CLIMATE READINESS INSTITUTE

Land Acquisition and Ecosystem Carbon in Coastal California

Produced for the California State Coastal Conservancy
A Project of the Climate Readiness Institute, UC Berkeley

Updated and revised as an External Report for the California Fourth Climate Change Assessment

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PREFACE

California's Climate Change Assessments provide a scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. These Assessments contribute to the advancement of science-based policies, plans, and programs to promote effective climate leadership in California. In 2006, California released its First Climate Change Assessment, which shed light on the impacts of climate change on specific sectors in California and was instrumental in supporting the passage of the landmark legislation Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), California's Global Warming Solutions Act. The Second Assessment concluded that adaptation is a crucial complement to reducing greenhouse gas emissions (2009), given that some changes to the climate are ongoing and inevitable, motivating and informing California's first Climate Adaptation Strategy released the same year. In 2012, California's Third Climate Change Assessment made substantial progress in projecting local impacts of climate change, investigating consequences to human and natural systems, and exploring barriers to adaptation.

Under the leadership of Governor Edmund G. Brown, Jr., a trio of state agencies jointly managed and supported California's Fourth Climate Change Assessment: California's Natural Resources Agency (CNRA), the Governor's Office of Planning and Research (OPR), and the California Energy Commission (Energy Commission). The Climate Action Team Research Working Group, through which more than 20 state agencies coordinate climate-related research, served as the steering committee, providing input for a multisector call for proposals, participating in selection of research teams, and offering technical guidance throughout the process. California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. It includes research to develop rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health.

The Fourth Assessment includes 44 technical reports to advance the scientific foundation for understanding climate-related risks and resilience options, nine regional reports plus an oceans and coast report to outline climate risks and adaptation options, reports on tribal and indigenous issues as well as climate justice, and a comprehensive statewide summary report. All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor and relevance to practitioners and stakeholders.

For the full suite of Fourth Assessment research products, please visit www.climateassessment.ca.gov. This report analyzes California's ecosystem carbon sequestration and evaluates the potential impact of avoided development.

ABSTRACT

Terrestrial ecosystems play a critical role in the global carbon cycle and will influence the rate of global climate change. Ecosystems remove carbon from the atmosphere, via photosynthesis, and release carbon to the atmosphere, primarily through decomposition and wildfire. As a result, ecosystem management will play an important role in climate change mitigation.

This report for the State Coastal Conservancy (SCC) focuses on two components of California's ecosystem carbon sequestration: aboveground carbon sequestration in forests and the carbon storage consequences of avoided development. SCC acquisitions store more than 7 million Mg of aboveground carbon, with an average density of more than 50 Mg C/ha. This is more than 2.5 times higher than the California average, mostly due to contributions of redwood forests. From 2001 to 2010, SCC acquisitions exhibited a net gain (sequestration) in aboveground carbon of 2.6×10^5 Mg (+3%). This net change reflects losses from wildfires, balanced by post-fire recovery and plant growth in unburned areas, especially old-growth forest.

The second component evaluated the potential impact of avoided development due to land conservation on avoided CO_2 emissions. Based on the alternative 'highest and best use' for each property, we developed counterfactual scenarios for the loss of carbon that would have resulted from conversion, and by extension the value that can be attributed to land conservation. For a set of the largest acquisitions, we found that about 5% of the land would have been subject to conversion to residential development or agriculture; however, potential carbon losses would have been only <2% of the aboveground C. The lower value is because development mostly takes place in low carbon vegetation, especially grasslands and shrublands. Quantitative analysis of belowground carbon was beyond the scope of this proposal and is important in future studies.

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HIGHLIGHTS

- Lands acquired by the State Coastal Conservancy store more than 7 million Mg of aboveground carbon, or 50 Mg C/ha (2.5 times the state average, primarily due to conservation of redwood forests).
- Coastal Conservancy acquisitions exhibited a net increase (sequestration) in aboveground carbon of 3%; the net change reflects losses from wildfires, balanced by post-fire recovery and plant growth in unburned areas, especially old-growth forest.
- Conservation contributed to avoided conversion to residential or agricultural uses of about 5% of the land, but only an estimated 1-2% of the aboveground C, because most conversion occurs on low carbon ecosystems such as grasslands and shrublands.
- These analyses provide further support for the importance of forest management, especially avoidance of large-scale carbon losses from wildfire, to enhance the role of terrestrial ecosystems for sequestration of aboveground carbon. Quantitative analysis of belowground carbon was beyond the scope of this proposal and is important in future studies.

The previously published research referenced in this summary can be found at:
Ackerly, D.., Battles, J.J., Butsic, V., Gonzalez, P., Kelly, N.M., Silver, W.L., Saah, D., di Tommaso, S., Mayer, A., Moanga, D., Schroeter, I., and Riordan, B. (2017). Land acquisition and ecosystem carbon in coastal California; a report of the Climate Readiness Institute. California State Coastal Conservancy, Oakland, CA (https://figshare.com/articles/_/6662984)

EXECUTIVE SUMMARY

Terrestrial ecosystems play a critical role in the global carbon cycle and will have an important influence on the trajectory of atmospheric CO_2 and the rate of global climate change in the coming century. Ecosystems sequester carbon from the atmosphere, via photosynthetic fixation of CO_2 by plants, and release carbon to the atmosphere, primarily by decomposition and wildfire. Some of the carbon captured in photosynthesis can be stored in ecosystems, for short or long periods of time, in the form of accumulating woody biomass aboveground, and belowground biomass in roots. Some belowground carbon enters soil carbon stocks where it may be stored for very long periods (decades to centuries).

In this context, conservation and management of terrestrial ecosystems have the potential to play a critical role in climate change mitigation at a global and regional scale. The California Global Warming Solutions Act of 2006 set a goal of reducing state emissions to 1990 levels by 2020. The state set a target for ecosystems (primarily forest ecosystems) of no net loss of carbon by 2020. More recently, ecosystem carbon sequestration was identified by Governor Brown as one of six 'pillars' to achieve the State's new 2030 greenhouse gas reduction goals.

This report for the State Coastal Conservancy (SCC) focuses on two important components of California's ecosystem carbon sequestration: aboveground carbon sequestration in forests and the carbon storage consequences of avoided development due to land conservation. The SCC has facilitated the permanent protection of more than 400 acquisitions in coastal California, encompassing more than 375,000 acres (152,000 ha). These properties span California's 22 coastal counties, and a wide range of ecosystems from grasslands to redwood forests.

In the first of two parts of this project, aboveground storage of carbon (C) in vegetation, and net change from 2001 to 2010, were estimated by extracting relevant values for the SCC acquisitions from a statewide analysis based on LandFire vegetation mapping (note that some parcels included in this analysis were acquired after 2001). We found that SCC acquisitions store aboveground carbon stocks of more than 7×10^6 Mg (Mg = million grams = metric ton) of aboveground carbon, with an average density of more than 50 Mg C/ha. This is more than 2.5 x higher than the average for California statewide, and reflects the importance of redwood forests in the SCC portfolio, which hold more than 50% of the total carbon stock across all SCC acquisitions.

Based on the most recent LandFire methodology, net change in aboveground carbon stocks (2001-2010) for the SCC acquisitions is estimated as a net gain (ecosystem sequestration) of 2.6×10^5 Mg (+3%). This net change reflects significant losses from properties that experienced wildfire, balanced by post-fire recovery and plant growth in unburned areas, especially old-growth forest.

The second component of this project evaluated the potential role of avoided development, and avoided CO_2 emissions, that could be attributed to conservation and protection of SCC acquisitions. Based on appraisals listing the alternative 'highest and best use' that the property could have been converted to, we developed counterfactual scenarios for the loss of carbon that would have resulted from conversion, and by extension the value that can be attributed to land conservation. For a selected set of 75 of the largest acquisitions, we found that about 5% of the land would have been subject to conversion, either to residential development or agriculture (primarily vineyards). Potential carbon losses from this conversion would have been approximately 1.4% of the total aboveground carbon estimated in the studied properties. This

value is lower than the amount of land converted because, based on the land conversion trends recorded within the buffer areas surrounding the studied properties, development mostly took place in areas covered by lower carbon vegetation types, especially grasslands and shrublands. In addition, some of the carbon that would be lost during development could potentially be recovered by tree planting in residential areas and crop growth on agricultural lands. Higher values of avoided carbon loss occur in limited cases where conversion of high carbon forest ecosystems may have been prevented by conservation.

Several important policy and management implications emerge from this research, both for the Coastal Conservancy and for agencies and organizations engaged in land conservation along the California Coast and Coast Ranges:

- The first is the value of forest conservation and management in the cool, moist forests of northwest California (especially redwoods) for sequestration and long-term storage of ecosystem C. These forests have some of the highest carbon densities of any ecosystem in the world; the maritime climate reduces fire risk, enhancing sequestration and long-term storage. Management for carbon sequestration may create tradeoffs with other objectives (habitat diversity, recreation, etc.), and these should be balanced to align with regional and organizational goals.
- The second is the critical importance of fuels and fire management, especially in more fire-prone ecosystems. Carbon losses from wildfire offset productivity in unburned ecosystems. However, reducing the risks of high severity fire, for example by fuels reduction or prescribed burning, may result in near-term carbon emissions to accomplish long-term sequestration goals. Relevant policies and management activities are the subject of extensive ongoing research and discussion statewide, and future actions will need to incorporate advances in this area.
- Third, the direct benefits of land conservation in terms of avoided development appear to be limited, due to the small footprint for residential development and the concentration of development in low-carbon ecosystems (grasslands and shrublands). Total impacts of conservation on emissions may depend more on locations of alternative development, effects on commute and vehicle travel, and land management actions following protection (as above). Future research considering the carbon consequences of conservation and land use in a systematic, regional context would be valuable.
- This report focuses on aboveground carbon, due to greater data availability for spatial analyses. Continued improvements to belowground carbon inventories, spatial data products, and research on how wildfire and management affect belowground carbon sequestration are critical to fill data gaps and better inform management strategies. Recent research and management proposals have focused on rangelands, and the potential value of compost amendment together with appropriate grazing regimes. These topics are addressed in detail in technical reports submitted to the 2018 California Fourth Climate Change Assessments.

BACKGROUND

Terrestrial ecosystems play a critical role in the global carbon cycle and will have an important influence on the trajectory of atmospheric CO_2, and hence the rate of global climate change in the coming century. Ecosystems sequester carbon from the atmosphere, via photosynthetic fixation of CO_2 by plants, and release carbon to the atmosphere by decomposition and other plant, microbial, and animal respiration, as well as wildfire. Some of the carbon captured in photosynthesis can be stored in ecosystems, for short or long periods of time, in the form of accumulating woody biomass aboveground, and belowground biomass in roots. Some belowground carbon enters soil carbon stocks where it may be stored for very long periods (decades to centuries).

Each year at a global scale, approximately 123 x 10^9 Mg carbon is fixed in photosynthesis (gross primary productivity) by terrestrial ecosystems, and a slightly smaller amount is released by respiration and fire (Ciais *et al.*, 2013). The imbalance between uptake and release of carbon result in the land surface acting as a carbon 'sink' when there is a net flux of carbon from the atmosphere into terrestrial ecosystems, or a 'source' when ecosystems are net emitters of carbon to the atmosphere. Due to human activities, approximately 7.8 x 10^9 Mg of carbon are being emitted into the atmosphere by fossil fuel combustion each year, and an additional 1 x 10^9 Mg due to land use change and replacement of natural vegetation by agricultural or developed uses. Rising CO_2 in the atmosphere is the primary cause of rising temperatures and global climate change. Decarbonization of energy sources is critical to reducing carbon emissions, and active CO_2 removal from the atmosphere is increasingly being viewed as a necessity to achieve global targets to keep temperature rise $\leq 2°C$ (above pre-industrial levels) (Boysen *et al.*, 2017; Tokimatsu *et al.*, 2017).

Uptake and loss of carbon by ecosystems also has important potential to offset or exacerbate the emissions of carbon to the atmosphere by the burning of fossil fuels. Human activities play a central role in this balance, through activities such as deforestation and land use change which can release carbon stores through the burning and decomposition of woody biomass and release of soil carbon to the atmosphere; alternatively, management strategies such as reforestation, ecosystem restoration and improved agricultural practices have the potential to enhance net ecosystem carbon sequestration. Thus, management of natural ecosystems, forest plantations, rangelands, and agricultural lands, including biofuels, can potentially make an important contribution to net removal of CO_2 from the atmosphere during this century. Forests were estimated to be a net carbon sink in the United States from 1990 to 2012 (US EPA, 2014), with net emissions of ~200 x 10^6 Mg C/yr. However, there are still gaps in ecosystem carbon accounting, especially concerning the impacts of wildfires, and the balance of sink and source activity depends on fluctuations in climate.

In California, ecosystem carbon sequestration was recently identified by Governor Brown as one of six 'pillars' to achieve 2030 greenhouse gas reduction goals[1]. The state set a target for ecosystems (primarily forest ecosystems) of no net loss of carbon by 2020 (California Air Resources Board, 2017), as part of meeting the goals of the California Global Warming Solutions Act of 2006 to reduce state emissions to 1990 levels by 2020.

[1] https://www.arb.ca.gov/cc/pillars/pillars.htm

This study addresses the contribution of lands conserved by the State Coastal Conservancy (SCC) on the storage and net ecosystem sequestration of aboveground C. Two components of ecosystem carbon sequestration that are of most relevance to this report are aboveground carbon sequestration in forests and belowground sequestration in grasslands and rangelands[2]. (Another component that could be important for the SCC is the role of wetlands, salt marshes, and Delta islands; this topic was beyond the scope of this report).

Forest management to enhance carbon sequestration is the focus of the California Forest Carbon Plan (Forest Climate Action Team, 2018). As discussed further below, management of fuel loads and fire regimes is central to forest carbon dynamics, as well as implementation of sustainable forest management systems. Enhanced soil carbon sequestration, as well as soil moisture retention and grassland productivity, is a focus of the Healthy Soils Initiative[3], also under development during 2017. Forest and soil protocols, developed under the aegis of the American Carbon Registry and overseen by the CA Air Resources Board, create a mechanism to certify forest and soil management plans so they can be incorporated into the state's cap-and-trade program, providing a revenue source for continued management.

Considerable research is now focused on improving estimates and accounting of terrestrial ecosystem carbon in California in an effort to determine the source/sink balance of the land surface, and its contribution to California's greenhouse gas emissions. Gonzalez et al. (2015), using remote sensing data, combined with forest plot analysis of carbon stocks, estimated that California wildlands had 850 ± 230 Tg aboveground carbon (95% CI) in 2010 (1 Tg = 1 trillion grams = 1 million tons), and had undergone a net loss of 69 ± 15 Tg from 2001 to 2010. The majority of aboveground carbon is found in forest ecosystems, which can store up to 600 Mg ha^{-1}, while grasslands typically contain only about 1 Mg ha^{-1} and shrublands can range from <1 Mg ha^{-1} in deserts up to 50 Mg ha^{-1} in chaparral. Two-thirds of the losses were recorded on lands that experienced wildfires during the decade of analysis, including large fires in the Klamath, Big Sur, Transverse and Peninsular Ranges. Saah et al. (2015) updated the methods and analysis of Gonzalez et al., accounting for urban and agricultural lands as well as correcting for growth underestimates in intact mature forests. The methods and results of these studies are discussed in more detail below, as both data sets were incorporated into the analyses for this project. See Battles et al. (2018) for recent updates and innovations in the measurement of forest carbon.

Estimates of belowground carbon are more difficult due to high spatial heterogeneity and limited ability to calibrate and scale estimates using remote sensing. At a global scale, it is estimated that soils contain over 2000 Pg of carbon (1 Pg = 10^{15} g), several times more than total aboveground biomass (Batjes, 2016); belowground carbon is especially important in grasslands and rangelands where plants tend to allocate a high proportion of their photosynthate to roots in search for water and nutrients. California is estimated to have approximately 25 million ha of rangelands (DeLonge *et al.*, 2014). Silver et al. (2010) reviewed the literature for soil carbon stocks in California, and found soil carbon levels as high as 250 Mg ha^{-1} in the top meter of soil in grasslands, with higher values in systems with woody plants and roots extending deeper in the soil profile. Biogeochemical models provide a powerful method to estimate ecosystem carbon dynamics over long periods of time, and their potential response to changing climate and land management practices (Ryals et al. 2015). This approach has been utilized recently to evaluate

[2] https://www.arb.ca.gov/cc/natandworkinglands/natandworkinglands.htm
[3] https://www.cdfa.ca.gov/oefi/healthysoils/

potential strategies to enhance belowground soil carbon in California grasslands across a gradient of coastal climate conditions (Silver *et al.*, 2018). We recognize the importance of belowground carbon sequestration and storage in shrublands and forests; unfortunately, a quantitative synthesis of available data was beyond the scope of the analyses in this report (see Flint *et al.*, 2018).

Given the importance of terrestrial ecosystems for climate change and climate change mitigation, it is important to consider the role of open space conservation in ecosystem carbon sequestration. At a global scale, land use change and deforestation are the major source of carbon emissions from ecosystems, contributing more than 10% of total greenhouse gas emissions worldwide (IPCC, 2014). In California, 49.2 million acres (19.9 million ha)[4] are protected, managed by over 1000 different agencies and organizations[5], representing almost 50% of the state. The majority of these lands (>85%) are federally owned, primarily distributed across the Sierra Nevada, Klamath, Transverse and Peninsular Ranges, and the desert. State, non-governmental organization (NGO) and private ownership is more important in the Coast Ranges and along the coast itself. The strength of protection and types of management activities vary widely across different ownership and legal designations. Broadly speaking, land protection ensures that the ecosystems will not be converted in development, and can be managed for biodiversity conservation, wildlife habitat, watershed protection, public enjoyment, and to enhance their potential for carbon sequestration.

In the coming century, the impact of climate change on ecosystem carbon stocks and sequestration is also a growing concern. The area burned in wildfire has risen over the last several decades at least in part due to warming temperatures and an extended fire season (Dennison *et al.*, 2014). The incidence and size of high severity fire, such as the 2012 Rim Fire and the 2015 and 2017 Lake county and North Bay fires, also raise the possibility of increased carbon losses due to wildfire in the coming century, and long-term declines in the ecosystem carbon storage (Liang *et al.*, 2017; see critical review in Moghaddas *et al.*, 2018). Management practices that may reduce the potential for catastrophic fire are a major focus of research and policy consideration.

Climate change may also alter ecosystem function, even without wildfire, and thus impact carbon sequestration. The 2012-2016 California drought has led to tree mortality across more than 20% of California's forest lands[6], and the majority of the carbon stored in the dead trees will be emitted to the atmosphere as the trees either decompose or burn (a fraction will also be transferred to the soils from decomposing litter and wood or as charred biomass following fires). Increasing heat stress and drought may reduce photosynthetic productivity of surviving trees, further reducing carbon sequestration (Schlesinger *et al.*, 2016). Fire suppression as well as wildfire events may trigger vegetation type conversion, with long-term consequences for carbon sequestration and storage (Russell & McBride, 2003; Hurteau & Brooks, 2011). Rapid regrowth of forests following fire and drought has the potential to partially offset these losses over time, though rates and trajectories of recovery are uncertain.

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[4] In this report, we use acres when describing the size of properties due to conventions, but switch to metric units for describing the density and amounts of C. 1 acre = 0.4047 ha

[5] http://www.calands.org/

[6] https://www.fs.fed.us/news/releases/new-aerial-survey-identifies-more-100-million-dead-trees-california

In rangelands, increased drought can lower plant production, decreasing forage for the state's livestock industry (Chou *et al.*, 2008). Management approaches such as compost amendments have been proposed to enhance resilience to drought and increase soil carbon sequestration while maintaining or increasing plant growth and forage production for livestock (Ryals & Silver, 2013; Ryals *et al.*, 2014). The sensitivity of grassland carbon cycling to predicted changes in climate is poorly understood, as is the ability of compost to potentially help mediate some of these impacts.

The factors outlined above set the context for the present study evaluating the role of land conservation in the maintenance of ecosystem carbon stocks and net sequestration from the atmosphere. The State Coastal Conservancy (SCC) was created by the California State Legislature to promote open space conservation across a broad swatch of coastal California (Figure 1.1). From 1980 to 2013, the SCC has facilitated protection of more than 400 properties covering approximately 375,000 acres. Acquisitions range in size from less than 1/10 of an acre to the 80,733 acre Hearst Ranch, and span 22 of California's counties, across the SCC's jurisdiction from San Diego to Humboldt.

This project included two tasks related to SCC acquisitions and ecosystem C. The focus on the SCC properties was conducted to consider how the statewide tools and analyses for carbon sequestration can be applied in the context of an individual agency or landowner.

- Task 1. Spatial analysis of land cover, vegetation types, climate zones, and aboveground carbon stocks and net carbon sequestration (2001-2010) across the SCC jurisdiction.
- Task 2. Analysis of avoided development and potential for avoided carbon emissions based on counterfactual scenarios of the alternative 'highest and best use' for the acquired parcels.

Note that the original report prepared for the State Coastal Conservancy (Ackerly *et al.*, 2017) included a third task examining belowground carbon sequestration in rangelands linked to compost addition. This topic is covered in greater detail in two technical reports in the Fourth Assessment (Flint *et al.*, 2018; Silver *et al.*, 2018), and has been omitted from this revised report.

The original report can be accessed at: https://figshare.com/articles/_/6662984 (doi: 10.6084/m9.figshare.6662984); results of the project were presented in a public webinar, available at: https://figshare.com/articles/_/5594437 (doi: 10.6084/m9.figshare.5594437)

Task 1: Land Cover, Vegetation, Climate, Fire History, & Aboveground Carbon Storage and Sequestration (2001-2010)

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The objective of Task 1 was to conduct a series of spatial analyses overlaying the SCC parcel maps on GIS data for vegetation, climate, fire history, and aboveground carbon stock datasets, providing a synthetic overview and spatial context for the SCC portfolio.

SCC Acquisitions – Geography, Climate, Vegetation, and Fire History

In collaboration with SCC, we constructed a well-curated GIS project including shapefiles for 408 parcels protected by the SCC from 1980 to 2013[7]. Acquisitions range in size from less than 1/10 of an acre to the 80,733 acre Hearst Ranch, for a total of just over 375,000 acres. Acquisitions span 22 of California's counties, across the SCC's jurisdiction from San Diego to Humboldt (Table 1.1, Figure 1.1); county maps showing outlines of the acquisitions are shown in Appendix 1 (Figure A1). More than half of all SCC acreage was acquired during the decade from 2001-2010, including the Hearst Ranch. As a result, the analysis of changes in carbon stocks from 2001-2010 starts before many acquisitions were added to the portfolio. This analysis is not intended to credit changes in carbon stocks to SCC acquisition or management, but rather to highlight the key factors influencing aboveground carbon stocks and changes in these coastal California ecosystems.

Climate

Coastal California spans 9.5 degrees of latitude and a corresponding range of climate conditions. Temperature is strongly influenced by latitude as well as proximity to the ocean, with cool summers and mild winters close to the coast; precipitation increases in the north, exceeding 4 m per year in the far NW of the state (Figure A2). The Basin Characterization Model Flint *et al.*, 2013 integrates precipitation and temperature, as well as solar radiation, topography, and soil mapping, to estimate actual evapotranspiration (AET, a measure of plant productivity) and climatic water deficit (CWD, a measure of excess energy load in summer that is not met by available water). CWD provides an important measure of summer drought stress. Both AET and CWD can contribute to wildfire intensity, as higher AET can increase plant growth and fuel production during the growing season, while high CWD contributes to fuel moisture drying out in summer, setting the stage for wildfires.

By extracting climate data and plotting variables against each other, the climate space of the SCC jurisdiction can be visualized, and the distribution of acquisitions viewed in context (Figure A3). Though the SCC jurisdiction extends inland encompassing coastal counties, and much of the Klamath Basin, most acquisitions have been focused along the coast. This is reflected in climate space, with the protected lands falling in mild to warm winter temperatures (Figure A3a). Due to the extensive geographic coverage from south to north, SCC parcels span a broad range of precipitation, AET and CWD (Figure A3b-d). Acquisitions do not cover the cooler winter temperatures and the lower AET-CWD combinations that would represent Klamath highlands and some other interior regions.

[7] 65 of the acquisitions were missing acquisition dates, so earliest date may have been before 1980.

Vegetation

Vegetation types captured in SCC acquisitions were analyzed based on the LandFire vegetation mapping (Ryan & Opperman, 2013), which provides the basis for mapping carbon stocks in California (Gonzalez *et al.*, 2015; Saah *et al.*, 2015). LandFire classifies the existing vegetation type of a pixel through classification tree algorithms that relate field-observed vegetation in a network of field inventory plots to reflectance from seven Landsat spectral bands, topography, and climate variables (Rollins *et al.*, 2006). As vegetation changes, spectral reflectance in the Landsat images also changes, leading to reclassification of a pixel.

SCC lands cover a wide range of vegetation, from coastal redwood forests to Southern California coastal sage (Table 1.2). Redwood forests covered the largest area (23%), followed by grassland (16%), mixed woodlands (12 and 8% in two different classes), and a range of shrublands and mixed shrubland/oak woodlands. Vegetation types can be grouped into three broad classes – grassland, shrublands, and woodlands/forests – to capture patterns in geographic and climatic space. Following broad patterns in vegetation distributions across the state, acquisitions primarily covered in woodlands and forest are mostly distributed in the northern and central regions, while grassland and shrub-dominated acquisitions prevail in the central and southern regions (Figure. A4).

Wildfire

From 1980-2015, wildfires impacted 49 of the 408 SCC acquisitions (Figure 1.3). Net and cumulative area burned were calculated for each decade (1980-1989, 1990-1999, 2000-2009), the 2010-2015 half-decade, and 1980-2015 overall. Net area is the area burned in each time period, counting multiple burns on the same pixels once, and cumulative area is the total area burned, counting repeat burns separately (cumulative area burned can exceed the total size of a parcel due to multiple fires). Over the 1980-2015 time period, net area burned across the 49 acquisitions was 26,531 acres (7.1% of total SCC acquisition area), and cumulative area burned was 38,798 acres (10.3% of total area) (Table 1.3).

Though there is some uncertainty in the assignment of vegetation types to individual pixels, discrimination of grassland, shrubland and woodland/forest is fairly reliable. Changes recorded from 2001 to 2010 in the acquisitions that experienced at least one fire demonstrate a significant reduction in shrub-dominated ecosystems and corresponding increase in grasslands, with little change in area of woodlands and forests (Figure 1.4). These changes likely represent two distinct phenomena: one would be actual type conversion from shrubland to grassland, as has been observed in Southern California, especially in response to multiple fires that occur at short intervals of < 5 years. Alternatively, the early successional shrubland environments may be classified as grassland in the first several years after fire, until the shrubs resprout and recover. Either way, these represent significant short-term changes in aboveground carbon storage, as discussed below.

Two properties contributed a large portion of the total area burned, and the vegetation change shown in Figure 1.4 (see Table A1.1). Lauff's Ranch, a 12,000 acre parcel in northeastern Napa Co. on the border with Yolo Co., was impacted by two large fires. The Sixteen Fire, in 1999 (~40,000 acres), burned the northern portion of the property and the Rumsey Fire, in 2004 (>40,000 acres) burned the entire acquisition. The property was classified primarily as shrubland in 2001, but in 2010 virtually all of that area was classified as grassland.

Malibu Creek Watershed-Ahmanson Ranch, a 2,200 acre acquisition in Los Angeles Co., was almost entirely burned by the Topanga Fire in 2005 (23,000 acres) and also a smaller fire in the 1980s. This property also exhibited a shift from mostly shrubland to mostly grassland (possible early successional shrubland, as noted above), though it is a smaller acquisition so it contributes less to the overall patterns in Figure 1.4.

Carbon storage and sequestration

Total carbon stocks and net change from 2001 to 2010, representing either sequestration (if positive) or emissions (if negative), were calculated using the LandFire project methodology (Gonzalez *et al.*, 2015; Saah *et al.*, 2015, also see Battles *et al.*, 2018). LandFire classification of vegetation type, height, and cover, were combined with calibrated measures of carbon density in each class, based on field estimates (all forests and some shrublands), literature values (shrublands), and remotely sensed estimates of net primary productivity (grasslands). Carbon density estimates were assigned to each pixel based on the 2001 and 2010 LandFire maps to individual biomass classes, addressing natural lands only. Gonzalez et al. (2015) validated carbon stock estimates against independent field- and Lidar-derived stocks quantified in coast redwood and Sierra Nevada mixed conifer forests. These showed reasonable accuracy, with no statistically significant differences between the Gonzalez et al. (2015) results and the independent estimates. In addition, comparison of Gonzalez et al. (2015) statewide forest carbon stock estimates with three national remote sensing efforts showed no statistically significant differences with the two most recently published estimates. The analyses of Gonzalez et al. (2015) only examine the aboveground live carbon pool because of the lack of independent repeat field measurements and spatial data of dead wood, other carbon pools (including belowground), and harvested wood products at the temporal and spatial resolutions of the aboveground biomass data.

Uncertainty in both total carbon storage and net change was estimated in relation to three factors: 1) carbon density of biomass, 2) biomass density of each biomass class, and 3) uncertainty in the vegetation type mapping (the latter contributed the greatest source of uncertainty overall). Collectively, these uncertainties allow for an assessment of statistical significance of inferred changes, i.e. if the entire range of the 95% confidence interval values is either greater than or less than zero, then the change is inferred to represent, respectively, significant net sequestration or emissions. Gonzalez et al. also noted that this methodology could underestimate carbon accumulation in intact, mature forests. This limitation is due to the inability of LandFire to resolve small increases in height over the observation period. Saah et al. (2015) addressed this by inputing an average 0.67% yr^{-1} growth adjustment in mature forest pixels (based on estimates from US Forest Service Forest Inventory and Analysis data). This update reflects the current methodology for evaluation of carbon stock and change adopted by the CA Air Resources Board. However, the updated data set does not allow for direct calculation of uncertainties or confidence intervals in the inferred changes. P. Gonzalez and D. Saah both extracted and analyzed carbon stocks and change from their data sets for each parcel in the SCC portfolio, as well as totals across acquisitions summed by dominant vegetation class and in burned vs. unburned parcels.

Following the methodology used in Gonzalez et al. (2015), the 408 SCC acquisitions contained a total of 7.3 (±3.3 95% CI) million metric tons (7.3×10^6 Mg) of aboveground carbon in vegetation in 2010. The 20 properties with the highest aboveground carbon contributed over 85% of the total across the SCC portfolio (Table A1.2); the top three are the Garcia River and

Mill Creek acquisitions, both of which are large tracts of redwood forest, and the Hearst Ranch, which has a wide mix of vegetation and is by far the largest acquisition in the portfolio. Across the entire SCC portfolio, 5% of aboveground carbon was stored in shrub-dominated ecosystems, 36% in broadleaf and mixed forests, and 58% in conifer forests (56% in redwoods, 2% in other conifer forests).

Average aboveground carbon density across all acquisition was 53 Mg/ha. The highest aboveground carbon density in the SCC portfolio is the Big Lagoon Acquisition in Humboldt Co. (370 Mg/ha) and 24 acquisitions had aboveground carbon density > 100 Mg/ha (Table A1.3). For reference, aboveground carbon of California vegetation varies from less than 1-2 Mg/ha in sparsely vegetated ecosystems and grasslands to almost 600 Mg/ha in tall, closed canopy coastal redwood forests. Across the state, average aboveground carbon density in 2010 was 20 Mg/ha (based on Gonzalez et al. 2015). Thus, the ecosystems within the SCC portfolio on average have about 2.5 times higher carbon density compared to statewide averages.

In shrub and tree-dominated vegetation, carbon density increases with rainfall (Figure 1.5). For tree-dominated systems, these patterns reflect the taller forests, higher canopy cover, and prevalence of redwoods at very high rainfall levels on the North Coast. The trend is weaker in shrublands, and carbon densities are much lower overall (compare y-axis values in Figure 1.5), but the pattern presumably reflects taller and/or higher density shrub cover detected in the LandFire remote sensing methodology in the wetter regions of the North Coast compared to the hotter, drier South Coast where shrublands are more widespread.

Carbon stocks in 2001 and 2010, and the change over the decade, are shown for the state of California (Figure 1.6) and for the Preservation Ranch, Sonoma Co., as an illustration of a single SCC acquisition (Figure 1.7). Based on Gonzalez' methodology, total change in aboveground carbon on SCC parcels from 2001 to 2010 was a significant reduction of -1.5×10^5 Mg (95% confidence interval: -1 to -2×10^5 Mg), representing a 2% reduction from 2001 levels (Table 1.4, Figure 1.8a). A 2% reduction is higher than the average of 0.8% recorded statewide for the same time period. The net emissions recorded on SCC lands were almost entirely attributable to net losses from shrublands, with a small but significant loss from tree-dominated systems as well. Note that the modest emissions from forest lands reflect the net effect of losses, primarily on parcels that burned, balanced by net sequestration in other locations.

Saah's updated methodology suggests positive, net sequestration of carbon, with total change in aboveground carbon on SCC parcels of 2.6×10^5 Mg, representing a 3.4% increase from 2001 to 2010 (Figure 1.8a). Net changes were close to 0 for parcels that experienced fire, and the totals gains were contributed on the remaining lands that did not burn. Significance values for change in carbon stores are not available from Saah's study at this time. The most important difference between the two methods, which likely accounts for most of the difference in results reported here, is the attribution of 6% net growth in old-growth forest pixels that were not recorded to transition to a higher height or canopy cover category. As redwoods contribute most of the carbon in the SCC spatial footprint, imputed growth of 6% across some substantial number of pixels would lead to the assessment of net sequestration.

Occurrence of fires was recorded by two different methods. Gonzalez et al. (2015) overlaid the national Monitoring Trends in Burn Severity (MTBS) dataset for fire occurrence from 2001-2010 on the LandFire vegetation map to determine which pixels had burned. For this report, we also tabulated total losses from acquisitions that had experienced any fire, even if only to a

portion of the property, vs. those that had experienced no fire. Based on the MTBS overlay, 63% of the net losses originated from pixels that burned (Table 1.4, Figure 1.8b). Losses from unburned pixels in this analysis may reflect low-intensity fires that are not recorded by MTBS, harvesting in managed forests, or changes in vegetation classification of individual pixels; we were not able to determine the relative importance of these factors. Based on the acquisitions overall, we found that 98% of net losses occurred on 21 acquisitions that experienced wildfires in the 2001-2010 interval (individual assessments were negative for all 21 of these properties) (Figure 1.8b, see Table A1.1). The single largest loss was recorded on Lauff's Ranch, in northern Napa County, where extensive areas of shrubland were recorded as converted to herbaceous (i.e. grassland) vegetation (see Discussion). Based on Saah's updated methodology, net losses on burned acquisitions were close to 0 (growth balancing fire losses) while net carbon accumulation was almost entirely attributed to parcels that did not burn. While estimates vary based on different combinations of methods, the overall conclusion is a clear indication that wildfire is the primary factor leading to loss of aboveground carbon in California's forests and shrublands, balancing growth and accumulation in unburned vegetation, especially old-growth forest.

Discussion

Two important conclusions emerge from these analyses regarding the role of land acquisition and management in relation to aboveground carbon storage and sequestration: 1) the importance of forests, particularly redwoods, for aboveground carbon storage in California ecosystems; and 2) the critical role of fire, and fire-management, in maintaining existing aboveground carbon stocks in shrublands and forests.

Forests are the primary reservoirs of aboveground carbon in terrestrial ecosystems. In particular, California's redwoods represent some of the highest carbon density forests in the world (Van Pelt *et al.*, 2016). SCC acquisitions, together with investments and holdings of Save the Redwoods, CA State Parks, the National Park Service, local non-governmental organizations and private holdings, play a critical role in the conservation and management of these ecosystems. Only about 5% of old-growth redwood survives, as most of the original forest area is now converted following logging to younger, secondary redwood forest, offering potential for continuing management to enhance carbon sequestration[8].

California has played an important role in the development of carbon offset protocols for sustainable forest management, creating an income stream for management actions than enhance carbon sequestration by participation in California's cap-and-trade market as offsets. Three SCC acquisitions are currently registered carbon offset projects, all of them dominated by coastal redwood forests and managed by The Conservation Fund[9]: Garcia Forest, Big River & Salmon Creek, and Preservation Ranch. Based on 2016 assessments, the three projects manage stocks of 5.3, 3.6, and 3.9 million metric tons of C, respectively, and have received credits for enhanced annual sequestration of 1.9 to 2.6% of stocks (i.e. sequestration credited to sustainable management practices, over and above the baseline scenario of forest growth in the absence of these practices) (Table 1.5). SCC funding played an important role in initial financing of the acquisition and establishment of these projects, and their long-term success will be an important

[8] https://www.savetheredwoods.org/about-us/faqs/

[9] https://www.conservationfund.org/projects/north-coast-forest-conservation-initiative

indicator of the state's ability to incentivize sustainable forest management as a component of achieving overall emissions reductions goals.

The second point emerging from these analyses, and highlighted in Gonzalez et al. (2015), is the critical role of fire as a factor that impacts long-term carbon storage and sequestration. Just as forests represent the most important reservoirs of aboveground carbon, fire management in forests presents the greatest challenges to enhance net aboveground carbon sequestration. Many decades of experience demonstrate that fire suppression is not feasible, nor ecologically desirable, in California's Mediterranean-type climate. Additionally, it is now well documented that fire suppression can lead to accumulation of fuels and contribute to catastrophic wildfire, such as the 2012 Rim Fire, that results in high fire severity and carbon emissions. This problem is most apparent in the mid-elevation pine forests of the Sierra Nevada, though recent fires in the North Coast have also exhibited very high severity and tree mortality (e.g., 2015 Valley Fire in Lake Co.). The California Forest Carbon Plan (Forest Climate Action Team, 2018) focuses on the important role of forests in the state's climate action plan, and the critical challenges posed by forest management in relation to wildfire. Coastal forests, especially redwoods, are less susceptible to carbon loss from wildfire due to cooler climates and prevalence of lower intensity fires, so these management issues are less critical in SCC acquisitions and other conserved forests along the California coast, compared to challenges in the Sierra Nevada.

Grasslands and shrublands also experience frequent fire, but the impact on aboveground carbon sequestration is minimal as these systems have little potential for long-term accumulation of carbon in aboveground stocks (see Silver *et al.*, 2018 for discussion of potential belowground carbon sequestration in grasslands). California's grasslands are primarily composed of exotic annual species which grow and die within one season. Aboveground carbon in these systems is essentially in balance, as net primary productivity each growing season will be balanced by decomposition after the grasses die, though some of the organic carbon in the decomposing litter may find its way into the soil and enhance belowground C. Fire will have little influence on this cycle, as it simply represents an alternative to decomposition as a mechanism to release carbon in the biomass back to the atmosphere.

California's shrublands are highly flammable, and also offer little opportunity for long-term accumulation of aboveground C. Chaparral, the dominant shrubland on dry slopes in central and southern California, typically experiences stand-replacing or canopy fires in which all aboveground biomass is incinerated or left as standing or fallen woody material which will eventually decompose. Shrublands may accumulate carbon for many decades in the absence of fire, which could offer short-term climate benefits, but in the long-term California's flammable shrublands should be viewed as essentially carbon neutral with respect to aboveground biomass. Consideration of belowground carbon in shrublands was beyond the scope of this proposal, and may be an important consideration as root and soil carbon increase through repeated fire cycles, through carbon allocation to roots that decompose belowground, litter inputs from the canopy, and charred plant matter following fire events. See Underwood et al. (2018) for extensive treatment of carbon cycling and a range of ecosystem services of chaparral vegetation.

Dynamic vegetation modeling for California projects that warmer and drier future climates may lead to contraction of shrubland and some forest types, with the potential for more than 25% reductions in live woody carbon, and smaller reductions in soil and litter carbon pools (Lenihan *et al.*, 2008). These results generally follow multi-model analyses of global projections that suggest significant net losses of carbon from temperate latitude ecosystems under a wide range

of future climate projections (Ahlström *et al.*, 2012). The widespread tree mortality during the 2012-2016 drought is an example of climate induced changes in standing biomass that may lead to long-term changes in fire behavior and vegetation (Stephens *et al.*, 2018). These net losses of biomass and productivity will be manifest as changes in vegetation type, or reductions in tree density and canopy cover of existing vegetation types. Management strategies to enhance drought resilience, for example by actively reducing canopy density, are being discussed (Bradford & Bell, 2017), and could become important in future decades.

In sum, the SCC acquisitions store a large amount of aboveground C, relative to their land area, primarily due to the large area of redwoods spread across a number of acquisitions. It is important to recognize that these conclusions were based on analyses for one decade (2001-2010) and for a limited land area defined by the SCC portfolio. Future analyses of the 2011-2020 decade will likely detect the importance of the recent drought, as well as large fires. As drought and warm temperatures contribute to fire risk, the contributions of climate and fire cannot be fully disentangled. The results may also differ for other regions of California, or other sets of properties. The methods for measuring carbon sequestration are most efficiently applied at a state or regional level; methods to rapidly extract results for individual agencies or landowners may be useful for applications of the results to policy and management. Sustained net carbon sequestration in forestlands will depend critically on the frequency, extent, and severity of wildfire, which generates large carbon emissions, as well as the implementation of sustainable forest management practices in properties which are harvested. Climate change poses a challenge, as warmer and potentially drier conditions could lead to enhanced fire probability, as well as changes in forest densities and vegetation types. Managing for these climatic changes and ecosystem transitions poses new conservation challenges for the 21st century.

Task 1 – Tables and Figures

Table 1.1 Distribution of State Coastal Conservancy parcels and acres across California counties

County	Number of acquisitions	Acreage in county
Alameda	10	3,654
Contra Costa	26	10,562
Del Norte	5	1,038
Humboldt	35	12,728
Lake	1	8
Los Angeles	29	3,512
Marin	25	12,056
Mendocino	36	64,611
Monterey	45	14,616
Napa	16	24,373
Orange	13	1,201
San Diego	17	1,176
San Francisco	1	2
San Luis Obispo	29	90,375
San Mateo	33	12,564
Santa Barbara	15	5,979
Santa Clara	13	7,766
Santa Cruz	20	18,319
Solano	13	13,379
Sonoma	32	45,620
Ventura	10	6,323
Yolo	1	141
Total*	**425**	**350,003**

*Total number of acquisitions is greater than 408 due to parcels that straddle county lines

Table 1.2 Total acreage of vegetation types across all SCCacquisitions. Sorted in decreasing order by 2010 totals

Biomass Order Name	Total 2001	2001 % of total	Total 2010	2010 % of total	Change 2010-2001	percent change
California Coastal Redwood Forest	86,599	23.1%	88,537	23.6%	1,938	2.24
Grassland	45,830	12.2%	59,812	15.9%	13,982	30.51
Central and Southern California Mixed Evergreen Woodland	46,369	12.4%	46,386	12.4%	17	0.04
Water or non-California	26,648	7.1%	32,446	8.6%	5,798	21.76
Mediterranean California Mixed Evergreen Forest	31,091	8.3%	32,344	8.6%	1,253	4.03
California Mesic Chaparral	34,354	9.2%	28,526	7.6%	-5,828	-16.96
Southern California Coastal Scrub	16,804	4.5%	14,221	3.8%	-2,583	-15.37
Southern California Oak Woodland and Savanna	12,767	3.4%	12,885	3.4%	118	0.92
California Montane Woodland and Chaparral	9,696	2.6%	7,781	2.1%	-1,915	-19.75
Southern California Dry-Mesic Chaparral	8,399	2.2%	7,615	2.0%	-784	-9.34
Northern and Central California Dry-Mesic Chaparral	13,893	3.7%	7,090	1.9%	-6,804	-48.97
Herbaceous-shrub-steppe	6,220	1.7%	5,913	1.6%	-307	-4.93
California Montane Riparian Systems	4,548	1.2%	5,505	1.5%	957	21.04
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	5,342	1.4%	5,458	1.5%	116	2.16
Herbaceous Wet	11,212	3.0%	4,042	1.1%	-7,169	-63.94
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	3,717	1.0%	3,604	1.0%	-113	-3.04
Other (summed)	11,670	3.1%	12,995	3.5%	1,325	0.11
Total	**375,159**		**375,160**			

Table 1.3 **Summary of area burned by wildfire, by time period and cumulative from 1980-2015. For SCC parcels, net area refers to the acres burned per time period, counting multiple fires in the same pixel once; For parcels, jurisdiction and statewide, cumulative area refers to total area of all fires, counting locations burned twice or more independently each time. Cumulative totals also shown as a percentage of total parcel number and areas (shown on bottom line). See Figure 1.1 for map of SCC jurisdiction (coastal California) and locations of individual SCC acquisitions.**

TimePeriod	SCC Parcels Burned (num)	SCC Net Area Burned (acres)	SCC Acquisitions Cumulative Area Burned (acres)	SCC Jurisdiction Cumulative Area Burned (million acres)	Statewide Cumulative Area Burned (million acres)
1980_1989	20	6,322	6,412	1.83	3.05
1990_1999	28	10,393	10,663	1.37	3.36
2000_2009	20	20,264	21,092	3.67	6.54
2010_2015	4	630	630	0.82	3.07
1980_2015	49	26,531	38,798	7.68	16.02
1980_2015 (% total)	12.0%	7.1%	10.3%	27.1%	15.8%
	SCC Parcels (Num)		SCC Acquisitions Total Area (acres)	SCC Jurisdiction Area (million acres)	Statewide Area (million acres)
Totals for reference	408	375,167	375,167	28.3	101.2

Table 1.4 Aboveground carbon stocks and change from 2001-2010 summed across SCC parcels, in tons of carbon (values extracted from Gonzalez et al. 2015)

	2001	± 95% CI	2010	± 95% CI	2001-2010	± 95% CI	Significant*
Total coast	7.4×10^6	3.9×10^6	7.3×10^6	3.3×10^6	-1.5×10^5	0.48×10^5	Yes
Trees	6.9×10^6	3.2×10^6	6.9×10^6	3.2×10^6	18×10^3	8.3×10^3	Yes
Shrubs	0.52×10^6	0.36×10^6	0.39×10^6	0.31×10^6	-140×10^3	80×10^3	Yes
Herbaceous	25×10^3	49×10^3	33×10^3	89×10^3	7.9×10^3	19×10^3	No
No dominant	83	480	240	1 200	160	960	No
Non-vegetated	390	3 800	390	4 400	6	83	No
Fires	0.19×10^6	74 000	97 000	58 000	-93 000	35 000	Yes
No fires	7.2×10^6	3.2×10^6	7.2×10^6	3.2×10^6	-55×10^3	23×10^3	Yes

* 95% confidence intervals do not include zero

Table 1.5 Summary of size, carbon stocks and GHG reductions credited to three forest carbon offset projects supported by the Coastal Conservancy. Data from project reports filed by the Conservation Fund with the Air Resources Board (see https://www.arb.ca.gov/cc/capandtrade/offsets/registries/registries.htm).

	Garcia Forest Reserve	**Big River/Salmon Creek**	**Preservation Ranch (Buckeye Forest)**
Acquisition	2003	2006	2013
Size (acres)	22,455	15,911	19,552
Aboveground Carbon stocks (million MtCO2e)	5.261	3.572	3.901
Net GHG reductions (MtCO2e)	102,161	91,213	98,559
GHG reductions (% of Aboveground Carbon stocks)	1.94%	2.55%	2.53%

Figure 1.1

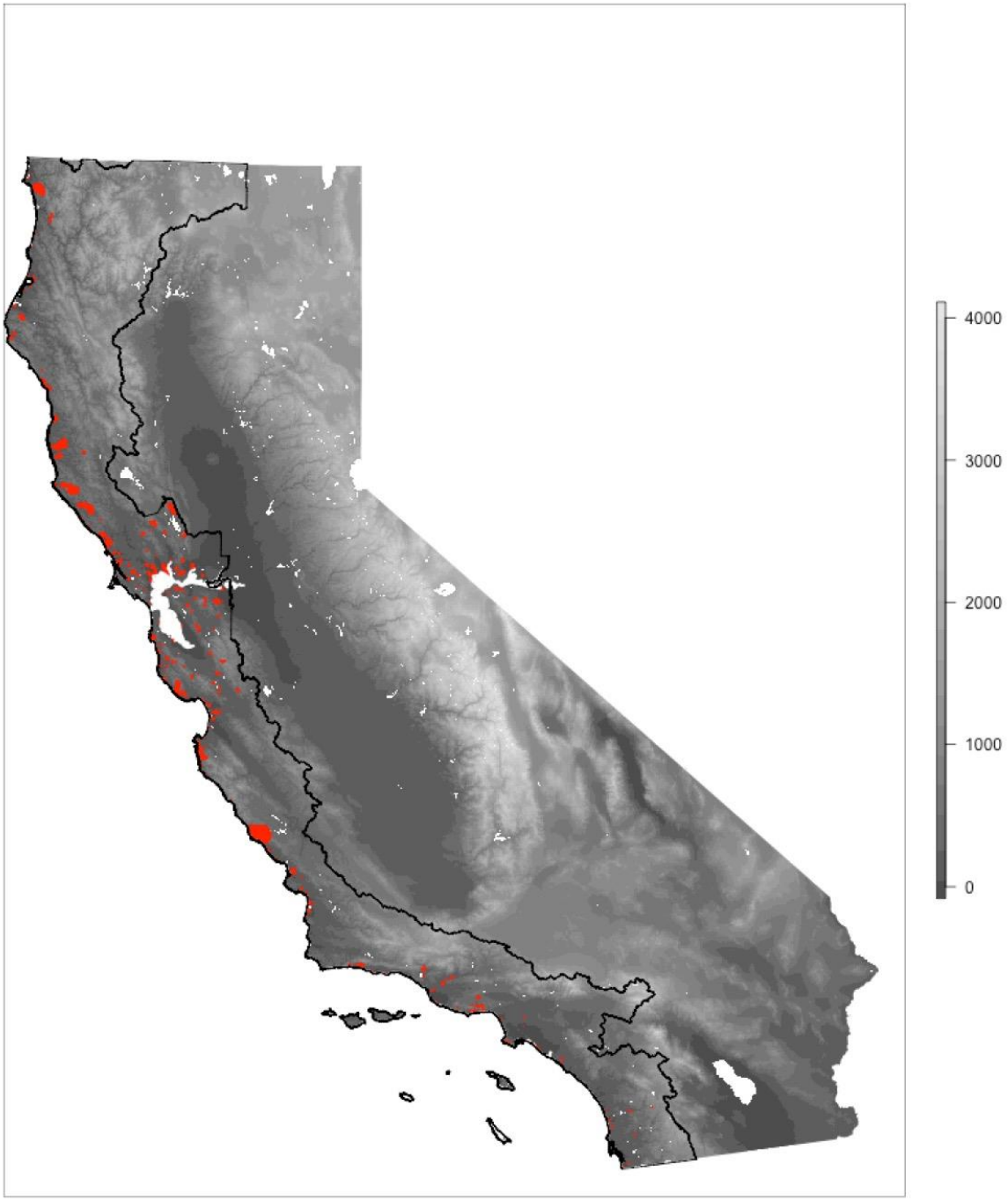

Figure 1.1. Location of State Coastal Conservancy legal jurisdiction (black outline) and acquisitions (red). Acquisitions are shown to scale; for greater detail, see county maps in Figure A1. Background shows elevation (m).

Figure 1.2

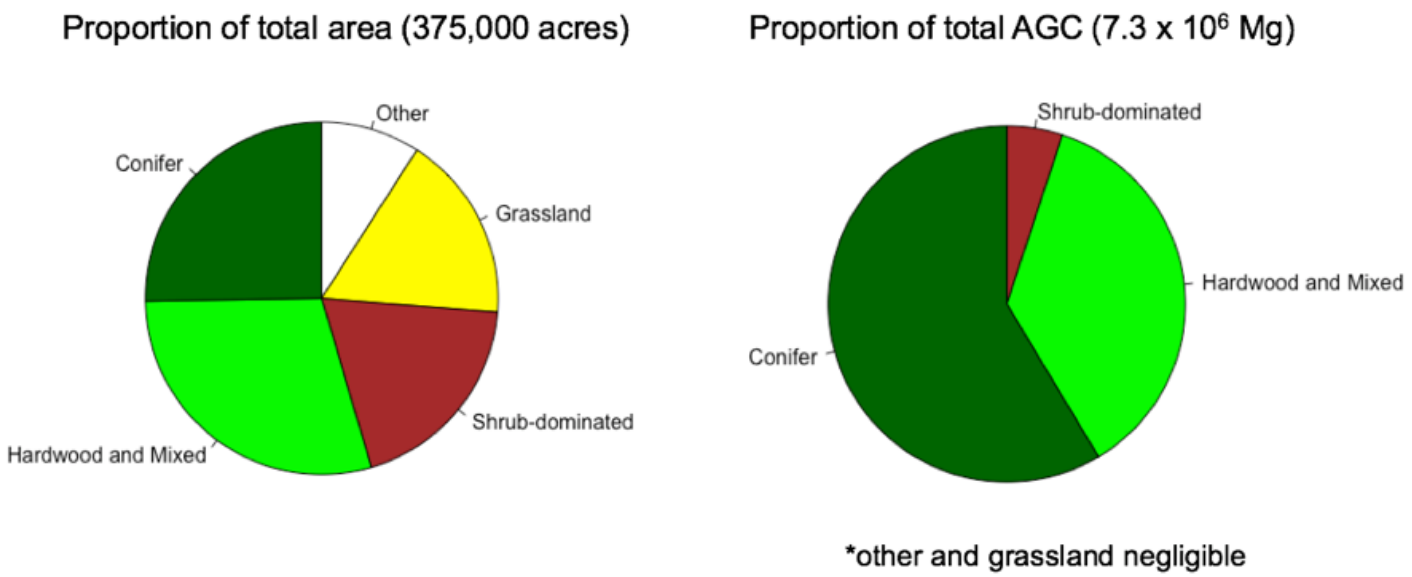

Figure 1.2. Vegetation and carbon in Coastal Conservancy acquisitions. Pie diagrams show proportion of total area (a) and total aboveground carbon (b) distributed among four major vegetation groups ('Other' refers to water and other non-vegetated areas).

Figure 1.3

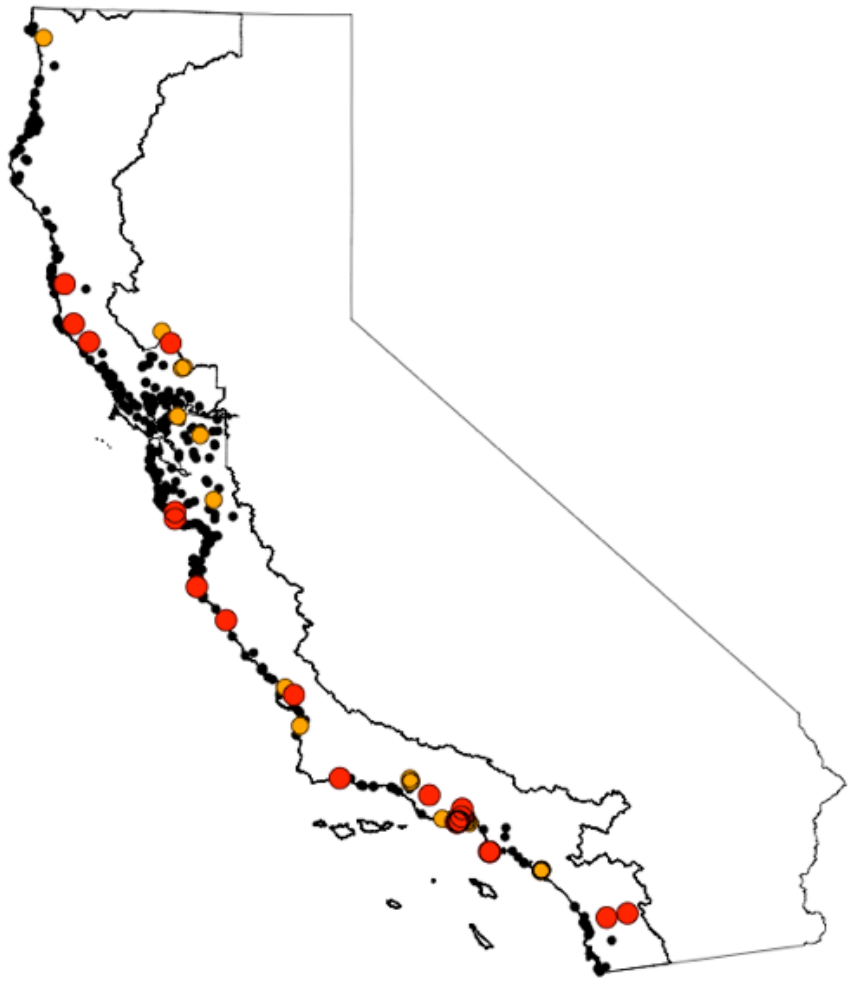

Figure 1.3. Location of acquisitions that experienced wildfire between 1980-2015 (orange or red) and 2001-2010 (red).

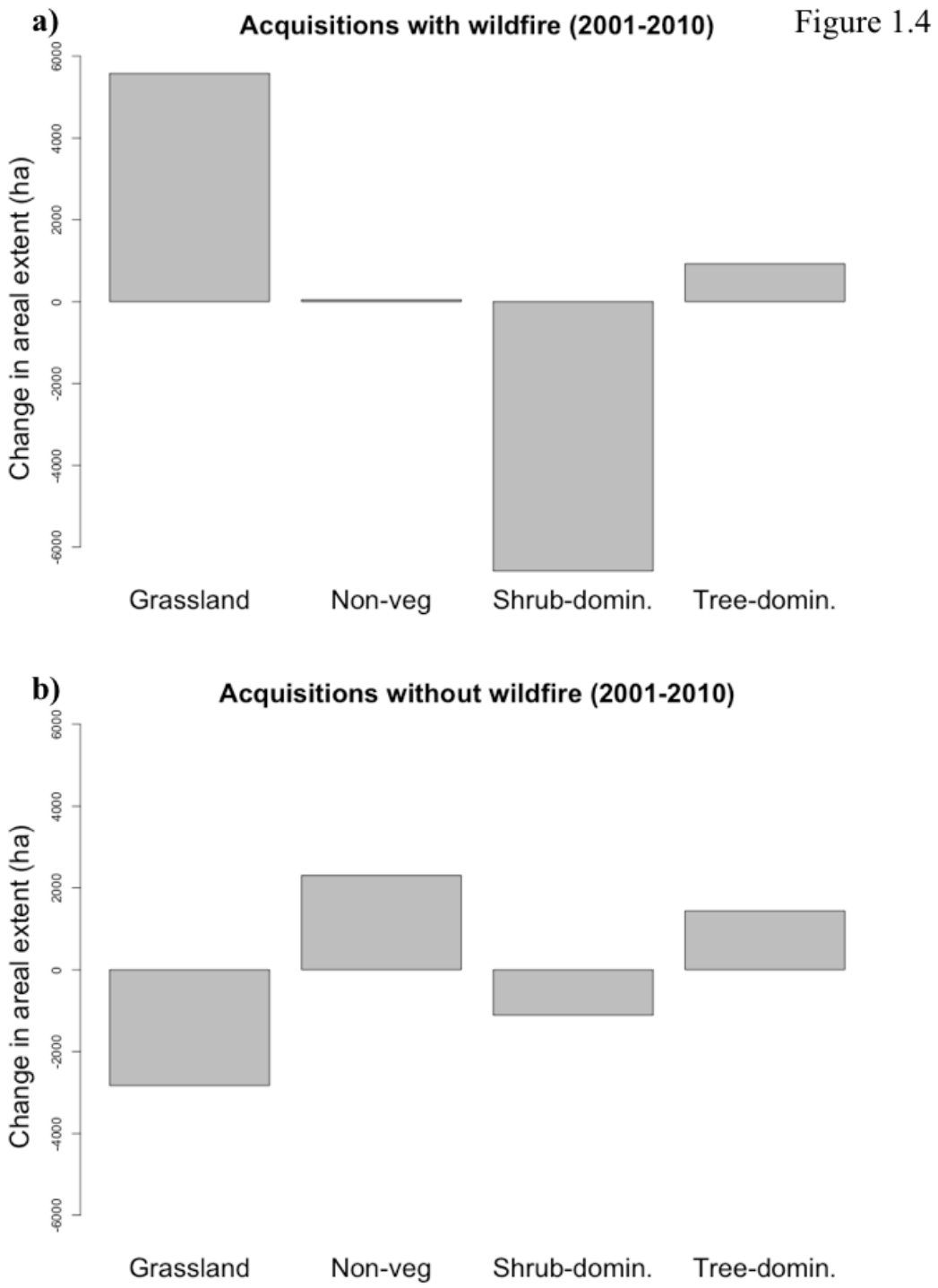

Figure 1.4. Changes in areal extent of major vegetation classes in a) acquisitions that experienced at least one wildfire (2001-2010), and b) acquisitions that did not experience wildfire (2001-2010).

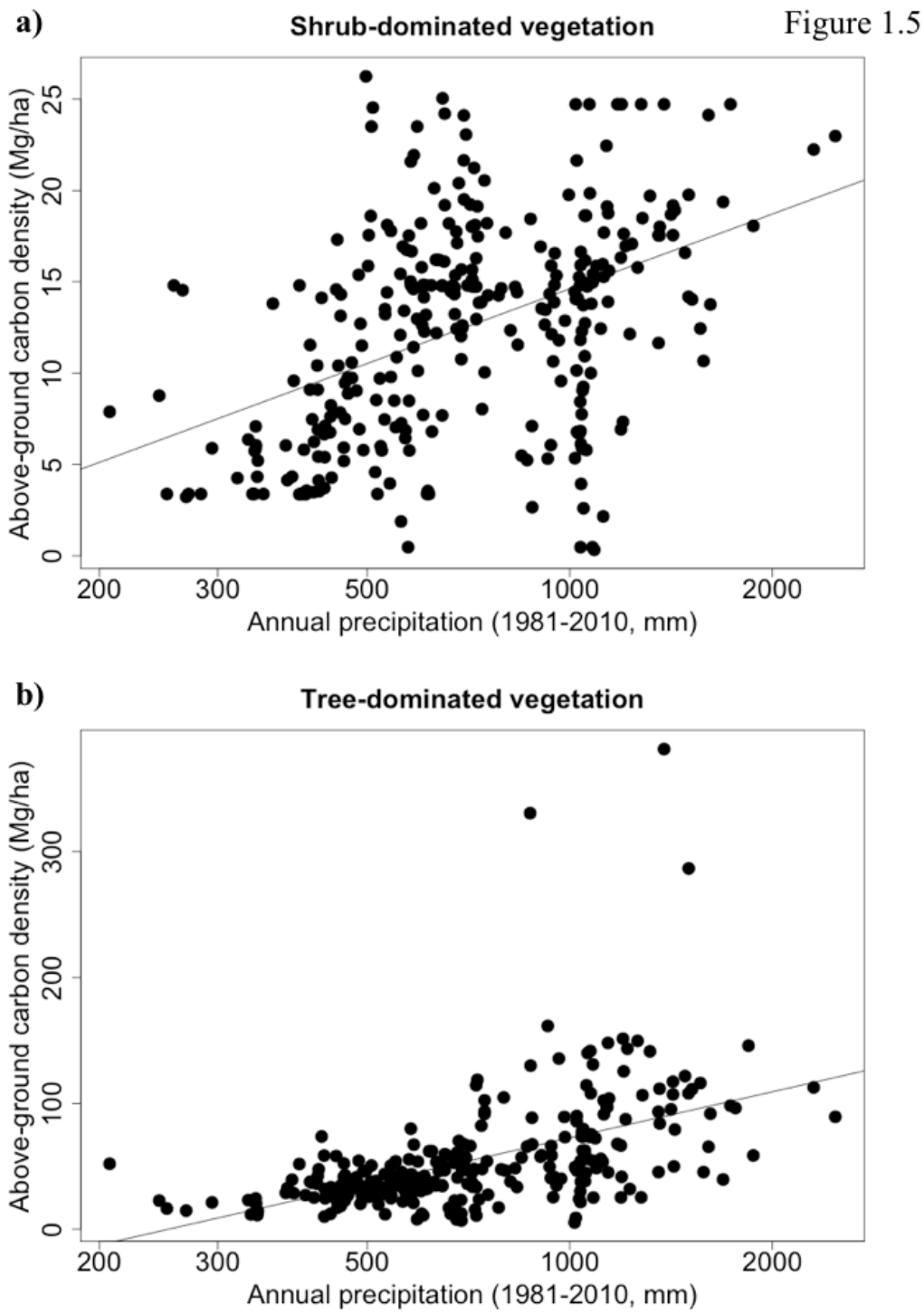

Figure 1.5. Average carbon density (Mg/ha) of vegetation in relation to mean annual precipitation (1981-2010, mm). a) Shrub-dominated ecosystems; b) Tree-dominated ecosystems. Note differences in scale on y-axis.

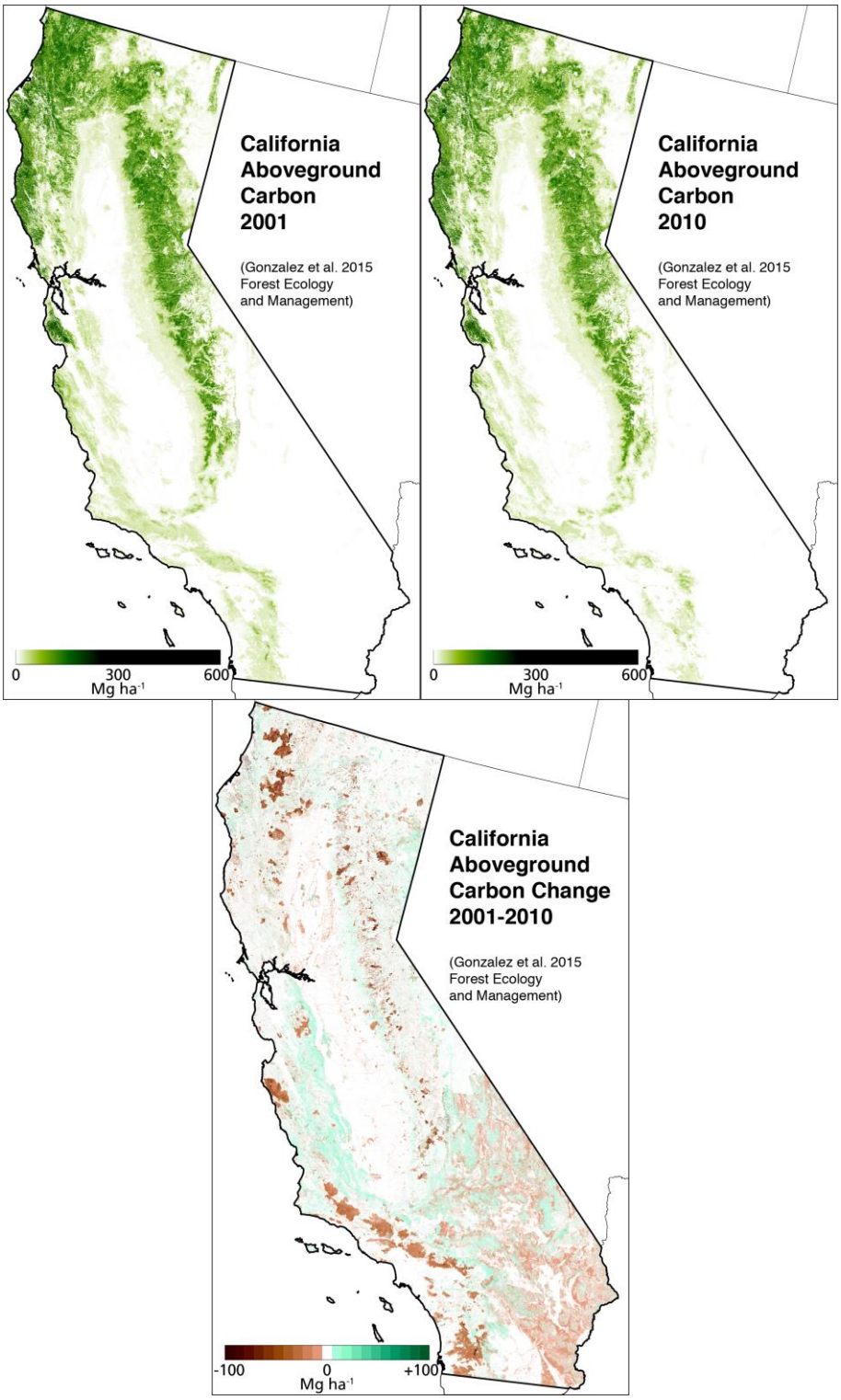

Figure 1.6. Aboveground carbon stocks (Mg/ha) in 2001 and 2010, and change over the decade, for state of California. From Gonzalez et al. (2015).

Figure 1.7

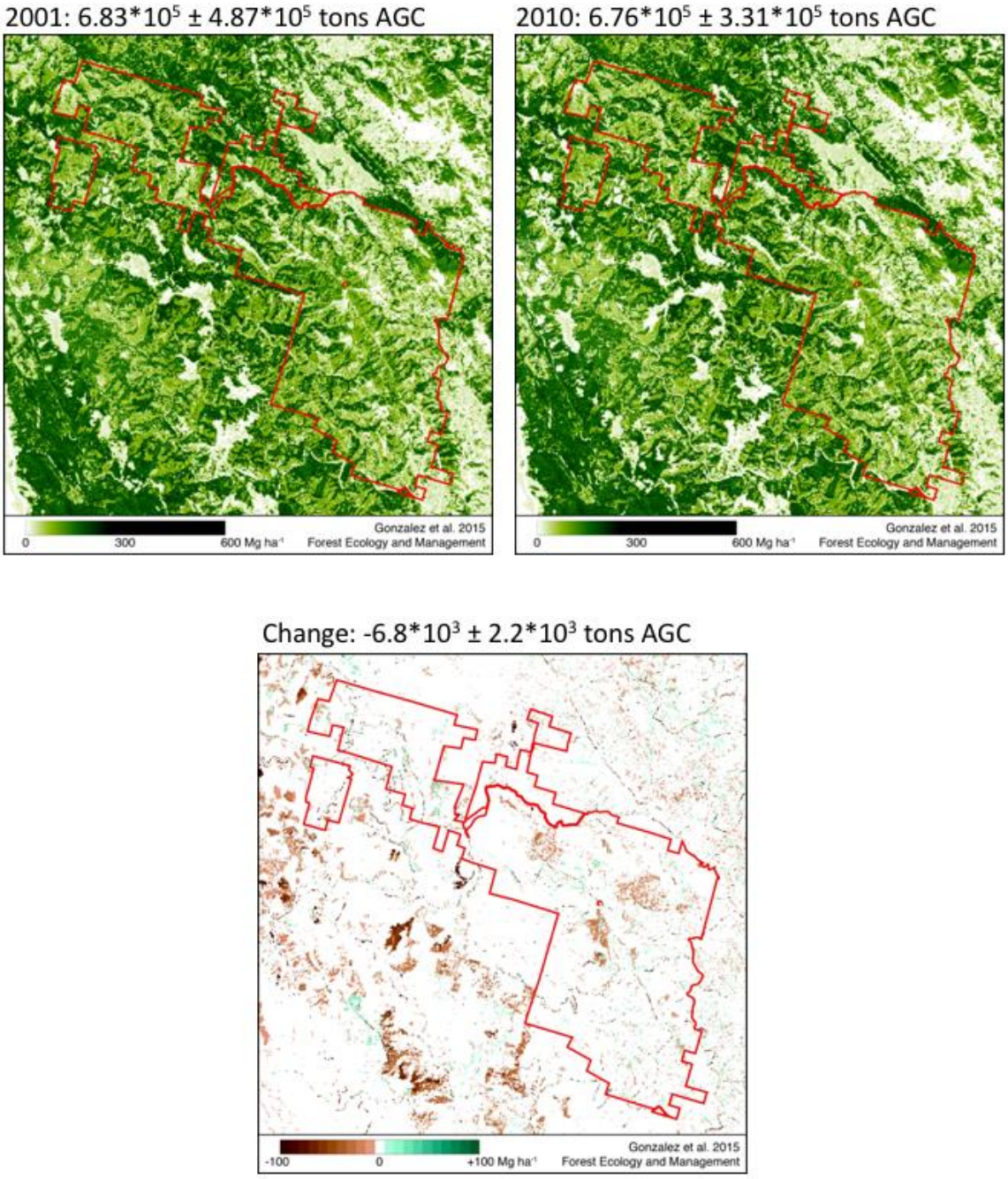

Figure 1.7. Aboveground carbon stocks (Mg/ha) in 2001 and 2010, and change over the decade, for Preservation Ranch, Sonoma Co. illustrating analyses for individual acquisitions. Figure prepared from data in Gonzalez et al. (2015).

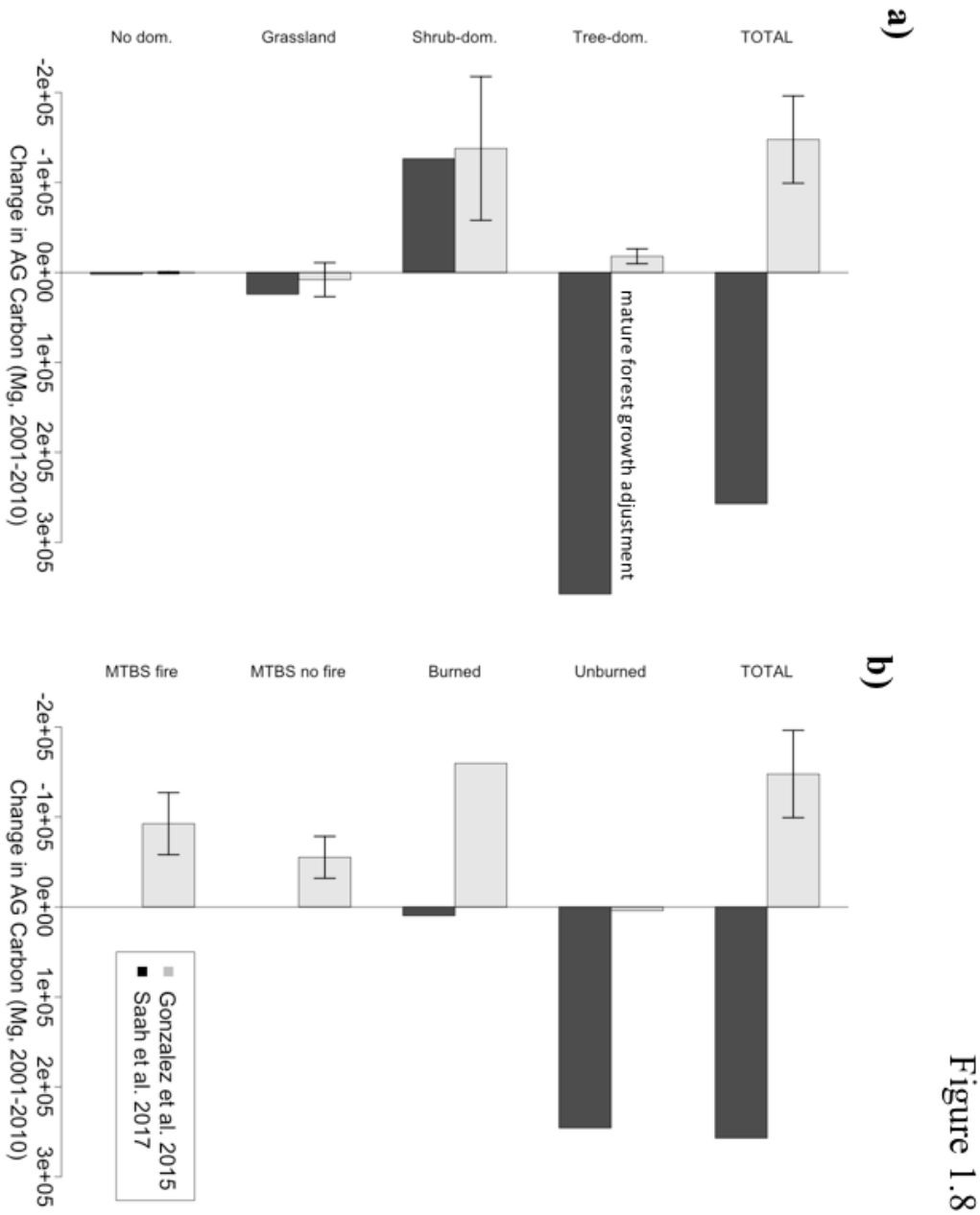

Figure 1.8

Figure 1.8. Change in total carbon stocks (2001-2010, Mg) for all SCC acquisitions (top row, a and b), for areas occupied by different vegetation types (a) and for burned vs. unburned areas (b). Error bars represent 95% confidence intervals where available for Gonzalez et al. (2015) analyses. a) Breakdown by major vegetation classes. 'No-dom.' = no-dominant vegetation or non-vegetated areas. b) Breakdown by burned vs. unburned areas. Rows 2 and 3 (from top): acquisitions that had one or more fires vs. no fires (2001-2010) with carbon change summed over the entire acquisition (including areas that may have been outside CalFire FRAP fire perimeters). Rows 4 and 5: pixel-level breakdown for areas burned vs. not burned based on national MTBS data set (not available for Saah analysis).

Task 2: Avoided Land Use Conversions and Aboveground Carbon Loss

Authors: Van Butsic, Diana Moanga, Isabel Schroeter

Development for residential and agricultural uses is a significant driver of land use change in California, and a major goal of Coastal Conservancy land acquisitions is to maintain open space by purchasing land threatened by development. Preventing conversions through land acquisitions may also lead to avoided carbon emissions if the baseline land cover (e.g., conifer forest) has more aboveground carbon than potential converted land uses (e.g., residential development or vineyards). The goal here was to quantify the avoided land use conversions and the associated avoided emissions from aboveground carbon created by Coastal Conservancy acquisitions.

Developing a counterfactual landscape

The first step in calculating avoided conversions and emissions is to develop a counterfactual scenario for each property. This scenario represents what would have happened if the Coastal Conservancy had not acquired the property. Developing counterfactual scenarios is an uncertain exercise since it is impossible to know exactly what would have happened if the Coastal Conservancy had not acted. Many methods exist for developing such scenarios, including statistical modeling and scenario building. Here, to determine the counterfactual land use, we relied on detailed appraisal reports solicited by the Coastal Conservancy which described the "Highest and Best Use" (HBU) of each property. The HBU represents what a professional appraiser familiar with the property and the local land market believes the property would be used for in order to maximize economic rents. HBU's therefore are a good representation of what would have happened if the property had been used to maximize economic gains instead of being purchased by the Coastal Conservancy for the public good.

HBUs broadly describe land use (e.g., 300 acres of residential development and 200 acres of vineyard development would take place on a particular parcel), but typically do not describe precisely where the conversion would occur. Therefore, it is usually impossible to tell from the HBU alone what vegetation cover would be converted in the counterfactual. Since carbon emissions are dependent not only on the amount of land converted, but also the vegetation type converted, we estimated the vegetation type of the counterfactual conversion by assuming that conversions on each property would follow similar trends to conversions nearby.

For example, if the HBU called for 300 acres of residential development, we looked at all conversions to residential development between 2001-2011 within 50 km of the property and calculated the percent conversion from each vegetation type (i.e., 20% of all residential conversion was from conifer forest, 40% from grasslands, and 40% from deciduous forest). We then applied this to the counterfactual scenario such that 20% of residential development called for by the HBU on the SCC acquisition would come from conifer forest, 40% from grasslands and 40% from deciduous. This process was repeated for each property in our study for both residential development and agricultural lands (See Appendix 2A for more details on building the counterfactual scenarios). For this analysis, when lands converted to either residential development or vineyards, we assumed an aboveground carbon value of 0.0 MG C/ha (i.e. all carbon is lost during development). Other impacts on carbon emissions due to development, such as vehicle travel to/from location, building energy use, or fertilizer applications, were not considered.

Avoided land use conversions and avoided aboveground carbon loss

Overall, we developed counterfactual scenarios for 73 Coastal Conservancy properties which had detailed HBU's. These properties represented 284,133.25 acres (76% of all Coastal Conservancy holdings by area) with the largest parcel in our sample being the 80,733 acre Hearst Ranch and the smallest parcel the 307 acre Rancho Corral Acquisition. The mean property size was 3,894 acres and the median size was 1,293 acres.

Out of the 73 properties, the HBU of 16 of these properties was such that no conversions would have occurred, so none were avoided by acquisition. These properties fell into three main categories. First, there were properties where conversions to residential or agricultural uses were unlikely due the location of the property, steepness of the terrain, or the general unsuitability of a parcel for home development or agriculture. Second, a number of properties were best suited for continued timber operations and had no potential for residential development or agriculture. Third, on a number of parcels, the presence of endangered species coupled with strong local opposition to rural development created barriers to development that appraisers regarded as insurmountable. These properties actually would have been in high demand as rural residential lots, but the barriers to successfully gaining approval for development were so great that appraisers thought investment in the properties for such a purpose would be unlikely. For these 16 properties, we concluded that there were no avoided conversions or avoided emissions due to the Coastal Conservancy purchases.

There were 57 properties, covering a total of 238,002 acres, that would have undergone some conversion to either agricultural or developed uses under the counterfactual scenario. Based on the counterfactual scenarios, a total of 13,859 acres (5.82% of the total acres studied) were prevented from converting to residential development or agricultural uses on these parcels, of which 6,867 acres were predicted to convert to development and 6,992 to agricultural uses.

A closer look at several properties reveals that Lauff's Ranch was the largest single property in terms of avoided conversions, with 3,500 acres of conversion prevented (all from vineyard establishment) (Figure 2.1), while Hearst Ranch was the single largest location of avoided conversions to residential use with 1,277 acres of residential development avoided (Figure 2.2). Preservation Ranch (Figure 2.3), the second largest property that would have been converted under the counterfactual scenario, is one of the five properties (Hearst Ranch, North Point Ranch, Roche Ranch and Wildlake Ranch) that would have been converted to both residential development and vineyard production. As a percent of area, the properties with the largest avoided conversions were: Bahia Ranch (65.5% avoided), Gleason Ranch (41.9% avoided), Cowell Ranch (33.4% avoided) and North Point Joint Venture (32.3% avoided).

The avoided land use conversion for all 57 properties translates into 55 x 10^3 Mg of avoided aboveground carbon loss (1.35% out of a total of 4 x 10^6 Mg total aboveground carbon on the 57 properties). Sixty-three percent of all avoided aboveground carbon loss came from two properties – Usal Forest Shady Dell (25 x 10^3 Mg) (Figure 2.4) and Montesol ranch (12 x 10^3 Mg) (Figure 2.5) – properties with both high development potential and vegetation with extremely high carbon density. Lauff's Ranch, which had the largest area of avoided conversions had only the fourth most carbon avoided and had only 7% of the avoided carbon as Usal Forest Shady Dell, despite contributing 2,872 more acres of avoided conversion. The top 10 properties in terms of lost aboveground carbon under the counterfactual scenario are: Usal Ranch, Montesol Ranch, Cemex Redwoods, Lauff's Ranch, Wildlake Ranch, North Point Ranch, Roche Ranch, Bahia Ranch, Gleason Ranch and Cowell Ranch (Figure 2.6). In terms of percent of vegetation

cover lost and percent carbon lost, we found that the properties that have the highest percent of vegetation cover lost do not necessarily also have the highest percent of carbon lost under the counterfactual scenario (Figure 2.7).

Discussion

Overall, the low avoided carbon loss (1.35% of all potential C) relative to avoided conversions (5.82% of all potential acres) is likely driven by two factors. First, the highest carbon ecosystems in the Coastal Conservancy's portfolio are located along the North Coast where there is less demand for residential development, and agricultural production is generally low. Therefore, there are fewer overall avoided conversions in these ecosystems than in areas closer to urban centers, or in areas with potential for high value vineyards. Second, even on properties with high carbon ecosystems, past conversions show that developers have a preference for converting grasslands rather than higher carbon ecosystems. In the properties we analyzed, over 60% of all conversions occurred on grasslands while another 17% take place on chaparral. In concert then, both low demand for conversion in high carbon ecosystems coupled with a preference for converting low carbon areas in all ecosystems, means that the total effect of Conservancy purchases on avoided carbon loss is modest.

One area of uncertainty in our analysis is the assumption that aboveground carbon is 0.0 Mg C/ha after conversion to residential development and vineyards. This estimate will be approximately true immediately after conversion, but as yards and vineyards mature, aboveground carbon stocks will increase over time in most situations. While highly variable, aboveground carbon can be substantial on developed lots where trees have been planted. For instance, urban forests in coastal California have carbon densities averaging > 15 Mg C/ha, with values as high as 35 Mg C/ha in Marin County (Bjorkman *et al.*, 2015). Likewise, mature vineyards can contain over 4 Mg C ha^{-1} (Carlisle *et al.*, 2010). Both of these values are greater than average aboveground carbon values for grasslands and some shrublands. Therefore, avoided conversions from grasslands and shrublands may actually have a negative impact on long term aboveground carbon stocks, since residential development and vineyards can actually have more aboveground carbon than these natural systems.

Another area of uncertainty is that we do not know if the avoided conversions eventually took place somewhere else on the landscape, and if so where. When a Coastal Conservancy acquisition prevents conversion in one area, it does not decrease the overall demand for housing or agricultural lands. Therefore, this demand many simply manifest somewhere else on the landscape, causing conversions in other places. However, it is also true that by decreasing the supply of land for housing and agriculture, local prices for land may go up, reducing demand and potential conversions. These competing forces make it unclear how much, if any, of the avoided conversions took place in other locations. Likewise, if some conversions did happen, we do not know if these conversions happened in places with higher or lower carbon density. We also do not know if these conversions took place in areas that would lead to greater emissions through vehicle miles traveled (VMT). In addition, other sources of emissions from new conversions (e.g., urban development, fertilizer applications, etc.) were not included in the study. Given these uncertainties, it is important to interpret our results as only the direct impacts of property acquisition. The indirect consequences discussed here are not calculated in this study.

It is important to note that, while our study looks only at avoided carbon loss through avoided land use conversions, there are other ways in which Coastal Conservancy parcels can impact carbon storage not modeled here. Most significantly, we do not address how changes in

forest and range management brought about by Conservancy ownership may increase aboveground carbon stocks. Given the magnitude of changes in carbon stocks possible via different forest management strategies (project 1, above), as well as the large potential for increased carbon storage in grasslands (project 3, below), the Coastal Conservancy may make more substantial contributions to increasing carbon stocks in California via ecosystem management, rather than avoided emissions of aboveground C.

Indeed, a number of the Coastal Conservancies most iconic purchases are of carbon dense redwood forest in the northern part of the state. These forests are some of the most carbon dense in the world, and the additional carbon that can be sequestered under optimal management is substantial. For instance, experiments along the North Coast have shown that redwood stands optimally managed for carbon sequestration can increase sequestration rates by over 40% vs non-optimal management (Jones & O'Hara, 2012). In addition, management to prevent wildfire in these carbon rich areas can substantially limit emissions. Therefore, it may be that the greatest impact the Coastal Conservancy can have on carbon sequestration is through management.

Task 2 - Figures

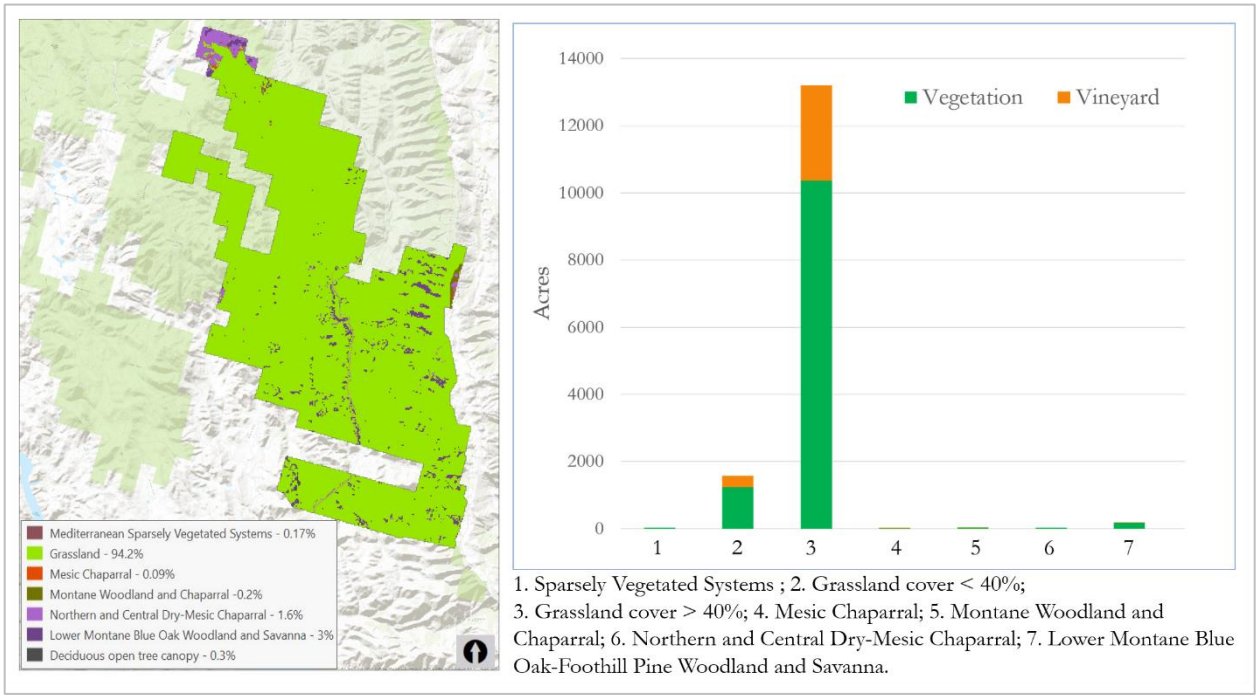

Figure 2.1. Lauff's Ranch vegetation cover (left), and land cover under counterfactual (right).

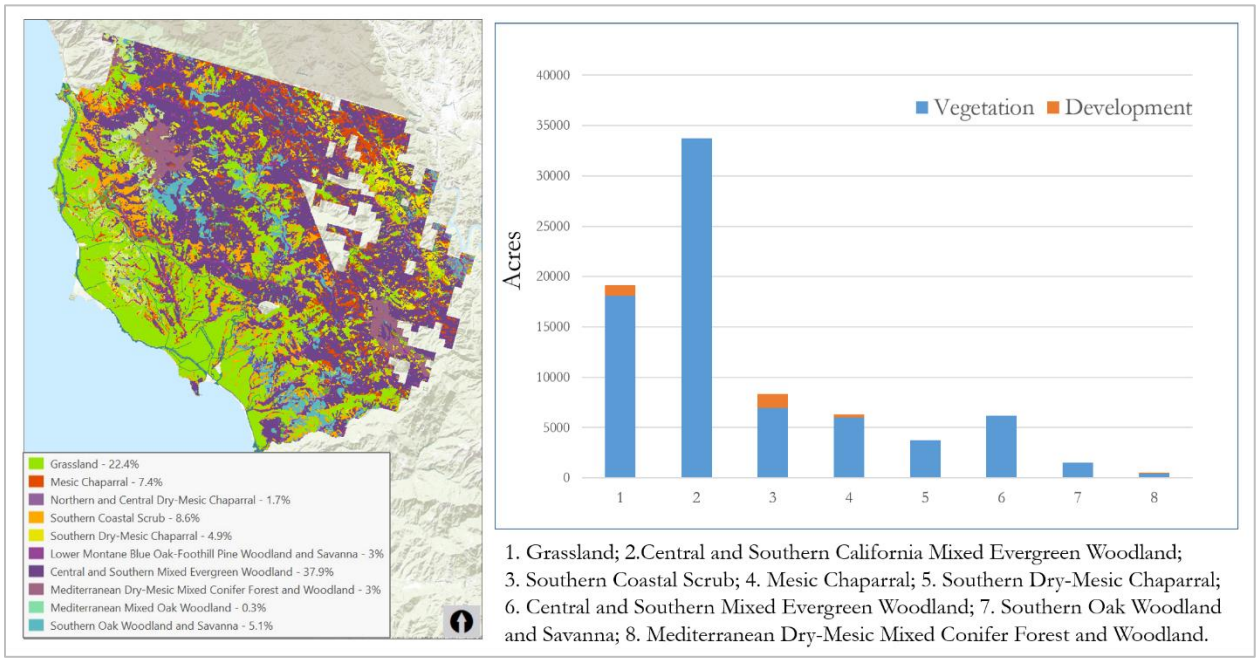

Figure 2.2. Hearst Ranch vegetation cover (left) and land cover under counterfactual (right) (showing only 6 land cover classes). *Note:* Not all vegetation classes are illustrated.

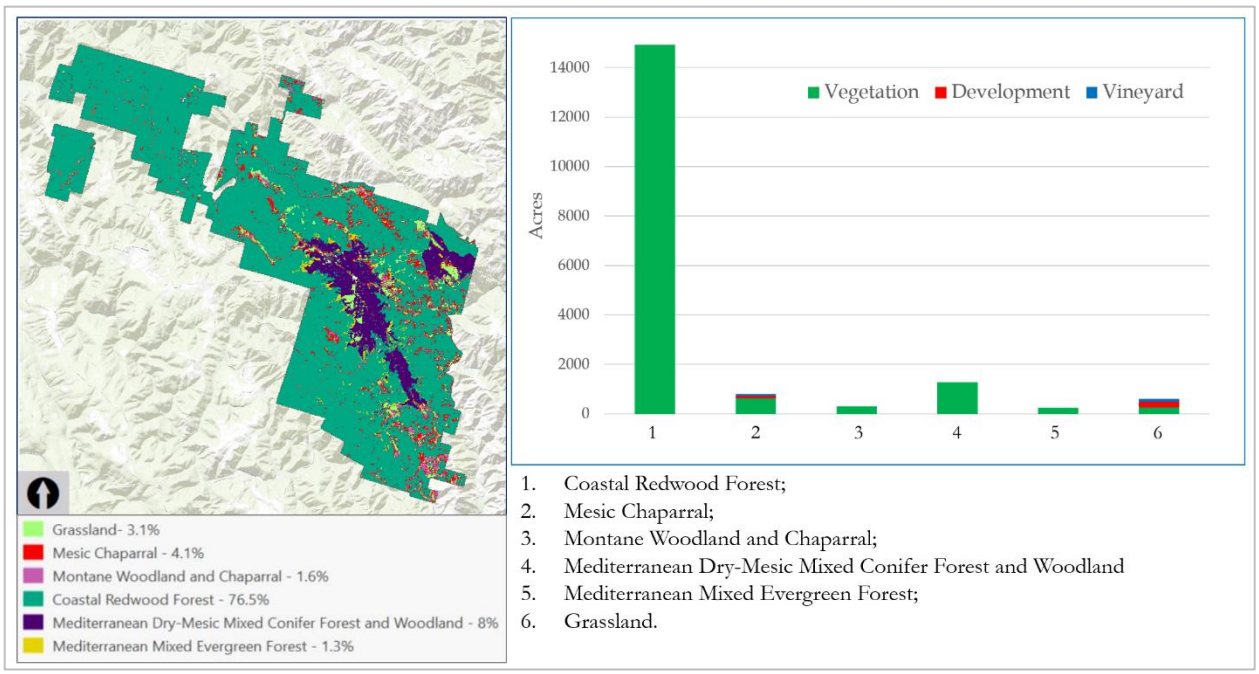

Figure 2.3. Preservation Ranch vegetation cover (left) and land cover under counterfactual (right) (showing only 6 land cover classes). *Note:* Not all vegetation classes are illustrated.

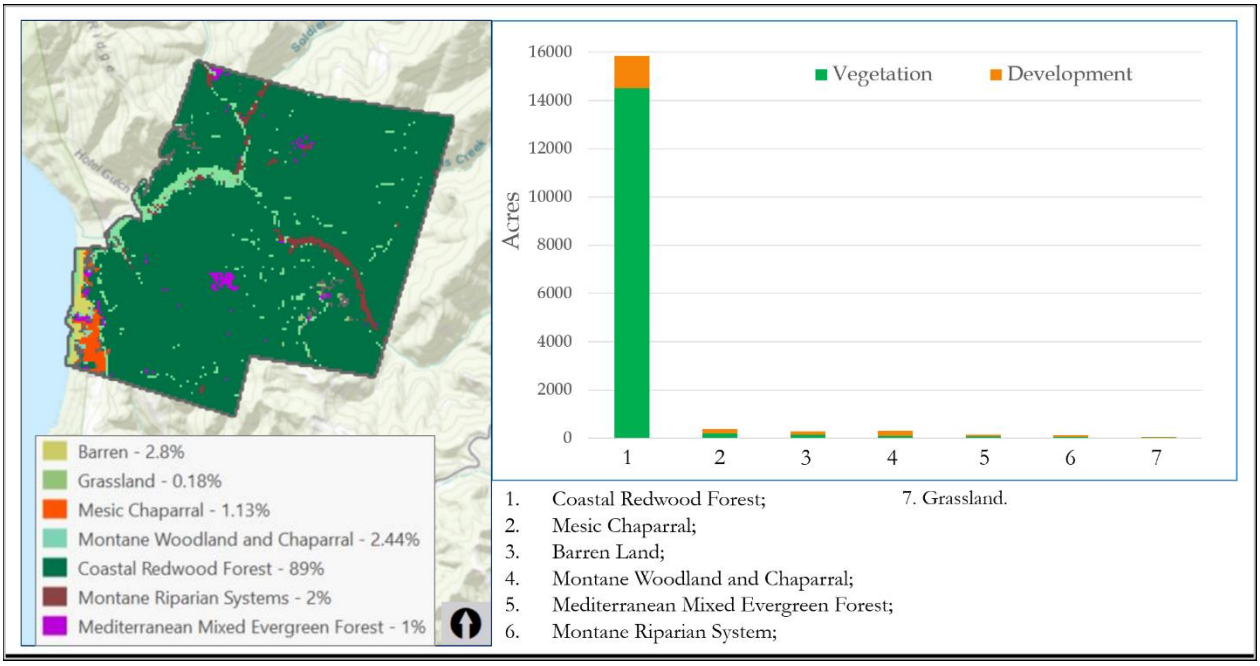

Figure 2.4. Usal Forest Shady Dell Acquisition vegetation cover (left) and land cover under counterfactual (right) (showing only 6 land cover classes).

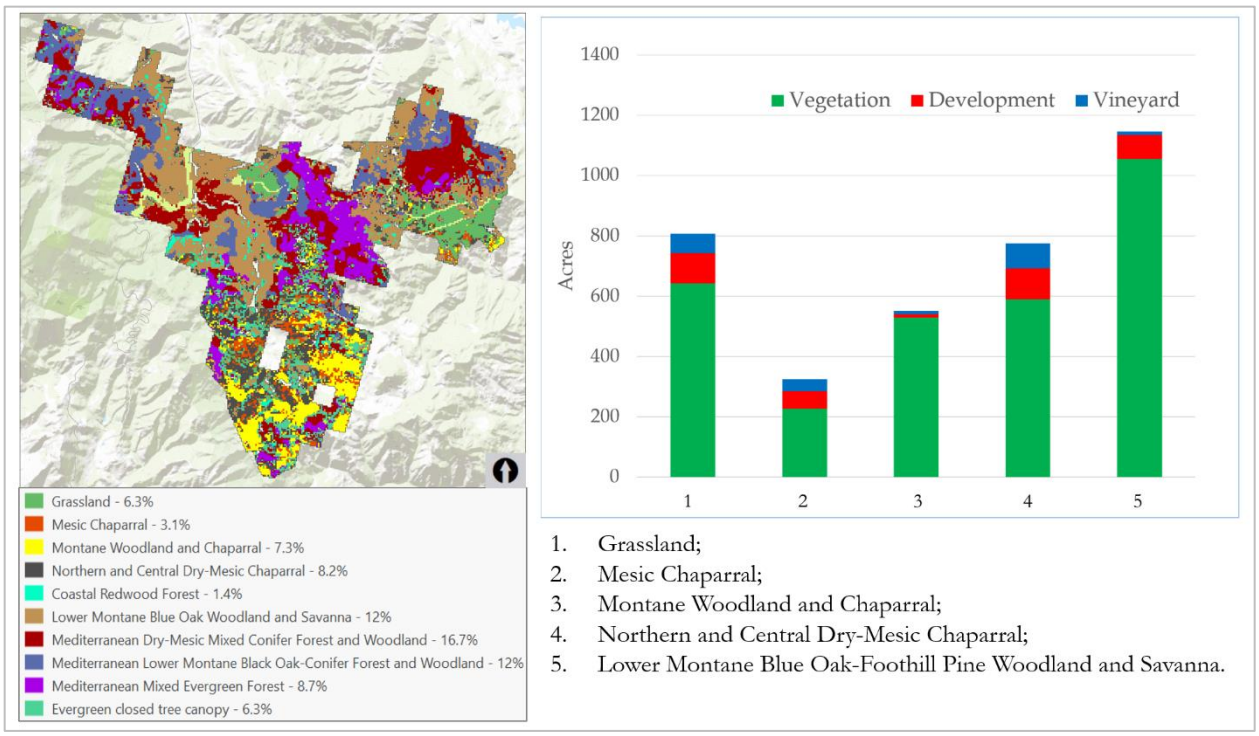

Figure 2.5. Montesol Ranch vegetation cover (left) and land cover under counterfactual (right) (showing only 6 land cover classes). *Note:* Not all vegetation classes are illustrated.

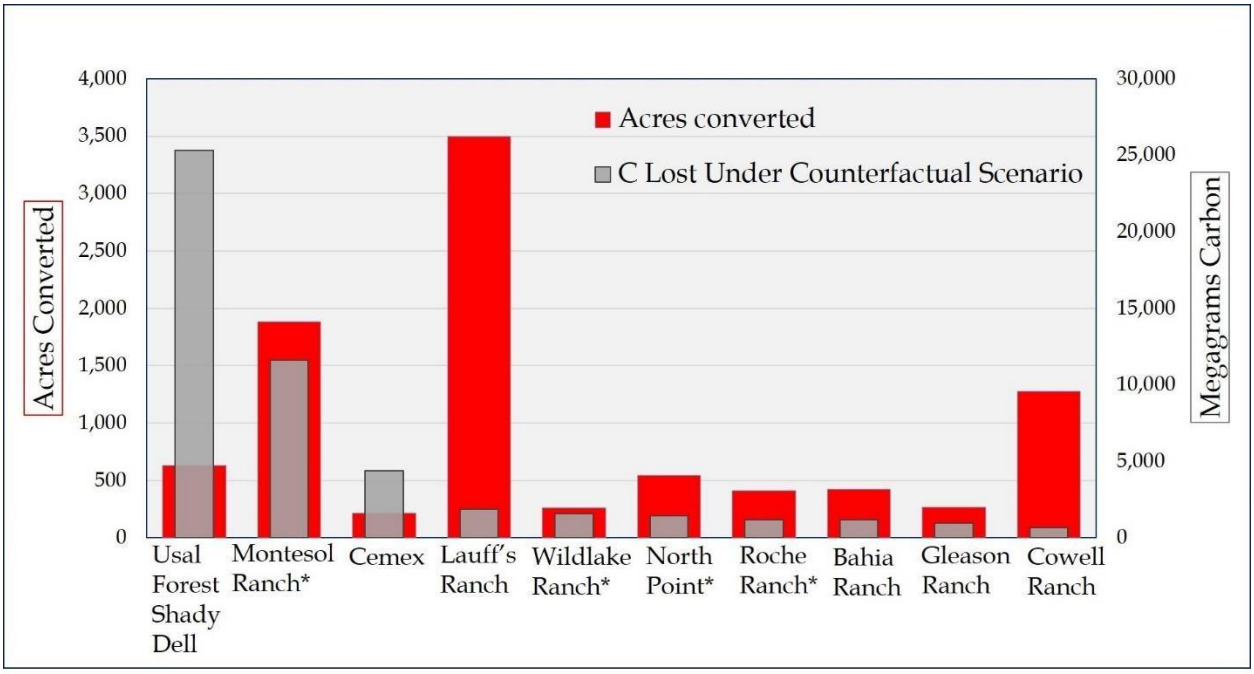

Figure 2.6. Top 10 properties in terms of acreage (red) and carbon (gray) that would have been lost under the counterfactual development scenario. *Properties that were converted to both development and vineyards.

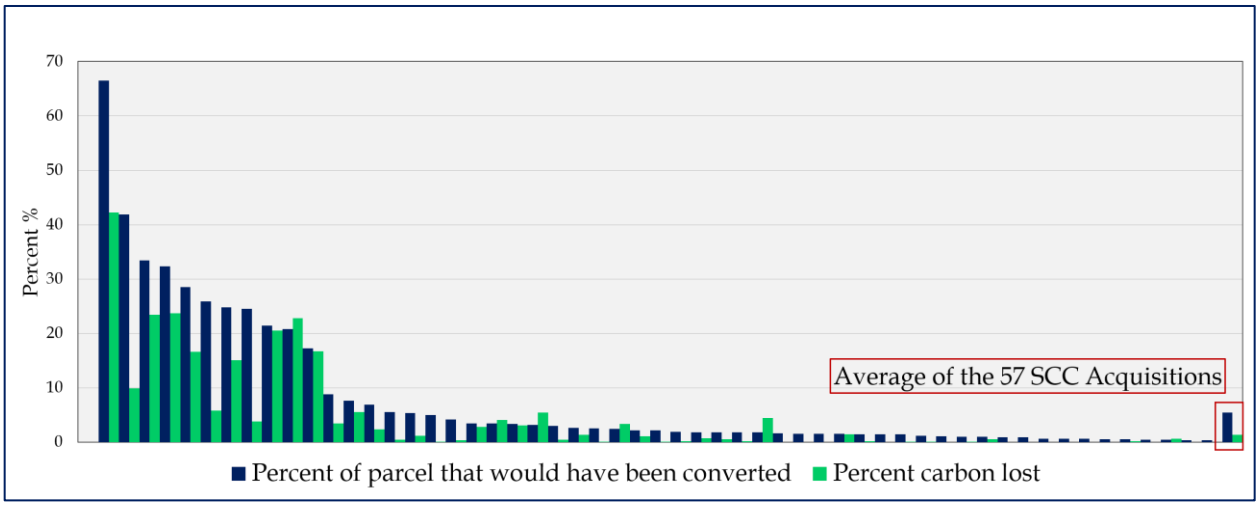

Figure 2.7. Percent of parcel that would have been converted to agricultural or developed uses (blue), and percent carbon that would have been lost (green) for all studied properties.

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