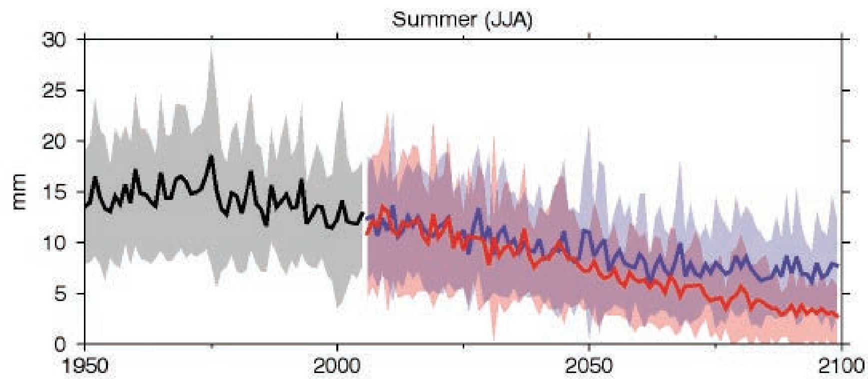
In Sonoma County, areas close to the coast, lower elevation river valleys such as the Russian River Valley, the Santa Rosa Plain, and the Baylands are relatively less stressed by moisture limitations due to lower evaporative demand in cooler areas and the accumulation and storage of water in floodplain soils (Figure C10). These will become even more important for supporting floral communities as the region experiences higher temperatures and more evaporative deficit in the coming century. However, these areas have already experienced high degrees of landscape conversion and are therefore less accessible to species whose movement is impeded by infrastructure and development (Figure C11). Alternatively, the Sonoma Coast Range and the Northern Mayacamas are largely permeable landscapes and contain some smaller regions with locally lower CWD. These areas may be increasingly important in supporting biodiversity in a changing climate.

Figure C7. Maximum summer-season air temperature projections for Sonoma County (historic (black), RCP4.5 (blue), and RCP8.5 (red)). The range of all climate models is shown in the shaded areas around the lines that represent the model average.



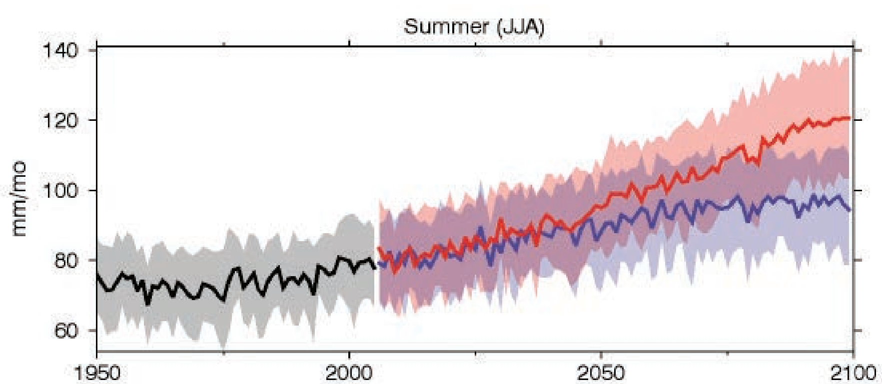
Data from National Climate Change Viewer, http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp

Figure C8. Summer-season soil water storage (mm) projections for Sonoma County (historic (black), RCP4.5 (blue), and RCP8.5 (red). The range of all climate models is shown in the shaded areas around the lines that represent the model average.



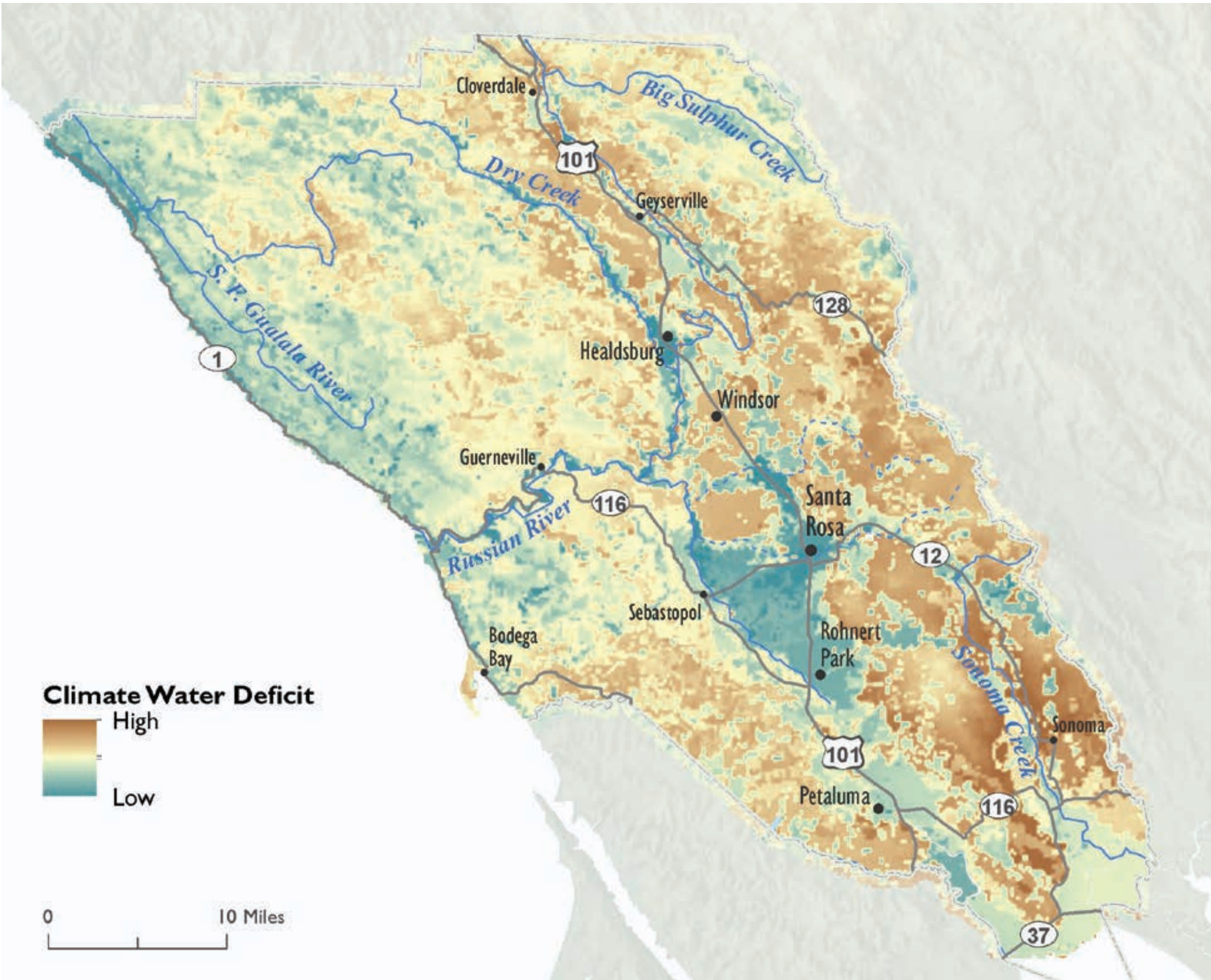
Data from National Climate Change Viewer, http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp

Figure C9. Summer-season evaporative deficit projections for Sonoma County (historical (black), RCP4.5 (blue), and RCP8.5 (red). The range of all climate models is shown in the shaded areas around the lines that represent the model average.



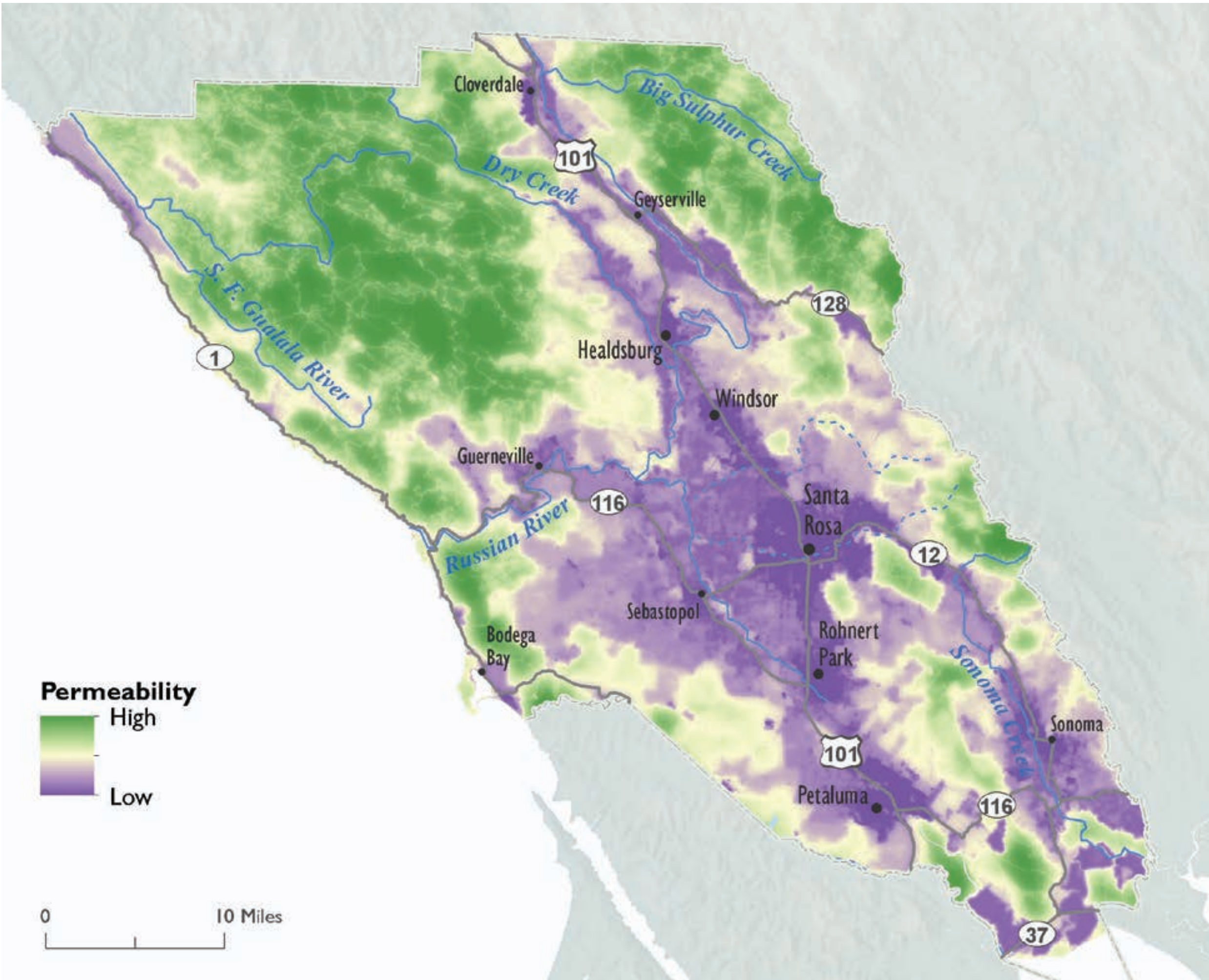
Data from National Climate Change Viewer, http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp

Figure C10. Climatic water deficit. Areas with lower CWD represent areas less stressed by moisture limitations. Data show annual average CWD from 1981-2010.



Data Sources: USGS California Basin Characterization Model (CA-BCM 2014)

Figure C11. Permeability for Sonoma County. Green areas show regions that facilitate local movement based on the resistance to movement from development and infrastructure such as roads. Because permeability is a species-specific concept and we are looking at it in a generalized way, there are still many species that can traverse the habitats in the areas shown in purple on this map.

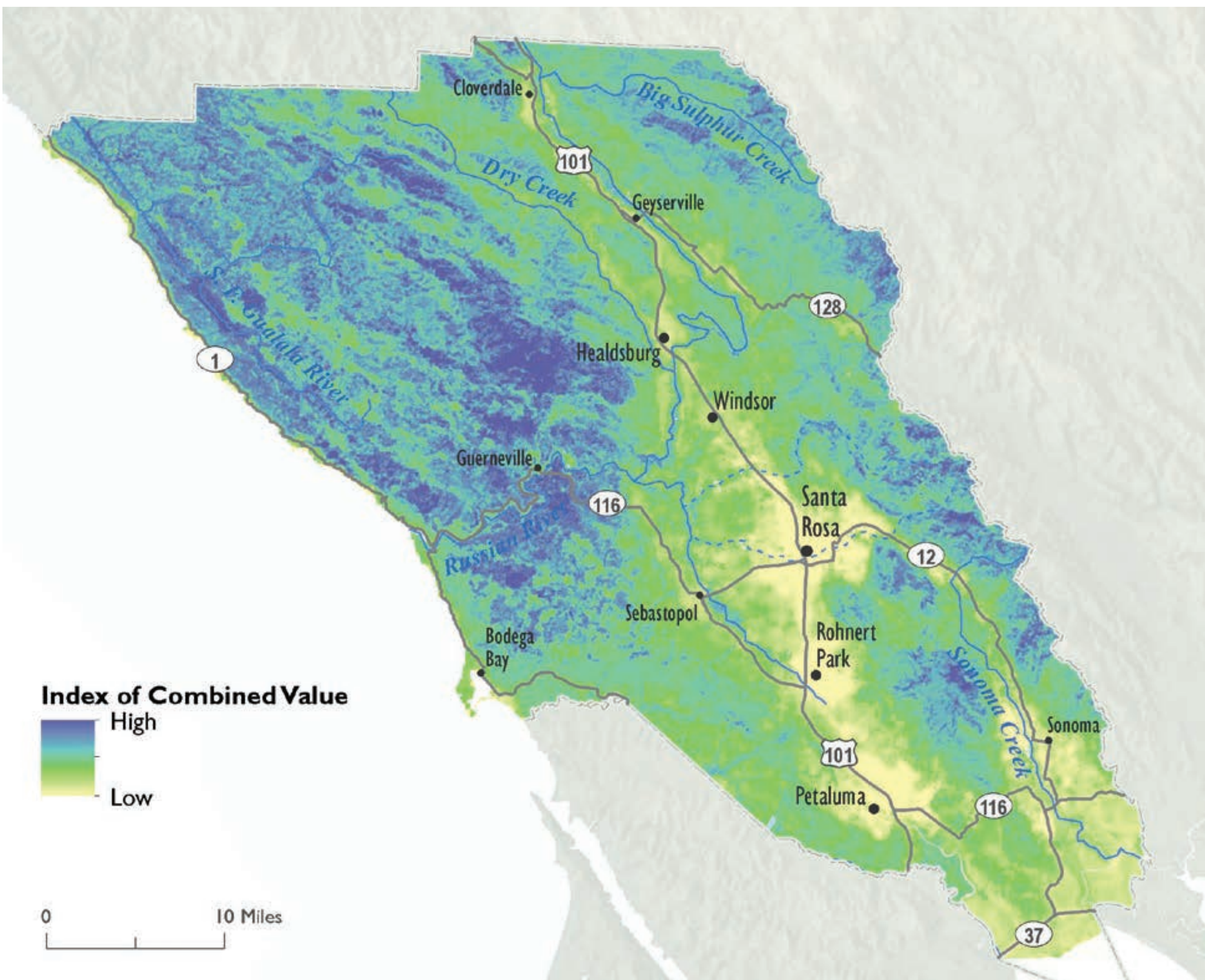


Data Sources: TNC California from USGS, Ventyx, ESRI, US DOT, Cal Fire, US FS

Integrated analysis and reporting

Through the integration of the individual conservation value layers we can define areas that have high values for multiple values, or "multi-benefit" areas. There are many methods that can be used to perform these summary analyses, and specific combinations would best be defined by the decision context of stakeholder groups asking the questions. Below, we present an example of multi-benefit areas and maps that synthesize many of the values described above (Figure C12). In Appendix D, we describe an application of a tool that integrates conservation value data, with scenarios modeling land-use and land-management changes to quantify the benefit of activities for land-based carbon sequestration and conservation.

Figure C12. An example of an integrated analysis to show the relative value of multiple ecosystem service and habitat values. In this case, we scaled the carbon storage, aggregate terrestrial biodiversity conservation value, and water yield data from 0 to 1 and summed the data for each pixel. Areas in the western part of the county with dense forest and significant water yield score high for all inputs.



Data Sources: Habitat, Water Yield and Carbon Storage (2010) inputs

Intensive agriculture, terrestrial habitat, and groundwater recharge (or floodplain habitat)

Assessments of conservation value can help guide on-the-ground action by defining relative resource value and locating areas where multiple values stack atop one another (i.e., "multi-benefit areas"). To illustrate multi-benefit mapping, we present a case study of the Santa Rosa Plain (Figure C13). The combination of unique species and natural resources present on the Santa Rosa Plain makes it well suited for use as an illustration of this type of map-based assessment.

The 50,000-acre Santa Rosa Plain is one of the most agriculturally active and biologically rich areas in Sonoma County. A major feature of the Santa Rosa Plain is the Laguna de Santa Rosa, the second-largest freshwater wetland complex on California's North Coast. Designated in 2011 as a Wetland of International Significance by the Ramsar Convention, the Laguna de Santa Rosa provides habitat for threatened and endangered salmonid species and myriad other animal and plant species. Scattered across the Plain's valley oak savanna are ancient vernal pools that support endangered species including a distinct population of California tiger salamander and three endemic flowering plants. The Plain also contains important groundwater recharge zones, particularly along stream reaches, and its rich soils produce a variety of agricultural products that includes wine grapes, truck crops, grazing forage, and ornamental plants and turf.

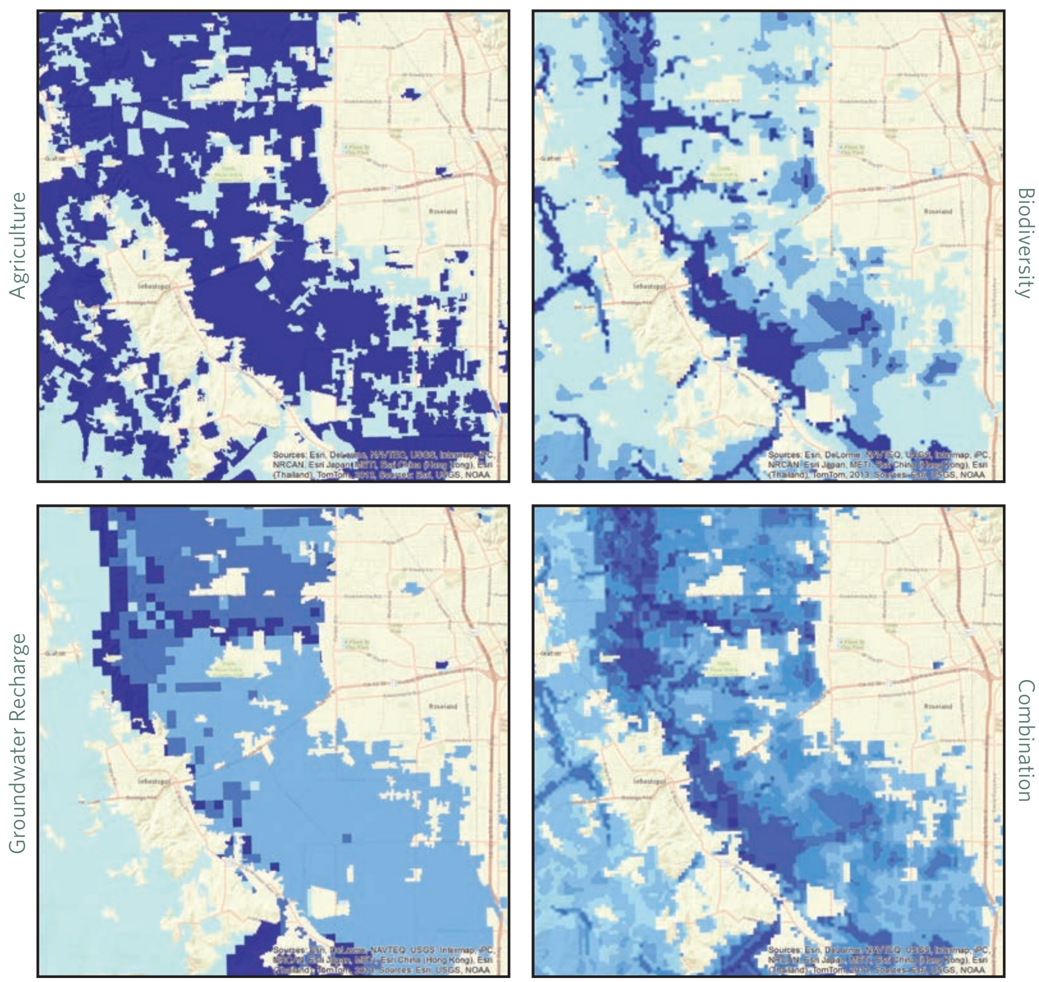
Figure C13. The Santa Rosa Plain in Sonoma County, CA.

Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Situated between five of the county's nine cities, the Santa Rosa Plain has been significantly impacted by urban and rural development. Approximately half of the Plain has been converted from a natural state to intensive human uses. Protection and enhancement of the remaining biodiversity and natural resources is a high priority for the area's conservation and natural resource management organizations and agencies. For example, the Laguna de Santa Rosa Foundation works to collect and disseminate information about the Laguna and its watershed and carry out restoration projects that improve habitat functioning. In addition, the Sonoma County Agricultural Preservation and Open Space District, the California Department of Fish and Wildlife, and Sonoma Land Trust combined have protected 48 properties on the Santa Rosa Plain totaling 3,700 acres.

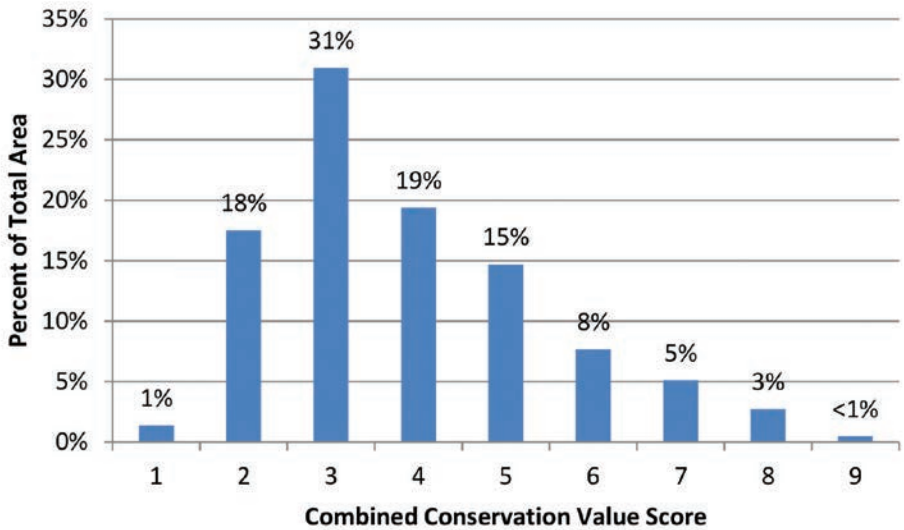
A key question for these and other organizations is: Of the remaining 22,000 unprotected and undeveloped acres, which contain the highest conservation value? We demonstrate in Figures C14 and C15 below how conservation values across three themes (agriculture, biodiversity, and groundwater recharge) can be combined to estimate the degree to which overlaps exist. Locations of significant overlap are considered multi-benefit areas. Although these themes were chosen for their particular relevance to the Santa Rosa Plain, other resources, such as water quality, urban sprawl abatement, or recreation, could be analyzed.

Figure C14. Combining multiple conservation values: (a) agriculture; (b) biodiversity; and (c) groundwater recharge. A combination (or sum) of a, b, and c is shown in d. In these figures, light to dark blue correspond to low to high conservation values.



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013, Sources: Esri, USGS, NOAA

Figure C15. Combined scores of agriculture, biodiversity, and groundwater recharge values shown by percentage of the Santa Rosa Plain study area (as shown in Figure C13). Agricultural value scores were either very high or low (1 or 0), whereas biodiversity and groundwater recharge were ranked as low, medium, high, or very high (1, 2, 3, or 4). Thus, areas received a maximum score of 9 where all three conservation themes were very high.



Although combined scores provide a valuable picture of overall conservation value, it may also be important to identify the locations and the degree to which high or very high values are shared between themes. Table C5 below clarifies this relationship of high or very high values between themes.

Table C5. Degree of shared conservation value across themes. In this table, "high value" includes lands rated as either "high" or "very high" for a given conservation value.

	...and where agriculture value is high as well	...and where biodiversity value is high as well	...and where groundwater recharge value is high as well	...and where both remaining values are high as well
Where agricultural value is high ...		24%	25%	8%
Where biodiversity is high ...	77%		34%	25%
Where groundwater recharge value is high ...	46%	20%		14%

Overlap with carbon storage

Locating high-conservation-value and multi-benefit areas enables analysis of the connection with ecosystem services such as carbon storage. For example, using overlay techniques, we estimate that greater than 30% of the carbon-rich areas[2] in this analysis are found on lands with high values for multiple conservation themes (Figure C16). Furthermore, we estimate that greater than 50% of the carbon-rich areas in the Santa Rosa Plain analysis area are found on lands that are high value for at least one conservation theme.

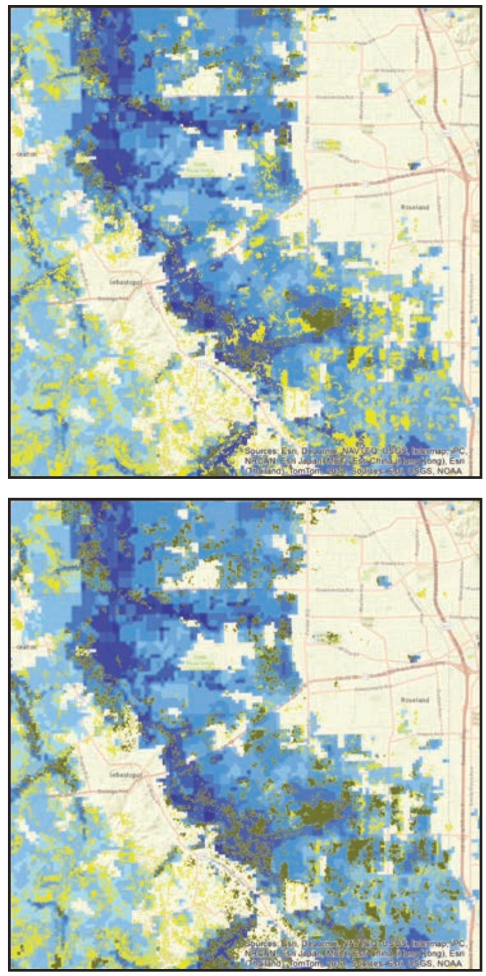
In conclusion, since most landscapes are complex and contain multiple conservation values, map-based conservation value assessments can illuminate areas where conservation actions can secure multiple benefits. These assessments also facilitate analysis with other resources to determine where conservation actions further benefit society through the protection of ecosystem services such as carbon storage.

2 Carbon-rich areas correspond to the upper two of four classes (Jenks natural breaks classification method) of carbon storage quantity (as determined using the methods described in Appendix B.)

Figure C16. Carbon-rich areas (yellow and dark green) and combined conservation values (light to dark blue, corresponding to low to high values).

Top: Carbon-rich areas shown in dark green are those found on lands with high values for multiple conservation themes (~30% of total carbon-rich areas; remainder shown in yellow).

Bottom: Carbon-rich areas shown in dark green are those found on lands that are high value for at least one conservation theme (~50% of total carbon-rich areas; remainder in yellow).



Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013, Sources: Esri, USGS, NOAA

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APPENDIX D

The Conservation Carbon Accounting Tool (C-CAT)

This appendix was prepared by Tukman Geospatial LLC.

Table of contents

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1. Introduction

1.1. Overview

This appendix reviews the development of a conceptual framework and associated geoprocessing tool designed to aid county jurisdictions in understanding the impacts of land-use/land-cover (LULC) change on carbon storage, and to locate where conservation goals are closely aligned with emissions reduction potential. The initial Conservation Carbon Accounting Tool (C-CAT) has been developed for Sonoma County, although ultimately the framework has the capability of being widely applied at a county level throughout the Unites States. The conceptual framework is implemented via a geospatial processing tool and a reporting structure to answer the following questions:

- What are the impacts of land conversion?
- How do different land-use change scenarios affect carbon stock?
- How do different land-use change scenarios affect conservation values?

1.2. Study areas

1.2.1. Sonoma County

This initial draft of the tool was developed for Sonoma County, California. There is growing pressure within Sonoma County to convert natural lands and diversified agriculture to residential housing and vineyards. At the same time, the county has a significant quantity of high-value habitat conservation areas and groundwater recharge areas. As the pressure for urbanization and vineyard conversion grows, there is a need to spatially quantify the carbon storage co-benefits of conserving lands at high risk of conversion. The outputs of the carbon analysis model are intended to help the county account for planning-related greenhouse gas reductions that relate to positive benefits as identified in California's regulatory framework (Assembly Bill 32).

1.2.2. Buckeye Forest

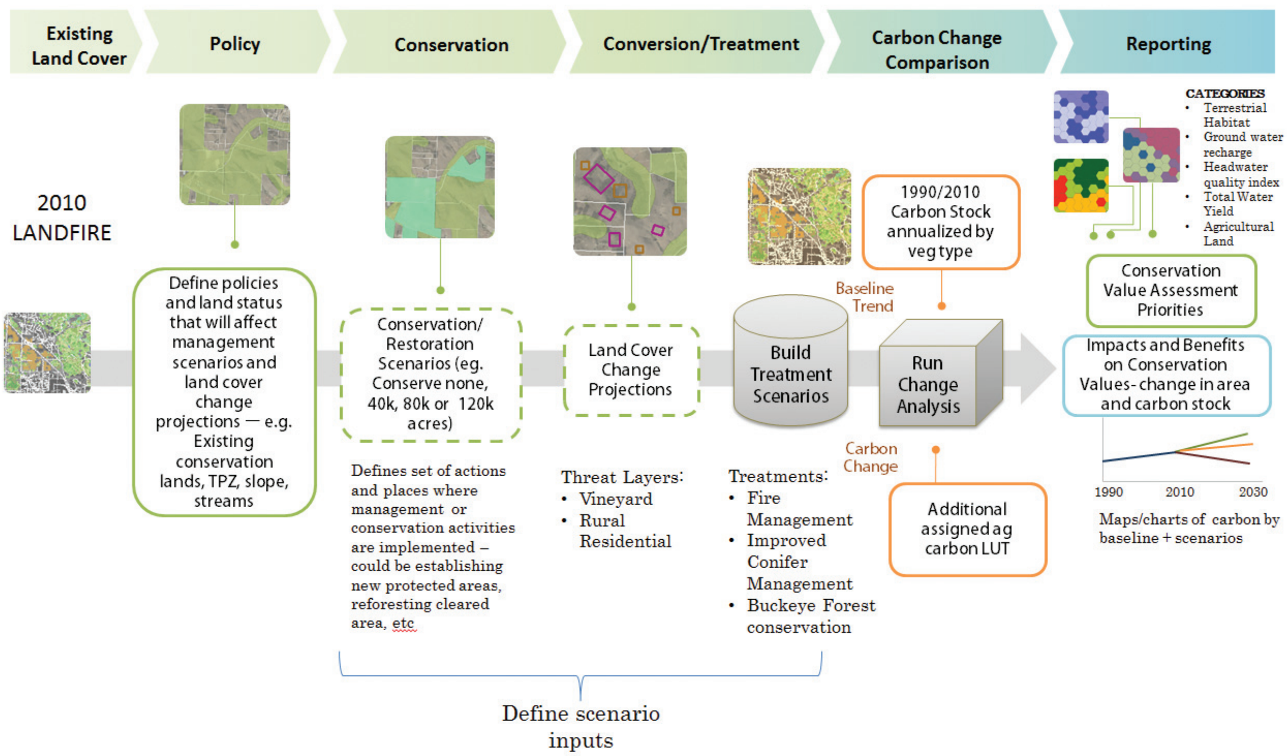
Buckeye Forest was chosen as a case study for the geoprocessing tool, as it is an example of a successful forest conservation project in Sonoma County. The initial plan for the approximately 19,000-acre property ("Preservation Ranch") was to develop over 2,000 acres of proposed vineyards and 63 proposed vineyard estates, with an overall management goal of grape and timber production. Instead, several conservation groups collaborated to purchase the land (now referred to as "Buckeye Forest") for conservation. This effort effectively merged dozens of parcels to reduce the number of developable lots to seven, eliminated the threat of vineyard conversion, and provided an overall management objective of encouraging the growth of large trees through selective harvesting.

2. Methods

2.1. Conceptual framework

Tukman Geospatial designed a conceptual workflow that incorporates primary drivers of change (vineyard and rural residential conversion), existing land-use policies, conservation priorities, and treatment scenarios to highlight areas that optimize the co-benefits of carbon storage and land conservation. The geospatial framework was developed in such a way that it can incorporate varying inputs and multiple scenarios.

FIGURE D1. Conceptual framework

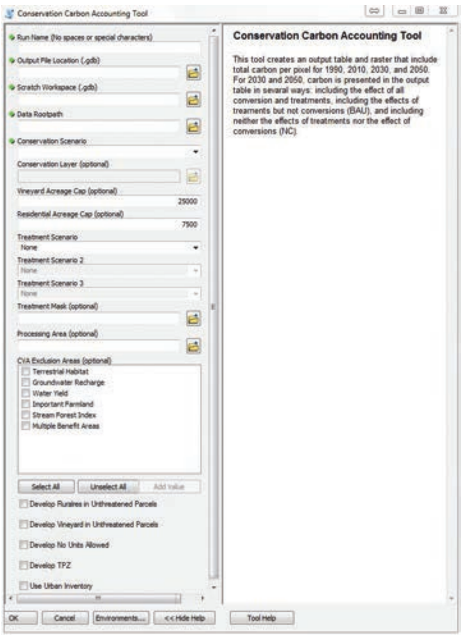


2.2. Geoprocessing tool—the conservation carbon accounting tool (C-CAT)

To implement the conceptual framework, Tukman Geospatial created a spatially explicit geoprocessing toolbox called the Conservation Carbon Accounting Tool (C-CAT). The toolbox accepts a diverse set of inputs and is thereby capable of producing a variety of land conversion/conservation scenarios. The tool, which runs within ESRI's ArcMap software, produces raster outputs, tabular outputs, and reports that characterize projected change in tCO_2e between 2010 and 2050 based on user-defined scenarios.

The toolbox was designed for the internal team—TNC and Open Space District staff. ArcGIS and Python are the primary building blocks for the tool box.

FIGURE D2. C-CAT tool user interface in ArcMap



2.3. Installation instructions for C-CAT

2.3.1. Downloading C-CAT and supporting data

The C-CAT tool can be downloaded at: https://tukmangeospatial.egnyte.com/dl/bhR8svcqd6

The supporting data that the tool requires can be downloaded at: https://tukmangeospatial.egnyte.com/dl/oJUWSFqXnH

2.3.2. System Requirements

To use the tool on your local computer, first make sure that you meet the following system requirements (the toolbox will alert you if you don't when you first run it):

- ArcGIS Advanced (ArcInfo), *version 10.2.2* or greater
- Spatial Analyst extension

2.3.3 Installing tool in ArcMap

Installation steps are as follows:

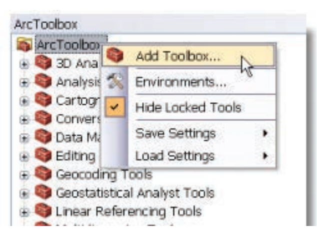
1. Download C-CAT and the supporting data from the link above. Extract the contents of "MASTER_DATA.zip" (which contains a single folder called "MASTER_DATA") to a folder on your hard drive. The local folder that contains the "MASTER_DATA" folder will be the "Data Rootpath" tool input when you run the tool.
2. Extract the "Carbon_Tool" folder from inside of "Carbon_tool_v1.zip" onto your hard drive. The "Carbon_Tool" folder contains the Python script and the ArcMap Python toolbox.
   - Add the Conservation Carbon Accounting Tool to the ArcMap Toolbox window within ArcMap. To do this, right-click the Arc Toolbox folder (see below) and click **Add Toolbox**. Browse to the location containing the toolbox that you extracted above in step 2, and select the "Conservation Carbon Accounting" toolbox.

Once your .mxd is saved, the contents of the Arc Toolbox window are also saved within the map document. The next time you open the document, the Toolbox window will be the same as when you saved the document.

2.3.4. Expected run times and batch-running C-CAT

If small user-defined areas of interest are specified, the tool runs in as little as 5 minutes on a mid-range GIS workstation. For countywide runs, the tool takes between 45 minutes and 1.5 hours to run on a mid-range GIS workstation.

FIGURE D3. Adding the carbon tool to arc toolbox



For an analyst who is familiar with Python, the tool can be batch-run with multiple runs as in the code below. This is convenient for running the toolbox numerous times (for example, over a weekend) with different inputs. See the sample Python code below, which would run the tool three times with different inputs/scenarios.

```
def run_all():

    import arcpy
    import os
    arcpy.ImportToolbox("D:/TGS/code/carbon/Carbon Change Tool.tbx")


    consnone = "No conserved lands in next 20 years"
    cons40 = "Less than 40K acres conserved in the next 20 years"
    cons80 = "Less than 80K acres conserved in the next 20 years"
    cons120 = "Less than 120K acres conserved in the next 20 years"

    treatnone = "None"
    treatcon = "Improved Conifer Forest Management"
    treatoak = "Valley Oak Restoration"
    treatrip = "Riparian Area Restoration"
    cva2="'Terrestrial Habitat';'Groundwater Recharge'"
   cva_all ="'Terrestrial Habitat';'Groundwater Recharge';'Water Yield';'Important Farmland';'Stream
Forest Index';'Multiple Benefit Areas'"

    #run name, out location, scratch workspace, data root, conservation scenario, conser-
vation mask, vineyard cap, res cap, treatment 1,
    #treatment 2, treatment 3, treatment mask, processing area, cvas, develop ruralres in
unthreatened, develop vineyards in unthreatened,
    #develop no units allowed, develop TPZ
    #define_runs below
    runs=[]

    runs.append(["A1", "D:/temp2/runs/A1.gdb", "D:/temp2/runs/A1.gdb", "D:/CLOUD/Shared/Open
Space/Carbon Framework/GIS Data",
     consnone, "","40000", "15000", "None","None", "None","", "", "","true", "true", "true",
"true", "true"])

    runs.append(["B1", "D:/temp2/runs/B1.gdb", "D:/temp2/runs/B1.gdb", "D:/CLOUD/Shared/Open
Space/Carbon Framework/GIS Data",
      cons120, "","20000", "5000", treatoak,treatrip, treatcon,"", "", "","false", "false",
"false", "false", "false"])


    for i in runs:
        if arcpy.Exists(i[1]):
            arcpy.Delete_management(i[1])
        arcpy.CreateFileGDB_management("D:/temp2/runs/", os.path.basename(i[1]))
        print i
        arcpy.CarbonChangeTool(i[0], i[1],i[2],i[3],i[4],i[5],i[6],i[7], i[8], i[9], i[10], i[11],
   i[12], i[13], i[14], i[15], i[16], i[17], i[18])
```

2.4. C-CAT input data and sources

Currently the model incorporates a combination of built-in inputs and user inputs. Some data sets, including policy knockouts and land conversion threat data sets, are currently built into the model; however, in future versions the model could be modified so that these inputs are selected by the user. Conservation and treatment scenarios are optionally selected by the user, but are ultimately based on built-in layers.

Geoprocessing in the toolbox requires a Teale Albers coordinate system. This coordinate system was chosen because Teale Albers can be used effectively across the state of California. Layers (such as user-defined AOIs for use as processing masks) that are not already in Teale Albers will be projected to Teale Albers by the toolbox. However, it is assumed that the entire collection of layers used in the tool that reside in the "MASTER_DATA" folder (such as LANDFIRE, CVA layers, threat layers, etc.) is already in the Teale Albers coordinate system.

2.4.1. C-CAT inputs (built-in)

Land-use/land cover—LANDFIRE

The primary land-use data driving the tool are the 1990, 2001 (v5), and 2010 (v20) LANDFIRE raster data sets, with attributes designating type, size, and density. The foundation of LANDFIRE's vegetation layer is Landsat imagery. The native spatial resolution of LANDFIRE is 30 meters. EVT values within the LANDFIRE dataset are used to relate land cover to carbon (tCO2e) values in the toolbox. Crosswalks from LANDFIRE values to carbon were provided by Dick Cameron at The Nature Conservancy (see the "carbon tables" section below).

Changes in land cover during the period modeled by the tool (2010-2050) are based on changes in LANDFIRE type, size, and density. All areas where a change occurs receive adjusted carbon totals based on lookups between LANDFIRE type/size/density and carbon values (by LANDFIRE class) provided by TNC. For example, an area converted to vineyard from forest will receive a vineyard label for 2030 and its carbon value will be adjusted downward to reflect the conversion. In forested areas, where no change in LANDFIRE type has occurred, the forest is "grown" using a multiplier provided by TNC.

Policy knockouts

Several vector layers contribute to the policy knockouts in the model. At present, these layers are specific to Sonoma County and are built into the model; however, with minimal additional scripting, future versions of the tool may have this layer chosen by the user. Currently the policy knockout layers include areas within a user-defined distance from streams (default is 500 feet), areas of very steep slope (default threshold is 55%), Timber Protection Zones (TPZs), easements, and lands owned by public agencies or conservation organizations.

Carbon tables and carbon calculations

The table "tbl_cht_90_10_atts_gen_class_stock_change_lut" (in "MASTER_DATA/CarbonTables.gdb") contains all of the relevant attributes to support queries about land-cover or carbon-stock change both in terms of the baseline (1990-2010) and the modeled time frame (2010-2050).

Changes in land cover during the period modeled by the tool (2010-2050) are based on changes in LANDFIRE type, size, and density. All areas where a change occurs as a result of a treatment or a conversion receive adjusted carbon totals based on lookups between LANDFIRE type/size/density and carbon values provided by TNC. For example, an area converted to vineyard from forest will receive a vineyard LANDFIRE EVT for 2030 and 2050 and its forestland carbon value will be changed to vineyard carbon inventory values for 2030 and 2050.

In pixels where no change in LANDFIRE EVT has occurred (untreated, unconverted pixels), the tons/acre values from the carbon inventory are area-weighted to account for LANDFIRE EVT acreage changes modeled non-spatially in the TNC inventory in 2030 and 2050. These non-spatially modeled EVT acreage changes are not explicitly integrated into the 2030 and 2050 rasters (untreated and unconverted pixels retain their 2010 EVT in 2030 and 2050), but the effects of these acreage changes are captured in C-CAT's 2030 and 2050 carbon estimates by applying this area weighting.

2.4.2. C-CAT user inputs

There are several customizable parameters for user scenario creation. For example, the user can choose from one of three conservation scenarios (acres to be conserved over the 2010-2050 period), decide on a treatment application (such as improved conifer management, which will result in increased tree size over the 2010-2050 period), or select certain high conservation value areas (CVAs) that won't be converted by the tool to vineyard or rural residential areas. At present, many of these customized inputs rely on data sets that are specific to Sonoma County. That said, in the future, this tool may be modified to be more flexible such that the customized inputs may be applicable in any county where the necessary data sets are available.

The tool has help and descriptions for each user input; please refer to this information for specific parameters when running the tool from within ArcMap. The following discussion provides additional background information on a number of the user-defined inputs.

Processing area (mask)

The default processing area is the entire extent of Sonoma County. However, a user may be interested in only executing the tool on a specific area or region. In this case, the user may select a customized polygon mask as the processing area for analysis. For example, this polygon may be a single watershed or park boundary. When a processing area is selected, the tool will only be run within the extent of the selected polygon.

Acreage caps

The Vineyard Acreage Cap is the maximum number of acres that the model will allow to be converted to vineyard between 2010 and 2030. This cap is based on 20-year averages for vineyard conversion between 1990 and 2010. The user can define this input; otherwise the default 25,000-acre cap is based on a compromise between two data sources for past agricultural change extrapolated to a 20-year period. One of these studies was the Farmland Mapping and Monitoring Program (FMMP), which documented 23,070 acres of conversion to agriculture in Sonoma County (this figure is extrapolated from the most recent two years of data) (Kovner 2014). The second data source was a UC Berkeley study that showed 33,322 acres of conversion to agriculture (this figure is extrapolated from seven years of conversions between 1990 and 1997) (Brooks et al. 1999).

The Residential Acreage Cap is the maximum number of acres that the model will allow to be converted to rural residential between 2010 and 2030. This cap is based on 20-year averages for rural residential conversion between 1990 and 2010. The user can define this input; otherwise the default 7,500-acre cap is based on a compromise between two data sources for past urban change extrapolated to a 20-year period. One of these data sources, NCLD, showed 8,874 acres converted to rural residential (extrapolated from a 10-year period) (Xian and Homer 2010). The second data source, FMMP, reported 4,730 acres converted to rural residential (extrapolated from report based on most recent two years of data) (Kovner 2014).

Note: At this time, all vineyard and rural residential conversions occur in the model between 2010 and 2030; no "second round" of conversion occurs between 2030 and 2050.

Conservation scenarios

The user can select from a list of conservation scenarios. The conservation scenarios are based on high conservation value lands located within the Sonoma County Agricultural Preservation and Open Space District's priority focus areas that are not currently conserved. The District works only will willing sellers, therefore any long-term conservation scenario is subject to the availability of land conservation opportunity. There are three conservation scenarios available to the user with varying acreages of conserved land: 40,000 acres, 80,000 acres, and 120,000 acres. 80,000 acres is the "business as usual" scenario, as about 4,000 acres per year were conserved between 1990 and 2010. The scenarios are cumulative, for instance the 120,000-acre scenario incorporates all of the lands in the 40,000- and 80,000-acre scenarios. Conservation lands are off limits to the carbon tool in terms of conversion, meaning that the tool will not convert conservation lands to rural residential or vineyard.

For use in counties outside of Sonoma, the conservation scenarios feature class could be replaced with a locally appropriate feature class and the code could be updated accordingly. This would be a very minor change.

Treatment scenarios

The user can select one or both of two treatment scenarios from a list of treatment options, including Improved Conifer Forest Management, Valley Oak Restoration, and Riparian Restoration. Selecting "None" will skip the treatment process of the model.

By default, treatment scenarios are applied countywide. However, the user can constrain the application of treatments to specific geographies by adding a polygon feature class to the "Treatment Mask" tool parameter.

In the **Improved Conifer Forest Management Treatment Scenario**, a random selection of 2010 conifer forest pixels with certain combinations of LANDFIRE size and density are given a one-size class increase between 2010 and 2030; an additional random selection of pixels are "grown" between 2030 and 2050. This treatment is meant to model the effects of the silvicultural practice known as "thinning from below." At present, only parcels zoned timber production ("TP") are treated. The size-class increases were developed by John Nickerson based on his analysis of inventory and growth and yield data. See Section 5E of this appendix for details on the application of this treatment scenario.

In the **Valley Oak Restoration Treatment Scenario**, currently (2010) non-forested areas of potential valley oak habitat are allowed to "grow" some forest cover between 2010 and 2030 and "grow" larger between 2030 and 2050. Forest is grown in a randomly selected percentage of non-forested pixels in these areas. The area of potential valley oak habitat is defined by combining several existing GIS layers including selected classes from the USGS "land surface forms" layer.

In the **Riparian Restoration Treatment Scenario**, currently (2010) non-forested areas of potential riparian forest habitat are allowed to "grow" some forest cover between 2010 and 2030 and "grow" larger between 2030 and 2050. Forest is grown in a randomly selected percentage of non-forested pixels in these areas. The area of potential riparian forest habitat is defined by combining several existing GIS layers including hydric soils, the FEMA 100-year floodplain, and the "drainage channel" landform from the USGS "land surface forms" layer.

Note that if multiple treatments are applied and treatment areas overlap, the second treatment overwrites the first treatment. For example, if there is a conifer improvement area that is also a fuels reduction area and both scenarios are applied, the pixel will be changed according to the fuels reduction scenario and the Conifer Improvement scenario will not be applied.

For more information on the model logic behind the treatment scenarios, see Section 5.B of this appendix.

New treatment scenarios outside of Sonoma County could be developed easily and added to the tool. This would require minimal changes to the toolbox and the Python code.

CVA exclusion areas

The user has the option to exclude areas with high conservation values from vineyard and rural residential conversion areas. There are six options for excluding conservation values areas, and any number of the options can be selected for a model run. The options are as follows:

- **FMMP Exclusion Areas** consist of Prime Farmland (P), Farmland of Statewide Importance (S), Farmland of Local Importance (L), and Unique Farmland (U).
- **Aggregate Terrestrial Biodiversity Value Areas** are the top quintile of a weighted overlay of landscape intactness, serpentine soil, rare communities, rare species density, tree size, and linkages.
- **Groundwater Recharge Areas** are the top quintile of average annual groundwater recharge.
- **Water Yield Areas** are the top quintile of average annual water yield, calculated by summing runoff and recharge. They are based on output from the Basin Characterization Model.

- **Headwater Stream Quality** are areas adjacent to first-order streams within the top quintile of forest cover.

- **Multi-Benefit Areas** are those in the top quintile of areas with multiple conservation values. This exclusion area is based on a normalized and summed composite of the CVAs listed above.

For more information on CVA Exclusion Areas, see Section 5.C. of this appendix.

CVA exclusion areas outside of Sonoma County could be added without modifying the Python code as long as the names and thematic content of the CVA exclusion areas were the same as above.

C-CAT miscellaneous parameters

At the bottom of the tool's user interface, there are several checkbox options that control how and where vineyard and rural residential polygons are modeled on the landscape. These checkboxes are described in the bullets below.

- **Develop Unthreatened RR**—When unchecked (Default), new rural residential will not be modeled in areas of 0 Newburn threat.

- **Develop Unthreatened Vineyard**—When unchecked (Default), new rural residential will not be modeled in areas of 0 Newburn threat.

- **Develop No Units Allowed**—When unchecked (Default), new rural residential developments will not be modeled in areas with 0 "units allowed" in the county parcel layer.

- **Develop TPZ**—When unchecked (Default), new vineyards and rural residential developments will not be modeled in timber protection zones (TPZs).

Urban forest inventory

At the very bottom of the tool, there is an option to "Use Urban Forest Inventory." Doing so replaces the LANDFIRE urban forest carbon values with values from John Nickerson's urban forest inventory.

When unchecked (Default), the LANDFIRE inventory is used for all areas. When checked, John Nickerson's urban inventory is used. In the latter case, urban areas are applied a default carbon value based on John Nickerson's urban inventory number of 168.73 tCO_2e (whole trees)/acre. For each LANDFIRE pixel, this 168.73 value is converted from acres to 900 square meters and then multiplied by the percent of the pixel that is forested (% of pixel with canopy height greater than eight feet). Canopy cover information is derived from 2013 LiDAR data.

Specifically, C-CAT does the following when this button is checked:

- For existing land cover (1990 and 2010) the urban inventory numbers are used.

- For lands converted to rural residential in 2030 by the tool, the urban inventory numbers are used.

- For all other areas, the tool uses the LANDFIRE inventory.

- There is no urban tree growth assumed—the inventory numbers applied are static across the years.

- Urban pixels get the following values:
  - » 168.73 tCO_2e/acre x .222395 (converts to 900 square meters) x LiDAR Percent Cover (range of values—0 to 1)

2.5. C-CAT methods and rules for developing vineyard and rural residential polygons

The toolbox converts suitable areas of the landscape to vineyard and rural residential development. Conversions are limited to areas where conversions are appropriate and legal (e.g., privately owned non-wetland parcels not exceeding a certain slope, etc.). Vineyards are converted first and their converted area is added to the knockout layer used for rural residential. Consequently, the tool does not convert areas that it has converted to vineyard into rural residential developments and vineyard conversions have precedence over rural residential conversions. Sections 2.5.1 and 2.5.2 discuss the order of operations and rules that the tool uses for vineyard and rural residential conversions.

2.5.1. Vineyards

Vineyards are converted by the toolbox and added to the landscape as rectangular shapes. Vineyards are converted by the toolbox in the following sequence of events:

- Areas that fall within policy knockouts are excluded from candidacy for vineyard development. These are steep areas, areas of conservation lands (parks, land trust lands, and some easements), and areas immediately adjacent to streams. In addition, county-defined timber production zones (TPZs) are considered a policy knockout by default. However, this can be overridden by clicking on the "Develop TPZ" checkbox near the bottom of the tool.
- Areas that fall within selected CVA exclusion areas (e.g., important farmland, groundwater recharge areas) are excluded from candidacy for vineyard development.
- Areas NOT IN the area of Roehrdanz's 2050 wine-growing suitability zone (Roehrdanz 2014) PLUS Roehrdanz's current wine-growing suitability areas. Essentially, these areas are those not climatologically suitable for wine-growing now OR in 2050—these polygons are used as part of our vineyard conversion knockout areas.
- Areas of salt marsh (as defined by SFEI) are excluded from candidacy for vineyard development.
- A Euclidian distance raster is created that assigns each pixel with its closest distance to a policy knockout area, a CVA exclusion area, a conservation area, or a threat parcel boundary (whichever of these is closest).
- If the Euclidian distance is greater than a minimum distance, the pixel is recoded to 1—all other pixels are recoded to NODATA.
- The resulting binary mask is vectorized and combined with the Newburn threat layer (Newburn and Berck 2006) using the" identity" function.
- A cursor loops through the resulting polygons, creating centroids for each one in a new point layer. The centroids are used as "seeds" for new vineyards (large Newburn polygons can have multiple seeds).
- The seeds are grown into rectangles in descending order of threat (seeds with the highest Newburn "PVINE" threat are grown into polygons first). Vineyard rectangles are grown in the orientation that best fits them into the shape of the Newburn threat parcel. Polygons stop growing when a policy knockout or CVA exclusion area stops their expansion.
- If the acreage cap is reached, no additional vineyard polygons are created.
- If a polygon has a Newburn threat value of 0 (PVINE = 0), it is not converted. This can be overridden—allowing vineyards to be developed in these areas—by clicking on the "Develop Vineyard in Unthreatened Parcels" checkbox near the bottom of the tool's GUI.
- Vineyard conversion is done between 2010 and 2030—no additional vineyard conversion is done between 2030 and 2050.

2.5.2. Rural residential

Rural residential areas are converted by the toolbox and added to the landscape as rectangular shapes. Rural residential developments are converted by the toolbox in the following sequence of events:

- Areas that fall within policy knockouts are excluded from candidacy for rural residential development. These are steep areas, areas of conservation lands (parks, land trust lands, and some easements), and areas immediately adjacent to streams. In addition, county-defined timber production zones (TPZs) are considered a policy knockout by default. However, this can be overridden by checking (turning on) the "Develop TPZ" checkbox near the bottom of the tool's GUI.
- Areas that fall within selected CVA exclusion areas (important farmland, groundwater recharge areas, etc.) are excluded from candidacy for rural residential development.
- Areas with 0 "UNITS_ALLOWED" in the Sonoma County parcel zoning data are excluded from candidacy for rural residential development. However, this can

be overridden by checking (turning on) the "Develop No Units Allowed" checkbox on the tool's GUI.

- A Euclidian distance raster is created that assigns each pixel with its closest distance to a policy knock-out area, a CVA exclusion area, a conservation area, or a threat parcel boundary (whichever of these is closest).
- If the Euclidian distance is greater than a minimum distance, the pixel is recoded to 1—all other pixels are recoded to NODATA.
- The resulting binary mask is vectorized and combined with the Newburn threat layer (Newburn and Berck 2006) using the" identity" function
- A cursor loops through the resulting polygons, creating centroids for each one in a new point layer. The centroids are used as "seeds" for new rural residential polygons (large Newburn polygons can have multiple seeds).
- The seeds are grown into circles in descending order of threat (seeds with the highest Newburn "RRES" threat are grown into polygons first). Rural residential polygons are set to a fixed one-acre size. Overlapping rural residential polygons are dissolved into a single shape.
- If the acreage cap is reached, no additional rural residential polygons are created.
- If a polygon has a Newburn threat value of 0 (RRES =0), it is not converted. This can be overridden—allowing rural residential to be developed in these areas—by clicking on the "Develop RR in Unthreatened Parcels" checkbox near the bottom of the tool's GUI.
- Rural residential conversion is done between 2010 and 2030—no additional rural residential conversion is done between 2030 and 2050.

Note: The Newburn threat polygons are specific to Sonoma County. They provide threat rankings for all parcels in the county in terms of both threat of vineyard development ("PVINE" attribute) and threat of rural residential development ("RRES" attribute). The toolbox relies on this threat layer for conversions and will not convert parcels where the respective threat is 0. However, this default behavior can be overridden by clicking on the "Develop RR in Unthreatened Parcels" and/or "Develop Vineyard in Unthreatened Parcels" at the bottom of the tool's GUI.

The toolbox could easily be modified to use another threat layer, as long as it was parcel-based.

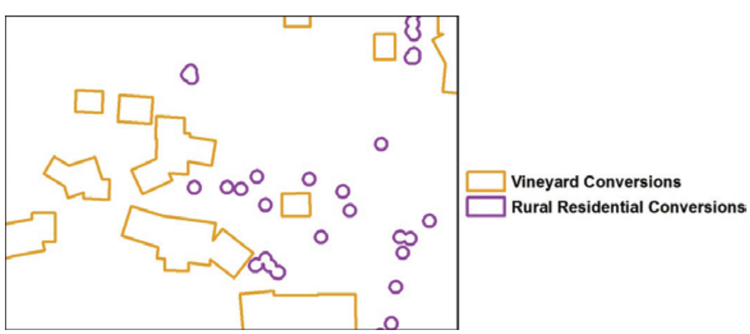
2.6. C-CAT Output data and reporting

For each user-configured scenario, the toolbox provides reports and charts illustrating the scenario's emission reduction potential and conservation implications.

2.6.1. Vineyard and rural residential polygons

For each toolbox run, polygons representing the modeled vineyard and rural residential conversion areas are generated and are accessible in the user-defined "Output File Location" tool parameter (a file geodatabase).

FIGURE D4. View of model-converted vineyard and rural residential polygons



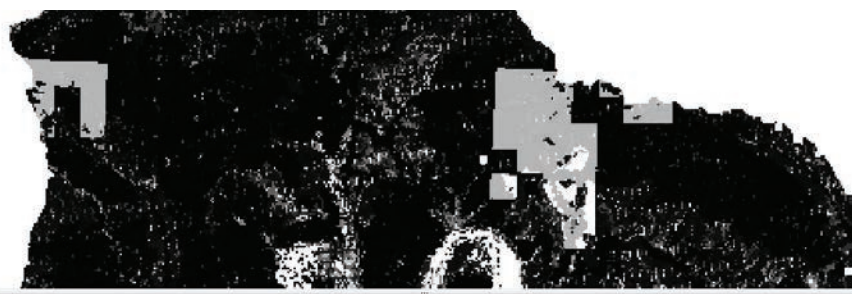
2.6.2. Raster outputs

For each toolbox run, a raster output is generated with its associated attribute table. This output raster—named "RUNNAME"_CARBON_ALL—is placed by the tool in the user-defined "Output File Location" tool parameter (a file geodatabase). For each pixel, the value attribute table of the raster includes land-use values, carbon in Megagrams per acre (tCO_2e/ac), and total tCO_2e values for 1990, 2010, 2030, 2030 BAU (business as usual), 2030 NC (no-change), 2050, 2050 BAU, and 2050 NC. See Figure D5 below for a view of raster results.

Note: The "business as usual" (BAU) attributes include vineyard and rural residential conversions, but do not include treatments such as improved conifer forest management. The "No Change" (NC) attributes do not include any conversions or treatments. The 2030/2050 attribute (not-BAU or NC) include both treatments and conversions.

The attribute table of this raster can be joined to the carbon table called "tbl_cht_90_10_atts_gen_class_stock_change_lut" (in "MASTER_DATA/CarbonTables.gdb") to access expanded information on the EVTs. The 1990 attributes in the output raster join to the "VALUE_1990" attribute of "tbl_cht_90_10_atts_gen_class_stock_change_lut." The 2010, 2030, and 2050 attributes of the output raster join to the "VALUE_2010" attribute of "tbl_cht_90_10_atts_gen_class_stock_change_lut."

FIGURE D5. View of raster results—the "CARBON_ALL" raster



MLweds_CARBON_ALL

OBJECTID *	Value	Count	LU_10	LU_90	LU_30	LU_30BAU	Mg_ac90	Tot_C_90	Mg_ac10	Tot_C_10	Mg_ac30BAU	Tot_C_30BAU	Mg_ac30	Tot_C_30
1	1	20	32	34	32	32	362.518927	1612.448	404.244293	1798.038	404.2443	1798.038	404.244293	1798.038
2	2	528	1	14	1	1	430.136161	50508.55	645.246429	75767.78	715.5512	84023.28	715.55119	84023.28
3	3	4	55	34	55	55	362.518927	322.4896	678.647545	603.7113	678.6475	603.7112	678.647545	603.7113
4	4	14	9	45	9	9	396.769499	1235.354	0	0	0	0	0	0
5	5	1	9	48	9	9	251.365215	55.90237	0	0	0	0	0	0
6	6	54852	1	16	1	1	562.890214	6866591	645.246429	7871239	715.5512	8728874	715.55119	8728873
7	7	147	55	6	55	55	579.988254	18961.01	678.647545	22186.39	678.6475	22186.39	678.647545	22186.39
8	8	92	1	13	1	1	37.8341	774.0986	645.246429	13201.96	715.5512	14640.42	715.55119	14640.42
9	9	453	3	16	3	3	562.890214	56708.34	327.006495	32944.25	362.6365	36533.79	362.636468	36533.79
10	10	19819	2	45	2	2	396.769499	1748820	436.269138	1922920	483.8041	2132438	483.804151	2132438
11	11	230	2	44	2	2	307.379932	15722.76	436.269138	22316.54	483.8041	24746.99	483.804151	24746.99
12	12	45	22	16	22	22	562.890214	5633.279	500.804508	5011.939	555.3712	5558.03	555.371166	5558.03
13	13	2	3	6	3	3	579.988254	257.973	327.006495	145.4492	362.6365	161.2971	362.636468	161.2971

2.6.3. C-CAT carbon summary tables (1990, 2010, 2030, BAU 2030, 2050, BAU 2050)

For each model run, a total carbon summary table ("RUNNAME"_ CARBON_STATS) is generated for the study area (see Figure D6) showing the total sum of tCO_2e in 1990 (SUM_Tot_C_90), 2010 (SUM_Tot_C_10), 2030 BAU (SUM_Tot_C_30), and 2050 (SUM_Tot_C_50). These fields represent total carbon with all conversions and treatments**.** In addition, the tool creates carbon summaries for business as usual (BAU) and no conversion (NC) for 2030 and 2050. BAU provides total tCO_2e not accounting for any treatments—it provides total tCO_2e as if no treatment were applied in the run. The NC fields provide total tCO_2e not accounting for any conversions or any treatments—it provides total tCO_2e as if no treatments or conversions were applied in the run. NC and BAU are provided as points of comparison for the scenario.

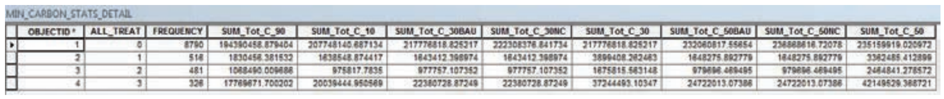
FIGURE D6. View of the Summary Carbon Table Results

MIN_CARBON_STATS

OBJECTID *	FREQUENCY	SUM_Tot_C_90	SUM_Tot_C_10	SUM_Tot_C_30NC	SUM_Tot_C_30BAU	SUM_Tot_C_30	SUM_Tot_C_50NC	SUM_Tot_C_50BAU	SUM_Tot_C_50
1	10113	215059076.970825	230401952.29562	247310275.220551	242778717.204033	260596535.754298	264218602.156914	259410802.992674	283136775.081164

If treatment(s) are applied, the tool also outputs a detailed carbon table ("RUNNAME"_CARBON_STATS_DETAILED—see Figure D7). This table breaks down the carbon summary by treatment, providing detailed summary information by treatment. This table is provided so that the effects of individual treatments can be obtained from the tool outputs. In the detail table, the field named "ALL_TREAT" refers to the treatment. ALL_TREAT = 0 provides tCO_2e values for all untreated cells; ALL_TREAT=1 provides tCO_2e values for the first treatment applied in the tool, ALL_TREAT=2 provides tCO_2e values for the second treatment applied, etc.

FIGURE D7. View of detailed carbon table results



MIN_CARBON_STATS_DETAIL

OBJECTID *	ALL_TREAT	FREQUENCY	SUM_Tot_C_90	SUM_Tot_C_10	SUM_Tot_C_30BAU	SUM_Tot_C_30NC	SUM_Tot_C_30	SUM_Tot_C_50BAU	SUM_Tot_C_50NC	SUM_Tot_C_50
1	0	8790	184390458.879404	207748140.687134	217776818.825217	222308376.841734	217776818.825217	232060817.55654	236868616.72078	235159919.020972
2	1	516	1830456.381532	1638548.874417	1643412.398974	1643412.398974	3899408.262463	1648275.892779	1648275.892779	3362485.412899
3	2	481	1068490.009686	975817.7835	977757.107352	977757.107352	1675815.563148	979696.469495	979696.469495	2464841.278572
4	3	326	17769671.700202	20039444.950569	22380728.87249	22380728.87249	37244493.10347	24722013.07386	24722013.07386	42149529.388721

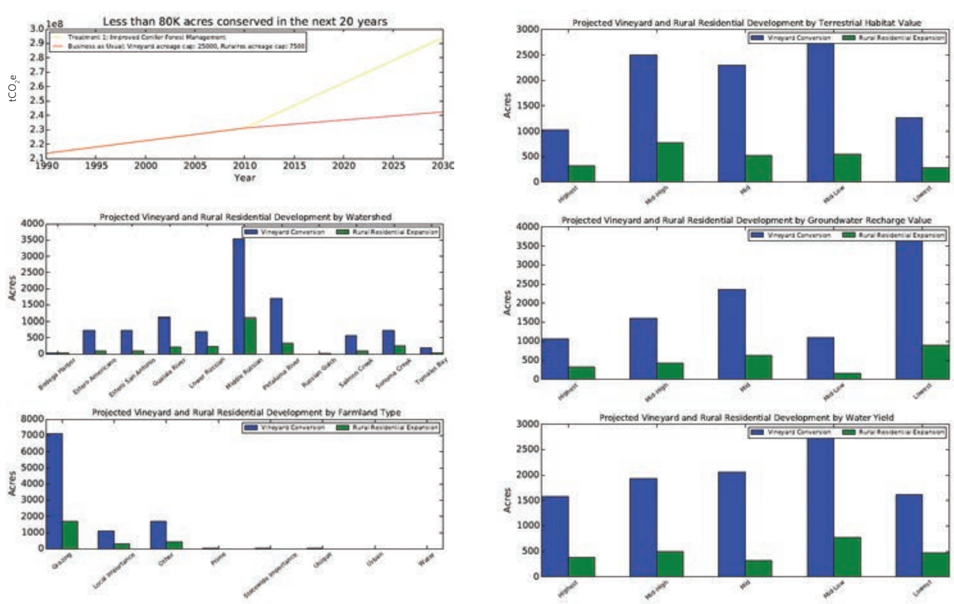
2.6.4. C-CAT Reporting Charts (Carbon Change and Acreage Change)

For each model run, a graphical summary report is generated in PDF form. **Note: tThe report.pdf file is placed inside of the output file geodatabase folder.** Charts include:

- Impacts of the chosen conservation and treatment scenarios reported in tCO_2e by year
- Projected Vineyard and Rural Residential Development by Watershed
- Projected Vineyard and Rural Residential Development by Farmland Type
- Projected Vineyard and Rural Residential Development by Terrestrial Habitat Value
- Projected Vineyard and Rural Residential Development by Groundwater Recharge Value
- Projected Vineyard and Rural Residential Development by Water Yield

FIGURE D8. Example of "Report.pdf" that is automatically generated for each scenario. This PDF is located in the output file geodatabase folder.

Note: Messages for each run of the toolbox are output to a text file that resides in the output file geodatabase folder. The text file is named "logfile.txt."



2.7. Python Script Summary by Module

C-CAT runs on a series of interconnected Python modules. In order, the modules run as follows:

- The **main_program.py** module receives variables ("Parameters" in ESRI-speak) from the ArcMap tool and calls functions from the other modules. This is the main calling script.
- The **generic.py** module sets the paths and workspaces and defines several functions that will be used throughout the remaining modules.
- The **policy.py** module creates a vector knockout for all policy areas including distance from streams, areas of steep slope, TPZs, easements, conservation lands, and CVA exclusion areas.
- The **conservation.py** module updates the policy knockout layer, but only if the user selects an optional conservation scenario based on a target threshold (e.g., 80,000 acres of conservation in the next 20 years).
- The **conversion.py** module creates vineyards and rural residential polygons that do not overlap with policy and conservation knockout areas. The module then converts existing EVT values within polygons to vineyard and RRD EVT values, respectively.
- The **treatment.py** module creates treatment raster(s) based on the treatment options(s) selected by the user.
- The **carbon_change.py** module calculates total carbon per pixel for 1990, 2010, and 2030. For 2030, carbon is presented in the table for conversions/scenarios as well as for business as usual (BAU). BAU only includes urbanization and vineyard conversion, not treatments such as improved conifer forest management.
- The **reporting.py** module generates tables and graphs.

For more information on the Python modules, see Section 5.D. of this appendix.

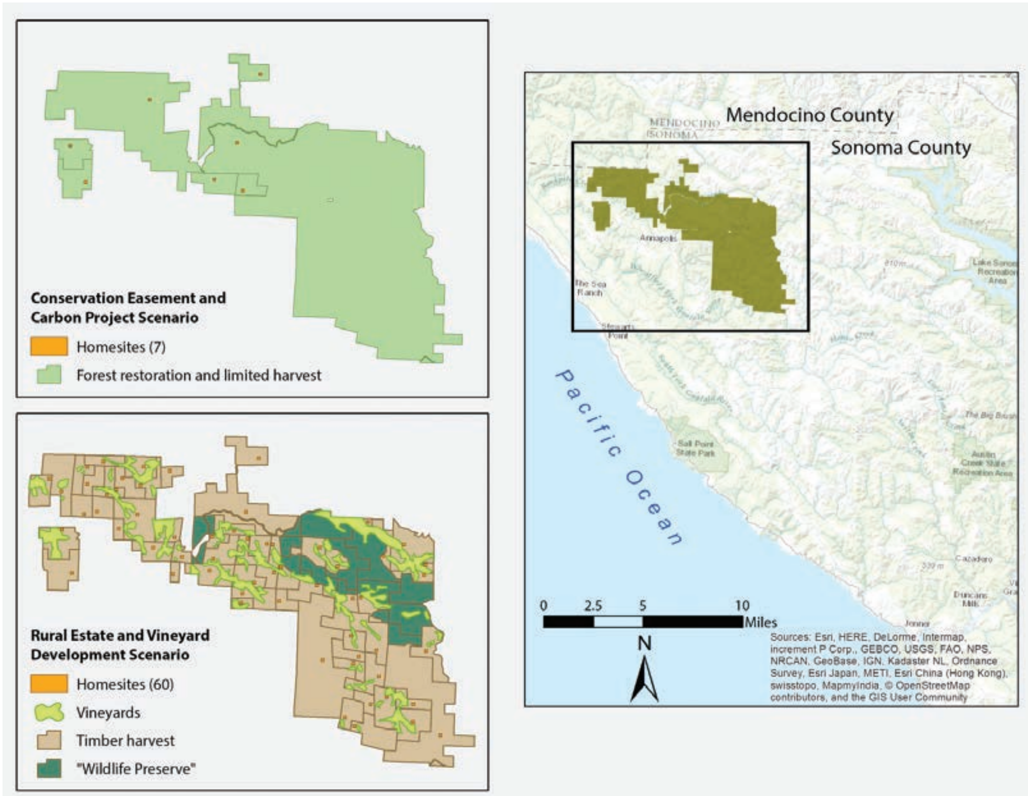
2.8. C-CAT case study—Buckeye Forest scenario

Buckeye Forest was selected as a case study to illustrate the use of C-CAT to quantify the carbon storage benefit of a recently successful large-scale conservation project in northwestern Sonoma County. The 19,000-acre site had at one time been proposed for extensive vineyard and residential estate development ("Preservation Ranch"), but was instead purchased by a collaboration of non-profits for conservation ("Buckeye Forest"). To understand the differences, carbon storage between the two projects, two scenarios were run.

- In the **Preservation Ranch Treatment Scenario (Conversion Scenario)**, all pixels within the extent of 60 pre-selected estate polygons are converted to an EVT value associated with residential development, and all pixels within the extent of the proposed vineyard boundaries are converted to an EVT value associated with vineyards.
- In the **Buckeye Forest Treatment Scenario (Conservation Scenario)**, all pixels within the extent of seven pre-selected rural residential polygons are converted to an EVT value associated with rural residential development.

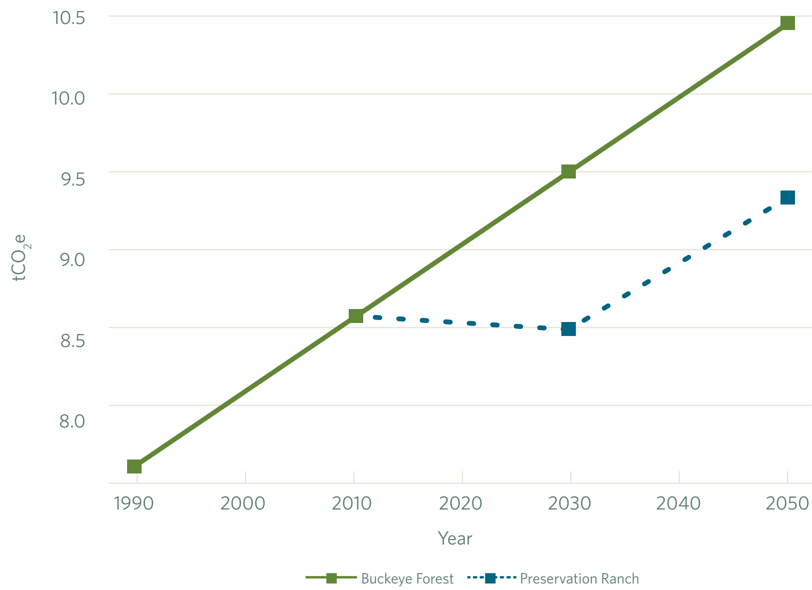
Comparing the Preservation Ranch Scenario and the Buckeye Forest Scenario revealed that the latter conservation project resulted in significant carbon savings, or rather, prevented carbon losses. Applying the carbon change analysis model to both scenarios reveals that the Preservation Ranch development scenario would have resulted in a net total carbon loss of approximately 1 million tCO_2e by 2030 in the 19,000-acre project area.

FIGURE D9. Preservation Ranch plan vs. Buckeye Forest conservation scenario



	SUM_Tot_C_90	SUM_Tot_C_10	SUM_Tot_C_30
Buckeye	7.7×10^6	8.7×10^6	9.6×10^6
Preservation Ranch	7.7×10^6	8.7×10^6	8.6×10^6

FIGURE D10. Comparison of carbon totals between Preservation Ranch Plan and Buckeye Forest conservation scenario



3. Next steps

Potential refinements to the model include:

- Add a conversion module so that conversion can occur between 2030 and 2050—at this time all vineyard and rural residential conversion in the model occurs during the 2010-2030 period.
- Refined allocation rules to better model conversion to rural residential
- Reporting that better integrates the CVAs and co-benefits
- More education about assumptions

This model was developed for Sonoma County and currently includes several built-in data sets specific to the county. Future iterations of the model could be amended so that users in other counties have more control over which county-specific GIS layers (e.g. zoning or policy knockouts) are included within the model.

4. References

C. N. Brooks, E. Heaton, D. Newburn, and A. M. Merenlender, "Modeling Vineyard Expansion in California's North Coast: Developing Statistical Models and Evaluating Consequences for the Surrounding Oak Woodland Landscape," ESRI International User Conference, 1999.

G. Kovner, "Statewide Farmland Loss Felt Least in Sonoma County," Santa Rosa *Press Democrat,* July 14, 2014.

D. A. Newburn and P. Berck, "Modeling Suburban and Rural-Residential Development Beyond the Urban Fringe," *Land. Econ.* 82 (2006): 481–99.

G. Xian and C. Homer, "Updating the 2001 National Land Cover Database Impervious Surface Products to 2006 Using Landsat Imagery Change Detection Methods," *Remote Sens. Environ.* 114 (2010): 1676–86.

P. Roehrdanz and L. Hannah, "Climate Change, California Wine, and Wildlife Habitat," *Jrn. of Wine Economics* 2014, doi: http://dx.doi.org/10.1017/jwe.2014.31.

5. Additional information

5.A. Input data summary tables

Generic name	File name	Type	Path	Source	Date acquired
Zoning/units allowed	PLA_ZONING_PARCELS	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Parcels.gdb	Tom	Egnyte transfer August 14, 2014
Protected areas (fee and easement)	Sonoma County Public and Protected Areas	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Policy.gdb	Tom	email April 17, 2014
TPZ ("LEGEND" = 'TP')	SOCO_PRMD_Zoning_Area	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Policy.gdb	http://www.sonoma-county.org/PRMD/ gisdata/data_download.htm	Downloaded September 18, 2014
Newburn threat layer	ThreatModels_parcel_ based_probabilities	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Threat.gdb	Dick	Egnyte transfer August 14, 2014
DEM	dem_123_10m_elevM_TA; dem_124_10m_elevM_TA	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ DEM.gdb	Mark (reprojected to UTM)	September 18, 2014
LANDFIRE	cht90_10stat	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ LANDFIRE.gdb	Dick	Dropbox transfer August 25 2014
LANDFIRE tables	LANDFIRE_Sonoma_08. accdb - tbl_cht_90_10_atts_gen_ class_stock_change_lut	access DB	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Access DBs	Dick	Dropbox transfer August 25 2014

Generic name	File name	Type	Path	Source	Date acquired
Fire Hazard	FIREHAZARD_06_3_49_TA	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Fire.gdb	(Mark)	Fall 2014
Streams	Sonoma_County_SCWA_ Streams	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Streams.gdb	(Tom) "based on a USGS 1:24k DLG, but the linework has been modified in some areas by Water Agency and other County staff to better reflect current conditions. Reach names have been added to the attribute table as well. It is housed on the County's GIS server, but I believe the Water Agency is the steward."	10/14/2014
Coastline	coastline_vineyard_exclusion	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Policy.gdb	(Mark) "made by buffering the coastline by 2 miles. Compared the county's very detailed vineyards layers, there are essentially no vineyards in this immediate coastal buffer"	10/14/2014
Vineyard Exclusion Areas	vineyard_exclusion	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Policy.gdb	Areas NOT IN the super-set of Roehrdanz's 2050 winegrowing pixels (PCA50. tif—BAU Scenario, PCA GCM) PLUS Roehrdanz's current winegrowing pix-els—see below for that layer. Essentially, these areas are those ......not climatologically suitable for winegrowing now OR in 2050—these polygons are used as part of our vineyard conversion knockout areas.	8/17/15
Existing Agriculture	ag_fields_TA	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Landuse.gdb	(Mark)	Fall 2014

Continued on next page

5A. Input data summary tables continued

Generic name	File name	Type	Path	Source	Date acquired
Existing Buildings	building_footprints_TA	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Landuse.gdb	(Mark)	Fall 2014
Water Bodies	Water Bodies	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Streams.gdb	(Mark)	Fall 2014
Water	NHD_Waterbody_Areas_ Merge_TA	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ Streams.gdb	(Mark and Sarah) merged layer combining layers "NHDArea_1801," "NHDArea_1805," and "NHDWaterBody"	10/15/2014
Water Yield	son_yld_ave	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ CVA.gdb	(Dick) Annual average water yield, 0-403 (mm)	10/31/2014
Groundwater Recharge	son_rch_ave	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ CVA.gdb	(Dick) Annual average recharge 0-206 (mm)	10/31/2014
Headwater Stream Quality	frst_ndx2	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ CVA.gdb	(Dick) Reclassified 2010 LF data on modified gen types for conifer, redwood, riparian, and oak woodlands. Generated a binary grid- 100 m. I smoothed the grid to get % forest in 10-cell neighborhood using a rectangular search radius. This grid was then multipiled by a grid where all cells within 100m of first-order streams had a value of 1 and all other cells had a value of 0. This generated the relative % forested with the buffer for streams.	11/14/2014
Aggregate Terrestrial Habitat	biosum_c7	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\ GIS Data\MASTER_DATA\ CVA.gdb	(Dick) This layer ("biosum_c7") is the result of a weighted raster overlay of various inputs, including both fine-scale and coarse-scale inputs. Each input layer was normalized to max at 1.	11/26/2014

Generic name	File name	Type	Path	Source	Date acquired
Multi-Benefit CVA	sum3vale_v2	raster	C:\Egnyte\Shared\Open Space\Carbon Framework\GIS Data\MASTER_DATA\CVA.gdb	(Dick) This layer is a summary of the normalized value of total ecosystem carbon storage (units CO_2e /acre), terrestrial habitat relative conservation value, and the water yield (recharge plus runoff) as modeled by USGS. The carbon storage maximum value was adjusted to max t 1.25 because of the skewed distribution of values (very few areas with highest storage).	11/26/2014
FMMP	FMMP_LPSU_Importance_Only_TA	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\GIS Data\MASTER_DATA\CVA.gdb	(Sarah) Farmland of L, P, S, or U Importance Only	10/31/2014
Buckeye Forest RRD	buckeye_RRD	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\GIS Data\MASTER_DATA\Buckeye_forest.gdb	(Tom)	10/17/2014
Preservation Ranch Vineyards	preservation_ranch_vine-yards	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\GIS Data\MASTER_DATA\Buckeye_forest.gdb	(Tom) Digitized vineyards from Preservation Ranch Plans	10/17/2014
Preservation Ranch Estates	preservation_ranch_estates	vector	C:\Egnyte\Shared\Open Space\Carbon Framework\GIS Data\MASTER_DATA\Buckeye_forest.gdb	(Sarah) Estimated RRD polygons for each parcel zoned TP in Preservation Ranch Plan	10/27/2014

5.B. Geographies for applying treatments and treatment lookup tables

Treatment scenario	Geographic area of application	Constraining query	Lookup table	Logic
Improved Conifer Forest Management	"../MASTER_DATA/Parcels.gdb/PLA_ZONING_PARCELS_TA_PVINE_RR"	'TP' = 1 (all Timber Protection Zones)	"../MASTER_DATA/CarbonTables.gdb/TP_TREATMENT_LUT" (see look up table below)	In a random subset of conifer forest pixels in parcels zoned TP, increase EVT size class according to the rules below. This treatment is meant to model the effects of the silvicultural practice known as "thinning from below."
Valley Oak Restoration	"../MASTER_DATA/ForestScenarios.gdb/OAK_RESTORATION_AOI"	None	"../MASTER_DATA/CarbonTables.gdb/OAK_TREATMENT_LUT" (see look up table below)	Currently (2010) non-forested areas of potential valley oak habitat are allowed to "grow" some forest cover between 2010 and 2030. Forest is grown in a randomly selected percentage of non-forested pixels in these areas. The area of potential valley oak habitat is defined by combining several existing GIS layers including selected classes from the USGS "land surface forms" layer.
Riparian Area Restoration	"../MASTER_DATA/ForestScenarios.gdb/RIPARIAN_RESTORATION_AOI"	None	"../MASTER_DATA/CarbonTables.gdb/RIPARIAN_TREATMENT_LUT" (see look up table below)	Currently (2010) non-forested areas of potential riparian forest habitat are allowed to "grow" some forest cover between 2010 and 2030. Forest is grown in a randomly selected percentage of non-forested pixels in these areas. The area of potential riparian forest habitat is defined by combining several existing GIS layers including hydric soils, the FEMA 100-year floodplain, and the "drainage channel" landform from the USGS "land surface forms" layer.

Lookup Table for the Valley Oak Restoration Scenario

LANDFIRE EVT (2010)	LANDFIRE closure (2010)	LANDFIRE size (2010)	LANDFIRE EVT (2030/2050)	LANDFIRE closure (2030)	LANDFIRE size (2030)	LANDFIRE closure (2050)	LANDFIRE size (2050)	Percent of pixels "grown"*
Western Cool Temperate Fallow/Idle Cropland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Pasture and Hayland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Undeveloped Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Undeveloped Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Fallow/Idle Cropland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Pasture and Hayland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Undeveloped Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Barren	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Quarry-Mines-Gravel Pits	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Annual Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Mesic Serpentine Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Northern Coastal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Introduced Upland Vegetation-Perennial Grassland and Forbland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
North Pacific Montane Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Maritime Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Mesic Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Montane Woodland and Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
California Xeric Serpentine Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Mediterranean California Sparsely Vegetated Systems	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Northern and Central California Dry-Mesic Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Northern California Coastal Scrub	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Developed Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Developed Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Urban Herbaceous	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Cool Temperate Urban Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Developed Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Developed Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Undeveloped Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Urban Herbaceous	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25
Western Warm Temperate Urban Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Medium	Medium	25

**For example, for the first row in this table, 25% of randomly selected Western Cool Temperate Fallow/Idle Cropland pixels inside of the treatment area will be changed to medium closure/small size (in 2030) and to medium closure/medium size in 2050.*

Lookup Table for the Riparian Restoration Scenario

LANDFIRE EVT (2010)	LANDFIRE closure (2010)	LANDFIRE size (2010)	LANDFIRE EVT (2030/2050)	LANDFIRE closure (2030)	LANDFIRE size (2030)	LANDFIRE closure (2050)	LANDFIRE size (2050)	Percent of pixels "grown"*
Western Cool Temperate Fallow/Idle Cropland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Pasture and Hayland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Undeveloped Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Undeveloped Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Fallow/Idle Cropland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Pasture and Hayland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Undeveloped Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Barren	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Quarry-Mines-Gravel Pits	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Annual Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Mesic Serpentine Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Northern Coastal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Introduced Upland Vegetation-Perennial Grassland and Forbland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
North Pacific Montane Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Maritime Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Mesic Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Montane Woodland and Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
California Xeric Serpentine Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Mediterranean California Sparsely Vegetated Systems	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Northern and Central California Dry-Mesic Chaparral	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Northern California Coastal Scrub	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Developed Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Developed Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Urban Herbaceous	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Cool Temperate Urban Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Developed Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Developed Ruderal Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Undeveloped Ruderal Grassland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Urban Herbaceous	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25
Western Warm Temperate Urban Shrubland	NA	NA	Mixed Oak Woodland	Medium	Small	Dense	Medium	25

**For example, for the first row in this table, 25% of randomly selected Western Cool Temperate Fallow/Idle Cropland pixels inside of the treatment area will be changed to medium closure/small size (in 2030) and to dense closure/medium size in 2050.*

Lookup table for the improved conifer forest management treatment

LANDFIRE EVT (2010)	LANDFIRE Closure 2010	LANDFIRE Size 2010	LANDFIRE EVT 2030	LANDFIRE Closure 2030/2050	LANDFIRE Closure 2030/2050	Percent of Pixels "Grown"*
California Coastal Redwood Forest	Open	Medium	California Coastal Redwood Forest	Medium	Large	25/50
California Coastal Redwood Forest	Medium	Medium	California Coastal Redwood Forest	Dense	Large	25/50
California Coastal Redwood Forest	Dense	Medium	California Coastal Redwood Forest	Dense	Large	25/50

**For example, for the first row in this table, 25% of randomly selected Redwood pixels inside of the treatment area (timber production zones) will be changed from open closure/medium size (in 2010) to medium closure/large size (in 2030). An additional 25% of randomly selected Redwood pixels inside of the treatment area (timber production zones) will be changed from open closure/medium size (in 2030) to medium closure/large size (in 2050).*

5.C. CVA exclusion areas summary table

CVA Exclusion Areas were generated using the ArcGIS Splice function (Equal Area option) with five categories. The resulting raster was then converted to a polygon file. The top quintile of each feature class was selected for the CVA exclusion area (except for FMMP, which relied on a categorical selection of the following classes: Prime Farmland (P), Farmland of Statewide Importance (S), Farmland of Local Importance (L), and Unique Farmland (U).

Cva exclusion area	File name	Type	Origin raster
Aggregate Terrestrial Biodiversity Value*	TerrestrialHabitat_TopQuintile_TA	vector	biosum_c7
Groundwater Recharge	GroundWaterRecharge_TopQuintile_TA	vector	son_rch_ave
Water Yield	WaterYield_TopQuintile_TA	vector	son_yld_ave
FMMP	FMMP_LPSU_Importance_Only_TA	vector	FMMP_sonoma2012_TA
Headwater Stream Quality	StreamForestIndex_TopQuintile_TA	vector	frst_ndx2
Multi-Benefit CVA	SumNorm_BioD_Carbon_WaterYld_TopQuintile_TA	vector	sum3vale_v2

**Terrestrial Habitat Layer Notes: This layer is the result of a weighted raster overlay of various inputs, including both fine-scale and coarse-scale inputs. Each input layer was normalized to max at 1. The weighted values grid was smoothed using focal mean 300meter radius to create this layer.*

The calculation to create this layer is:

("rds_urbag_to1"*3)+("chtfor_fm" *2)+ "rip500_link_mrg01"+("serp_fm_500"/2)+ "ff_veg_rarfm_max1"+ "spp_dn_5k2"+ ("BioVal Inputs\flood012" * 2)

The inputs:

- "rds_urbag_to1"—relative fragmentation due to anthropogenic land cover and roads in the county.
- "chtfor_fm"—weighting of forest habitat value based on combination of tree size class and canopy cover. These weights were assigned based on the following categorization (below).
- "rip500_link_mrg01"—riparian buffers (500-meter buffer) and linkages from BACL.
- "serp_fm_500"—serpentine soils derived from SSURGO—soil types where parent materal contains serpentine.
- "ff_veg_rarfm_max1"—fine filter habitats from CLN—value of .5 for class 2 rarity and 1 for class 1 rarity—updated to remove ag and urban areas from FMMP 2010. Smoothed using a focal mean with radius of 500-meter.
- "spp_dn_5kf2"—Smoothed focal mean of NDDB (5000-meter) occurrences weighted by GRANK and SRANK.

	Cover			
Size	1	2	3	4
1	0.1	0.1	0.1	0.1
2	0.1	0.25	0.25	0.25
3	0.25	0.75	0.75	1
4	0.75	0.75	1	1

5.D. Python module summary table

Module	Module description	Main function(s)	Main function description
main_program.py	Module receives variable ("Parameters" in ESRI-speak) from the ArcMap tool and calls functions from the other modules. This is the main calling script.		
generic.py	Sets paths and workspaces, defines several functions that will be used throughout the remaining modules	set_paths_and_work-spaces()	
policy.py	Creates a vector knockout for all policy areas including distance from streams, areas of steep slope, TPZs, ease-ments, conservation lands, and CVA exclusion areas (optionally selected by user)	create_policy_knock-outs()	Creates a vector ("knockout" = 1) for all policy knockout areas. These include areas within a user defined distance from streams (default is 500 ft.) and areas of very steep slope (default threshold is 55%). Other knockout areas include Timber Protection Zones (TPZs), easements, and lands owned by public agencies or conservation organizations. Output feature class is in Teale Albers.
conservation.py	Updates policy knockout layer if user selects optional conservation scenario as based on a target thresh-old (e.g., 80,000 acres of conservation between 2010 and 2030)	create_conserva-tion_Scenarios()	Function updates the POLICY_KNOCKOUT vector in the scratch folder. Original knockout ("POLICY_KNOCKOUT_TEMP") includes policy knockouts (TPZ, Fee, Easement, Stream Buffer and Slopes), which is then unioned with conservation knockouts based on a target threshold (e.g., 80,000 acres).
conversion.py	Creates vineyards and rural residential polygons that do not overlap with policy and conservation knockout areas. Converts existing EVT values within polygons to vine-yard and RRD EVT values, respectively.	convert_vineyards_and_ruralres()	Vineyards are converted first, then their converted area is added to the knockout layer used for rural residential.

Module	Module description	Main function(s)	Main function description
treatment.py	Creates treatment raster(s) based on the treatment option(s) selected by the user.	create_treatment_scenario()	Function creates TREATMENT raster(s).
carbon_change.py	Calculates total tCO_2e per pixel for 1990, 2010, 2030, and 2050. For 2030 and 2050, carbon is presented in the table for conversions/scenarios as well as for business as usual (BAU). BAU only includes business as usual urbanization and vineyard conversion.	carbon_change()	Function creates a CARBON_ALL raster in the scratch folder that includes total tCO_2e per pixel for 1990, 2010, and 2030, and 2050. For 2030 and 2050, carbon is presented in the table for conversions/scenarios as well as for business as usual (BAU). BAU only includes business as usual urbanization and vineyard conversion. This function also applies scenarios, by 'flipping pixels' in the areas that are overlapped by treatment rasters.
reporting.py	Generates tables and graphs	create_reports ()	

5.E. Improved Conifer Management Treatment Scenario

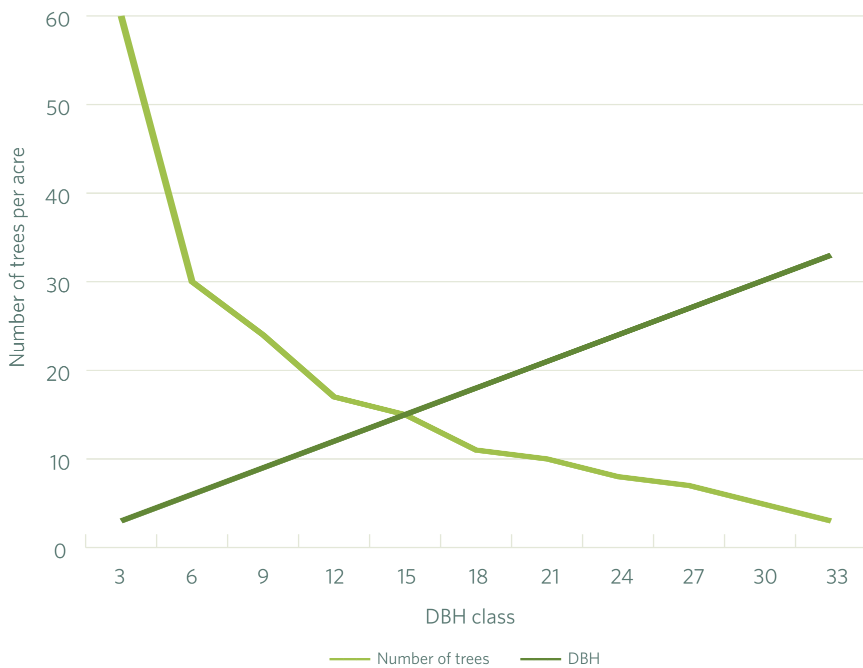
The improved conifer management strategy is based on changes in the way trees are harvested in existing forest stands. Specifically, the focus of the harvest shifts from large, high-profit trees (the business-as-usual case) to smaller understory trees.

C-CAT applies the improved conifer management strategy outlined in this document geographically to private forest ownerships with Timber Production (TP) zoning within areas defined by LANDFIRE as redwood forest. We did not exclude areas where timber harvest might be restricted for riparian, endangered species, or other similar considerations. The tool is intended to provide initial estimates of the magnitude of potential carbon sequestration and results should be considered accordingly. A more precise estimate would require a deeper analysis.

A total of ten, 20-year modeled harvest scenarios were run. Modeling was performed in the US Forest Service's growth and yield simulator, Forest Vegetation Simulator (FVS) (www.fs.fed.us/fmsc/fvs). Tree lists were created for the model runs. Modeled harvests were applied to forested stands that had between 160 and 215 square feet of basal tree area (all species) per acre. The general proportion of species by basal area was assumed to be 50% redwood, 35% Douglas-fir, and 15% tanoak. The site class modeled was assumed to be a Site Class III for redwood, which is the dominant site class in Sonoma County.

The distribution of trees by diameter at breast height (DBH) class in the stands was adjusted for each model run. Each pre-harvest stand contained a large number of trees with small diameters and a small number of trees with large diameters; Figure D11 shows the disposition of DBH classes between the small and large diameter trees.

Figure D11. Distribution of dbh classes in pre-harvest stands by number of trees per acre



The business-as-usual harvest, in this case, focused on harvesting the larger trees in the stand in an effort to maximize harvest value. Understory trees were retained to grow into the future. Harvest occurs immediately (in year zero) and the stand is left to grow for the subsequent 20 years, after which CO2e is evaluated, both in wood products (including landfill) and in the forested stands.

The improved conifer management deferred some of the initial value and focused on maintaining growth on dominant and co-dominant trees within the stand. The theory behind this form of harvesting is that the stand is still growing toward a peak rate. Leaving the best growing trees is a way to maximize the carbon sequestration in the stand. The focus of harvesting thus shifts to the understory: smaller trees below the dominant and co-dominant trees. This type of harvest has an added advantage of reducing the ladder fuels, thereby reducing the risk of catastrophic wildfire, though we did not attempt to quantify the benefit of this risk reduction.

The basal area retention for business-as-usual harvesting and improved conifer management harvesting were set in the model to be approximately equal. Following harvest, the improved conifer management stands would consist of fewer and bigger trees than the business-as-usual stand, which would have many more small trees in the forest understory.

Following the 20-year modeling scenarios, the changes in tree diameters and tree heights were summarized and CO2e stocking levels were quantified and added to the CO2e sequestered in harvested wood products and landfill. The average CO2e sequestered in the improved conifer management areas exceeded the business-as-usual approach by approximately 1.8 tCO2e per acre per year.

To translate the effect of the improved conifer management activity into C-CAT, the increased forest growth was applied as a change from a smaller or less dense LANDFIRE cover class to a larger and denser LANDFIRE cover class, which would reflect the higher CO2e stocking levels. On average, 25% of the forested stands to which this strategy would apply were assumed to increase one size and one density class. Again, this method provides initial estimates of potential carbon sequestration opportunities; more precise estimates would require detailed site data.

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