Energy Research and Development Division
FINAL PROJECT REPORT

DEFORESTATION IN CALIFORNIA – A POORLY UNDERSTOOD GHG EMISSION SOURCE AND EMISSION REDUCTION OPPORTUNITY

Options For Policy And Carbon Offset Methodology

Prepared for: California Energy Commission
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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Deforestation in California – a poorly understood GHG emission source and emission reduction opportunity: Policy and Carbon Offset Methodology Options is the final report for the Deforestation in California project (contract number PIR-08-008) conducted by Winrock International. The information from this project contributes to Energy Research and Development Division's Energy Related Environmental Research Program.

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ABSTRACT

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. The significance of small-scale development as a source of greenhouse gases is therefore currently unknown.

This report summarized the research conducted over three years to improve estimates of greenhouse gas emissions from small-scale development in California. The research included a spatial analysis, development of emission factors and an estimate of emissions from developments across four study areas, and an analysis of the economic impacts of deforestation for development.

The report provided an overview of existing policy and recommendations for additional policy action that could address emissions from development. Recommendations were focused on four potential policy options: promoting appropriate locations for development, including infill and urban growth boundaries; reducing tree removal through cluster developments; incentive programs; and revising the timberland conversion process.

Additionally, the report analyzed the potential for developing a carbon offset project methodology for reduced emissions from conversion for development.

Keywords: greenhouse gas emissions, development, deforestation, carbon stocks, urban forest, policy, accounting methodology

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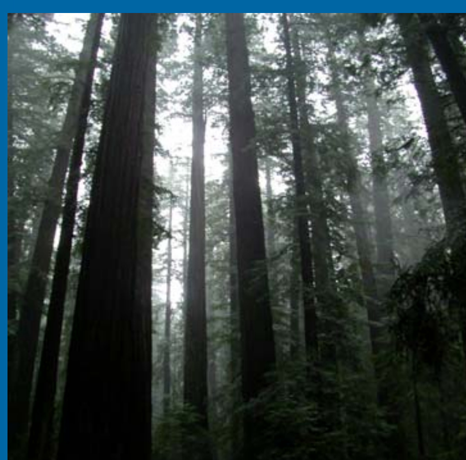
Swails, E, T. Pearson, K. Goslee, S. Petrova, and S. Brown. 2009. Desk Study: Deforestation in California: a poorly understood GHG emission source and emission reduction opportunity. Report to PIER under #PIR-08-008.

Grant #PIR-08-008
June 2009

Deforestation in California: a poorly understood GHG emission source and emission reduction opportunity
Product 1: Desk Study

Erin Swails, Timothy Pearson, Katherine Goslee,
Silvia Petrova, Sean Grimland and Sandra Brown



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We appreciate the comments and feedback of attendees at the stakeholder meeting at CALFIRE in Sacramento on July 1st 2009.

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Swails, E, Pearson, T, Goslee, K, Petrova, S, and Brown S, 2009. Desk Study: Deforestation in California: a poorly understood GHG emission source and emission reduction opportunity. Report to PIER under #PIR-08-008

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1.0 BACKGROUND

In a poll in 2000, urban sprawl was classified, tied with crime, as the leading local concern in the US. Across the country, urban area has doubled over the past 40 years. In California during the same period there was a 252% increase in the urban area. Among regions in the US, California has the lowest current number of developed acres per capita, but the second highest population growth rate and an average income growth rate that outstrips population growth.

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown. This knowledge is invaluable in order to consider the costs and benefits of different forms of development and to make policy decisions to influence the magnitude of emissions associated with development.

The first step towards reducing California's greenhouse gas emissions from deforestation in the urban development sector is to develop a better understanding of the current impacts of development on greenhouse gas (GHG) emissions and removals. Our focus on this first step is to assess the direct impacts on emissions and removals associated with different practices of forest canopy reduction and on the fate of the removed trees during development. Assessments of deforestation for development do exist but no confident emission estimates can be paired with the estimates of rates of deforestation. In addition, deforestation is monitored using coarse scale imagery which can only poorly track the most common form of urban development - scattered development. It is therefore likely that deforestation rates are underestimated and actual emissions are entirely unknown.

When development impacts on greenhouse gas emissions and removals are understood more clearly, it will be possible to model the economic and greenhouse gas costs and benefits of clearing vs. leaving trees. Limiting the clearance of tree cover during development would prevent direct emissions from the felled vegetation and will allow not only the future sequestration in that vegetation, but could also lead to indirect benefits such as decreased demand for heating and cooling, erosion control and flood prevention and indirect impacts on urban fire risk. With this new knowledge base it will be possible to create policy recommendations to minimize emissions due to development. The study will provide a greenhouse gas perspective on the policy decisions on development density and the costs and benefits of centralized versus dispersed development. Where clear benefits are shown from development decisions, an additional outcome could be project methodologies for development-based carbon projects.

A study on small-scale development also has wider implications for California beyond the direct climate change benefit:

a) The California Air Resources Board is tasked with recording emissions and sequestration across the state. The study will provide both a more precise baseline of development emissions plus factors that can be used for calculating emissions moving forward.

b) Climate change mitigation activities can not achieve 100% success of halting global warming. Consequently, climate change will happen. This will have profound implications on development especially at the urban / wildland interface. Increased wildfires, floods, droughts and erosion are all possibilities that should be considered when weighing planning with respect to density and location of development.

2.0 OBJECTIVES OF DESK STUDY

The purpose of the desk study is to solidify an understanding of development and associated deforestation in California to inform analyses of areas deforested for development and emissions from deforestation. For this task Winrock gathered information and obtained input from different stakeholders in California including developers, government institutions, and conservation organizations. Information was gathered on the relationship between deforestation and urban development, forms of forest conversion to development, and site preparation practices of developers. The costs and benefits of the different forms of conversion of forested land to development were evaluated on the local, county, and state level.

The California Department of Housing and Community Development predicts that the number of households in California will grow from 14,112,180 in 2010 to 16,174,519 in 2020, an increase of 14% over the next ten years.[1] This predicted population growth will further increase the demand for housing in the state. Increased demand for housing will not be met by existing development and new housing will need to be created. To create new housing, developers have different choices. They may build new structures on already developed areas, increasing housing density (infill development), they may redevelop previously developed areas (brownfield development or revitalization), or they may develop previously undeveloped areas (greenfield development). Each form of development presents unique opportunities as well as obstacles to developers. Greenfield development is often an attractive option for developers because undeveloped land may be acquired relatively inexpensively and it is possible to amass large quantities of land.[2] Greenfield development may be concentrated at the edges of urban development or scattered throughout the "wildland-urban intermix" area.

Although California's population has been steadily increasing over the past decade, population growth has not been uniform across all counties. According to U.S. Census estimates of population from 2000 to 2007, while populations in some counties have grown by as much as 33%, in other counties population size has actually decreased.[3] This pattern is due in part to migration of residents from one part of the state to another, for example the diffusion of populations from urban centers to remote, high quality environments, a trend found in several studies of the Sierra Nevada.[4] During the 1990's in particular, California experienced population growth coupled with the expansion of development into previously forested areas.[5] The spatial distribution of California's population has changed as more people move to the periphery of the dense Los Angeles and San Francisco Bay metropolitan areas and to the historically lower density Central Valley and Sierra Nevada foothills.[6] Population growth, increased demand for housing and the trend of "counterurbanization"[7] described above has caused deforestation but the extent and impact of deforestation varies by degree and type of forest cover and the intensity of the development.

Developers recognize the costs and benefits associated with deforestation for development. Zoning regulations can present obstacles to developers who seek permits to convert forested land to other purposes. Various existing legislation and local legal processes that specifically regulate development of lands with tree cover for residential and commercial purposes are described in this study. According to the California Department of Forestry and Fire Protection (CALFIRE) there are at least 90 state and federal laws that regulate the management of forest and range resources as well as at least 25 relevant executive orders and other initiatives

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[1] California Department of Housing and Community Development 2000
[2] Samelson 2007
[3] U.S. Census Bureau 2000
[4] Greenwood and Saving 1999; Loffler and Steinicke 2006; Walker, Marvin, and Fortmann 2007
[5] Hammer et al. 2007
[6] Saving and Greenwood 2002
[7] Loffler and Steinicke 2006

implemented in the last decade.[8] While CALFIRE regulates management of forest lands at the state level, local governments also play a key role in influencing the use of lands with tree cover, particularly through zoning ordinances and land use policies.[9] Local governments can impose restrictions on tree removal and are responsible for setting the minimum parcel size for forest classification. In addition, AB32 Global Warming Solutions Act of 2000 has created new initiatives on the local and county level, where zoning and development decisions are primarily made, that address deforestation from development. At the state level, an interagency effort is underway to reduce California's greenhouse gas emissions, in part by changing land use policy.

Conversion of different forest types in California are regulated by different legal processes, and the different forest types are subject to distinct forms of development. Forests in California may be divided into public and privately owned forests and hardwood or conifer dominated forest types. Public forests, which include state and national forests and parks, are protected from clearing for development, and were not considered by the study.

The process of conversion of forested land involves a series of steps that may begin with the purchase of theland and extend over several years as rezoning, subdivision, and permitting take place. While the desk study examines the longer legal process to create a better understanding of the context in which conversion takes place, field work will focus on development project implementation and the associated emissions from site preparation. A range of housing densities are considered to capture the effects of different forms of development. Analysis will also track changes is forest cover caused by other forms of conversion for development other than residential uses including but not limited to agricultural, commercial, and industrial uses. Definitional terms for the study are detailed in the following section.

3.0 DEFINITIONS

The following working definitions were used for the desk study:

Forest – Land with at least 10% canopy cover with live trees in a minimum area of 0.1 acre[10]

Conversion – Removal of part or all of the existing tree cover for conversion to other land uses

Development – Change in the actual or intended land use coupled with the modification of land cover associated with site preparation practices

Timber Lands – Land, other than federal land, which is "available for, and capable of, growing a crop of trees of any commercial species used to produce lumber and other forest products including Christmas trees"[11]

Timber Production Zone – Lands that are or have the potential to produce timber for which annual property taxes are modified provided that the lands are dedicated to timber production or compatible uses for a period of at least ten years

Hardwood Woodland – Lands characterized by hardwood cover with little or no presence of conifers found at relatively low elevations

Hardwood Forest – Lands characterized by hardwood cover with conifer presence found at relatively high elevations

Urban Forest – Native or introduced trees and related vegetation in urban and near-urban areas including, but not limited to, urban watersheds, soils and related habitats, street trees, park trees, residential trees, natural

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[8] California Department of Forestry and Fire Protection 2003
[9] Sokolow 1997 in Christensen, Campbell, and Fried 2008
[10] Areas of chapparal will not be included
[11] California Public Resource Code 4526

riparian habitats, and trees on other private and public properties where an urban area is an urban place of 2,500 or more persons[12]

Wildland Urban Interface – Area where homes and other structures abut or intermingle with wildland vegetation[13]

4.0 CALIFORNIA'S FOREST COVER

Due to California's climate and geography, most of California's forests are located in the mountainous regions of the state. Figure 1 shows the location of forests in California.

Figure 1. Map of California's forest cover (source NLCD 2001)

[12] California Public Resource Code 4799.09
[13] Hammer et al. 2007

Classification systems used to describe California's forest land are typically based on forest type and productive capacity. Classification based on productive capacity divides forest lands into timberland and other forest lands. Classification by forest type divides forest lands into conifer dominant forests and hardwood dominant forests. However, as the definition of timberland is applied by the Board of Forestry in California, commercial species include conifers but not hardwoods,[14] therefore the timberlands include conifer dominated forests but not hardwood dominated forests.

We used the National Land Cover 2001 Dataset to produce maps to visualize and better understand forest cover in California for the desk study. Figure 2 shows conifer and hardwood forest cover in California.

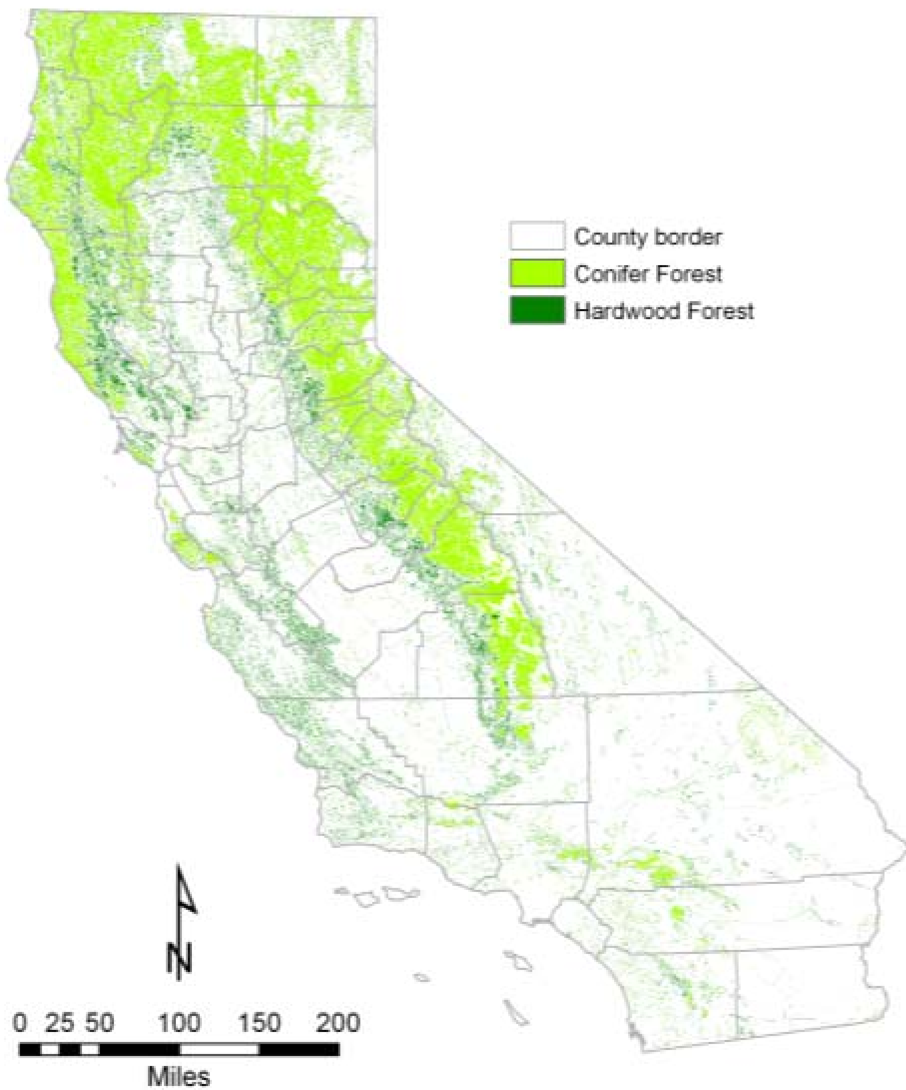

Figure 2. Map of conifer and hardwood forest cover in California (source NLCD 2001)

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[14] Shih 2001

California has approximately twice the amount of conifer dominated forest land as hardwood dominated land. Of forest land, 68% is conifer dominated and the remaining 32% is hardwood dominated.[15]

The federal government owns and manages more than half of the forested land in California. The other half is owned by private entities including families, individuals, conservation organizations, unincorporated partnerships, associations, clubs, corporations, and tribes. Figure 3 shows the extent of public and private forested land in California.

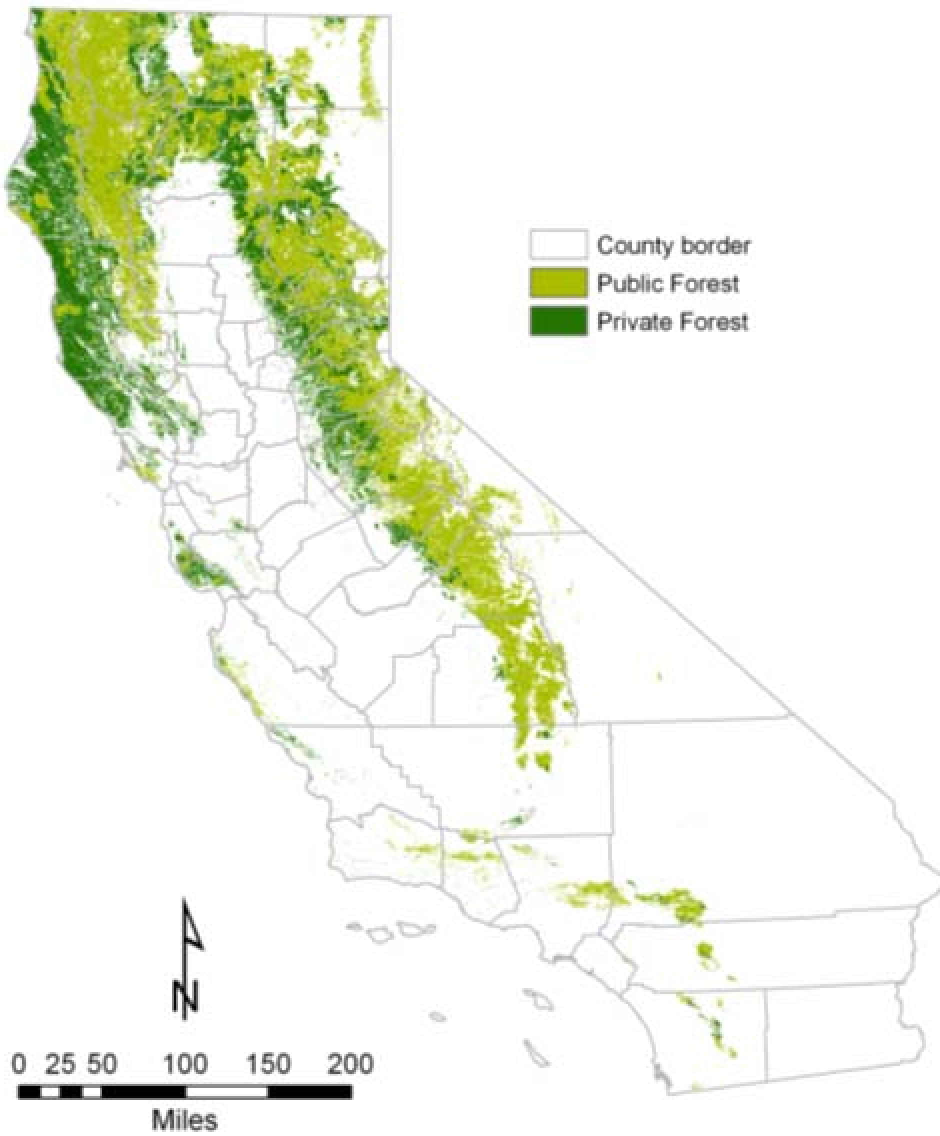

Figure 3. Map of public and private forested land in California (source NLCD 2001)

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[15] California Department of Forestry and Fire Protection 2003

Land use choices and conversion of forests to development are regulated differently for the different categories of forest land[16] and for the different types of forest land owners. National forest is effectively protected from development, although national forests can be managed for timber production. For conifer forests, most land is under public ownership, and the opposite is true for hardwood forest.[17]

For the purpose of our study, we focused on privately owned forested lands and woodlands, because these are the forests that are directly affected by development pressures. Increased demand for real estate creates an attractive opportunity for forest owners to sell land, and forest owners are doing so. According to the National Woodland Owner Survey of 2008 4 to 7% of landowners planned to "sell, subdivide, or convert" their forests in the future.[18] Timber companies have also sold land to developers due to decreasing timber prices in recent years.[19] However, it is important to note that federal land can concentrate growth in some areas.[20] For example, in the Eastern Sierra, higher elevations are occupied by national forest, and future development to accommodate population growth is expected to be concentrated at lower elevations in the foothills.[21]

The classification of forest cover of California is described in the desk study because the characteristics of existing forest cover have implications for development impacts. The legal processes by which forest land is converted to development is different for timberland and other forest land. In addition, hardwood woodlands and forests are found at elevations relatively lower to elevations where conifer forest is found and generally closer to population centers. Due to their proximity to population centers it would be expected that hardwood cover types are more often subject to conversion at the fringes of urban development while conifer cover types are more affected by scattered development in the wildland-urban interface. Furthermore, although hardwood cover is being converted to development at a faster rate than conifer cover[22] hectare for hectare conversion of conifer cover could have a greater impact in terms of GHG emissions.

5.0 FOREST CONVERSION

Although in the National Resource Inventory, conversion of forest land to development in California from 1990 to 1995 accounted for only 1 to 3% of change across California[23] this does not mean that change in forest cover due to development was insignificant. In fact, in some counties the percentage of change attributed to development was quite high. For example, in Butte County 15% of change was attributed to development. Residential or commercial development was also a major cause of change in hardwood canopy cover in El Dorado County from 1991 to 1996, accounting for 9% (393 acres) of change.[24] Furthermore, changes in land cover and canopy closure due to rezoning and development are more permanent than changes driven by other causes such as fire. In order for forest land to be converted to other uses, the necessary permits must be obtained at the state, county or local level. The following sections describe the processes by which different types of forest cover are converted to development.

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[16] Biles and Love 1998
[17] California Department of Forestry and Fire Protection 2003
[18] Christensen, Campbell, and Fried 2008
[19] Ritter 2005, Eilperin 2006, Braxton 2008
[20] McBride, J., Russell, W., Kloss, S. 1996
[21] Christenson, Campbell, and Fried 2005
[22] Wayburn, Tuttle, and Swedeen 2008
[23] Christenson, Campbell, and Fried 2005
[24] ibid

5.1 Conversion of Timberlands

The U.S. Forest Service Pacific Northwest Research Station's (USFS PNW) Pacific Resource Inventory, Monitoring and Evaluation Program conducts a Forest Inventory Assessment (FIA) each year and is the primary source of timberland data for FRAP. Timberland as defined by the FIA is forest land capable of producing 20 cubic feet or more of industrial wood per acre per year not in reserved status. Lands falling under this definition account for 42% of total forest lands in California and approximately one quarter of private forest lands.[25] Timberlands include the following forest types: Douglas fir, mixed conifer, Ponderosa/Jeffrey pine, Redwood, true firs, other softwoods, and hardwood (19%).[26] Figure 4 shows timber production zones and non-TPZ private timberlands in California.

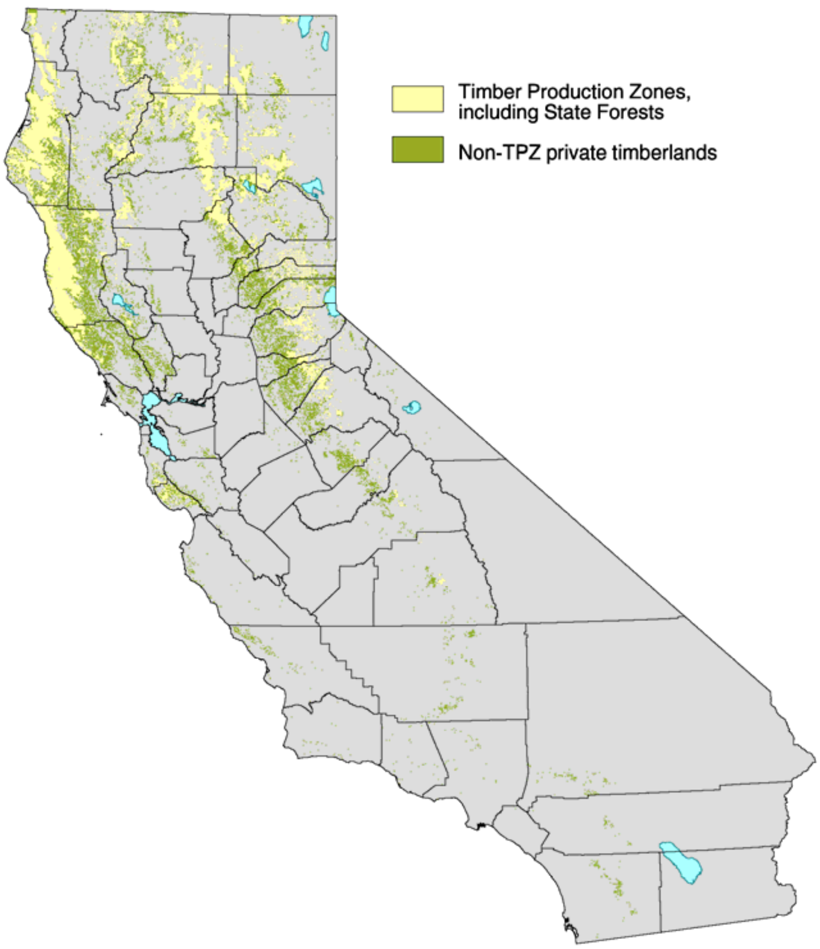

Figure 4. California's timber production zones and non-TPZ private timberlands (source Shih 1998)

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[25] California Department of Forestry and Fire Protection 2003
[26] Shih 2001

Timberlands with Timberland Production Zone status are afforded some protection from conversion for development under existing laws, most notably the California Forest Taxation Reform Act of 1976.. This law was enacted to protect the productivity of California's land base that grow timber and forest products and later amended by the Timberland Productivity Act of 1982.[27] This legislation, which is enforced by the CALFIRE, created the classification of Timberland Production Zones which are conifer-growing lands that are or have the potential to produce timber. Annual property taxes on these lands are modified provided that the lands are dedicated to timber production or compatible uses for a period of at least ten years. The ten year contract is self-renewing each year until it is cancelled.[28] Timberland Production Zones on private lands in California are comprised of the following general forest types: young-growth redwoods, whitewoods, and a third category that includes both ponderosa pine and mixed conifers.[29]

Conversion of timberlands or a TPZ to other uses usually requires permitting at the state government level except under certain exemptions. When a landowner wishes to convert their timberland to other non-timber growing uses or wishes to change the TPZ zoning to allow for alternative uses, they must submit an Application for Timberland Conversion Permit to CALFIRE unless otherwise exempt.[30] A Timberland Conversion Permit (TCP) exempts the timberland owner from the timber stocking requirements of the forest practice rules or, where immediate rezoning of TPZ is sought, it gives the owner the right to obtain final rezoning by local government. Timberland conversion occurs outside of permitting processes under exemptions for areas of less than three acres, rights of way, subdivisions, and TPZ "rollout" described below. Under circumstances where exemptions apply CALFIRE's influence is extremely limited. Timberland conversion permits and exemption records from the California Department of Forestry and Fire Protection show that from 1969 to 1998, each year on average 3,762 acres of timber production zones were converted to other uses.[31] During this thirty year period, conversions for subdivision development of former timberland grew from 4% during the first decade to 24% over the last decade.

In the past decade, the form of conversion of timberlands to other uses has changed with less area converted through direct permitting, and a relatively greater area converted through non-permitting processes. From 2003 to 2007 CAL FIRE received on average 13 TCP applications per year totaling 416 acres. During this same time period, CAL FIRE received an average of 13 *Notices of Exemption from Timberland Conversion for Subdivision Development* (Sub-Division Exemptions) per year totaling 1,157 acres of timberland conversion.[32]

Subdivision exemptions, which are approved by local governments resulted in almost twice the area of conversion approved by the department from 2003 to 2007, however even more acreage was converted through the process of "rollout."[33] Rollout is accomplished through the ten-year-roll-out process wherein local government's rezone approval to a new zoning class that does not become effective for ten years and a TCP is not required. Generally, the new zoning class's restrictions are similar to TPZ and permit timber management; however, such timberlands may be rezoned again, without Board or CALFIRE approval, to allow uses that are in conflict with timber management.[34]

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[27] California Department of Forestry and Fire Protection 2003
[28] California Department of Forestry and Fire Protection 2003
[29] Shih 2003
[30] CCR 1104.1
[31] Shih 2003
[32] Robertson 2008
[33] ibid
[34] ibid

5.2 Conversion of Hardwood Woodlands and Forests

For the FRAP California Forest and Range 2001 – 2003 Assessment, hardwood land cover was divided into hardwood woodland and hardwood forest classes. Figure 5 shows hardwood cover in California.

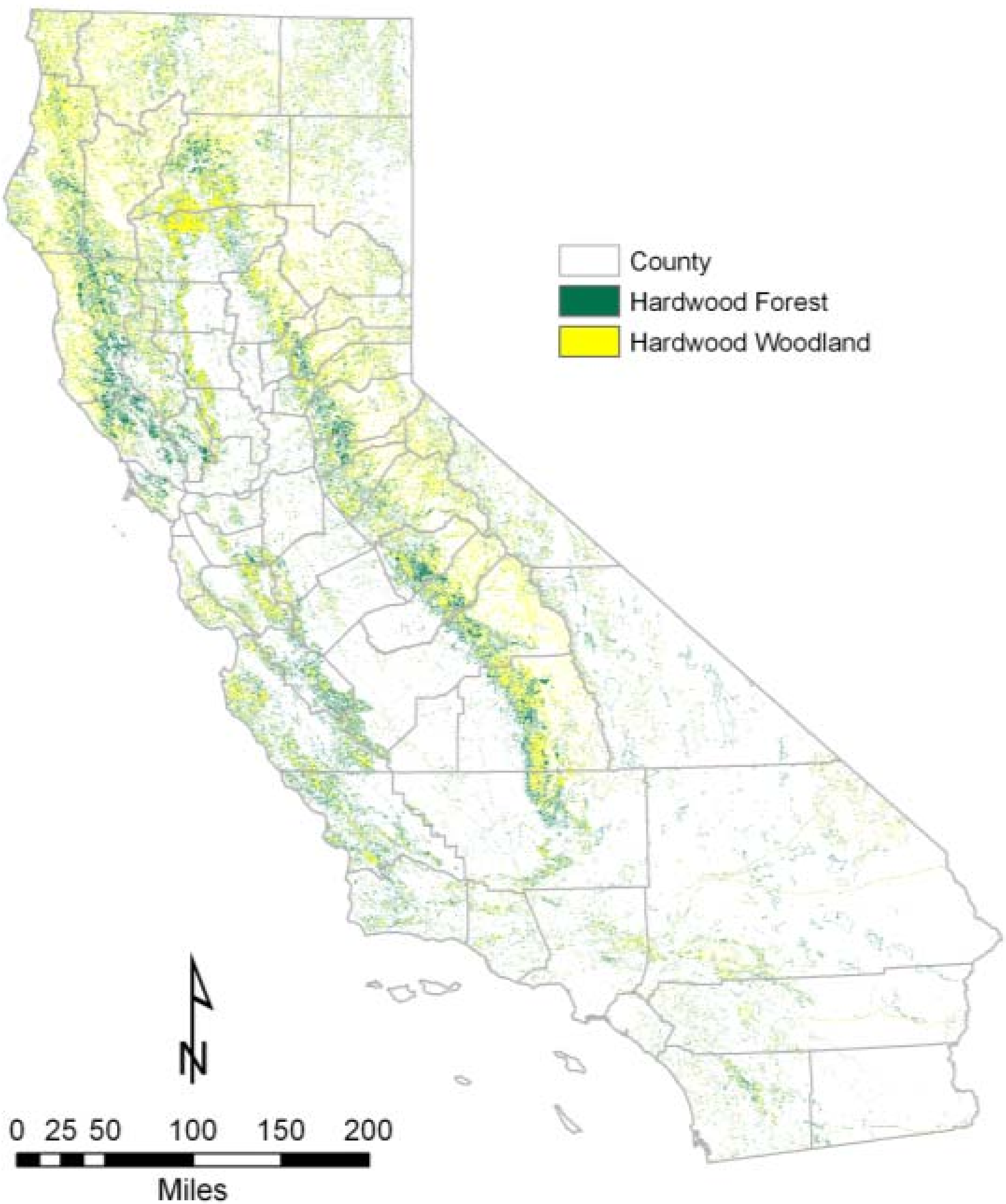

Figure 5. Map of hardwood cover in California (source FRAPVEG)

Hardwood woodlands are found at lower elevations and are characterized by low or no presence of conifers. Oak is the dominant species in California's hardwood cover and hardwood woodlands are also known as "oak woodlands."[35] Hardwood forests are found at higher elevations and are characterized by the presence of conifers and low development pressures due to their location in higher, more rugged environments further from urban centers. Hardwood woodland and forest accounts for close to 9.9 million acres[36] (roughly 10%) of land cover in California. For later analyses this study will consider both hardwood woodland and hardwood forest as one category, "hardwood woodland."

In addition to their physical proximity to development pressures, most hardwood forest lands and hardwood woodlands are privately owned (over 73% of all cover types)[37] increasing the vulnerability of hardwoods to development compared to conifers. Hardwood land cover has the lowest percentage of lands reserved from management activities compared to all other land cover types[38] indicating less permanent protection from development pressures. Hardwood cover is more subject to pressures for conversion to agricultural uses than conifer cover. Change in hardwood cover is related to the expansion of vineyards, particularly in Sonoma and Santa Barbara counties.[39] Nearly 800,000 acres of hardwood land cover are projected to be developed to a density of at least one house per 20 acres between 2000 and 2040 and seven of nine hardwood habitats are projected to lose at least 10% of the base 2000 acreage to development.[40] This study will consider conversion of forest land for agricultural uses in addition to residential and commercial uses.

Land trusts play an important role in preventing the conversion of hardwood rangelands (as well as some timber lands) to development by acquiring the land or the rights to development of the land from land owners. According to the Land Trust Alliance 2005 Land Trust Census total acreage protected by local and state land trusts grew from 1,250,509 acres in 2000 to 1,732,471 in 2005, an increase of 39%.[41] Protection of forest lands with land trusts is supported by the Forest Legacy Program (FLP) which was created to "protect environmentally important forest land threatened with conversion to non-forest uses, such as subdivision for residential or commercial development."[42] The FLP encourages the use of conservation easements to preserve forest lands and their traditional uses with support from federal funds and the cooperation of state and local governments. In addition, in 2000 the Governor signed into law the California Forest Legacy Act which allows CALFIREto acquire conservation easements, and permits Federal agencies, State agencies, local governments and nonprofit land trust organizations to hold conservation easements acquired under the California Forest Legacy Program. Money to fund the Program is obtained from gifts, donations, federal grants and loans, other appropriate funding sources, and from the sale of bonds pursuant to the Safe Neighborhood Parks, Clean Water, Clean Air, and Coastal Protection Bond Act of 2000.[43]

Other laws specifically target lands with hardwood cover for conservation like the Natural Heritage Preservation Tax Credit Act of 2000 that gives tax incentives to owners of hardwood lands and associated habitats that donate land or water rights to State and local agencies or designated non-profit organization for conservation purposes, and the Oak Woodlands Conservation Act of 2001 which created a fund to be used to buy oak woodland conservation easements and land improvements.[44] The State has strongly encouraged local governments to develop policies that address the protection of hardwoods and by 2000 almost all counties in California had implemented processes to govern privately owned hardwood resources within their boundaries.

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[35] California Department of Forestry and Fire Protection 2003
[36] ibid
[37] Christenson, Campbell and Fried 2005
[38] California Department of Forestry and Fire Protection 2003
[39] Merenlender 2000 and Standiford et al 2000
[40] California Department of Forestry and Fire Protection 2003
[41] Land Trust Alliance 2005
[42] http://www.fire.ca.gov/resource_mgt/resource_mgt_forestryassistance_legacy.php
[43] ibid
[44] California Department of Forestry and Fire Protection 2003

Conservation plans, joint projects, conservation easements, and even acquisition of lands in fee (purchase and title changes) all protect hardwoods and hardwood habitats and involve landowners, non-profit organization, and governments at all levels.

5.3 Conversion of Urban Forests

Urban forests can lower energy costs while improving property values and providing important habitats for wildlife. Reduction in urban forest cover will most certainly have an effect on urban environments and could make a significant contribution to GHG emissions. The most recent assessment of California's urban forests by the CALFIRE found that the ratio of plantings to removals of urban trees had decreased when compared to earlier assessments.[45] While urban tree inventories have increased by roughly 4% per year between 1988 and the current assessment, most gains in urban forests have come from smaller cities.

A 1993 study attributed only 4% of urban tree removal in California to development.[46] Removal was more often a result of tree disease and death or damage. Nevertheless, the opportunity to expand urban forest coverage exists. Using aerial photography, McPherson and Simpson (2003) found 242 million empty tree planting sites in California cities.[47] In the San Francisco Bay area, while overall tree cover in urban areas increased from 1984 to 2002, it did not keep up with an increase in impervious surfaces.[48]

Many local governments are implementing programs to increase and enhance urban forest cover. The Million Trees LA project aims to increase urban forest canopy coverage in the city of Los Angeles from the current 21% to equal the national average of 27% by planting one million trees. Although the city of San Francisco exceeded its goal of planting 5,000 trees in 2008, its streets remain 47% unplanted. A critical challenge to the sustainability of urban forestry programs is funding. Without sufficient resources, local governments cannot adequately manage their urban forests.[49]

Very little information is available on the removal of urban trees and forests from private lands that do not seek rezoning. If local tree ordinances do not apply, then the removal of trees from private lands by landowners is not tracked. Small scale tree removalwould be very difficult to capture without fine scale satellite imagery and the cumulative impact of these events in terms of GHG emissions could actually be quite high.

5.4 Conversion at the Wildland Urban Interface

Development may occur either through the expansion of urban areas or through large lot development in rural areas. The term "Wildland Urban Interface" (WUI) is used in land cover assessments to describe the area where urbanized lands and undeveloped lands meet. WUI is comprised of "interface," where large urbanized areas abut areas of continuous vegetation, and "intermix" areas where small developed areas are like islands in a sea of vegetation. Initial development of forested lands is not as dense as development in and around urban centers[50] and analysis of changes in the WUI provides information on the relative intensity of concentrated and

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[45] Thompson 2006

[46] Bernhardt and Swieck 1993

[47] McPherson and Simpson 2003

[48] Simpson and McPherson 2007

[49] Thompson, Pillsbury, and Hanna 1994

[50] California Department of Forestry and Fire Protection 2003

dispersed development in forested areas. A study carried out at the University of Wisconsin showed that WUI development expanded substantially in California over the 1990's.[51]

Table 1. Wildland-urban interface area growth (km^2) in California from 1990 to 2000

	1990	2000	n	%
Interface	7,266	7,328	63	0.9
Intermix	18,998	21,219	2,221	11.7
Total WUI	26,263	28,547	2,284	8.7

Source: Hammer et al. 2007

Figure 6. Wildland-urban interface (2000). (Source: Radeloff et al. 2005)

As of 2000, 5.2 million acres of intermix WUI accounted for 74% of WUI area but only 32% of homes.[52] The area of WUI intermix has expanded more than the area of interface, indicating that dispersed development is expanding more rapidly than more concentrated development in terms of areas impacted. The FRAP 2003 Forest Assessment also found that parcelization (low density rural development at one housing unit per 20

[51] Hammer et al. 2007
[52] Hammer et al. 2007

acres) at the fringes was more extensive than urbanization (development with density of at least one house per acre with nearly complete loss of vegetation.) California law requires that rural homeowners areas within a radius of 100 feet around their homes to maintain a "defensible space" for protection from fires.[53] Thus each home in the WUI intermix accounts for at least 2,917 square meters of impacted land, though the intensity of fuel management depends on flammability of the structure, building standards, location, and type of vegetation. These parcelized areas are likely to become more densely developed at urban levels.[54]

Dispersed development is found in different areas of California. Large areas of WUI are found in the Sierra foothills region, the San Francisco Bay area margins and the mountains of Southern California. Research by the Sierra Nevada Alliance found that between 1990 and 2000 the area of WUI grew by 12% in the Sierra defined as a pattern of low-density development with one house every two to 80 acres, also referred to as "rural ranchette" development.[55] This pattern of development is advancing more quickly than urban development by a ratio of 10 to 1.[56] Now nearly one out of every two California homes is in the wildland urban interface.[57] In western Nevada County, the majority of the rural landscape is dominated by low density rural-residential development on parcels that range from 5 to 40 acres or more.

6.0 SITE PREPARATION PRACTICES

Practices used to prepare sites for development range from complete clearing of all vegetation and leveling to low-impact and conservation development practices that retain at least some of the natural land cover. While the amount of vegetation removed during site preparation is a function of the density of existing vegetation and the intensity of development, it also depends on local and state regulations. Local tree ordinances and conservation legislation vary in their restrictions on vegetation removal and mitigation measures. In addition, under California Environmental Quality Act guidelines, projects with a significant environmental impact are required to conduct Environmental Impact Assessments. On the other hand, developers can be limited in their ability to implement low impact and conservation development practices by local zoning laws that regulate housing density, making it difficult to cluster housing in one part of the development site.

Many local governments have adopted tree ordinances to prevent the degradation of urban and rural forest resources through development. These ordinances place restrictions on the removal of trees and require the implementation of mitigation measures such as replacement of removed trees or monetary contributions to conservation funds. When development sites fall under the classifications of landscapes and vegetation protected by regulation, developers must follow the guidelines of these ordinances. However, ordinances usually do not offer blanket protection for a broad set of tree sizes and species. Ordinances differ in their definitions of threshold size and regulated species. Ordinances also differ in the rate of tree replacement and species indicated for replacement depending on local conditions. In San Mateo County a *Significant Tree Ordinance* requires a permit for the removal of any significant tree (circumference of 38 inches or greater) or community of trees (a group of trees of any size which are "ecologically or aesthetically related to each other").[58] Also in San Mateo County, a *Grading Ordinance* requires a land clearing permit when 5,000 square feet or more are cleared within two years, or when 1,000 square feet or more are cleared in a county scenic corridor, in areas where slope is greater than 20% and in sensitive habitats or buffer zones.[59] In Placer County under the *County*

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[53] California Public Resource Code 4291

[54] California Department of Forestry and Fire Protection 2003

[55] Sierra Nevada Alliance 2007

[56] California Department of Conservation 2006

[57] Radeloff et al. 2005

[58] San Mateo County Ordinance Code Part Three, Division VIII

[59] San Mateo County Ordinance Chapter 8, Division VIII

Tree Protection Ordinance approval for tree removal requires in-kind replacement or payment into the Tree Planting Fund. Developers must submit information on all the trees on the site and specific conditions on tree retention are based on this information. In El Dorado County the *General Plan* canopy retention standards require discretionary projects on parcels having oak woodland canopy of at least 10 percent to retain or replace the existing canopy on an area basis.[60] Clustered development is emphasized to retain natural vegetation. Planned development projects, including subdivisions that create more than 50 new lots, must set aside at least 30 percent of the project area as open space, which can be used to meet canopy retention requirements. In Ventura County, a *Tree Protection Ordinance* restricts the alteration or removal of any oak or sycamore tree with a single trunk measuring 9.5 inches or more in circumference.[61] The ordinance also protects trees which are designated as "heritage" or "historic." Further analysis of the impact of development at specific project sites should take into account the impact (or lack or impact) of local ordinances.

The *California Environmental Quality Act* (CEQA) requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts if possible. Any private development project that must receive some discretionary approval from a government agency is also subject to the provisions of CEQA. As a result, most proposals for physical development in California are subject to the provisions of CEQA. At a minimum, an initial review of the project and its environmental effects must be conducted. Depending on the potential effects, a further more substantial review may be conducted in the form of an environmental impact report (EIR). Before the project can be implemented, significant environmental impacts must be addressed..

An initial survey of EIR's was conducted to gain insight into the development practices that are monitored and regulated at the county level with specific attention to the removal of trees. EIR's for current development projects were downloaded from county planning department websites where available, and if possible the responsible planner was contacted for more information. County planners were knowledgeable about specific development projects and were able to give detailed information about site preparation for the projects including vegetation clearing and land grading as well as contact information for the responsible developers. In Santa Clara County, the Castro Valley Ranch Subdivision project involved the subdivision of an 8,400 acre site into 16 parcels ranging in size from 182 acres to 2,412 acres. An area of 20 acres of non-riparian coast live oak forest was impacted. Mitigation measures included habitat replacement. Recent projects in Placer County involved substantial removal of on-site trees. In one project mitigation measures included oak tree timber and onsite reuse. In Mendocino County the Garden's Gate subdivision project would remove up to 25 oaks while preserving a forested area on the western part of the property. In some cases the area cleared of vegetation can be substantial. In Nevada County the Deer Creek Park 2 project would involve the removal of up to 175 acres of mixed conifer forest. Another project on 253 acres of forested property includes retention and replanting of trees as a mitigation measure. In San Bernardino County one project involved the removal of project involved the removal of 37% of 19,065 trees (roughly 7,000 individual trees). The Circle S. Ranch vineyard project in Napa County would remove approximately 289 acres of oak woodland while preserving 520 acres for tree management areas. The Bear Valley Village project in Alpine County would result in the loss of approximately 26.6 acres of conifer forest and chaparral. The Sierra Meadows project in Madera County is anticipated to impact 500 acres of foothill woodlands, and in Monterey County, the Harper Canyon subdivision project will remove 79 coast live oak trees from the property. Although the area of cleared vegetation can be relatively small compared to the total area of the project (and sometimes it is actually quite substantial), the collective impact of multiple projects could be significant at the regional and state level.

Once vegetation is cleared from the development site, it may be disposed of in a variety of ways. If timber cleared for development can be used for wood products, the bole may be sold while the stumps and branches

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[60] General Plan of El Dorado County
[61] Ventura County Ordinance Code

stay on site where they could be burned or chipped and scattered.[62] However, strict air quality laws in California limit the use of burning to dispose of waste. In counties where a biomass energy plant is accessible, wood waste from site preparation may be sold to biomass-fueled power plants. Biomass plants are found in 17 California counties. Alternatively, waste may be disposed of in landfills. However, limited landfill space and increasing disposal costs are prevalent in some jurisdictions and regions of California. In 1989 the California Integrated Waste Management Act (AB 939) mandated a 50% reduction in the disposal of green wastes by 2000, further reducing the amount of waste from cleared vegetation ending-up in landfills.

Information is available on the disposal of green woody waste from urban forestry programs, and the disposal of vegetation cleared from development sites may follow a similar pattern. The California Department of Forestry and Fire Protection Urban and Community Forestry Program studied the disposal of urban wood waste and found that almost 50% of the material was chipped for mulch.[63] The other two major disposal methods were dumping and sale of solid wood. The California Integrated Waste Management Board tracks wood waste that enters landfills, including prunings, trimmings, branches and stumps in organic waste as well as waste from construction and demolition. The fate of green waste that reaches landfills is also varied. While 56% of landfills reported that they bury at least part of the material, 45% reported that they utilize the waste in some way. Of the respondents, 41% utilized the material for mulch and 31% used the material for landfill cover.[64] The following local governments in the study area are currently considering or actively investigating landfill alternatives and conversion technologies: the City and County of Los Angeles, the City and County of Santa Barbara, Orange County and the cities of Sacramento and Santa Cruz.[65]

[62] Wickizer, D. Personal communication. June 2009.
[63] Thompson 2006
[64] Plumb et al. 1999
[65] California Integrated Waste Management Board 2009

7.0 IDENTIFICATION OF STUDY SITES

7.1 Analysis to identify candidate sites

An analysis of housing density, development trends, and land cover was conducted to determine the sites for further study. Information on county residential building permits from 2005 to 2007 and 2000 Census block data on new buildings were used to determine areas with the highest rates of recent development. In the U.S. Census data, building permits represent the number of new housing units authorized by building permits, and excludes conversions of and alterations to existing building. This information was compared with GIS data on land cover to identify the areas where high rates of development coincide with high forest cover. Public lands were excluded from the analysis.

We analyzed the U.S Census Bureau Building Permits data from 2005 to 2007, as we calculated the average permits issued per county for this period. Based on the average permits issued for this period, counties were grouped into four categories: (1) low – less than 1,000 permits, (2) moderate - between 1,000 and 5,000 building permits, (3) high – between 5,000 and 10,000 building permits and (4) very high –above 10,000 building permits (Table 2).

Table 2. Annual average category of building permits issued for 2005-2007 per county

County	Average 2005-2007	Category
Inyo County	14	low
Sierra County	15	low
Alpine County	21	low
Modoc County	21	low
Lassen County	42	low
San Benito County	50	low
Trinity County	60	low
Del Norte County	73	low
Mariposa County	80	low
Mono County	85	low
Colusa County	88	low
San Francisco County	149	low
Marin County	156	low
Glenn County	166	low
Siskiyou County	213	low
Amador County	219	low
Plumas County	236	low
Tuolumne County	251	low
Mendocino County	264	low
Humboldt County	372	low
Napa County	373	low

Lake County	407	low
Santa Cruz County	429	low
Tehama County	442	low
San Mateo County	485	low
Calaveras County	539	low
Nevada County	545	low
Sutter County	581	low
Santa Barbara County	628	low
Kings County	720	low
Monterey County	778	low
Shasta County	867	low
Yolo County	1,001	moderate
El Dorado County	1,025	moderate
Yuba County	1,123	moderate
Butte County	1,175	moderate
Imperial County	1,255	moderate
Solano County	1,271	moderate
San Luis Obispo County	1,296	moderate
Madera County	1,317	moderate
Sonoma County	1,378	moderate
Ventura County	1,440	moderate
Alameda County	1,608	moderate
Merced County	2,051	moderate
Santa Clara County	2,288	moderate
Stanislaus County	2,311	moderate
Tulare County	2,785	moderate
Fresno County	2,976	moderate
Placer County	3,260	moderate
Orange County	3,449	moderate
Contra Costa County	3,749	moderate
San Joaquin County	3,782	moderate
Kern County	5,110	high
San Diego County	5,643	high
Sacramento County	5,706	high
Los Angeles County	10,209	very high
San Bernardino County	11,291	very high
Riverside County	20,216	very high

Forest in California was defined by grouping the deciduous, evergreen and mixed forest classes from the NLCD 2001[66]. NLCD 2001 defines these major forest classes as follows:

- Deciduous forest is defined as area dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
- Evergreen forest is defined as area dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
- Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

Polygon data of National Parks was obtained from the National Park Service web site and was used to exclude all forest located in the National Parks in California. Figure 7 shows the remaining forest area (outside the National Parks) as percent of the total area of the county and average permits category per county.

[66] Deciduous forest , evergreen forest and mixed forest have values of 41, 42 and 43 respectively in the NLCS 2001 dataset

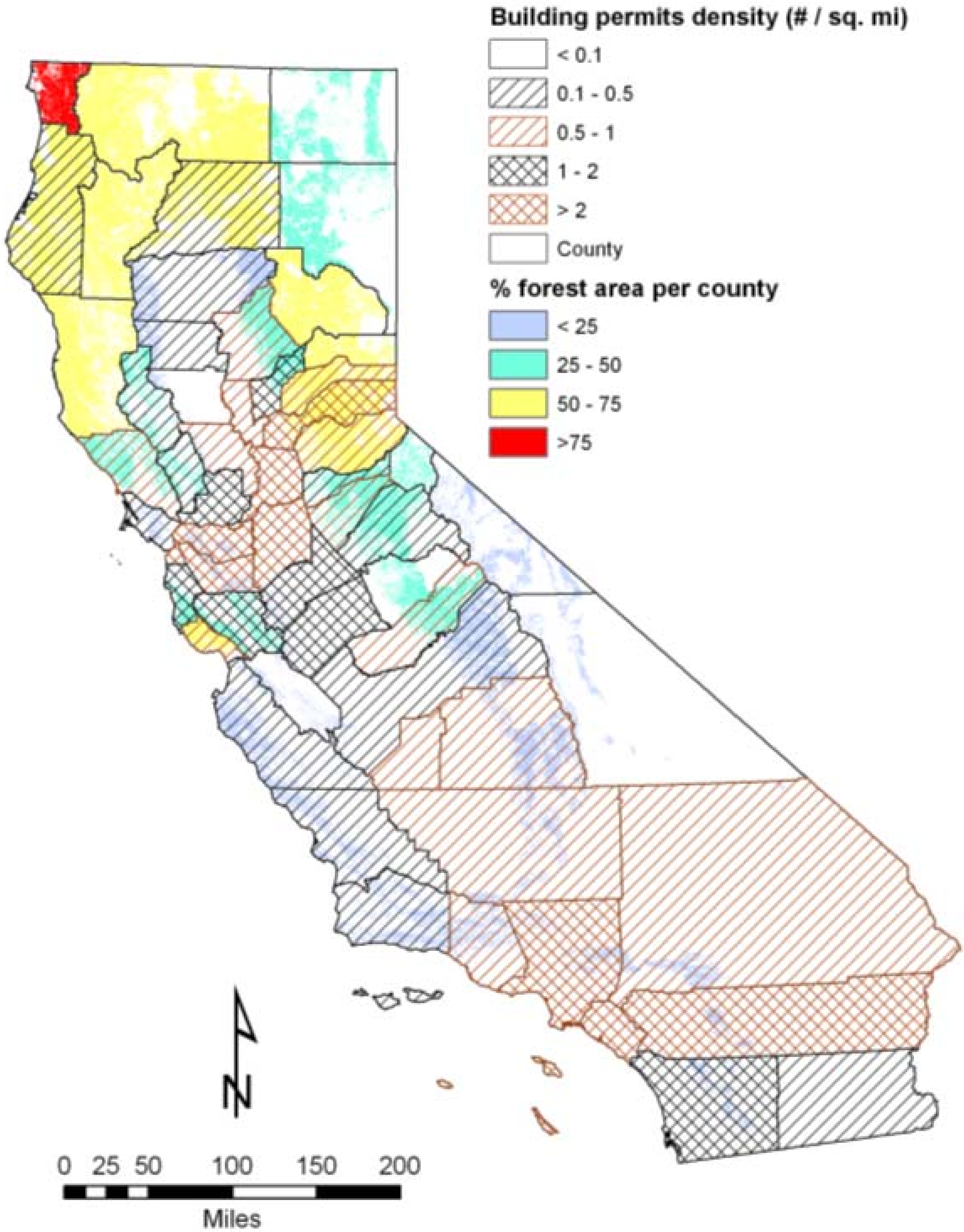

Figure 7. Map of forest land overlaid with 2005-2007 building permit density

7.2 Proposed sites for indepth study

Based on forest cover and recent development pressure paired with an attempt to incorporate varying vegetation types and achieve a balance across geographical regions the following areas are proposed for in depth study including remote sensing analysis and field data collection:

1. **The counties of Marin, Sonoma, Napa and Mendocino (north of the San Francisco Bay Area)**
2. **The Sierra Mountain counties of El Dorado, Placer and Nevada**
3. **Shasta County in far Northern California**
4. **Los Angeles and Ventura Counties in Southern California**

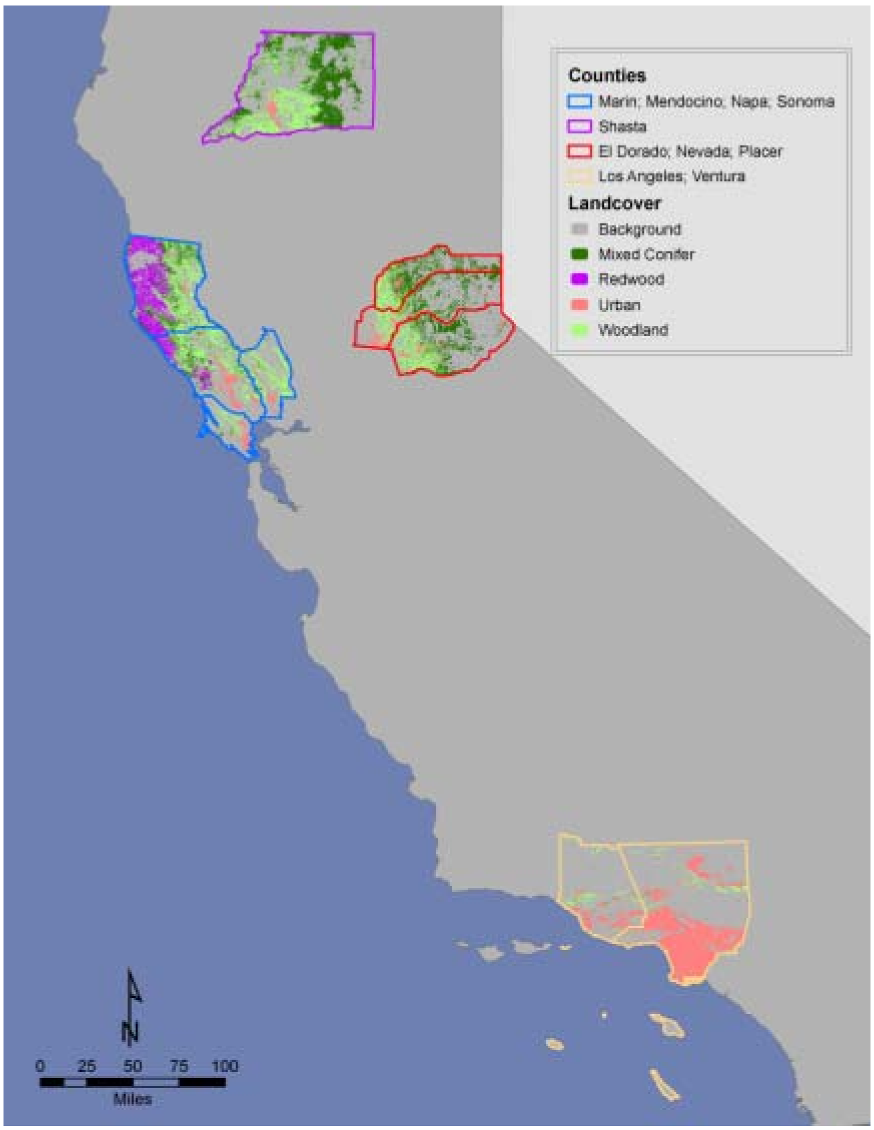

Figure 8. Map of sites for in-depth study.

The selected sites represent areas experiencing specific challenges with regard to deforestation and development and cover the major forest types found in California.

The Sierra Nevada region has experienced a high rate of population growth and development in recent years. El Dorado, Nevada and Placer counties alone accounted for approximately 58% of the population increase in the Sierra region during the 1990s[67] and these counties are projected by 2020 to have their populations increase by 84%, 42% and 38% respectively.[68]

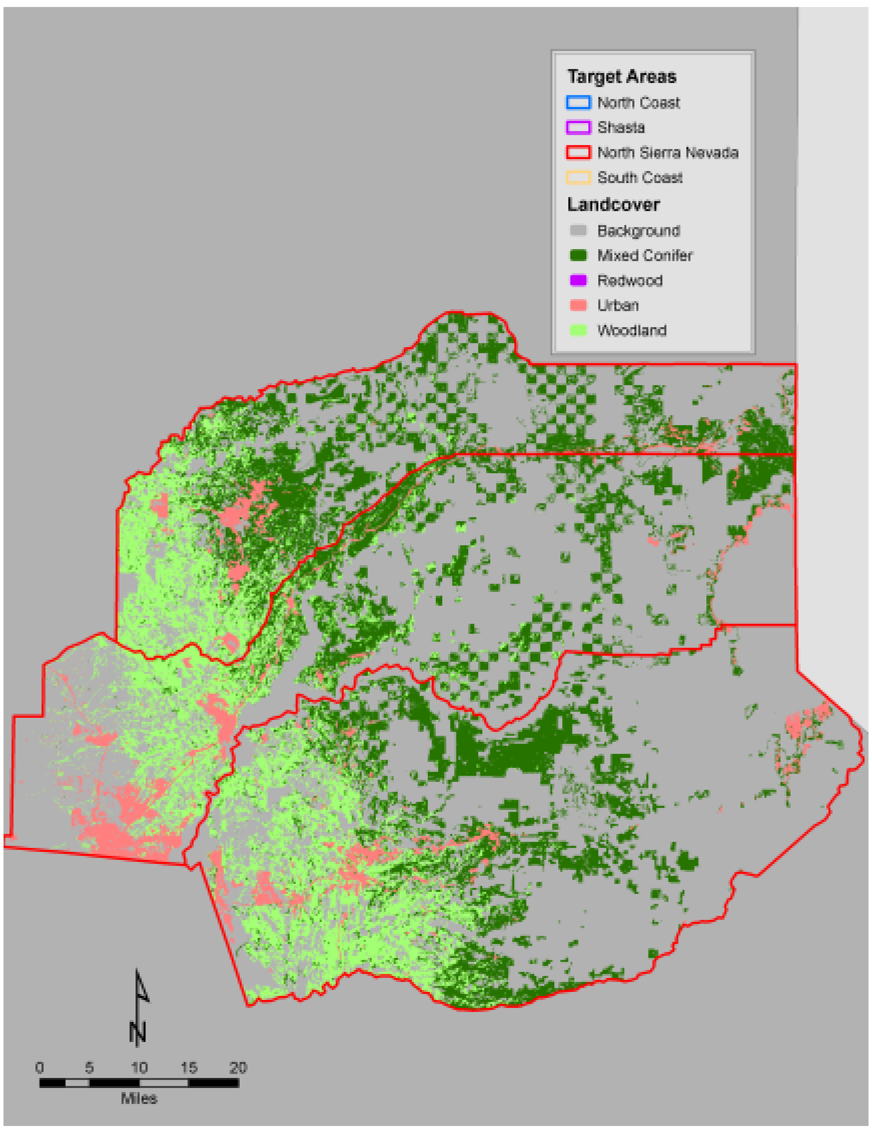

Figure 9. North Sierra Nevada target area.

[67] Hickey 2005
[68] ibid

Although much attention has been paid to the Sierra Nevada region, forested land in the San Francisco Bay area and greater Los Angeles also face pressures from large urban populations that continue to expand. For example, proximity to the Bay area where development pressures are particularly at risk puts oaks in Sonoma County at particular risk, where oak woodlands cover 40% of county land area and are 95% privately owned. The northern section of Mendocino county was dropped from the study due to the large size of the county, the limited amount of development, and the desire to focus more towards pressures emanating from the Bay Metro Area. This decision was discussed during a stakeholder meeting in Sacramento July 2009 and met with approval.

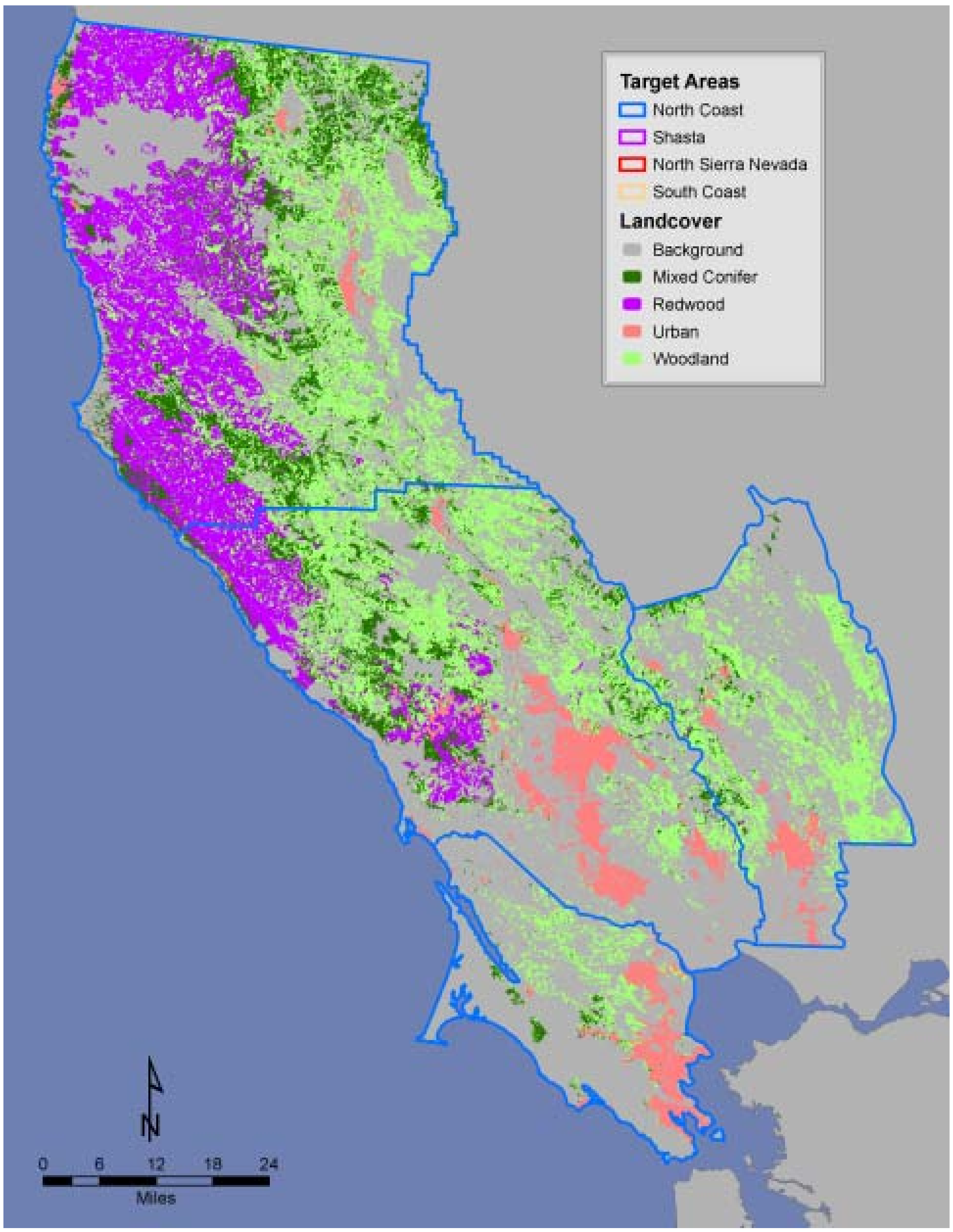

Figure 10. North Coast target area.

Extensive urban development in the Los Angeles area has left very little privately owned forest land. However, tree cover and ongoing canopy reduction in urban and suburban areas may not be well captured by the most widely available satellite imagery. Further study of the Los Angeles area will focus on small reductions in canopy cover that could have a significant cumulative impact.

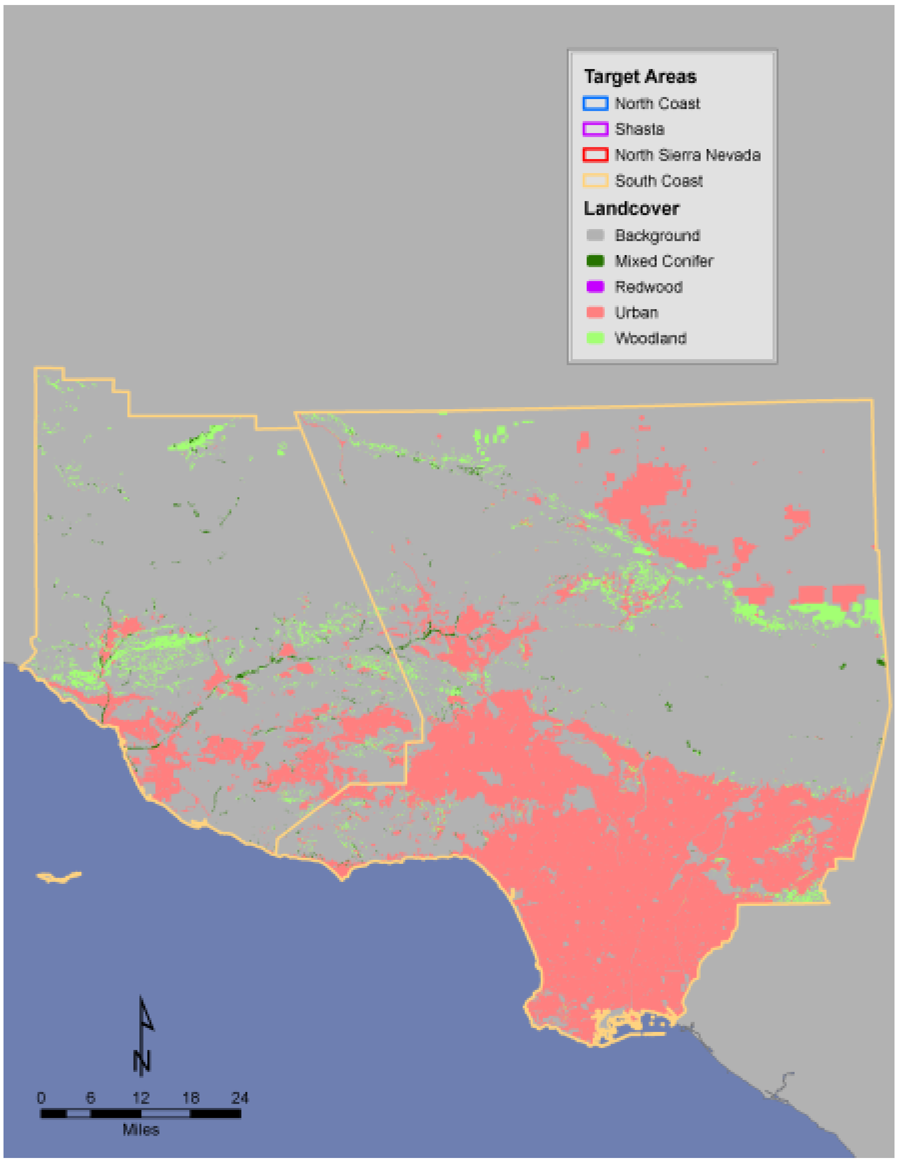

Figure 11. South Coast target area.

Shasta County has large areas of forest land and may face development and deforestation pressures similar to those of the Sierra Nevada. Further study of this area will help to identify differences in the impacts of development in the Sierra and Cascade regions.

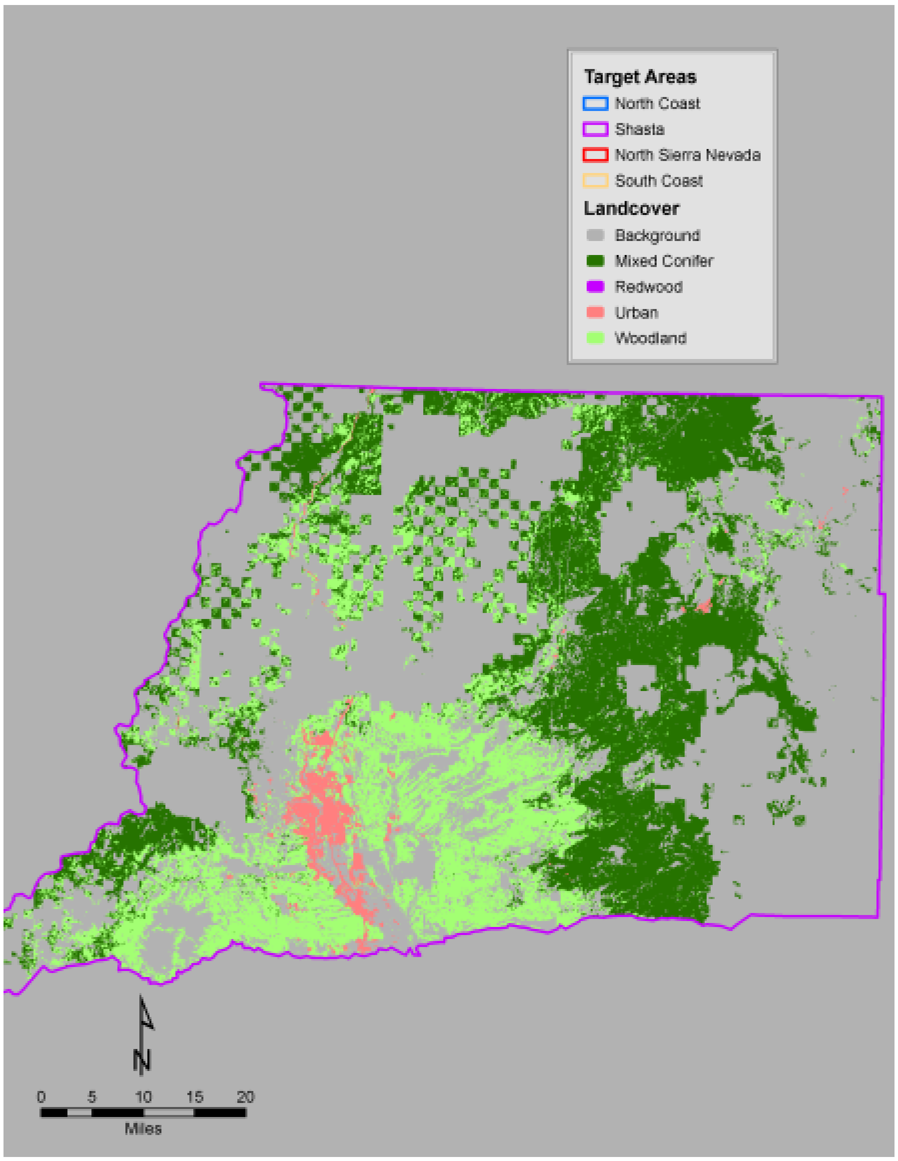

Figure 12. Shasta target area.

8.0 SUMMARY AND RECOMENDATIONS FOR FURTHER STUDY

One third of California's land base is covered with forest and over half of this forest land is owned by the federal government. For our study we consider only private forests, which are subject to pressure from development. Conifer forests are found at higher elevations farther away from urbanized areas. Most conifer forests are publicly owned. Privately owned conifer forests may be protected by timberland or Timber Production Zone status. However, the pattern of conversion of TPZs has changed from direct permitting to non-permitting processes with a corresponding lack of control by state agencies over the process. Hardwood forests and woodlands are mostly privately owned and found at lower elevations closer to urban areas. Lands with hardwood cover are overall more vulnerable to development than lands with conifer cover. Many programs that specifically target hardwood woodlands and forests for conservation have been implemented at the state and local level. In addition, the many programs and local regulatory processes implemented under AB32 could afford extra protection to wooded lands from development, but only if the benefit of protecting forests is understood. For example the California Air Resources Board has been mandated with the authority to set CEQA threshold limits for GHG emissions impacts, but the cost of removal in terms of GHG emissions is not known.

Analysis of changes in the Wildland Urban Interface in California over the past decade reveals that dispersed development is expanding more rapidly than more concentrated development. However, the relative impact of these two forms of development in terms of deforestation is not known. The impact depends both on the extent of development and the site preparation practices of developers. While deforestation for development is probably well captured at the urban fringe, it is not well understood, and development in the Wildland Urban Interface intermix area is probably not even well captured. Further study of areas of current development to gather field data on development of forested lands and its impact on climate change will occur in future phases of this study. Valuable information could also be gained from county planners who are knowledgeable about specific development projects. Information on the fate of vegetation removed from development sites may be obtained from waste management facilities.

However, zoning ordinances that restrict housing density could present obstacles to developers that wish to retain native vegetation on development sites. For example, county zoning ordinances impose density limits that make it difficult in some cases for developers to concentrate housing in one part of the development site because the resulting housing density would be too high for the local zoning. Also, in urban areas, zoning ordinances can limit infill development by preventing high density housing. In some cases, zoning ordinances will need to be revised by local and county governments to promote low impact, cluster, and conservation development. Avoiding deforestation for development could help local, county, and state governments meet targets for emissions reductions.

In 2006 the governor of California signed AB32 setting targets for emissions reductions and promoting programs that address climate change on the county and local level. Housing element policies and programs implemented by local governments to address climate change will directly and indirectly influence deforestation associated with development by increasing urban tree cover and changing patterns of urban expansion to encourage denser development and discourage urban sprawl.

As an example, Sonoma County's Climate Protection Campaign's Community Climate Action Plan outlines four strategies to mitigate climate change on the county level. Two of these strategies impact development patterns and deforestation – the "smart transit and land use" element and the "conserve and capture" element. The smart transit and land use element provides for the strengthening of transit-oriented mixed-use development, the use of urban growth limits to control sprawl, and the strengthening of zoning laws to protect lands that sequester carbon. The conserve and capture element encourages the use of conservation easements to protect agricultural and forest land through the use of zoning laws to promote cluster development and easements as well as tax incentives to increase the amount of land under conservation easement. Similar local legislation across the state could influence deforestation due to development and the associated greenhouse gas emissions now and in the future.

Retaining native vegetation during site preparation may present certain economic benefits to developers, including lowering the costs associated with clearing vegetation and enhancing the value of the property due to lower green house gas emissions. It is possible that in the future development will be regulated to comply with greenhouse gas emission standards, and developers that prepare themselves now will be better able to adapt to a new regulatory landscape in the future.

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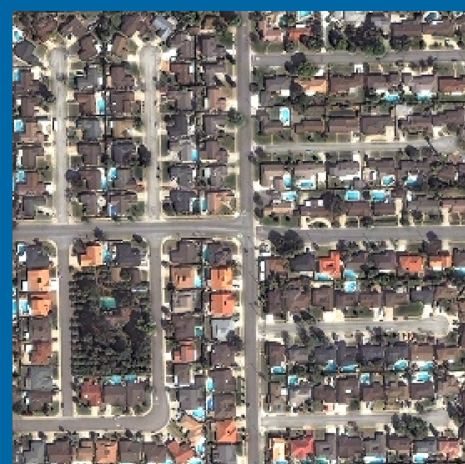
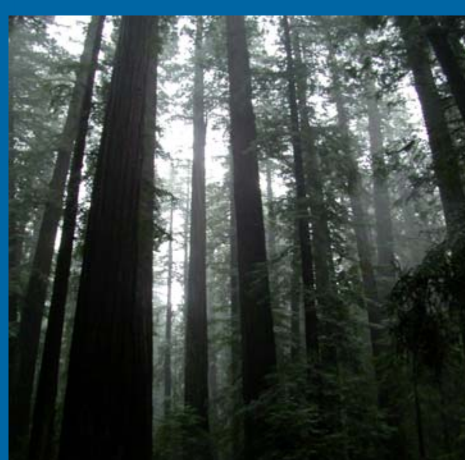
APPENDIX B:
Spatial Analysis

Pearson, Timothy, S. Grimland, K. Goslee, and S. Brown. (Winrock International). 2011. Spatial Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity. California Energy Commission. Report to PIER under #PIR-08-008.

Grant #PIR-08-008
January 2011

Spatial Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity

Timothy Pearson, Sean Grimland, Katherine Goslee and Sandra Brown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CONTENTS

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LIST OF TABLES AND FIGURES

EXECUTIVE SUMMARY

In a poll in 2000, urban sprawl was classified, tied with crime, as the leading local concern in the US. Across the country, urban area has doubled over the past 40 years. In California, during the same period, there was a 252% increase in the urban area. Among regions in the US, California appears to have the lowest current number of developed acres per capita, but the second highest population growth rate, and an average income growth rate that outstrips population growth. This trend in population and income growth rates makes one question if the area of development is captured correctly, thus the purpose of this project: to improve the assessment of forest conversion to development.

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown.

Assessments of deforestation for development do exist but no confident emission estimates can be paired with the estimates of rates of deforestation. In addition, deforestation is monitored using coarse scale imagery that can only poorly track the most common form of urban development - scattered development. It is therefore likely that deforestation rates are underestimated and actual emissions are entirely unknown.

The study focused on four landscape categories (redwood, other conifer forest, woodland and hardwoods, and urban) across four regions (Figure ES-1) that had previously been shown to be at high risk of deforestation for development.

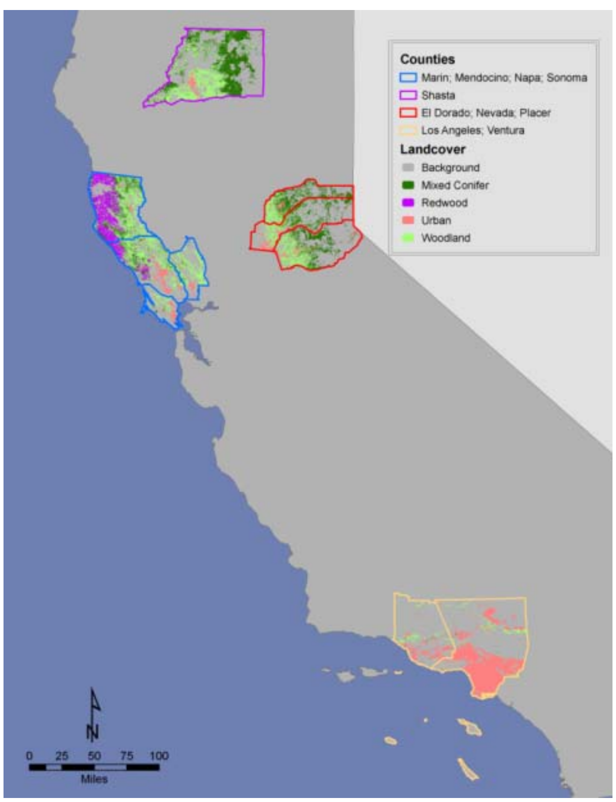

Figure ES-1. The four sampling regions

Twenty-eight sampling areas totaling 123,630 acres were sampled at two points in time, 3 – 7 years apart, both with high resolution (60 cm pixels) and medium resolution (Landsat 30 m pixels) imagery. Sampling was focused on privately owned forests, woodlands and urban landscapes with tree cover.

Figure ES-2. Example of deforestation as recorded in the high resolution imagery. Left image is before and right image is after development.

A total area of 568 acres of deforestation was recorded in the high resolution imagery and 220 acres in the medium imagery.

Focusing on the high resolution imagery, the annual area of deforestation was 110 acres. Deforestation was split as follows between the regions:

- 30% North Coast
- 22% North Sierra
- 36% Shasta County
- 12% South Coast

In terms of forest types deforestation was divided as follows:

- 9% Redwood
- 17% Other conifer forest
- 42% Woodland and hardwood
- 31% Urban landscapes

Housing development in rural areas tended to occur more frequently in non-forested areas. There were less than 12 instances of areas of forest that changed into housing developments (one or more streets of new houses, rather than one individual house). The majority of these areas were in the woodland category where the tree density is lower than either mixed conifer or redwood. None of these new developments occurred in the redwood category. Urban deforestation is more common but most instances are of single or few trees at one location. For example backyard trees are removed for construction of a swimming pool.

Extrapolating across the state, areas of annual deforestation for development were estimated as follows:

- 734 acres in redwood forests
- 3,081 acres in other conifer forests
- 6,994 acres in woodlands and hardwood forests

- 5,095 acres in urban landscapes

The medium resolution imagery systematically underrepresented deforestation relative to the high resolution imagery (except in two sample areas where large false deforestation areas were recorded by the medium resolution imagery) (e.g. Figure ES-3).

Figure ES-3. Example of deforestation on the same site as viewed by medium resolution imagery (yellow polygon) and high resolution imagery (red hatched polygon)

However, there was no simple correlation between deforestation area recorded in high and medium resolution imagery. Indeed in 50% of the scenes examined zero deforestation was recorded in the medium resolution imagery but an area of deforestation (up to 67 acres) was recorded in the high resolution imagery. On average, across the 28 sampling areas, the following correction factors were calculated:

- Redwood 2.2
- Other conifer forest 2.8
- Woodland and hardwood 2.1
- Urban landscapes 2.3

These results indicate that studies relying solely on medium resolution imagery are missing more than half of the deforestation that is occurring in the state.

1.0 BACKGROUND

In a poll in 2000, urban sprawl was classified, tied with crime, as the leading local concern in the US. Across the country, urban area has doubled over the past 40 years. In California during the same period there was a 252% increase in the urban area. Among regions in the US, California has the lowest current number of developed acres per capita, but the second highest population growth rate and an average income growth rate that outstrips population growth (cf Swails et al 2009). This trend in population and income growth rates makes one question if the area of development is captured correctly, thus the purpose of this project: to improve the assessment of forest conversion to development.

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown.

Assessments of deforestation for development do exist but no confident emission estimates can be paired with the estimates of rates of deforestation. In addition, deforestation is monitored using coarse scale imagery which can only poorly track the most common form of urban development - scattered development. It is therefore likely that deforestation rates are underestimated and actual emissions are entirely unknown.

A study on small-scale development also has wider implications for California beyond the direct climate change benefit:

a) The California Air Resources Board is tasked with recording emissions and sequestration across the state. The study will provide both a more precise baseline of development emissions plus factors that can be used for calculating emissions moving forward.

b) Climate change mitigation activities cannot achieve 100% success of halting global warming. Consequently, climate change will happen. This will have profound implications on development especially at the urban / wildland interface. Increased wildfires, floods, droughts and erosion are all possibilities that should be considered when weighing planning with respect to density and location of development.

One reason studies of deforestation inside urban areas and on small scales in forested areas has not happened is because it is labor and time intensive to do so. Field work is needed at the ground level, and remote sensing imagery, commonly used for such assessments, has been too coarse of a resolution to identify small to medium areas of change. Another reason has been that little is known about the emissions consequences of common urban development practices (there is little published information on the proportion of tree cover that is removed or the destination of removed biomass). In the last decade or so, remote sensing products at high resolution have appeared. These new products are being brought to the market by commercial enterprises that have developed and launched satellites to gather imagery at a much higher resolution than has been available from, for example, NASA (Landsat) and NOAA (AVHRR). Today it is possible to purchase satellite imagery with a ≤60 cm resolution, while a comparable image from the Landsat satellite is 30 meters. Therefore, the spatial aspect of this study will leverage the advances in remote sensing by using high resolution commercial imagery to investigate deforestation in Californian forests and urban areas over the course of 3 to 7 year periods (varying by location) between 2002 and 2009.

The purpose of the spatial study is to conduct an analysis of deforestation resulting from development in California. The analysis used high resolution imagery (< 1m) and moderate resolution imagery (30 m). The design sampled representative areas of CA to assess actual deforestation areas caused by development. The simultaneous analysis using the moderate resolution imagery was to determine what proportion of deforestation is not captured in the medium resolution imagery that is typically used for broad scale analyses at the state level.

2.0 STUDY LOCATIONS

Based on the desk study (Swails et al. 2009) the following areas were selected for in-depth spatial analysis of deforestation and development using remote sensing imagery:

1. **The Sierra Mountain counties of El Dorado, Placer and Nevada**
2. **The counties of Marin, Sonoma, Napa and Mendocino (north of the San Francisco Bay Area)**
3. **Los Angeles and Ventura Counties in Southern California**
4. **Shasta County in Northern California**

The selected regions represent areas experiencing specific challenges with regard to deforestation and development and cover the major forest types found in California.

The Sierra Nevada region has experienced a high rate of population growth and development in recent years. El Dorado, Nevada and Placer counties alone accounted for approximately 58% of the population increase in the Sierra region during the 1990s[1] and these counties are projected to have their populations increase by 84%, 42% and 38%, respectively, by 2020.[2]

Although much attention has been paid to the Sierra Nevada region, forested land in the San Francisco Bay area and greater Los Angeles also faces pressures from large urban populations that continue to expand. For example, proximity to the Bay area where development pressures are particularly high puts oak woodlands in Sonoma County at risk. Oak woodlands cover 40% of Sonoma county land area and are 95% privately owned. The northern section of Mendocino County was dropped from the study due to the large size of the county, the limited amount of development in that part of the county, and the desire to focus more towards pressures emanating from the Bay Metro Area.

Extensive urban development in the Los Angeles area has left very little privately owned forest land. However, tree cover and ongoing canopy reduction in urban and suburban areas may not be well captured by the most widely available satellite imagery.

Shasta County has large areas of forest land and may face development and deforestation pressures similar to those of the Sierra Nevada. Further study of this area will help to identify differences in the impacts of development in the Sierra and Cascade regions.

The location of the four regions together with the land cover in 2000 is shown in Figure 1.

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[1] Hickey 2005
[2] ibid

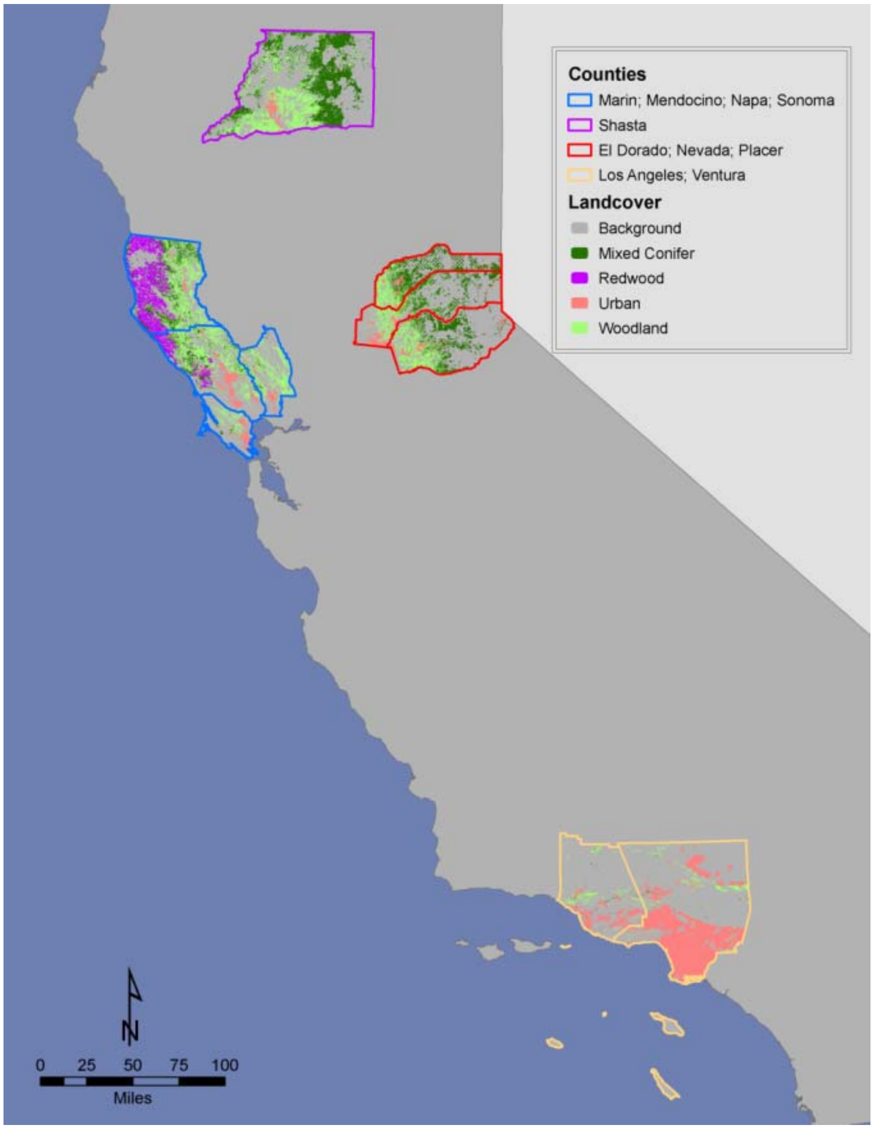


Figure 1. Map of sites for in-depth study. The land cover data are from the Multi-source Land Cover Dataset v02_2 (FVEG) originating from the California Department of Forestry and Fire Protection (CDF-FRAP)

The selection of the specific locations for remote sensing imagery analysis was made based on image availability and coverage of regions and forest type categories. A total of 28 sampling sites were selected as follows: with 3 for redwoods, 9 for mixed conifer, 8 for woodland, and 8 for urban landscapes; regionally 9 sites in the North Coast, 6 in Shasta, 7 in the North Sierra and 6 in the South Coast (Grimland et al 2009).

The relative cover of landscape types in the four regions is given in Table 1, together with the area sampled.

Table 1. Area of land cover for each landscape category for each of the four target regions

LOCATION	LANDCOVER	SAMPLING ACRES	REGION ACRES
North Coast	Mixed Conifer	8,454	265,664
	Redwood	14,086	420,342
	Urban	8,359	154,393
	Woodland	11,807	753,701
North Coast Total		42,708	1,594,102
North Sierra Nevada	Mixed Conifer	14,197	531,407
	Redwood	0	0
	Urban	4,347	108,947
	Woodland	13,113	374,501
North Sierra Nevada Total		31,658	1,014,857
Shasta	Mixed Conifer	8,719	593,277
	Redwood	0	0
	Urban	5,813	40,563
	Woodland	13,245	417,476
Shasta Total		27,778	1,051,316
South Coast	Mixed Conifer	65	13,152
	Redwood	0	0
	Urban	10,508	896,347
	Woodland	10,911	114,295
South Coast Total		21,484	1,023,794
Grand Total		123,629	4,684,071

The four regions with the specific high resolution sample locations (hatched boxes) are shown in Figures 2, 3, 4 and 5.

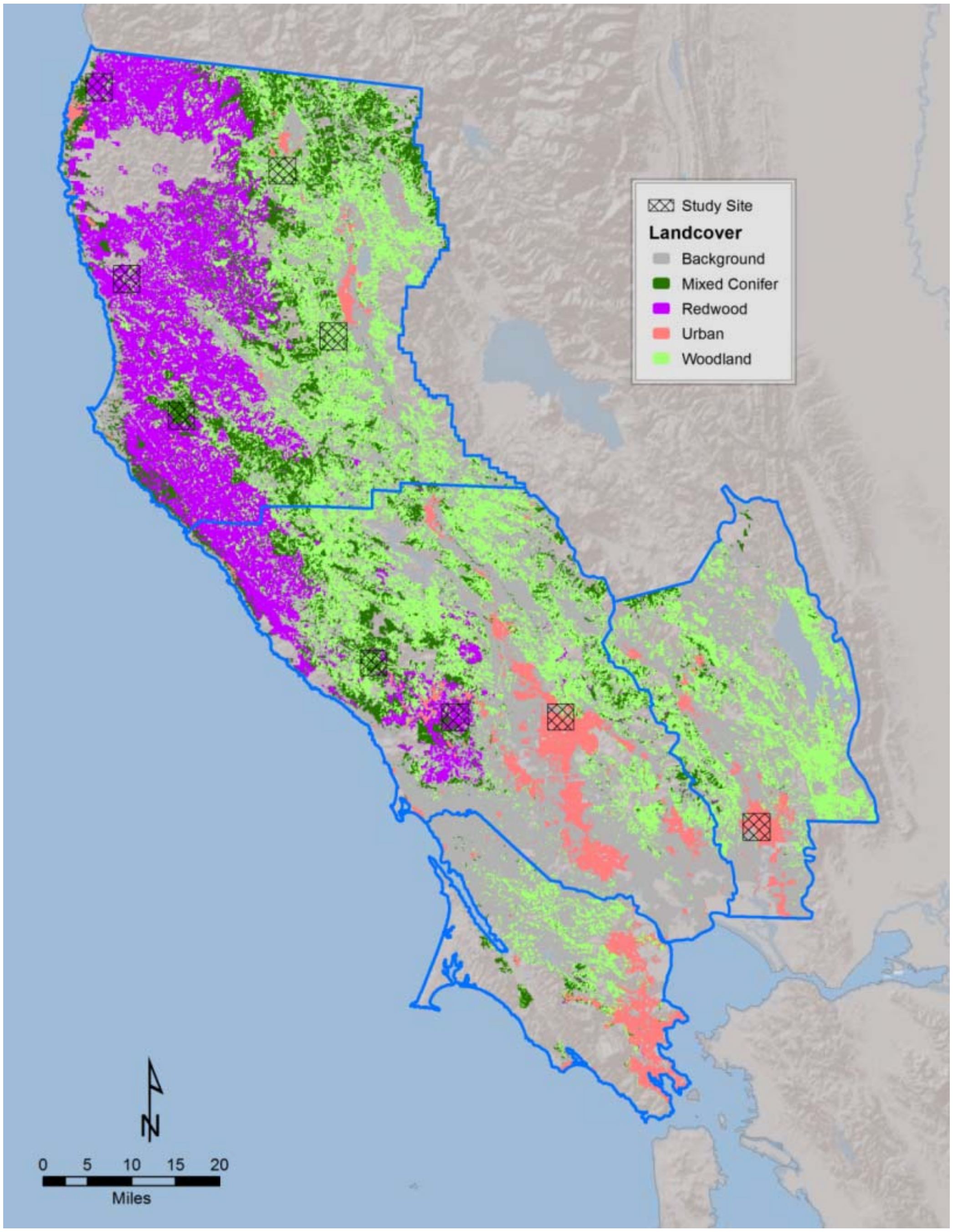


Figure 2. The North Coast target area with land cover and study site locations.

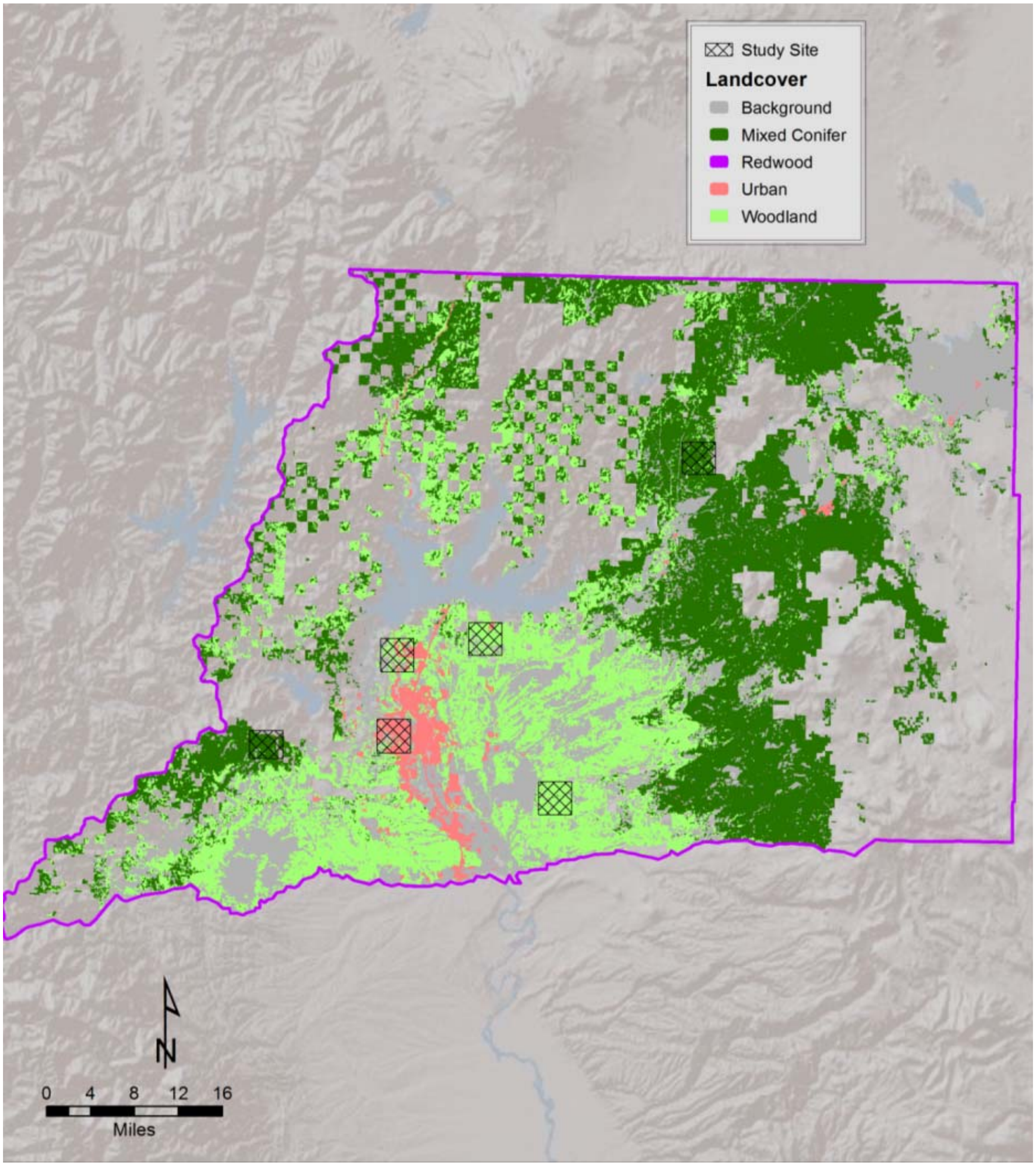


Figure 3. The Shasta target area with land cover and study site locations.

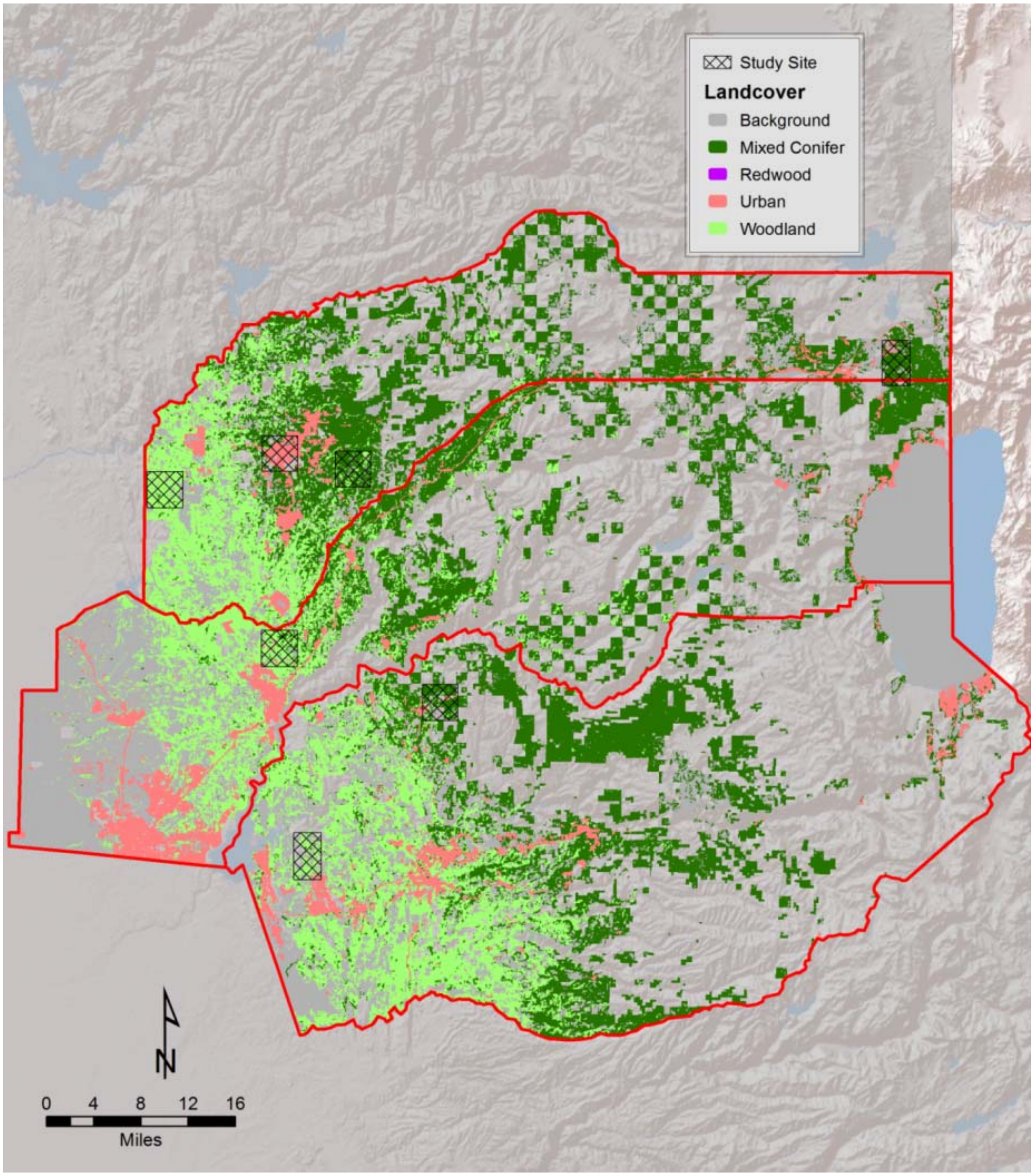


Figure 4. The North Sierra Nevada target area with land cover and study site locations.

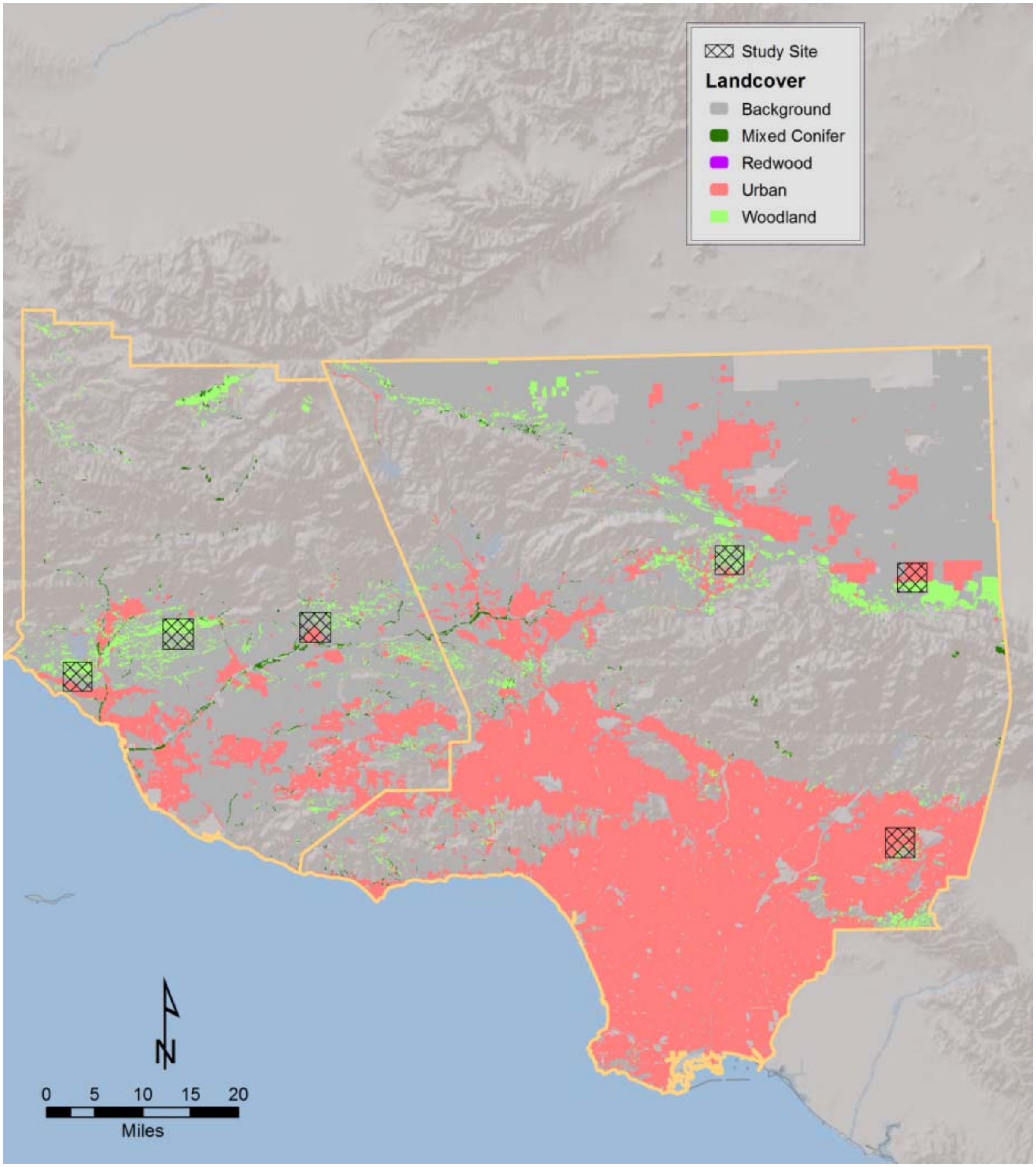


Figure 5. The South Coast target area with land cover and study site locations.

The details of the high resolution imagery sample sites are listed with the image dates and the land cover at the start of the analysis period In Table 2. The date for the second image is relatively consistent within a region (2007-2009), but the date for the first image is somewhat more variable within a region, spanning for example from 2002 to 2005 in the North Coast Region. Overall, the time difference between the two images spanned between 3 and 7 years.

Table 2. High resolution sample sites with location, dates for the imagery, and forest cover. Ineligible areas include public lands, agriculture, water and other non-forested land use types (see Annex 2)

Sample Location	REGION	COUNTY	First Image Date	Second Image Date	Redwood	Mixed Conifer	Woodland	Urban	*Ineligible*
1	North Coast	Mendocino	2002	2009	**69%**	5%	5%	0%	*22%*
2	North Coast	Mendocino	2003	2009	**73%**	1%	14%	0%	*12%*
3	North Coast	Mendocino	2004	2009	26%	**56%**	11%	0%	*6%*
4	North Coast	Mendocino	2003	2009	0%	13%	**55%**	0%	*31%*
5	North Coast	Mendocino	2003	2009	0%	12%	**63%**	0%	*25%*
6	North Coast	Sonoma	2005	2009	10%	**46%**	36%	0%	*8%*
7	North Coast	Sonoma	2004	2008	**68%**	14%	10%	1%	*7%*
8	North Coast	Sonoma	2004	2009	0%	0%	10%	**71%**	*19%*
9	North Coast	Napa	2004	2009	0%	0%	3%	**77%**	*20%*
10	Shasta	Shasta	2004	2008	0%	**94%**	3%	0%	*3%*
11	Shasta	Shasta	2003	2008	0%	1%	**49%**	28%	*22%*
12	Shasta	Shasta	2003	2008	0%	0%	11%	**78%**	*11%*
13	Shasta	Shasta	2003	2009	0%	0%	**92%**	0%	*7%*
14	Shasta	Shasta	2003	2009	0%	0%	**77%**	3%	*20%*
15	Shasta	Shasta	2003	2009	0%	**90%**	6%	0%	*4%*
16	North Sierra	Nevada	2003	2009	0%	2%	**84%**	0%	*14%*
17	North Sierra	Placer	2006	2009	0%	14%	**68%**	5%	*14%*
18	North Sierra	Placer	2004	2007	0%	**76%**	0%	7%	*17%*
19	North Sierra	Nevada	2003	2009	0%	21%	3%	**63%**	*13%*
20	North Sierra	Nevada	2000	2008	0%	**75%**	16%	0%	*9%*
21	North Sierra	El Dorado	2004	2009	0%	**76%**	9%	5%	*10%*
22	North Sierra	El Dorado	2004	2009	0%	2%	**50%**	4%	*44%*
23	South Coast	Ventura	2004	2009	0%	0%	**43%**	15%	*42%*
24	South Coast	Ventura	2003	2008	0%	1%	12%	22%	*65%*
25	South Coast	Los Angeles	2003	2009	0%	0%	**54%**	0%	*46%*
26	South Coast	Los Angeles	2005	2008	0%	0%	28%	**53%**	*19%*
27	South Coast	Los Angeles	2003	2009	0%	0%	**38%**	8%	*54%*
28	South Coast	Los Angeles	2004	2008	0%	0%	8%	**82%**	*9%*

4.0 METHODS FOR ANALYSIS

Change detection is a quantifiable difference in land cover characteristics, beyond normal variations that occur during seasons. This analysis looked for changes at each sample site in land cover between two dates spanning between 3 and 7 years (Table 2). The satellite images were from approximately the same time of the year, the difference in dates for any sample site never was greater than three weeks, and most were within a few days. This helped to minimize seasonal variations. The land cover classification was a combination of vegetation indices, visual interpretation and *a priori* knowledge.

The first step in change detection involves creating an NDVI, a normalized difference vegetation index, for each time period. A pair wise comparison of the NDVI images at the two time periods was conducted for qualitative change detection. The result contained categorical differences between the two time periods by area and direction. Areas of significant vegetation loss, that is values of 2 negative standard deviations or smaller, were extracted. The change areas were then filtered using a Gaussian algorithm to smooth out noise and sharpen edges. Only areas greater than 0.1 acre were retained. The minimum area cutoff maintained efficiency in the classification and filtered out changes that did not involve tree removal. Only changes occurring on privately owned lands were included in this analysis; public land, military land, protected areas and other government maintained lands were excluded from the study.

For the high resolution imagery, the areas of change were overlain on the original image and evaluated to identify false changes and removed them from the study (Figure 6). False changes mainly occurred along water bodies (stock tanks and ponds), at artificially irrigated areas such as football and baseball fields or commercially landscaped properties, and in green spaces along highways. The Landsat imagery was too coarse to visually interpret changes in the same way. A proxy method was developed to identify whether changes within the Landsat images were significant using the Wildland Urban Interface dataset (see below).

Two vital datasets released by the state of California were used in this analysis, the Development Footprint (DEVELOP05_1) and the Multi-source Land Cover Data v02_2 (FVEG), both originating from the California Department of Forestry and Fire Protection (CDF-FRAP). More information about how FVEG was used in the study can be found in Grimland et al (2009). The Development Footprint data contain several interesting attributes that were useful to this analysis. The dataset was created by CDF-FRAP to spatially define the development footprint of California.

Figure 6. An example of areas of deforestation as recorded in the high resolution imagery

For areas in the imagery that may be recently deforested, it is not always possible to confirm that deforestation is for the purpose of development rather than another use. for example, a clear cut in a forest under management. To cover this eventuality we used the Development Footprint dataset. The attribute chosen in the dataset was the Wildland Urban Interface (WUI_DENS20). The term “Wildland Urban Interface” (WUI) is used in land cover assessments to describe the area where urbanized lands and undeveloped lands meet. The CDF-FRAP Wildland Urban Interface dataset has four categories, each with a progressively greater development intensity (Table 3). The point of incorporating the WUI into the analysis was as a proxy for the Landsat images for visual interpretation and as an overall aid to understand the drivers of deforestation.

Table 3. The wildland urban interface categories (WUI)

WUI_Value	WUI_Definition
1	Less than 1 housing unit per 20 acres (DEVELOP10 classes 1, 2, 3, 4, 24, or 86)
2	1 or more housing units per 20 acres to 1 housing unit per 5 acres (DEVELOP10 classes 5 or 6)
3	1 or more housing units per 5 acres to 1 housing unit per 1 acre (DEVELOP10 class 7)
4	1 or more housing units per 1 acre

The following assumptions were made:

- If change occurred in the lowest density category (the least dense in terms of population) – WUI 1 – for the redwood and mixed conifer land cover types then:
    - Where the change is >5 acre then it is assumed to be forest management rather than deforestation for development;
    - Where the change is ≤5 acre then it is assumed deforestation occurred for development purposes.
- If change occurs in the one of the other three WUI categories, or in WUI category 1 areas in the urban or woodland land use type then it is assumed deforestation for development occurred.

During quality control, where areas were identifiable as forest management then the identified areas were removed from further analysis of deforestation for development.

5.0 ANALYSIS RESULTS

The FVEG land cover data used for this study is composed of four land use types (Mixed Conifer, Redwood, Urban, and Woodland) that cover over 17 million acres across the state of California (17% of the State; 52% of the forest in the State). Woodland accounts for 40% of that total. The WUI data also contains four levels of housing density, with WUI 1, the least dense category, covering 84% of the state. The majority of the areas for Mixed Conifer, Redwood, and Woodland categories are within the WUI 1 category. The Urban land cover is mostly located within the densest housing category, WUI 4. Statewide, 37% of the total loss of forested land occurred in the Woodland category, and 59% of the total loss was in the WUI 1 class.

5.1 Excluded areas

As discussed in Section 4.0 the following areas were excluded from the analysis even if apparent deforestation was recorded:

1. Areas of public land, military land, protected areas and other government maintained lands;
2. Areas of deforestation that were clearly identifiable as forest management rather than permanent deforestation; and
3. Areas of deforestation of redwood and mixed conifer of more than 5 acres in the North Coast, North Sierra and Shasta County regions that occurred in the least developed wildland urban interface category.

The total excluded area of deforestation of private lands (excluding numbers 1 and 2 above) was 229 acres in the high resolution imagery and 377 acres in the Landsat imagery (Table 4). Eighty-five percent of the area excluded in the high resolution imagery and 89% of the area excluded from the landsat imagery occurred in just one of the 28 sampling locations. In this sampling location (#15) in Shasta County clearly identifiable forest management was visible.

Table 4. Excluded areas of deforestation as recorded in the high resolution imagery.

Region	Forest Type	Excluded Area	
		High Resolution Imagery	*Landsat Imagery*
		Acres	
North Coast	Redwood	26.8	12.7
	Mixed Conifer	6.6	29.3
Shasta	Mixed Conifer	195.5	335.5

5.2 High Resolution Imagery

A total of 2,343 instances of deforestation were recorded with a total area of 568 acres – equivalent to 110 acres of deforestation per year between the sampling dates (Table 5). Area of tree loss ranged from 58 acres in the South Coast region (from 21,485 eligible sampled acres) to 219 acres in Shasta (from 27,778 eligible sampled acres) (Table 5). Average area of deforestation per instance was 0.24 acres, with the highest average (0.28 acres) in Shasta County and lowest in the South Coast region (0.19 acres). Annual deforestation as a percentage of total forested area in each region ranged from 0.06% in the South Coast to 0.14% in Shasta County.

Table 5. Deforestation based on interpretation of the high resolution imagery by the four study regions.

	Instances of Deforestation Recorded	Instances per acre	Total Area of Deforestation	Annual Area of Deforestation	Average Area of Deforestation per Instance	Annual Deforestation area as % of total forested area
			Acres	*Acres*	*Acres*	
North Coast	713	0.017	167.4	33.6	0.23	0.08%
North Sierra	558	0.018	124.2	24.2	0.22	0.08%
Shasta	774	0.028	218.5	39.5	0.28	0.14%
South Coast	298	0.014	57.5	12.9	0.19	0.06%

5.2.1 North Coast

In this region, there were a total of 713 instances of deforestation recorded in the high resolution imagery for a total of 167 acres (Table 6). The summed annual deforestation accounts for less than a tenth of a percent of the available privately owned forests in the region. Out of the area deforested, the urban landscape experienced the most change (accounting for 31% of the area of change in the region) followed closely by the redwoods and mixed conifer categories. Annual deforestation as a percentage of total forested area across the sampled units ranged from just 0.03% in the woodland category to 0.12% in the urban category.

Table 6. Deforestation based on interpretation of the high resolution imagery for the North Coast region by landscape type

		Instances of Deforestation Recorded	Instances per acre	Total Area of Deforestation	Annual Area of Deforestation	Average Area of Deforestation per Instance	Annual Deforestation area as % of total forested area
				Acres	*Acres*	*Acres*	
North Coast	Mixed Conifer	129	0.015	45.78	9.18	0.35	0.11%
	Redwood	161	0.011	49.78	10.25	0.31	0.07%
	Urban	321	0.038	51.74	10.35	0.16	0.12%
	Woodland	102	0.009	20.07	3.85	0.20	0.03%

The North Coast contains all of the Redwood land use type. In total, 50 acres of change were detected in the Redwood locations (an example of deforestation in the redwood category is included in Figure 7).

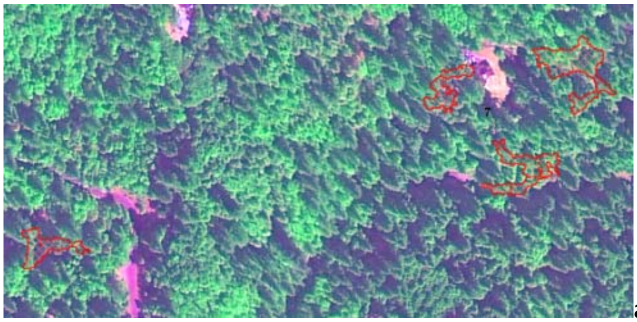
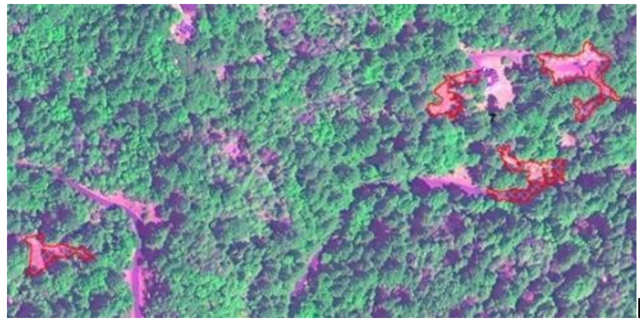

a.

b.

Figure 7. Sampling area 7, Sonoma county 2004(a) and 2008(b) showing changes in redwoods (totaling 0.79 acres).

5.2.2 Shasta

The Shasta county region showed a total of 219 acres of change across 774 instances. This was equivalent to 40 acres per year. Less than 0.5% of this annual deforestation was in mixed conifer forest while 67% was in woodlands and 33% in urban landscapes (Figure 8, Table 7). The deforestation rate on an annual basis was just 0.2% for woodlands and urban landscapes and practically zero for mixed conifer. Mixed conifer in this region, however, included significant areas of commercial forest management. Management was recorded in just one of the 6 sampling units (#15) in the county but in this one sampling unit 195 acres of tree cover loss was recorded.


a.

b.

Figure 8. Sampling area 12, Shasta county 2003 (a) and 2008 (b) showing changes in urban and woodland categories (total of 13.45 acres).

Table 7. Deforestation based on interpretation of the high resolution imagery for Shasta County by landscape type

		Instances of Deforestation Recorded	Instances per acre	Total Area of Deforestation	Annual Area of Deforestation	Average Area of Deforestation per Instance	Annual Deforestation area as % of total forested area
				Acres	*Acres*	*Acres*	
Shasta	Redwood	n/a	n/a	n/a	n/a	n/a	n/a
	Mixed Conifer	8	0.001	0.99	0.18	0.12	0.00%
	Urban	293	0.050	68.31	12.94	0.23	0.22%
	Woodland	473	0.036	149.21	26.40	0.32	0.20%

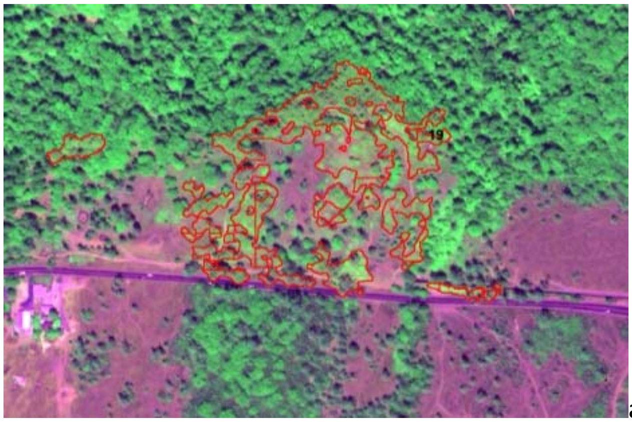
5.2.3 North Sierra Nevada

This region encompassed three counties surrounding the Lake Tahoe area. The region lost more Woodland than any other landcover category, 63 acres (Table 8). The Mixed Conifer category lost 44 acres and the Urban category lost 17 acres. The annual deforestation as a proportion of the eligible area for deforestation for all three landscape types is: 0.06% for mixed conifer, 0.07% for urban, and 0.10% for woodlands.

Table 8. Deforestation based on interpretation of the high resolution imagery for the North Sierra region, by landscape type.

		Instances of Deforestation Recorded	Instances per acre	Total Area of Deforestation	Annual Area of Deforestation	Average Area of Deforestation per Instance	Annual Deforestation area as % of total forested area
				Acres	*Acres*	*Acres*	
North Sierra	Redwood						
	Mixed Conifer	205	0.014	44.14	8.33	0.22	0.06%
	Urban	95	0.022	16.82	3.14	0.18	0.07%
	Woodland	258	0.020	63.21	12.58	0.25	0.10%

In Figure 9 is displayed an example of deforestation in woodland and mixed conifer forests in the North Sierra region .


a.

b.

Figure 9. Sampling area 19, Nevada county, 2003(a) and 2009(b) showing changes in mixed conifer and woodland forests (total of 6.4 acres).

5.2.4 South Coast

This region encompassed the Los Angeles metro area including the counties of Los Angeles and Ventura. This region is dominated by the Urban landscape. Across the six high resolution sampling units, 57 acres of change were recorded (Table 9). Eighty-nine percent of the changes were found to have occurred in the Urban and Woodland landscapes. The annual deforestation was equivalent to 2% of the eligible area for mixed conifer, 0.08% for urban and 0.03% for woodlands.

Table 9. Deforestation based on interpretation of the high resolution imagery for the South Coast region by landscape type

		Instances of Deforestation Recorded	Instances per acre	Total Area of Deforestation	Annual Area of Deforestation	Average Area of Deforestation per Instance	Annual Deforestation area as % of total forested area
				Acres	*Acres*	*Acres*	
South Coast	Redwood						
	Mixed Conifer	3	0.046	6.59	1.32	2.20	2.04%
	Urban	214	0.020	34.47	8.20	0.16	0.08%
	Woodland	81	0.007	16.43	3.36	0.20	0.03%

The change detection method worked very well in the Urban settings of the South Coast region for both large areas (Figure 10) and small areas (Figure 11) of tree cover loss. Individual trees that were removed were identified consistently. Several instances were noted where a tree was removed from a private property and replaced with a swimming pool.

a.

b.

Figure 10. Sampling area 24, Ventura county 2003(a) and 2008(b) showing changes in mixed conifer (rectangular polygon on left) and woodland (right polygon) (totals 7.8 acres).


a.


b.

Figure 11. Sampling area 24, Ventura county 2003(a) and 2008(b) showing changes in the Urban landscape (totals 0.35 acres).

5.3 Landsat imagery

When Landsat imagery is used in the identical sampling units as the high resolution imagery over the identical time periods, a total of 220 acres of deforestation are recorded divided among 176 different areas of deforestation (Table 10). Fifty-nine percent of the deforested area was in the South Coast, 36% in the North Coast region, and a combined 6% in the North Sierra and Shasta country regions (a total of just 5 instances in North Sierra and 11 instances in Shasta County). The average area of deforestation in each recorded instance was 1.25 acres based on the landsat imagery but ranged from 0.65 acres in Shasta County to 1.46 acres in the North Coast region.

Table 10. Deforestation based on interpretation of the Landsat imagery by region.

	Instances of Deforestation Recorded	Instances per acre	Total Area of Deforestation	Annual Area of Deforestation	Average Area of Deforestation per Instance	Annual Deforestation as % of Total Forested Area
			Acres	*Acres*	*Acres*	
North Coast	62	0.001	90.65	17.01	1.46	0.04%
North Sierra	5	0.000	7.09	1.28	1.42	0.004%
Shasta	11	0.000	7.15	1.30	0.65	0.005%
South Coast	98	0.005	115.52	27.94	1.18	0.13%

In the Landsat imagery analysis, 70% of the instances of deforestation and 77% of the recorded annual deforestation were in the urban and woodland landscapes (Table 11). Mixed conifer forests accounted for just 14% of the annual deforestation area despite accounting for 25% of the eligible forest area. In contrast, urban accounted for 23% of the eligible area but 31% of the recorded annual deforestation area. However, no deforestation in urban areas was recorded in the Landsat imagery for the North Coast region, and just three instances totaling 3.1 acres were recorded for the Shasta County and the North Sierra region combined. Therefore, 96% of the instances of deforestation and annual area of deforestation (58 acres) in urban areas occurred just in the South Coast region.

Table 11. Deforestation, by forest type and region, estimated by interpretation of the Landsat imagery

		Instances of Deforestation Recorded	Instances per acre per year	Total Area of Deforestation	Average Area of Deforestation per Instance	Annual Area of Deforestation	Annual deforested area as % of total forested area
				Acres	*Acres*	*Acres*	
North Coast	Redwood	25	0.002	22.52	0.94	4.57	0.03%
	Mixed Conifer	23	0.003	27.66	1.20	5.49	0.06%
	Urban	0	0.000	0.00	0.00	0.00	0.00%
	Woodland	15	0.001	40.47	2.70	6.95	0.06%
Shasta	Redwood	n/a	n/a	n/a	n/a	n/a	n/a
	Mixed Conifer	0	0.000	0.00	0.00	0.00	0.00%
	Urban	2	0.000	2.25	1.12	0.45	0.01%
	Woodland	9	0.001	4.90	0.54	0.85	0.01%
North Sierra	Redwood	n/a	n/a	n/a	n/a	n/a	n/a
	Mixed Conifer	1	0.000	1.21	1.21	0.20	0.00%
	Urban	1	0.000	0.89	0.89	0.15	0.00%
	Woodland	3	0.000	4.99	1.66	2.21	0.02%
South Coast	Redwood	n/a	n/a	n/a	n/a	n/a	n/a
	Mixed Conifer	4	0.062	5.23	1.31	1.05	1.62%
	Urban	64	0.006	58.03	0.91	14.35	0.14%
	Woodland	30	0.003	52.26	1.74	12.55	0.12%

5.4 Comparison between high resolution and Landsat results

Across the 28 sampling units the high resolution imagery captured a total area of deforestation of 568 acres while the Landsat imagery captured only 220 acres, or less than half as much. Identical dates and areas were examined but the Landsat imagery missed 61% of the deforestation that occurred (Table 12). However, the underestimation was not consistent. In 14% of the sampling units (4 units) the Landsat imagery recorded a higher area of deforestation (between 2 and 8 times higher – average 4.4 times higher). In 82% of the sampling units an underestimation occured. In exactly half the sampling units the Landsat imagery was unable to record any area of deforestation while deforestation was recorded in the high resolution imagery; this missed deforestation ranged between 1 acre and 67 acres and averaged 21 acres.

Table 12. Comparison of area of deforestation for each sampling unit based on interpretation of high resolution imagery and the Landsat imagery.

Location	Sampling Unit	Area of deforestation recorded (acres) High Resolution Imagery	Landsat Imagery	Difference
North Coast	1	0.1	0.8	-0.7
North Coast	2	9.2	0.1	9.1
North Coast	3	74.4	48.4	26
North Coast	4	2.9	6	-3.1
North Coast	5	8.9	31.7	-22.8
North Coast	6	2.7	0	2.7
North Coast	7	14.7	3.6	11.1
North Coast	8	19	0	19
North Coast	9	35.4	0	35.4
Shasta	10	0	0	0
Shasta	11	51	2.2	48.8
Shasta	12	42	0.9	41.1
Shasta	13	51.4	0	51.4
Shasta	14	66.6	0	66.6
Shasta	15	7.6	4	3.6
North Sierra Nevada	16	31.9	0	31.9
North Sierra Nevada	17	14.7	0	14.7
North Sierra Nevada	18	8.1	0	8.1
North Sierra Nevada	19	23.2	4.2	19
North Sierra Nevada	20	26.5	0	26.5
North Sierra Nevada	21	5	0	5
North Sierra Nevada	22	14.7	2.9	11.8
South Coast	23	1	0	1
South Coast	24	20.9	18.7	2.2
South Coast	25	1.9	0	1.9
South Coast	26	3.3	0	3.3
South Coast	27	6.3	0	6.3
South Coast	28	24.1	96.8	-72.7

Examining the regions separately, the Landsat imagery underestimated deforestation in three regions and overestimated in the South Coast (Table 13). The underestimation was greatest in the North Sierra and Shasta County regions where only about 5% of deforestation was captured. In the South Coast twice as much deforestation was recorded in the landsat as in high resolution imagery (although this was exclusively in one sampling image - #28). The average size of deforested areas was 0.25 acres in the high resolution imagery while in the landsat imagery the average size was 1.25 acres (associated with the large pixel size in landsat not allowing identification of any small areas of deforestation).

Table 13. Comparison between deforestation, by region, recorded in high resolution imagery with that in the landsat imagery.

	High Resolution Imagery			Landsat Imagery		
	Instances of Deforestation	Deforested Area	Average Deforested Area	Instances of Deforestation	Deforested Area	Average Deforested Area
	#	*Acres*	*Acres*	*#*	*Acres*	*Acres*
North Coast	713	167.37	0.23	62	90.65	1.46
North Sierra	558	124.17	0.22	5	7.09	1.42
Shasta	774	218.50	0.28	11	7.15	0.65
South Coast	298	57.49	0.19	98	115.52	1.18

The differences in the area deforested estimated by the two different sensors is caused by variations in the amount of tree removed in each instance. About half of the locations were completely deforested while the rest contained standing trees that in some locations accounted for a significant percent of canopy cover. In these locations with left trees, the Landsat imagery shows no significant changes (changes did not meet the cut off threshold of two negative standard deviations from the mean) while the high resolution imagery can pick out the individual trees removed. This is illustrated by the example in Figure 12. The yellow block represents the area deforested as interpreted in both the Landsat and high resolution images for the same area in the North Sierra Nevada region. In the high resolution imagery additional areas of deforestation are recorded surrounding and even some distance from the core area.

Figure 12. Sampling area 19, North Sierra Nevada region, changes detected in both high resolution (red 6.4 acres) and Landsat (yellow 3.3 acres).

Only two of the 28 sample sites recorded significantly higher deforestation in the Landsat imagery than in the high resolution imagery. In sampling unit 5 in the North Coast region, Landsat recorded 31.7 acres and the high resolution imagery recorded just 8.9 acres. The entire area of change is in a single location (Figure 13) and appears to be an area that was fire damaged. The fire appears to be have been a grass fire as trees remain. The Landsat imagery picks up a much larger area of change than the high resolution imagery likely indicating areas that went from live grass to dead burned grass.

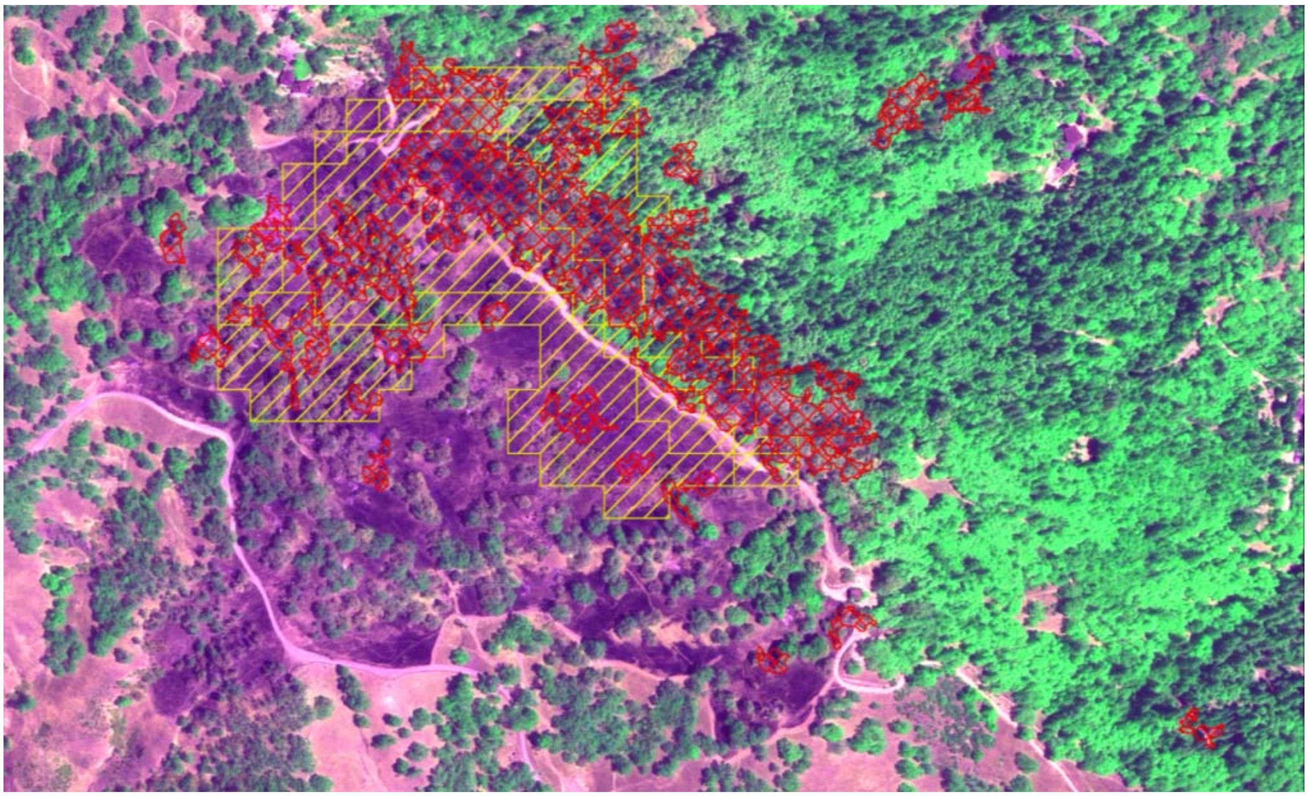


Figure 13. Deforestation as identified by Landsat (yellow polygons) and high resolution imagery (red polygons) in sampling unit 5 in the North Coast region

The second area is sampling unit 28 in the South Coast region. Here the Landsat imagery recorded an area of 97 acres of deforestation (84% of all Landsat-recorded deforestation in the South Coast region) while only 24 acres were recorded by the high resolution imagery. Examples of changes recorded in sampling area 28 are shown in Figure 14. The Landsat changes are predominantly false; changes are shown which meets the change threshold, but the land cover remains the same.

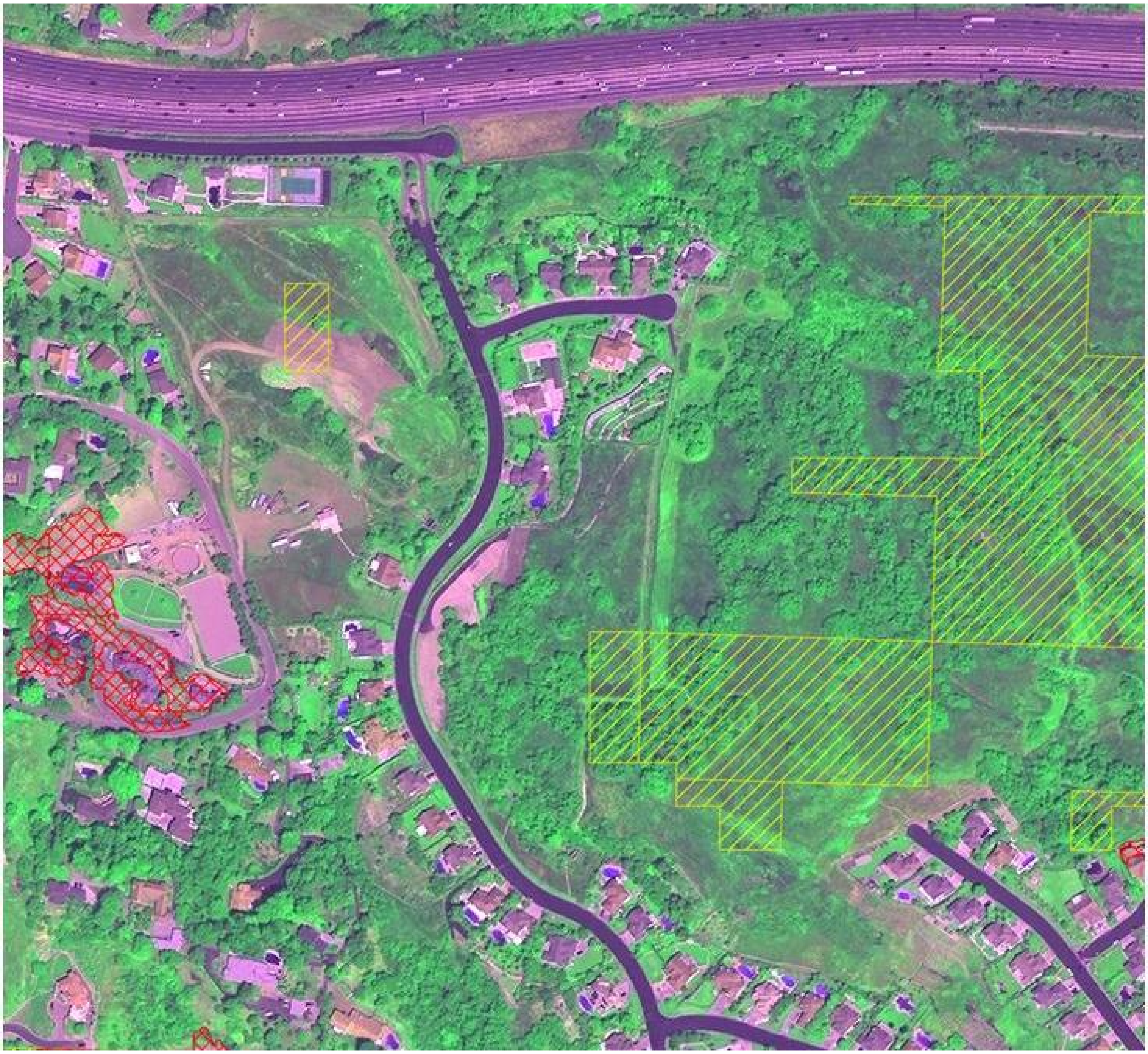


Figure 14. Deforestation as identified by Landsat (yellow polygons) and high resolution imagery (red polygons) in sampling unit 28 in the South Coast region

5.5 Extrapolation of results

5.5.1 Extrapolation to the complete region levels

The sampled areas represent between 0.5% (mixed conifer in the south coast) to 14% (urban landscapes in the Sierra Nevada region) of the total eligible areas in the represented regions, with an average of 4% (Table 14). Using these proportions to scale up gives the following total estimated annual areas of deforestation:

North Coast: 1,031 acres/year

Shasta County: 1,085 acres/year

North Sierra: 985 acres/year

South Coast: 1,002 acres/year

If the results from the landsat analysis were used instead of those from the high resolution imagery the totals would be:

North Coast: 752 acres/year

Shasta County: 35 acres/year

North Sierra: 84 acres/year

South Coast: 1,568 acres/year

Table 14. Extrapolation of the deforestation sampling results to the full region level (acres of deforestation per year)

				Annual area of deforestation (acres/yr)			
				Sampled		Extrapolated Across Region	
		Sampled Acres	Total Acres	High resolution	Landsat	High resolution	Landsat
North Coast	Mixed Conifer	8,455	265,665	9.18	5.49	288.6	172.4
	Redwood	14,086	420,342	10.25	4.57	305.8	136.3
	Urban	8,360	154,394	10.35	0.00	191.1	0.0
	Woodland	11,807	753,702	3.85	6.95	245.9	443.6
Shasta	Mixed Conifer	14,198	531,408	0.18	0.00	6.7	0.0
	Redwood	0	0	n/a	n/a	n/a	n/a
	Urban	4,348	108,948	12.94	0.45	324.2	11.3
	Woodland	13,113	374,501	26.40	0.85	753.9	24.1
North Sierra	Mixed Conifer	8,719	593,277	8.33	0.20	567.0	13.8
	Redwood	0	0	n/a	n/a	n/a	n/a
	Urban	5,814	40,563	3.14	0.15	21.9	1.0
	Woodland	13,245	417,476	12.58	2.21	396.5	69.6
South Coast	Mixed Conifer	65	13,152	1.32	1.05	268.2	212.9
	Redwood	0	0	n/a	n/a	n/a	n/a
	Urban	10,509	896,347	8.20	14.35	699.2	1223.9
	Woodland	10,911	114,295	3.36	12.55	35.2	131.5

Focusing on the high resolution results only shows that the highest deforestation occurred in the woodland landscape in Shasta County (754 acres/yr) followed by the urban landscapes in the South Coast (699 acres/year). The lowest deforestation occurred in the mixed conifer landscape in Shasta County (6.7 acres/year) followed by the urban landscapes in North Sierra (22 acres/year).

5.5.2 Extrapolation to the state level

Extrapolating the results for the four landscapes to the state level gives a total eligible area of 17.7 million acres or 18% of the total state area. The sampled area represents 0.7% of the total eligible area with redwood as the highest proportion (1.4%) and mixed conifer the lowest proportion (0.6)(Table 15). Extrapolation of the results to the state level gives an estimate of total annual deforestation of 15,904 acres/year across the four landscape types, with 3,081 ac/yr from mixed conifer, 734 ac/yr from redwood, 5,095 ac/yr from urban and 6,994 ac/yr from woodlands. If only Landsat imagery was used, the total estimated deforestation would be 7,044 acres or just 44% of the total estimated using the high resolution imagery.

Table 15. Extrapolation of sampled results to the state level (all values in acres or acres/year) for the approximate period 2002 to 2009.

			Annual area of deforestation			
			Sampled		Extrapolated	
	Sampled Area	Total State Area	High resolution	Landsat	High resolution	Landsat
Mixed Conifer	31,436	5,094,834	19.01	6.74	3,081	1,092
Redwood	14,086	1,009,182	10.25	4.57	734	327
Urban	49,077	7,222,231	34.62	14.95	5,095	2,200
Woodland	29,030	4,395,667	46.19	22.55	6,994	3,415
TOTAL	123,629	17,721,914	110.07	48.81	15,904	7,034

Additional sampling would be needed to further refine and develop higher confidence in the results. Sampling of between 5 and 10% of the eligible area would an ideal scheme.

5.6 Re-evaluation of the approach

The change detection method did well in capturing the area changes. It was better at capturing change in the areas where the forest canopy was dense. It was difficult to capture a large continuous area of change with the high resolution imagery. One reason that areas do not show large contiguous deforestation, i.e. > 5 acres, is because the high resolution imagery can delineate the individual trees, therefore open areas between trees are not counted as deforestation which may be the case in coarser imagery. Because the woodland category is so sparse, a new house can be built with only a couple of trees removed. This process of using high resolution imagery may even tend to undercount the deforestation in these situations as single tree canopies that are removed can have areas less than 0.1 acre. It was important though to maintain a cutoff threshold so as to maintain efficiency in the classification and to filter out changes where a single tree was removed or fell either through mortality or landowner decisions.

Locations of commercial logging in a more open forest area were not captured well in the change detection method due to shadows among the trees. Shadows provided a gradient between vegetation and non-vegetation values in the satellite image. This reduced the expected stark change in pixel values after a tree is removed. A future modification in the process could increase the efficiency of change detection by aggregating near change polygons into large continuous areas of change.

False changes are more common in the Urban land cover class. False changes occurred along water bodies (stock tanks and ponds), at artificially irrigated areas such as football and baseball fields, at commercially landscaped properties, and in green spaces along highways. False changes were easy to detect in Urban areas because the size of change is very small, from 0.1 to 0.8 acres. A large change, 5 acres or greater, is more likely to be a false change when set in the Urban land cover type than a 5 acre change in a Woodland location.

The steps for change detection developed for this study have been proven to detect changes using both high resolution imagery and coarser Landsat imagery in either forested or urban areas. The limit to the usage of high resolution imagery in change detection is the difficulty to capture large continuous areas of deforestation specifically in open canopy situations. The high resolution tends to capture very distinct changes better than broad areas. Landsat resolution images could not capture small-scale deforestation especially relevant to urban tree changes.

6.0 A METHOD TO CORRELATE HIGH WITH MEDIUM RESOLUTION RESULTS?

The study has revealed a systematic underrepresentation of deforestation when medium-scale imagery (such as Landsat) is used. Clearly medium-scale imagery is the most commonly used method for sampling of deforestation at broad-scales such as across states. Ideally therefore there would be a correction available to account for the proportion of small scale deforestation that is missed by the medium-scale imagery.

However, no simple relationship exists. In Figure 15 it can be seen that there is no relationship between area of deforestation recorded by Landsat and by high resolution imagery and divergence from a one-to-one relationship cannot systematically be predicted even when areas are divided by region or forest type.

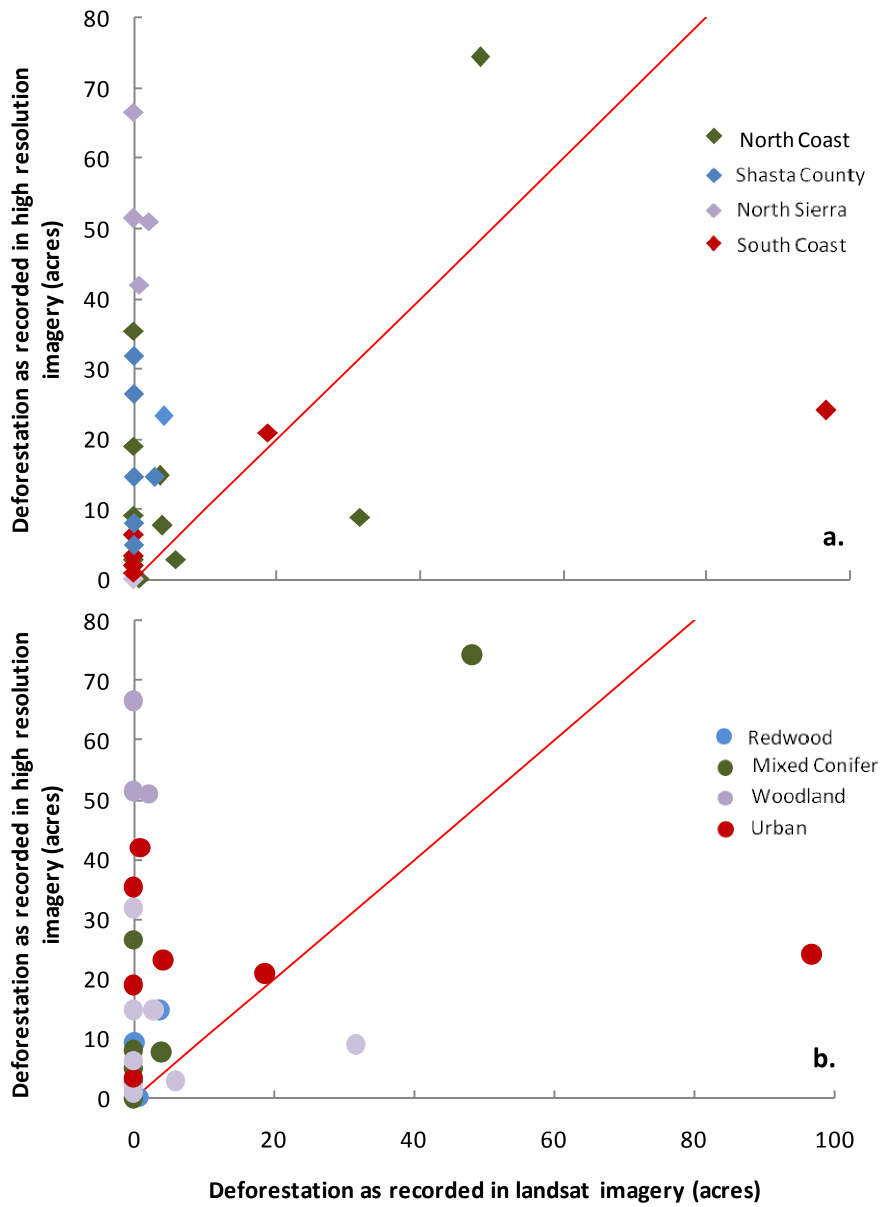


Figure 15. Plot of deforestation, by region and landscape type, recorded in the Landsat imagery against deforestation recorded in the high resolution imagery for the 28 sample sites. The 1:1 line is shown in red.

An average correction factor could be calculated and applied to the Landsat imagery based on averages from this analysis, however, the sites that recorded zero deforestation in the Landsat imagery but measurable deforestation in the high resolution imagery (50% of the sampling areas) are problematic. For these areas it is not a matter of multiplying the recorded area to give a higher real number – instead it is stating that deforestation occurred in an area in the high resolution imagery in which none was recorded in the medium resolution imagery. For a given sample unit (here approximately 5,000 acres) it is not possible to correlate actual area of deforestation with deforestation as assessed using Landsat imagery.

The question therefore is whether it is better to conduct broad assessment with medium-scale imagery or limited sampling with high resolution imagery?

An alternative would be look across larger sample areas thereby ensuring that all sample units record deforestation. Here for example we can look across the state at the area of deforestation under both systems for the four forest types based on the 28 sample sites (Table 16). This approach gives correction factors of between 2.1 (for woodlands) and 2.8 (for mixed conifer). Meaning that between 2 and 3 times as much deforestation actually occurred than was recorded in the Landsat imagery.

Table 16. Correction factors for calculation of actual deforestation from deforestation recorded using medium-scale imagery

	Sampled Acres	High resolution	Landsat	Correction Factor
		Annual deforestation (acres)		
Mixed Conifer	31,436	19.01	6.74	2.8
Redwood	14,086	10.25	4.57	2.2
Urban	49,077	34.62	14.95	2.3
Woodland	29,030	46.19	22.55	2.1

7.0 COMPARISON WITH OTHER STUDIES

We here estimate a net deforestation for development of almost 16,000 acres per year. This annual area of forest loss was divided between four classes: 19% conifer forest (excluding redwood); 5% redwood; 32% urban and 44% woodlands and hardwood forests.

Sleeter et al (2010) showed that through the use of sampling of medium resolution satellite imagery 26,000 acres were converted each year between 1992 and 2000 from other land uses to urban development in California (this includes conversion from forests but also conversion from croplands and grasslands). Over the entire period studied by the authors (1973 to 2000), 97% of the development occurred in three ecoregions, only one of which contained significant natural forests. Half of the development occurred in the Mojave Basin and Range (predominantly from shrub/grassland) and the Central California Valley (predominantly from agriculture); 47% occurred in coastal regions in chaparral and oak woodlands. The analysis of Sleeter et al (2010) leaves just 3% of development occurring in naturally high forest regions such as the Coast range, Sierra Nevada, the East Cascades and the Klamath Mountains. The actual area of conversion of forests and woodlands to urban development in the period 1992-2000 is 9,143 acres with a standard error of 3,707 acres (Sleeter pers. comm.), with 47% of loss occurring in the Coast Range region.

Pearson et al. (2009) analyzed data from the California Department of Forestry and Fire Protection Fire and Resource Assessment Program (CDF FRAP) for the period 1994-2002 and found a total of just 337 acres per year of identified conversion of forests/woodlands to urban development (153 acres/year of woodlands/hardwoods; 178 acres/year of mixed conifer, and 6 acres/year of redwoods). The development category included just areas where the cause of change could be positively identified. The area for which cause of canopy cover change was not verified totaled almost 16,000 acres per year. Pearson et al (2009) postulated that much of this area may be small-scale development, but undoubtedly a large proportion of this area of forest cover loss will not have been caused by development.

CDF FRAP (Stewart personal comment) reports that between 1989 and 2000 almost 70,000 acres per year experienced some development. Of this area about 28,000 acres/yr were parcelized on woodland and forestland and 82% of the parcelized acres had parcel sizes of more than 5 acres. Only 1% of the acres had parcels of less than 0.5 acres. Very large parcels are likely to be accompanied by a low proportion of deforestation, high proportions of tree removal are likely only in very small parcels.

The National Resources Inventory shows that from 2002 to 2007 8,280 acres per year were converted from forestland to developed land (USDA NRCS NRI 2010).

Clearly existing studies provide only an incomplete picture of deforestation for urban development in California. No study we are aware of looks at deforestation in urban landscapes and all studies we found use medium-resolution imagery which according to the results found here miss half or more of the actual area of tree cover loss.

However, it could be argued that estimating state level deforestation from this study is overreaching on the results. Only 28 sampling sites were included and the regions examined represent just 12% of the area of the State. In addition, the areas selected were areas at higher risk of deforestation for development. To conduct a complete census of deforestation for development with high resolution imagery would require systematic sampling across the forests and woodlands of the State.

8.0 SUMMARY

It is estimated that over the next decade California will add approximately 3.9 million residents (CDF 2010); depending on development density, between 200,000 and 550,000 acres of undeveloped or underdeveloped land will be needed to meet this population growth.

A total of 123,630 acres were sampled as part of this study across 4 regions of California:

- North Coast (Napa, Marin, Sonoma and the southern half of Mendocino)
- Shasta County
- North Sierra (El Dorado, Placer and Nevada)
- South Coast (Los Angeles and Ventura)

The area sampled was privately owned forests, woodlands and urban landscapes.

Sampling occurred at two resolutions:

- High resolution (60 cm pixels)
- Medium resolution (30 m pixels)

Medium resolution satellite imagery (e.g. Landsat) is typically used for such deforestation assessments due to ready availability and low cost.

A total area of 568 acres of deforestation was recorded in the high resolution imagery and 220 acres in the landsat imagery, or in other words about a 2.6-fold difference.

Focusing on the high resolution imagery, the annual area of deforestation was 110 acres. Deforestation was divided as follows among the regions:

- 30% North Coast

- 22% North Sierra
- 36% Shasta County
- 12% South Coast

In terms of forest types, deforestation was divided as follows:

- 9% Redwood
- 17% Other conifer forest
- 42% Woodland and hardwood
- 31% Urban landscapes

Housing development in rural areas tended to occur more frequently in non-forested areas. There were less than 12 instances of areas of forest that changed into housing developments (a street or more new houses not an individual house). The majority of these areas were in the woodland category where the tree density is lower than either mixed conifer or redwood. None of these new developments occurred in the redwood category. Urban deforestation is more common but most instances are of single or few trees at one location. For example backyard trees are removed for construction of a swimming pool.

Extrapolating across the state, results in the following estimated areas of annual deforestation:

- 734 acres in redwood forests
- 3,081 acres in other conifer forests
- 6,994 acres in woodlands and hardwood forests
- 5,095 acres in urban landscapes

The medium resolution imagery systematically underrepresented deforestation compared to the high resolution imagery (except in two sample areas where large false deforestation areas were recorded by the medium resolution imagery). However, there was no simple correlation between deforestation area recorded in high and medium resolution imagery. Indeed in 50% of the scenes examined zero deforestation was recorded in the medium resolution imagery but an area of deforestation (up to 67 acres) was recorded in the high resolution imagery. On average, across the 28 sampling areas, the following correction factors were calculated:

- Redwood 2.2
- Other conifer forest 2.8
- Woodland and hardwood 2.1
- Urban landscapes 2.3

These results indicate that studies relying solely on medium resolution imagery are missing more than half of the deforestation that is occurring.

We found no study with which we could directly compare our results.

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ANNEX 1: DEFINITIONS

Background – Land cover categories outside the scope of the study, includes water, public land, military land, agriculture, wetlands, or grassland among others.

Mixed Conifer – Coniferous dominated forest, includes old growth and second growth.

Redwood – Forests dominated by California Redwood (Sequoia sempervirens), includes old growth and second growth.

Urban – Land where the dominante cover is anthropogenic such as housing, commercial or transportation.

Woodland – Forests dominated by softwoods and deciduous trees such as oaks, includes old growth and second growth.

Target Areas – The 10 counties identified in Product 1: Desk Study for focused study on deforestation in and around urban areas. The counties were grouped into North Coast, Shasta, North Sierra Nevada, South Coast.

Study Site – Location of 25 km2 within a target area where high resolution imagery will be used to determine deforestation rate.

ANNEX 2: FOREST TYPES

We aggregated the diverse California forest types into more general categories based on similar physiological characteristics. The source data for land cover types was the California's Multi-source Land Cover Data (fveg) data which was used instead of the USGS National Land Cover Dataset (NLCD) because it contains 53 total land cover categories including 27 forest types. All forest types in fveg were aggregated into 3 broad forest types; redwood, woodland, and mixed conifer. The urban category did not need to be aggregated, fveg contains only one urban land cover category. All other land cover categories such as water, agriculture, grassland, etc in the fveg dataset were grouped into an ineligible class and removed from analysis. The new land cover data which the study was based contains 5 categories (Table A1).

Table A1. Reclassification of California's Multi-source Land Cover Data (fveg)

NEW CATEGORY	FVEG CATEGORY
Mixed Conifer	Eastside Pine Jeffrey Pine Klamath Mixed Conifer Lodgepole Pine Montane Hardwood-Conifer Montane Riparian Ponderosa Pine Red Fir Sierran Mixed Conifer Subalpine Conifer Unknown Conifer Type White Fir
Woodland (including Hardwood Forest)	Aspen Blue Oak Woodland Blue Oak-Foothill Pine Coastal Oak Woodland Eucalyptus Joshua Tree Juniper Montane Hardwood Pinyon-Juniper Riverine Valley Foothill Riparian Valley Oak Woodland
Redwood	Redwood
Urban	Urban
Ineligible	Agriculture

NEW CATEGORY	FVEG CATEGORY
	Alkali Desert Scrub
	Alpine-Dwarf Shrub
	Annual Grassland
	Barren
	Bitterbrush
	Chamise-Redshank Chaparral
	Coastal Scrub
	Desert Riparian
	Desert Scrub
	Desert Succulent Shrub
	Desert Wash
	Estuarine
	Freshwater Emergent Wetland
	Lacustrine
	Marine
	Mixed Chaparral
	Montane Chaparral
	Pasture
	Perennial Grassland
	Sagebrush
	Saline Emergent Wetland
	Unknown Shrub Type
	Water
	Wet Meadow

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APPENDIX C:
Emissions Analysis

Goslee, K, T. Pearson, S. Petrova, and S. Brown. (Winrock International). 2012. Emissions Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity. California Energy Commission. Report to PIER under #PIR-08-008.

Public Interest Energy Research (PIER) Program

PROJECT REPORT

Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity

Emissions Analysis

Prepared for: California Energy Commission

Prepared by: Winrock International

JULY 2012

CEC-PIR-08-008

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

"Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity: Emissions Analysis" is an interim report for the project Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity, grant number PIR-08-008 conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown.

In this report we analyze emissions associated with tree canopy loss/deforestation for urban development. The majority of deforestation for development occurred on areas of woodland forest cover, which have lower carbon stocks than redwood or mixed conifer forests. The development that was seen in redwood and mixed conifer forests was single home developments or clearing within existing developments. In all of the study areas, there appears to be little correlation between parcel size and the percent of forest cover loss in multi-parcel developments, though there is some correlation for single house developments.

Emissions factors were developed as total emission per unit area (t CO_2e/acre) for the area of deforestation within a development, based on forest type.

Keywords: greenhouse gas, development, deforestation, carbon stock, urban, forest

Please use the following citation for this report:

Goslee, Katherine, Pearson, Timothy, Petrova, Silvia, and Brown, Sandra. (Winrock International). 2012. ***Emissions Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity.*** California Energy Commission. Publication number: CEC-PIR-08-008.

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EXECUTIVE SUMMARY

In a poll in 2000, urban sprawl was classified, along with crime, as the leading local concern in the US. Across the country, urban area has doubled over the past 40 years. In California, during the same period, there was a 252% increase in the urban area. Among regions in the US, California appears to have the lowest current number of developed acres per capita, but the second highest population growth rate, and an average income growth rate that outstrips population growth. This trend in population and income growth rates makes one question whether the area of development is captured correctly in CA.   Thus the purpose of this project is to improve the assessment of forest conversion to development.

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown.

To date, we have shown that interpretation of very high resolution remote sensing imagery results in higher estimates of deforestation due to development compared to the results from interpreting the commonly used Landsat imagery. This report provides the results of an analysis of GHG emissions caused by this deforestation. The ultimate aim of the analysis was to develop emission factors that can be paired with areas of deforestation to give associated greenhouse gas emissions.

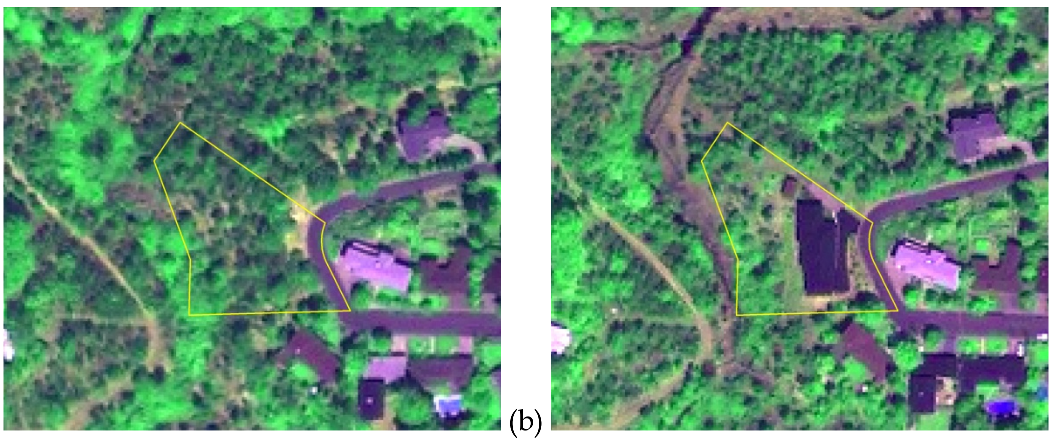
Classes of development activities are generally based on a combination of size thresholds (e.g. developments of <½ acre, ½-1 acre, <5 acres, 5-10 acres, 10-40 acres, and >40 acres) and overall size and density of development (e.g. single units versus multiple units, and number of dwelling units per unit area), though counties do not have the same minimum lot size and density standards. In some counties, such as Shasta, it may be easy to change zoning classifications, while in others, such as Marin, it is nearly impossible (pers. comm. Eric Haney, Shasta Co. and Curtis Havel, Marin Co.). While there are some regional similarities in zoning and development, it became clear through discussions with planning offices that differences between counties are significant enough that development practices should be defined by county rather than by region.

In order to build upon the spatial study described in *Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity* (Pearson et al, 2011), a subset of the spatial extent from that study was used to examine the amount of deforestation attributable to housing developments. Forest cover change due to development and resulting emissions were quantified.

Forest cover change due to development was quantified per parcel for new builds across seventeen sampling areas totaling 101,274 acres. Forest cover change was analyzed only for the parcels that have undergone new development for the sampled period; results were separated into multi-house and single house development (Figures A and B). To assess additional development emissions beyond new builds a subset of the study areas in one forest type (redwood) / one region (north coast) were further analyzed (four sample areas, totaling 20,270 acres).   Across the study, fourteen multi-house developments and 66 single house developments were identified, and in the subsample 5 secondary developments in already developed parcels.

(a) (b)

Figure A. A multi-housing development: (a) time 1 (pre-conversion) and (b) time 2 (post-conversion) from Sonoma County



(a) (b)

Figure B. A single house development: (a) time 1 (pre-conversion) and (b) time 2 (post-conversion) from Shasta County

Across the seventeen 9.7 square mile sampling areas analyzed, a total of 80 new developments, 5 secondary developments, and 26 forest clearings were identified (Table A)[1]. The developments included a total of 557 developed parcels within 14 multi-house developments and 66 single house developments, as well as 5 parcels with secondary development and 26 parcels with clearing.

[1] In one of the sampling sites in Mendocino County and two in Nevada County no forest loss was identified within the analyzed time period.

Table A. Parcels examined by county (NB. Does not include all development in counties, only in specific study areas.)

County	Sampling Area Count	Parcel Count	Multi-House Development Count	Single House Development Count	Secondary Development Count*	Forest Clearing without Development*
El Dorado	1	30	1	2	-	-
Los Angeles	3	51	2	2	-	-
Mendocino	3	24	0	1	2	19
Napa	1	26	1	8	-	-
Nevada	2	23	1	4	-	-
Shasta	5	345	7	39	-	-
Sonoma	2	58	2	10	3	7

*Those counties with no numbers for secondary development and forest clearing without development were only analyzed for forest loss resulting from new development.

Across counties, the average size of a parcel in a multi-housing development ranged from 0.17 acres in Sonoma to 1.83 acres in Los Angeles. The average forest loss ranged from 16% in Nevada to 88% in Los Angeles. For single house developments, the average size of a parcel ranges from 0.14 acres in Napa to 8 acres in El Dorado. The average forest losses range from 6% in El Dorado to 78% in Napa.

Carbon stock impact was calculated using biomass carbon stocks per forest type in all sampled counties, derived from the National Biomass and Carbon Dataset (NBCD). Area of forest cover loss was multiplied by the carbon emissions for specific forest type for the county where the loss was observed to estimate carbon emissions associated with residential developments (Table B). To develop emission factors, the percent of carbon stored in harvested wood products and in post-development plantings were subtracted from the carbon stocks.

Table B. Carbon stocks of live above and belowground tree biomass (tCO_2/ac) for forest types across 10 counties in California.

County	Land cover category		
	Mixed Conifer	Redwood	Woodland
		$t\ CO_2\ ac^{-1}$	
El Dorado	173		86
Los Angeles	73		38
Marin	253	329	144
Mendocino	217	311	121
Napa	158	317	61
Nevada	153		92
Placer	171		94
Shasta	174		61
Sonoma	206	311	109
Ventura	61		29
Average	164	317	83

Total CO_2 emissions in multi-house developments across the study areas ranged from 34 tons in a Shasta County development with 27 parcels averaging only 0.09 acres in size to 735 tons in another Shasta County development with 114 parcels averaging 0.39 acres. Average per parcel emissions by development ranged from 1.3 tons in the Shasta County development with small average parcel size to 21.4 tons in a development in El Dorado County with a higher average parcel size, moderate forest cover loss, and a moderately high emission factor.

For single house developments, the average CO_2 loss for single house parcels ranged from 2.0 tons in Napa County to 42 tons per development in Shasta County. It is important to note, however, that there was wide range in the emissions within each county, and all have a large confidence interval. Shasta County, in fact has the smallest confidence interval as a percent of the mean, although it is still fairly high at 18%. The average emissions per acre also ranged widely, with a low of 2.0 t CO_2/ac in El Dorado County, which has a relatively large average parcel size, and a high of 27 in Mendocino County, though this is based on only one development. Sonoma County, which has smaller parcels, relatively high percent forest loss, and high carbon stocks, had the second highest emissions per acre at 22 t CO_2/ac.

Due to the variation seen in percent forest loss across developments, it is not possible to create emission factors by size of development from this analysis. However, the carbon stocks by forest type can be used to develop emission factors based on area deforested. The variation across counties requires that these factors be county-specific. Because carbon emissions are linked directly with the acreage deforested, the carbon impact of the multi-housing developments varies greatly from county to county. It is not possible to make a generalization of the impacts of either multi-housing or single house developments that is applicable across the state. However, emission factors could be developed for areas of specific interest throughout the state, and applied to the relevant average percent forest loss to estimate total emissions.

CHAPTER 1:
Introduction

In a poll in 2000, urban sprawl was classified, along with crime, as the leading local concern in the US. Across the country, urban area has doubled over the past 40 years. In California during the same period there was a 252% increase in the urban area. Among regions in the US, California has the lowest current number of developed acres per capita, but the second highest population growth rate and an average income growth rate that outstrips population growth (cf Swails *et al* 2009). This trend in population and income growth rates makes one question whether the area of development is captured correctly in California. Thus the purpose of this project is to improve the assessment of forest conversion to development.

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown.

Assessments of deforestation for development do exist but no confident emission estimates can be paired with the estimates of rates of deforestation. In addition, deforestation is monitored using coarse scale imagery which can only poorly track the most common form of urban development – scattered development. It is therefore likely that deforestation rates are underestimated and actual emissions are entirely unknown. For these reasons, Winrock International, under funding and guidance from CA PIER, is conducting a multi-year study of small-scale development and its impacts on greenhouse gas emissions and reductions.

The project began with a desk study (Swails et al, 2009), which described development and associated deforestation in California, including the laws and regulations that govern development and the forest ecosystems in which development is most likely to occur. Based on recent development pressures and forest cover, this study identified these four geographic target areas on which to focus further analysis (see Figure 1):

1. **The Sierra Mountain counties of El Dorado, Placer and Nevada**
2. **The counties of Marin, Sonoma, Napa and Mendocino (north of the San Francisco Bay Area)**
3. **Los Angeles and Ventura Counties in Southern California**
4. **Shasta County in Northern California**

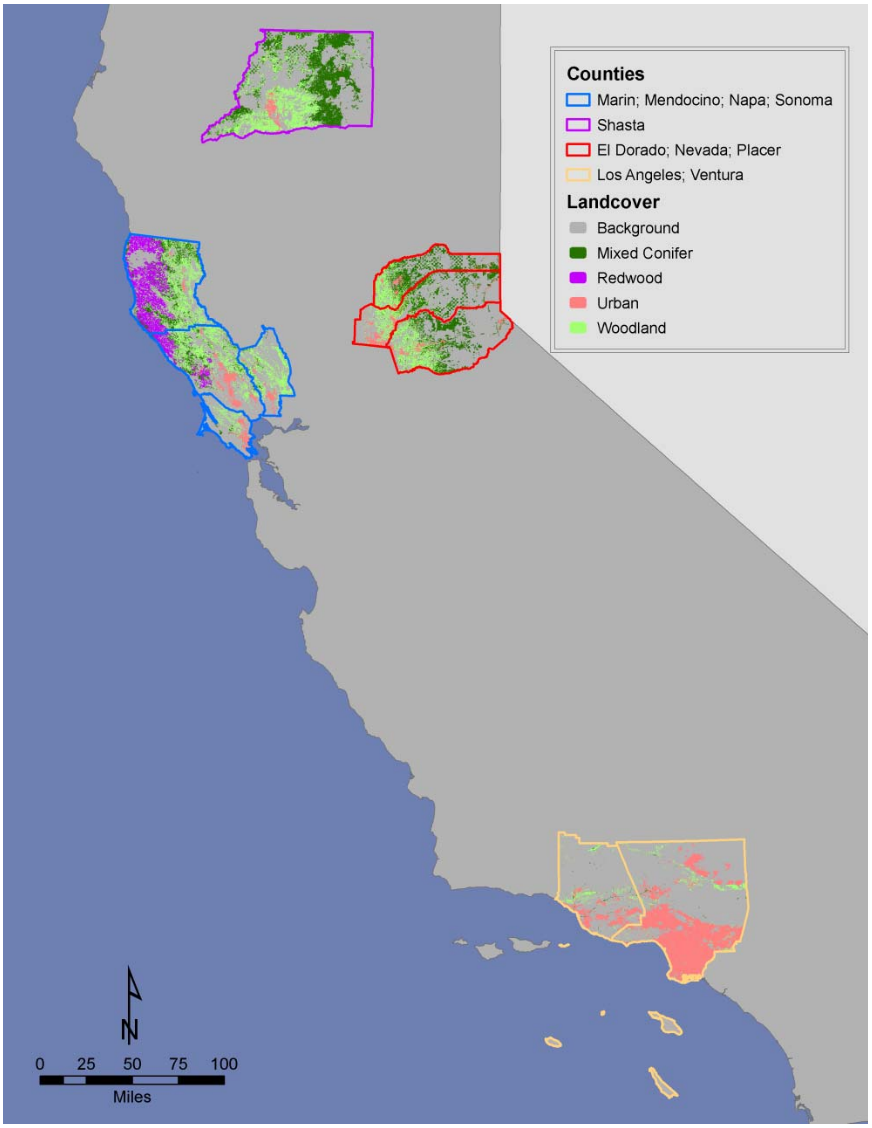


Figure 1. Sites chosen for in-depth study

Following the desk study, a spatial analysis study was conducted to assess deforestation resulting from development, by using a sampling of deforested areas to assess actual acreage of deforestation. This study showed that interpretation of very high resolution remote sensing imagery results in higher estimates of deforestation due to development in comparison to the results from interpreting the commonly used Landsat imagery (Pearson *et al.* 2011).

For the spatial analysis study, twenty-eight sampling areas totaling 123,630 acres were sampled at two points in time, 3-7 years apart, and change in forest cover was analyzed using both high resolution imagery (60 cm pixels) and medium resolution imagery (Landsat 30 m pixels). The high resolution imagery indicated that 569 acres (0.46%) were deforested, while the medium resolution imagery indicated that 220 acres were deforested (0.09%). According to the high resolution imagery, this was an average of 110 acres deforested annually, with 42% occurring on woodland and hardwood forests, 31% on urban landscapes, 17% on other conifer forests, and

9% on redwood forests. Thirty-six percent of this deforestation occurred in Shasta County, 30% on the North Coast, 22% in the North Sierra region, and 12% on the South Coast.

The ultimate aim of the emissions analysis described in this report was to determine the common practice for conversion of forest land to residential development and, if possible, create emission factors that can be paired with areas of deforestation to give associated greenhouse gas emissions. Although studies of urban forests and ecosystems in the United States and their associated carbon stocks exist[2], there is little information on carbon stock changes and GHG emissions associated with the conversion process itself. In addition, existing studies of urban forests have focused on average crown cover across urban land, and have not produced a consistent set of definitions of land classes within urban and suburban areas that could be used to estimate carbon storage per unit of land class within settled areas. This analysis could be used both for full accounting of greenhouse gas emissions associated with development and also potentially to develop a class of offset projects permitting market pressures and incentives to decrease total net greenhouse gas emissions and retain forests in California.

Organization of report

Section two provides an overview of development across California and a brief description of zoning regulations in California, especially in the context of their relationship to deforestation. Section three describes the methods used in analyzing the impact that residential development projects have on tree cover and in developing emission factors and calculating the carbon emissions resulting from deforestation. Section four provides the results of the deforestation analysis and Section five provides results of the emissions analysis. Section 6 provides a general discussion of the results.

CHAPTER 2: Background – Development and Zoning

2.1 Development on Forested Lands in CA

Using satellite data from 1986 to 2000, Sleeter (2010) estimated that in California an average of 64,000 acres were converted annually to urban development from other land uses. The California Department of Housing and Community Development (2000) predicts that the number of households in California will grow from more than 14 million in 2010 to more than 16 million in 2020, an increase of 14% in a ten year period. During this same time period, 200,000 to 550,000 acres of undeveloped or underdeveloped land will be developed in order to meet the demands for new urban housing (FRAP, 2010), though much of it will not be forested land. According to the 2010 Forest and Range Assessment, annual grassland is the habitat type most at risk from development throughout California. This is followed distantly by coastal

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[2] Hutyra, L.R., Yoon, B., and M. Alberti. 2011. Terrestrial carbon stocks across a gradient of urbanization: A study of the Seattle, WA region. *Global Change Biology*. 17 (2): 783 - 787.; Jo and McPherson. 1995. Carbon Storage and Flux in Urban Residential Greenspace. *Journal of Environmental Management*. 45: 109-133.; Nowack et al. 1996. Measuring and analyzing urban tree cover. *Landscape and Urban Planning*. 36: 49-57. Peper et al. 2001. Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. *Journal of Arboriculture*. 27: 6.

scrub, montane hardwood, and blue oak woodland. Nonetheless, across all forest and chaparral WHR vegetation types in high priority landscapes, 2,274,300 acres are at risk for development.

The amount of forested land converted for development has not been clearly identified in these sources. In our earlier work Pearson *et al* (2011) estimated that a total of 15,904 acres of forestland were deforested annually across California, broken down as follows:

- 734 acres or 0.06% of redwood forests,
- 3,081 acres or 0.07% of other conifer forests,
- 6,994 acres or 0.16% of woodlands and hardwood forests, and
- 5,095 acres or 0.07% of urban landscapes.

However, this may be an overestimate statewide, as it is based on extrapolation of deforestation on areas at high risk of conversion of forest to development, rather than a systematic sampling across forests and woodlands of California.

The National Resources Inventory shows that from 2002 to 2007, 8,280 acres per year were converted from forestland to developed land (USDA NRCS NRI 2010) although this analysis will have overlooked small scale degradation captured by Pearson et al (2011). Pearson et al. (2009) used FRAP data to determine that 16,000 acres per year are developed, though most of that was not previously forested land. Sleeter (2010, pers. comm.) states that between 1992 and 2000, 9,143 acres of forests and woodlands were converted to urban development, about 1,143 acres per year.

It is important to note that the economy has significantly changed patterns of development over the last few years, both decreasing the level of development and changing the type of development, generally reducing the number of production developments for middle income brackets (pers. comm. County Planners). So called “custom lots” have been less affected by the economic downturn. Individual custom lots are relatively larger compared to lots in production development subdivisions, and are generally sold as-is to home buyers who make improvements on the property.

2.2 Zoning and Types of Development

According to the California Department of Forestry and Fire Protection (CALFIRE, 2003) there are at least 90 state and federal laws that regulate the management of forest and range resources as well as at least 25 relevant executive orders and other initiatives implemented in the last decade. According to the Governor’s Office of Planning and Research (2009), the set of laws and regulations governing new developments in California is one of the most complex in the country. Many of these laws and regulations differ by county or municipality, with the type of allowable development determined by zoning and city ordinances. The initial desk study (Swails et al, 2009) describes many of the applicable state and federal laws and regulations in detail.

Classes of development activities are generally based on a combination of size thresholds (e.g. developments of <½ acre, ½-1 acre, <5 acres, 5-10 acres, 10-40 acres, and >40 acres) and overall size and density of development (e.g. single units versus multiple units, and number of dwelling units per unit area), though counties do not have the same minimum lot size and density standards. In some counties, such as Shasta, it may be easy to change zoning classifications, while in others, such as Marin, it is nearly impossible (pers. comm. Eric Haney, Shasta Co. and Curtis Havel, Marin Co.).

Across all counties, there are three common types of subdivisions: **production builders**, where the developer actually has the homes built and sold; **custom homes**, in which only the lots are sold, usually with services such as water and sewer available; and **rural subdivisions**, which are larger projects (~100 acres) and larger lots (~5 acres). For custom homes, the developer does not remove any vegetation or do any grading on the lot before it is sold to the home owner. Production lots are usually smaller than lots for custom homes, and are totally cleared before the developer builds a house on the lot. The front yard is landscaped before sale but the back yard is not. While these three general classes characterize the types of development activity in all of the counties addressed in this study, counties differ in which type is more common. In many counties, however, production subdivisions have slowed down or stopped due to the poor economy, and projects of one to five houses have become more common than any type of large subdivision.

Across all counties the process of submitting a project is very similar. First, the developer submits a tentative map with lot design and required reports (biological, traffic, archeological, geological, etc.). CEQA requires either an EIR or a Negative Declaration (no significant impact) for each project. There is a requirement of a 100′ set back from all watercourses. All improvements (sewer, road, etc.) must exist before map is recorded. For custom lots, the homeowner is responsible for driveways and septic – the developer only clears for access roads and the homeowner clears as needed. For production homes the lot is typically clear cut and graded if necessary. The planning departments review all building permits.

Most counties allow or require some type of clustering to create open space set aside, with the minimum lot size averaged across the development, and houses clustered in one area. Often, when a development utilizes clustering, it enables an increase of the total allowed number of units in the project. The undeveloped acres are then set aside, requiring a revision in order to develop them in the future. This type of development was increasing up to 2008 before the economic downturn.

The North Bay counties (Marin, Napa, and Sonoma) are experiencing very little development, especially of forested land. Marin, for instance, has a total of fewer than 12 new projects per year, most or all of them individual units. The primary development occurs along highway 101. Approximately 80% of the county is protected, and 98% of the unprotected areas are already built out, with much of the remaining land on difficult terrain for development (pers. comm. Curtis Havel). All permits are discretionary, requiring environmental review, public notice, and hearings. Zoning districts usually require that houses are clustered at the bottoms of hills and near roads.

While there are some regional similarities in zoning and development, it became clear through discussions with planning offices that differences between counties are significant enough that development practices should be defined by county rather than by region.

Table 1 shows the zoning categories for the counties examined in this analysis.

Table 1. Zoning categories and maximum densities (in dwelling units per acre for high density categories or acres per dwelling units for low density categories). NB. Not all counties use the same names for land use designations; the names used below are approximations.

Land Use Designation	Sonoma	Napa	Shasta	Nevada	El Dorado	Los Angeles
Multi-family Residential (units/ac)	NA	20	NA	NA	5-24	30-75
High-Density Residential (units/ac)	12-20	10	16	15-20	NA	18-30
Medium-Density Residential (units/ac)	6-12	5	NA	6	1-5	9-18
Low-Density Residential (units/ac)	4-6	NA	3	1.5	1-5	0-9
Rural Residential (ac/unit)	1-20	10	2	3	5-10	1-10
Remote Residential (ac/unit)	10-60	NA	5	>5	>10	>20

CHAPTER 3: Analysis Methods for Deforestation from Development

In order to build upon the spatial study described in *Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity* (Pearson et al, 2011), a subset of the spatial extent from that study was used to examine the amount of deforestation attributable to housing developments. Forest cover change due to development and resulting emissions were quantified.

Forest cover change due to development was quantified per parcel using two levels of analysis. The new development approach analyzed the forest cover change only from new development in parcels with no existing development and separated results into multi-house and single house development. Seventeen sample areas were analyzed for new development, totaling 77,116 eligible acres, across 7 counties. The total development approach analyzed additional development in parcels with existing buildings and parcels with tree clearing but no discernible development during the sampling period. Four of the seventeen sample areas were analyzed using this approach, totaling 20,270 acres across 2 counties. From the new development approach 14 multi-house developments and 66 single house developments were identified, while from the total development approach 5 secondary developments in already developed parcels and 26 instances of forest clearing with no development were identified on parcels with single house development zoning. Three areas showed no development during the time period analyzed, one in Mendocino County and two in Shasta County.

The new development approach resulted in less forest cover loss identified from high resolution images than expected based on forest cover loss identified in Pearson et al, 2011. In addition, within the randomly chosen sample areas this approach detected forest cover dominated by woodland and urban forest types. The total development approach was designed for very limited sample areas (primarily redwood dominated areas) to test whether a significant proportion of deforestation associated with development may be in areas that were not new builds.

Carbon stock impact was calculated using biomass carbon stocks per forest type in all sampled counties, derived from the National Biomass and Carbon Dataset (NBCD). Area of forest cover loss was multiplied by the carbon emissions for specific forest type for the county where the loss was observed to estimate carbon emissions associated with residential developments.

3.1 Deforestation from Development

3.1.1 Data

Parcel data for Sonoma, Napa, Shasta, and Los Angeles counties were purchased from a third party data provider. Additionally, parcel data for Nevada County were downloaded from the county website and parcel data for El Dorado and Mendocino County were purchased directly from the county GIS offices. From the parcel data, the year in which the main structure was built and the County Assessors code for current use, such as residential, commercial, etc., were used to identify parcels with new and additional development for residential use during the analyzed time period.

High resolution images Quickbird (60 cm resolution) and IKONOS (50 cm resolution) were purchased from Spatial Solutions, Inc in 2010 and covered 66,991 hectares across a total of 28 sample areas (Grimland *et al.*, 2009). Both images, Quickbird and IKONOS, are comparable in their spectral range for the multispectral bands (blue, green, red and infra-red) allowing for compatible analysis of difference in spatial resolution. For the sampled site where images of the same type were not available, the Quickbird images were resampled to match the IKONOS resolution.

For this analysis we analyzed the parcel data across 17 high resolution sampling areas (see **Error! Reference source not found.**).

Table 2. Sample Area descriptions

Sample Area	County	First Image Date	Second Image Date	Redwood	Mixed Conifer	Woodland	Urban	*Ineligible*	***Eligible Acres***
1*	Mendocino	2002	2009	**65%**	4%	4%	0%	*26%*	4,568
2*	Mendocino	2003	2009	**64%**	1%	12%	0%	*22%*	4,802
3*	Mendocino	2004	2009	25%	**53%**	11%	0%	*12%*	5,450
7*	Sonoma	2004	2008	**65%**	13%	9%	1%	*12%*	5,450
8	Sonoma	2004	2009	0%	0%	9%	**63%**	*28%*	*4,442*
9	Napa	2004	2009	0%	0%	3%	**72%**	*25%*	*4,654*
10	Shasta	2004	2008	0%	**62%**	2%	0%	*36%*	3,940
11	Shasta	2003	2008	0%	1%	**39%**	22%	*38%*	*3,859*
12	Shasta	2003	2008	0%	0%	10%	**70%**	*19%*	*4,987*
14	Shasta	2003	2009	0%	0%	**72%**	3%	*25%*	*4,615*
15	Shasta	2003	2009	0%	**78%**	6%	0%	*16%*	5,195
18	Nevada	2004	2007	0%	**67%**	0%	4%	*29%*	*4,522*
20	Nevada	2000	2008	0%	**70%**	15%	0%	*15%*	5,270
22	El Dorado	2004	2009	0%	1%	**41%**	3%	*55%*	*2,804*
26	Los Angeles	2005	2008	0%	0%	27%	**50%**	*24%*	*4,721*
27	Los Angeles	2003	2009	0%	0%	**35%**	8%	*58%*	*2,620*
28	Los Angeles	2004	2008	0%	0%	8%	**77%**	*16%*	*5,217*

* Analyzed for secondary development as well as new development

3.1.2 Quantifying Forest Cover Loss for New Development

The new development approach quantifies the forest cover change only for parcels that are not already developed. Using the parcel data within the sampled areas we identified parcels where new multi-house or single house developments were registered during the sampled time period.

Both multi-house and single house developments had to meet the following requirements in order for parcels to be included in the study:

- The parcel should be forested in Time 1
- No initial construction or landscaping had occurred in Time 1
- No existing house or building on the parcel in Time 1
- The construction has been completed by Time 2

3.1.2.1 Multi-housing developments

For multi-housing developments, deforestation areas within the sampling areas were identified using the deforestation data analyzed by Pearson et al. (2011). Large contiguous deforestation areas from the Pearson *et al.* (2011) data were identified and the locations were examined using high resolution imagery (60 cm pixels) to visually determine whether the deforestation resulted in new multi-house developments. Parcel attribute data were then used to substantiate the changes seen in the high resolution imagery. The parcel data obtained from the third party provider contain attribute information for the year a house was built. For the parcel data acquired directly from the counties, the year the parcel polygon was added to the database was used as an approximation of the year built. A multi-house development was loosely defined as several houses built simultaneously within a close proximity, often with new streets (Figure 2).

No minimum number of houses was defined, but none of the developments have fewer than 5 new buildings.


(a) (b)

Figure 2. A multi-housing development: (a) time 1 (pre-conversion) and (b) time 2 (post-conversion) from Sonoma County

3.1.2.2 Single house developments

Single house developments were identified using the parcel attribute information on the year built. Single house developments are, as the name implies, a new single house on a parcel (Figure 33). First, all parcels were restricted to years built that correspond to the time of the sampling site's high resolution imagery, plus one year on either side. For example, site 8 has imagery for the years 2004 and 2009. Parcels in site 8 were queried to give only those built during the years 2003 thru 2010. The extra year was included to account for time delays in the building permit process and uncertainty regarding how accurate the year built data was. Next, the deforestation change data created in Pearson *et al.* (2011) was overlaid on the queried parcels. Then the parcels with changes were examined visually using high resolution imagery and those which met the requirements listed above were included in the study.

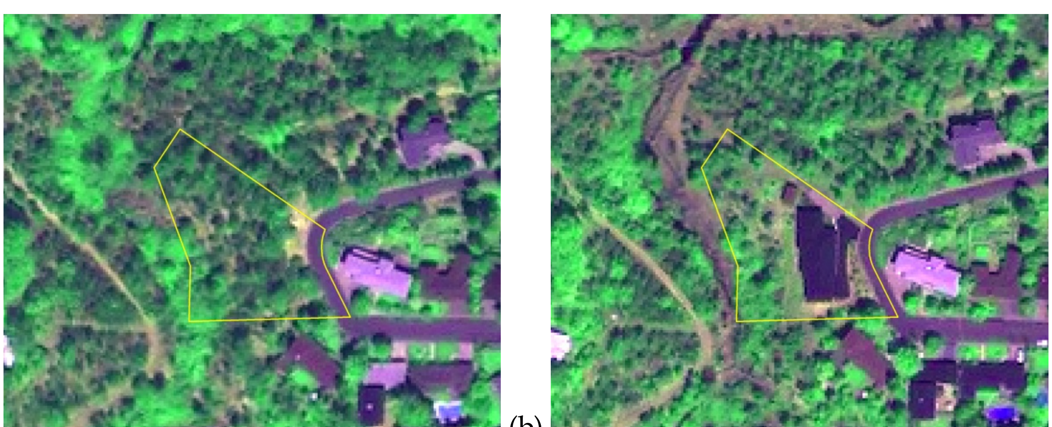

(a) (b)

Figure 3. A single house development: (a) time 1 (pre-conversion) and (b) time 2 (post-conversion) from Shasta County

After a new development was identified and confirmed visually, the high resolution images were clipped to the parcels with new development and classified into two categories, forest and non-forest. This was done using Maximum Likelihood classification in Idrisi GIS and Image processing software. The Maximum Likelihood classification assumes that the statistics for each category, forest or non-forest, in each image band are normally distributed and estimates the probability that a given pixel belongs to the forest or non-forest category. Training sites for forest and non-forest class are created and the classification assigns each pixel to the category that has the highest probability.

Training sites for forest and non-forest categories were digitized with a minimum of 100 pixels for time 1. The training sites were used to train the classification tool to classify the high resolution image into forest and non-forest category for time 1 and time 2. Manual editing of the classified image was performed by the image analyst to remove grass yards from the forest category. The forest cover change due to development was quantified as the difference in area of forest between time 1 and time 2 (Figure 4).

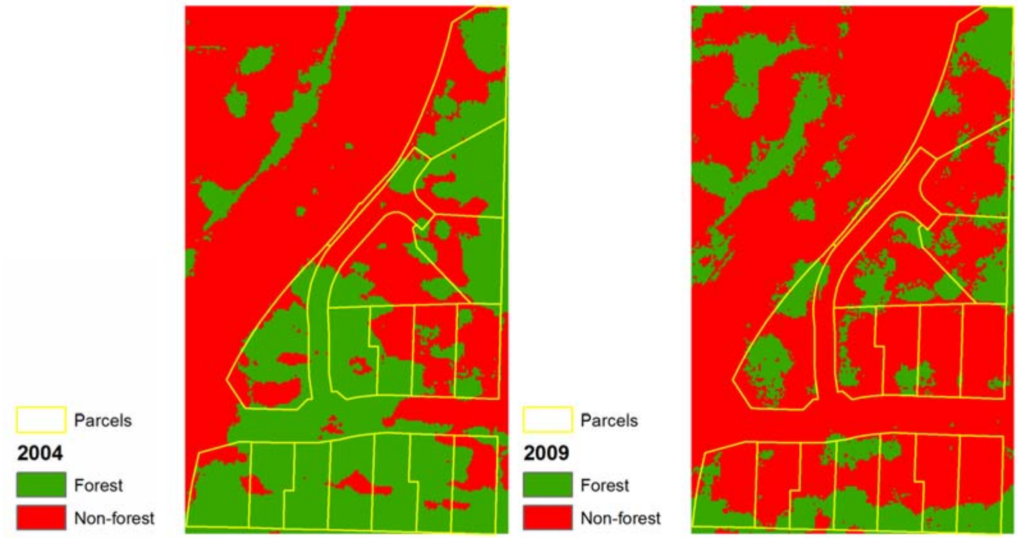


Figure 4 Forest and non-forest classification for a multi-house development in Sonoma Country for 2004 (left) and 2009 (right)

3.1.3 Quantifying Total Forest Cover Loss Due to Development

New development does not account for all tree losses occurring due to development. We therefore elected to include a sample to investigate the proportion of emissions omitted through focusing solely on new development. The sample covered four study areas (20,270 acres) in predominantly redwood forest in Sonoma and Mendocino Counties. We first quantified the forest cover change across the sampled site and then used parcel data to identify parcels with secondary development and forest clearings within a parcel that resulted in no structure development. This identification process was done through visual comparison of the images from the sampled time period and forest loss classified from the high resolution images.

3.1.3.1 Secondary development

Secondary development on a parcel was identified using following criteria:

- The secondary development should be in an area that is forested in Time 1
- A house or a building should be present on the parcel in Time 1
- The secondary development should be completed by Time 2

Figure 6 illustrate an example of secondary development during the sampled time period for a parcel in Sonoma County. The main building was present on the parcel at Time1 (Figure 5 (a)), while additional buildings were built during the sampled time as shown in the image of Time 2 (Figure 5 (b)).

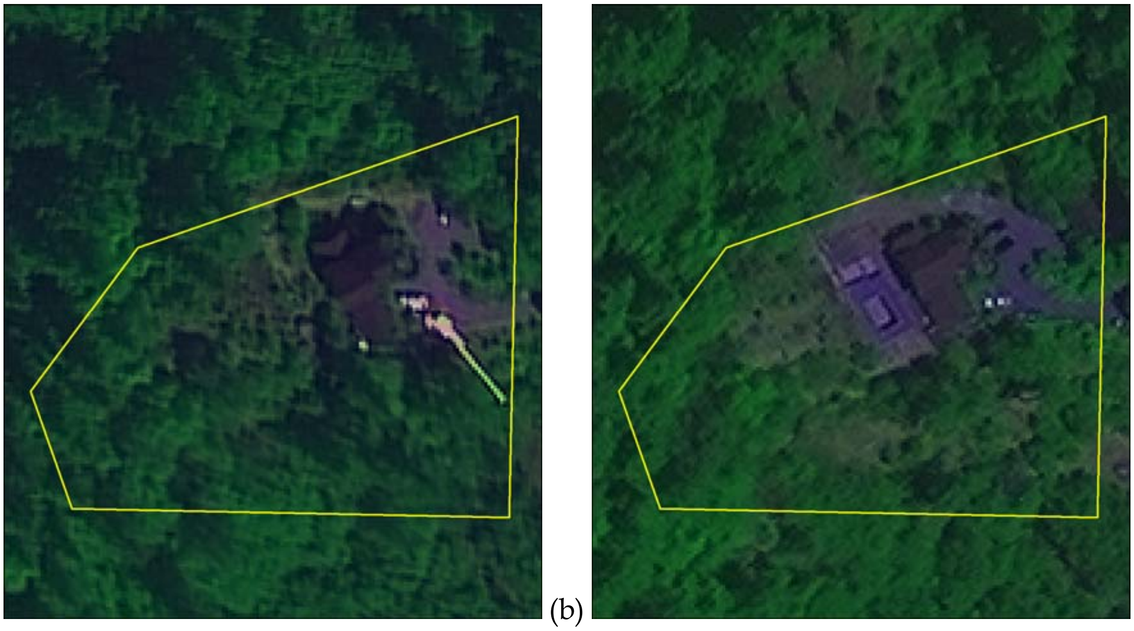
(a) (b)


Figure 5. Example of a secondary development in Sonoma County: (a) time 1 (pre-development) and (b) time 2 (post-development)

3.1.3.2 Forest clearing without development

Forest clearing within a parcel that did not result in housing development, but was not associated with commercial timber harvest, was also identified using the simple criterion that the area cleared in Time 2 should be forested in Time 1. Figure 6 shows an example of clearing for a parcel from Sonoma County that was entirely covered by forest in Time 1. These areas are included because they would have shown a forest loss in the initial spatial analysis (Pearson et al, 2009).

(a)  (b) 

Figure 6. Example of new clearing in Sonoma County: (a) time 1 (pre-clearing) and (b) time 2 (post-clearing)

3.2 Calculating Emissions

3.2.1 Carbon Stocks

The carbon stock impact was calculated using the National Biomass and Carbon Dataset (NBCD) (Kellndorfer et al, 2011). Distribution of biomass carbon stocks (t C/ac) across California for mixed conifer, redwood, and woodland land cover categories is shown on Figure 7.

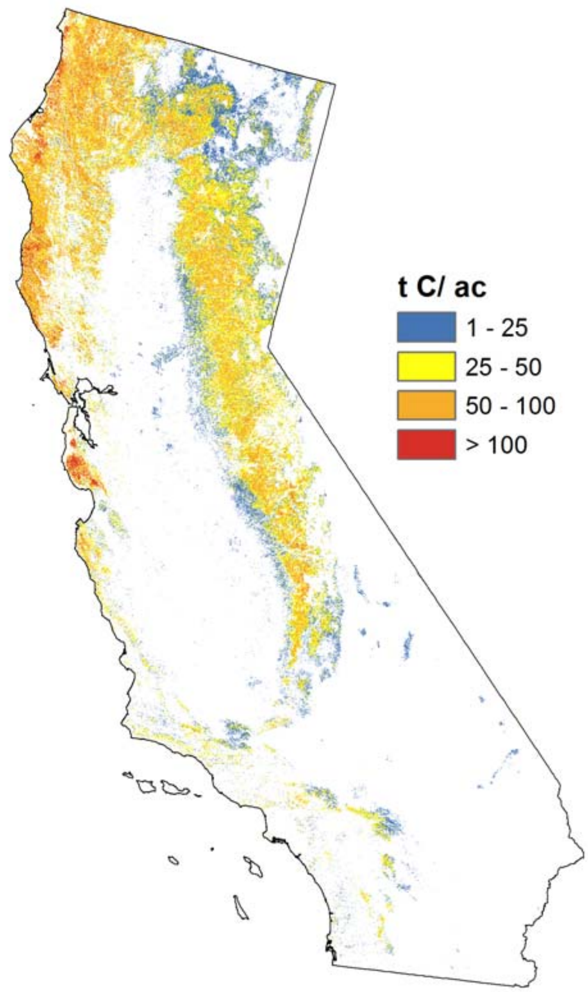


Figure 7. Distribution of biomass carbon stocks (t C/ac) across California for mixed conifer, redwood, and woodland land cover categories.

The NBCD data were developed by Woods Hole Research Center, representing the first spatially explicit inventory for the continuous USA. This dataset was developed based on an empirical modeling approach combining USDA Forest Service Forest inventory and Analysis (FIA) data, high resolution InSAR data acquired from the 2000 Shuttle Radar Topography Mission (SRTM) and Landsat ETM+ data collected for between 1999 and 2002. Land cover and canopy density from the National Land Cover Database 2001 (NLCD 2001) (Homer et al, 2004), existing vegetation type from LANDFIRE and national elevation Data (NED) were used as predictors of canopy height and biomass estimations. The FIA data was used for the modeling as well as for the model validation.

The NBCD data have a spatial resolution of 30 m and represent biomass carbon data only for the forest cover defined by the NLCD 2001, therefore when combined with high resolution data used in this study some areas defined as forest from the high resolution data had no coinciding NBCD data. Therefore, to overcome this, an area weighted average of the carbon stock from above and belowground live tree biomass was calculated by land cover category for each sampled county (Table 3).

Table 3. Carbon stocks of live above and belowground tree biomass (tCO_2/ac) for forest types across 10 counties in California.

County	Land cover category		
	Mixed Conifer	Redwood	Woodland
	$t\ CO_2\ ac^{-1}$		
El Dorado	173		86
Los Angeles	73		38
Marin	253	329	144
Mendocino	217	311	121
Napa	158	317	61
Nevada	153		92
Placer	171		94
Shasta	174		61
Sonoma	206	311	109
Ventura	61		29
Average	164	317	83

3.2.2 Harvested Wood Products and Landfill

When trees are cleared to make way for a development or single house, they decompose and emit stored carbon to the atmosphere. However, if some of the wood is put into wood products or is landfilled, the rate of decomposition is reduced, and there is some long-term storage of carbon, rather than total emissions in the short term. According to a national survey of urban tree residue, 67% of aboveground biomass was chipped, 28% remained unchipped logs, and 5% was classified as other (NEOS 1994). Forty-two percent of the material was given away, 17% landfilled, 12% sold, 11% left on site, 6% recycled, and 3% burned for energy. Most of this residue was produced by commercial tree care companies and municipalities. In the case of trees harvested for development in the wildland-urban interface it is likely that merchantable timber is put into harvested wood products. However, the majority of the forested areas that are converted to development are woodlands or hardwood forests, and there are very few viable markets for hardwood timber in California. This wood could be shipped to a co-gen facility as biomass energy, but in most cases the shipping distance is prohibitively far.

Because there are no published estimates of harvested wood product use on developments in California, we use the following estimate of the fate of wood removed for development. For all forest types, 17% of carbon from harvested wood is immediately captured and permanently stored in landfill, as described above. In addition, for mixed conifer and redwood forests, an additional 12.5% is stored in long-term wood products (either in use or landfilled) based on estimates of carbon remaining in harvested wood products after 65 years (Smith et al, 2006).

3.2.3 Post-development plantings

Following completion of a development, there is likely to be some planting by both developers and homeowners. This would lead to an increase in vegetative biomass in the form of grasses, shrubs, and trees, and therefore an increase in sequestered carbon. However, it is difficult to know the extent of such revegetation, and it is unlikely that it is uniform across counties, forest types, or even ownerships. California law requires the maintenance of 100' of defensible space around all homes, to reduce the risk of wildfire. This requirement does not prohibit the planting of trees and shrubs, but requires the removal of all flammable, dead, or dying vegetation within 30 feet of buildings and restricts vegetation in the remaining 70 feet. Landscaping after development is most likely to be associated with urban developments and it is likely that in such developments planting will be comprised of grasses, herbaceous vegetation, shrubs and ornamental or fruit trees – as such carbon sequestration is anticipated to be low.

Given the uncertainty of post-development planting and the limits based on defensible space requirements, we use the low estimate of 3 additional tons of CO_2e per acre sequestered, a reasonable figure for herbaceous species interspersed with small shrubs.

3.2.4 Emission Factors

Emission factors represent the carbon emissions per acre cleared, based on forest type and study area. They are calculated as follows

$$EF_i = C_i - (C_i * HWP_f) - P$$

Where

EF_i = Emission factor by county and study area
C_i = Carbon stocks by county and study area, including both above and belowground carbon (t CO_2e/ac)
HWP_f = Harvested wood products/landfilled biomass by relevant forest type, as a percent of carbon stocks
P = default herbaceous/shrub planting following development, 3 t CO_2e/ac

By definition urban areas will not have biomass data to calculate carbon stocks. To compensate for this, we assume that urban forests have the same overall composition as the study area in which they are located. Therefore, to estimate the emission factors for urban forests, we used the area weighted average of emission factors across the study area. For this reason, the emission factors for urban forests differs by study area, while the emission factors for all other forest types are the same across each county. The final emission factors are provided in Table 4.

Table 4. Emission Factors showing carbon emissions per acre cleared, by forest type and geographic area.

County	Study Area	Land cover category			
		Mixed Conifer	Redwood	Woodland	Urban Forest
		$t\ CO_2\ ac^{-1}$			
El Dorado	**22**	119	-	68	70
Los Angeles	**26**	48	-	29	29
	27				29
	28				29
Mendocino	**1**	150	216	97	206
	2				197
	3				162
Napa	**9**	108	220	48	48
Nevada	**18**	105	-	73	105
	20				107
Shasta	**10**	120	-	48	118
	11				50
	12				49
	14				48
	15				115
Sonoma	**7**	142	216	87	192
	8				89

CHAPTER 4: Deforestation Results

Seventeen 9.7 square mile sampling areas were analyzed for new development, and a subset of 4 was analyzed in addition for secondary development[3]. A total of 80 new developments, 5 secondary developments, and 26 forest clearings were identified across these sampling areas (Table 5). The developments included a total of 557 developed parcels within 14 multi-house developments and 66 single house developments, as well as 5 parcels with secondary development and 26 parcels with clearing. Appendix A has images of developments assessed for this study.

[3] In one of the sampling sites in Mendocino County and two in Shasta County no forest loss from development was identified within the analyzed time period.

Table 5. Parcels examined by county (NB. Does not include all development in counties, only in specific study areas.)

County	Sampling Area Count	Parcel Count	Multi-House Development Count	Single House Development Count	Secondary Development Count*	Forest Clearing without Development*
El Dorado	1	30	1	2	-	-
Los Angeles	3	51	2	2	-	-
Mendocino	3	24	0	1	2	19
Napa	1	26	1	8	-	-
Nevada	2	23	1	4	-	-
Shasta	5	345	7	39	-	-
Sonoma	2	58	2	10	3	7

*Those counties with no numbers for secondary development and forest clearing without development were only analyzed for forest loss resulting from new development.

4.1 Multi-house developments

The characteristics of multi-house developments varied widely both within and across counties (Table 66). The number of parcels ranged from a low of 4 in Shasta County, to a high of 114, also in Shasta County, and the average parcel size ranged from 0.09 acres in Shasta County to 1.55 acres in Los Angeles County. The average percent forest loss by parcel ranged from 15.6% in Nevada County to 96.4% in Shasta. It is important to note that parcels were not entirely in forest cover. Figure 88 shows an area in Shasta County, before and after development.

Table 6. Summary of impacts of multi-house developments

Development	Dominant Landcover Class	Number of parcels	Average Parcel Size (ac)	Average Forest Loss per Parcel (ac)	Average Forest Loss per Parcel (%)
El Dorado D16	Woodland	28	1.21	0.31	49
Los Angeles D17	Woodland	32	1.55	0.38	91
Los Angeles D18	Woodland	17	2.37	0.5	84
Napa D3	Urban	18	0.23	0.1	79
Nevada D15	Woodland	19	0.91	0.03	16
Shasta D10	Urban	27	0.09	0.03	93
Shasta D11	Urban	6	0.72	0.14	95
Shasta D13	Woodland	114	0.39	0.13	47
Shasta D14	Urban	4	0.49	0.2	54
Shasta D19	Urban	35	0.38	0.23	96
Shasta D6	Woodland	57	0.29	0.2	94
Shasta D7	Urban	63	0.35	0.17	93
Sonoma D1	Urban	22	0.2	0.07	76
Sonoma D2	Urban	16	0.13	0.07	80

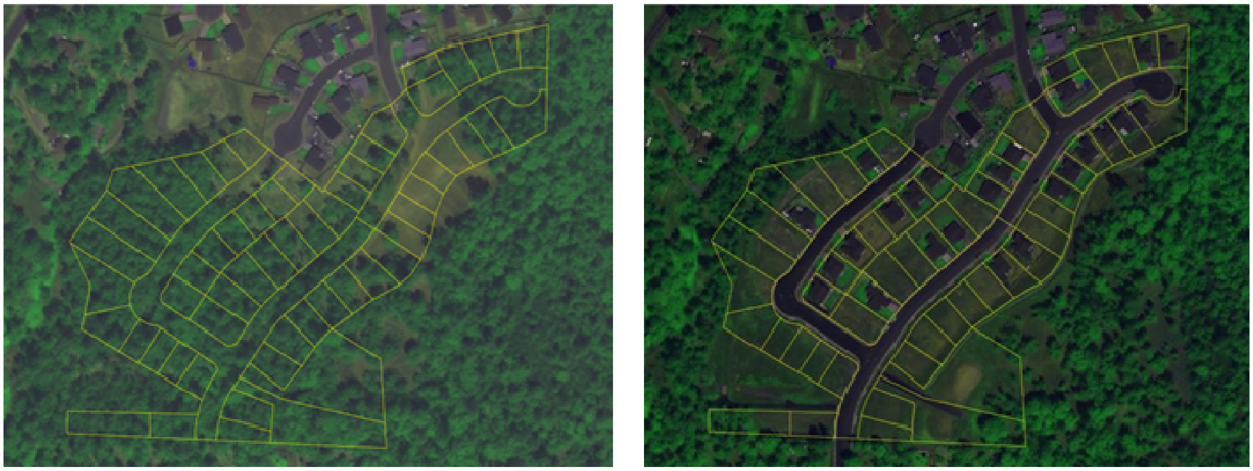


Figure 8. Multi-house development in Shasta County, showing parcels in 2003 before development (left) and in 2008 after development (right0

Across counties, the average size of a parcel in a multi-housing development ranged from 0.17 acres in Sonoma to 1.83 acres in Los Angeles. The average forest loss ranged from 16% in Nevada to 88% in Los Angeles. (See

Table 77) There is a correlation between initial forest area and final forest area (R^2=0.47, Figure 9), indicating that in multi-house developments, 72% of forest cover is cleared.

Table 7. Impacts of multi-house developments by county (±90% confidence interval)

County	Average Parcel Size (ac)	90% CI	Average Forest Loss (ac)	90 % CI	Average Forest Loss (%)	90% CI
El Dorado	1.21	*0.20*	0.31	*0.08*	49	*8.2*
Los Angeles	1.83	*0.81*	0.42	*0.18*	88	*2.7*
Napa	0.23	*0.04*	0.10	*0.02*	79	*11.9*
Nevada	0.91	*0.09*	0.03	*0.02*	16	*8.8*
Shasta	0.34	*0.03*	0.16	*0.02*	76	*2.9*
Sonoma	0.17	*0.10*	0.07	*0.03*	78	*8.4*

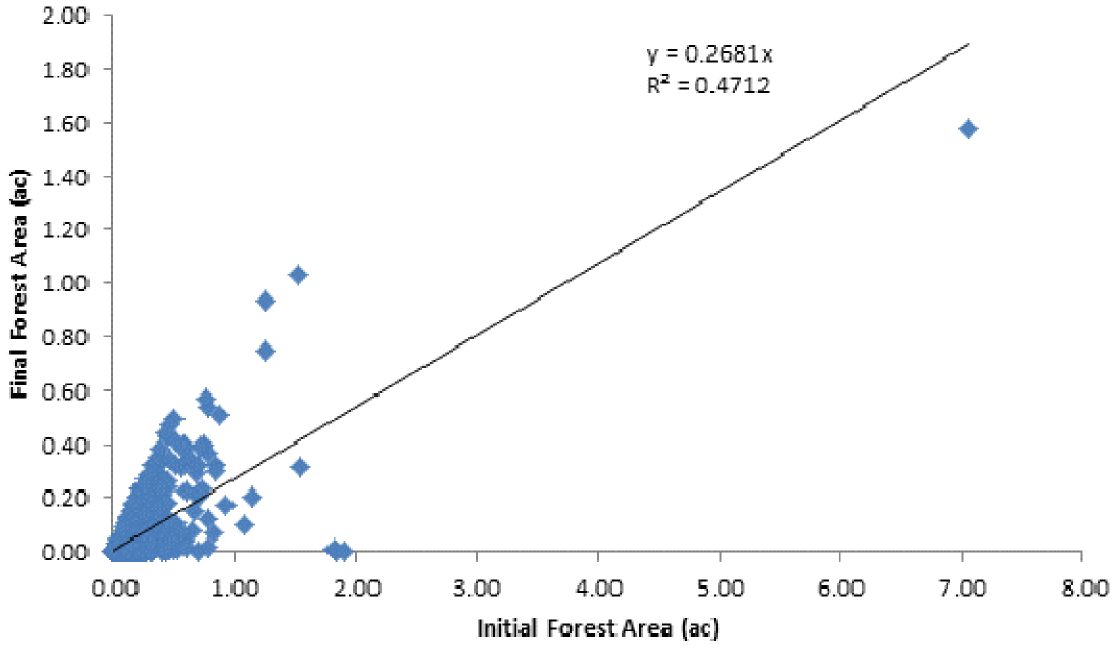


Figure 9. Correlation between initial forest area (ac) and final forest area (ac) in multi-house developments

4.2 Single House Developments[4]

The characteristics of single house developments also varied widely across and within counties (Table 8). Across 62 builds considered single house constructions the mean parcel size was 2.9 acres with a range of 0.12 to 13.29 acres (90% confidence interval = 0.70 acres and the median parcel size is 1.02 acres). When split by landcover class, the mean parcel size was just 0.35 acres in urban settings but 4.43 acres in extra urban locations.

Forest cover dropped from an average of 58% to 33% a mean loss of 48% cover. The 90% confidence interval for cover loss was 6.4%. Again dividing between urban versus non-urban locations, mean cover dropped from 47% to 15% in urban settings but from 65% to 43% in non-urban settings.

[4] The results of the basic and refined approaches are combined for single house developments. Multi-house developments were only found in the areas analyzed using the basic approach and secondary development and clearing without development were only analyzed in the refined approach.

Table 8. Summary of impacts of single house developments

Development	Dominant Landcover Class	Parcel Size (ac)	Initial Forest Cover (%)	Final Forest Cover (%)	Forest Loss (%)
El Dorado S41	Woodland	6.86	35	34	1
El Dorado S42	Woodland	10	51	45	11
Los Angeles S43	Woodland	2.5	21	14	31
Los Angeles S44	Woodland	0.98	63	10	84
Mendocino S62	Redwood	1.79	52	40	24
Napa S50	Urban	0.12	27	13	51
Napa S51	Urban	0.12	45	2	94
Napa S52	Urban	0.15	70	27	62
Napa S53	Urban	0.14	43	15	64
Napa S54	Urban	0.12	39	3	91
Napa S55	Urban	0.12	14	1	95
Napa S56	Urban	0.14	19	0	100
Napa S8	Urban	0.22	53	16	70
Nevada S63	Mixed Conifer	3.62	86	68	20
Nevada S64	Mixed Conifer	4.88	80	65	19
Nevada S65	Mixed Conifer	2.56	42	36	14
Nevada S66	Woodland	3.21	76	57	25
Shasta S9	Woodland	0.99	87	40	54
Shasta S10	Woodland	2.8	87	81	6
Shasta S11	Woodland	1.06	75	54	28
Shasta S12	Woodland	0.34	46	37	21
Shasta S13	Woodland	1.03	66	49	26
Shasta S14	Woodland	1.27	57	28	51
Shasta S15	Urban	0.14	55	11	80
Shasta S16	Urban	0.15	53	9	84
Shasta S17	Woodland	0.84	72	30	58
Shasta S18	Urban	0.4	31	10	69
Shasta S19	Urban	0.64	12	4	70
Shasta S20	Urban	0.47	61	6	90
Shasta S21	Woodland	2.18	88	50	43
Shasta S22	Woodland	5.37	70	67	5
Shasta S23	Woodland	4.83	72	53	26
Shasta S24	Woodland	6.18	85	68	20
Shasta S25	Woodland	5.09	49	42	15
Shasta S26	Woodland	8.04	81	75	8
Shasta S27	Woodland	4.92	69	68	1
Shasta S28	Woodland	5.17	63	53	15
Shasta S29	Woodland	5.18	60	48	21
Shasta S30	Woodland	6.01	64	51	20
Shasta S31	Woodland	5.93	78	50	36
Shasta S32	Woodland	6.18	88	67	24
Shasta S33	Woodland	5	58	53	8
Shasta S34	Woodland	5.15	76	54	29
Shasta S35	Woodland	7.37	32	9	72
Shasta S36	Woodland	9.39	65	16	76
Shasta S37	Woodland	13.29	49	32	34
Shasta S38	Woodland	10.66	57	17	70

Development	Dominant Landcover Class	Parcel Size (ac)	Initial Forest Cover (%)	Final Forest Cover (%)	Forest Loss (%)
Shasta S39	Woodland	7.33	48	16	66
Shasta S40	Urban	0.28	56	14	75
Shasta S45	Woodland	8.12	96	22	76
Shasta S46	Woodland	0.3	64	24	63
Shasta S47	Woodland	0.3	45	8	83
Shasta S48	Urban	0.19	53	37	30
Shasta S49	Urban	0.18	60	33	45
Shasta S57	Woodland	0.51	41	8	80
Shasta S58	Woodland	0.65	35	20	43
Sonoma S1	Urban	0.54	63	13	80
Sonoma S2	Urban	0.46	29	4	85
Sonoma S3	Urban	0.62	39	10	76
Sonoma S4	Urban	1.01	61	20	68
Sonoma S5	Urban	0.75	41	9	77
Sonoma S6	Urban	0.66	83	59	29
Sonoma S7	Urban	0.4	73	29	60
Sonoma S59	Redwood	1.3	100	89	11
Sonoma S60	Redwood	1.66	99	98	2
Sonoma S61	Redwood	6.04	75	69	8

An example single house development in Los Angeles County is shown in Figure 1010.

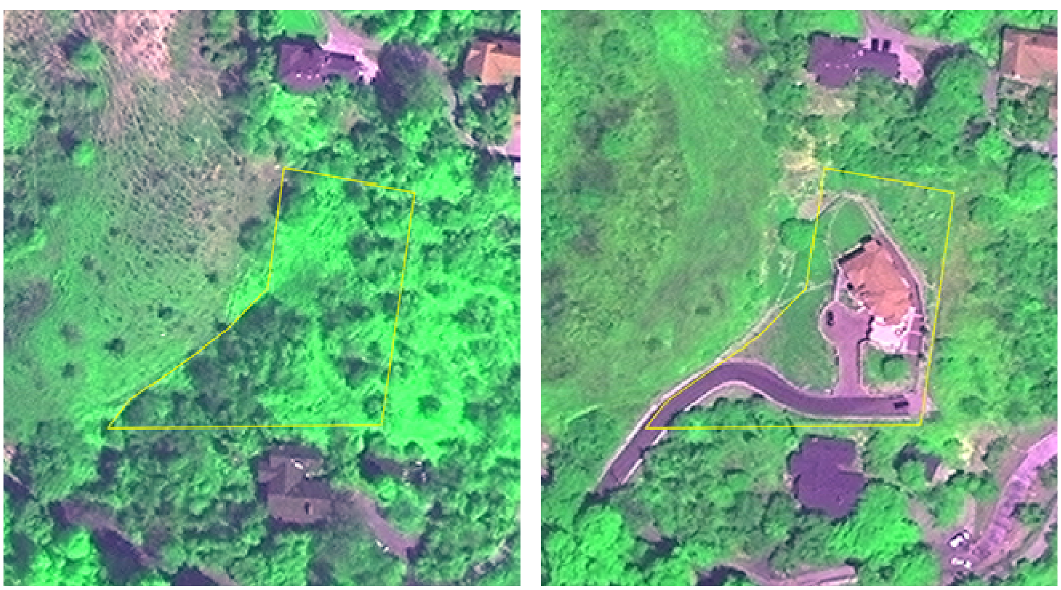


Figure 10. Los Angeles County single house development, showing parcels in 2004 before development (left) and in 2009 after development (right)

For single house developments, the average size of a parcel ranges from 0.14 acres in Napa to 8 acres in El Dorado. The average forest losses range from 6% in El Dorado to 78% in Napa (see Table 99). This correlates with parcel size (R^2 = 0.37, Figure 11), however, the clear pattern is a high likelihood of full forest clearance in very small parcels with significantly more variation the larger the parcels get depending on initial cover and the particular circumstances of the build. A stronger correlation exists between initial forest cover and final forest cover (R^2 = 0.75, Figure 12). This correlation shows a 35% loss in forest cover from before to after new development.

Table 9. Impacts of single house developments by county (±90% confidence interval)

County	Average Parcel Size (ac)	90% CI	Average Forest Loss (ac)	90% CI	Average Forest Loss (%)	90% CI
El Dorado	8.43	*4.58*	0.29	*0.78*	6	*14.6*
Los Angeles	1.74	*2.21*	0.34	*0.52*	58	*77.8*
Mendocino*	1.79	*NA*	0.22	*NA*	24	*NA*
Napa	0.14	*0.02*	0.04	*0.02*	78	*12.4*
Nevada	3.57	*1.04*	0.53	*0.28*	20	*5.2*
Shasta	3.69	*0.94*	0.88	*0.37*	44	*7.3*
Sonoma	1.34	*0.97*	0.21	*0.07*	49	*19.3*

**Only one development found in study area in Mendocino County.*

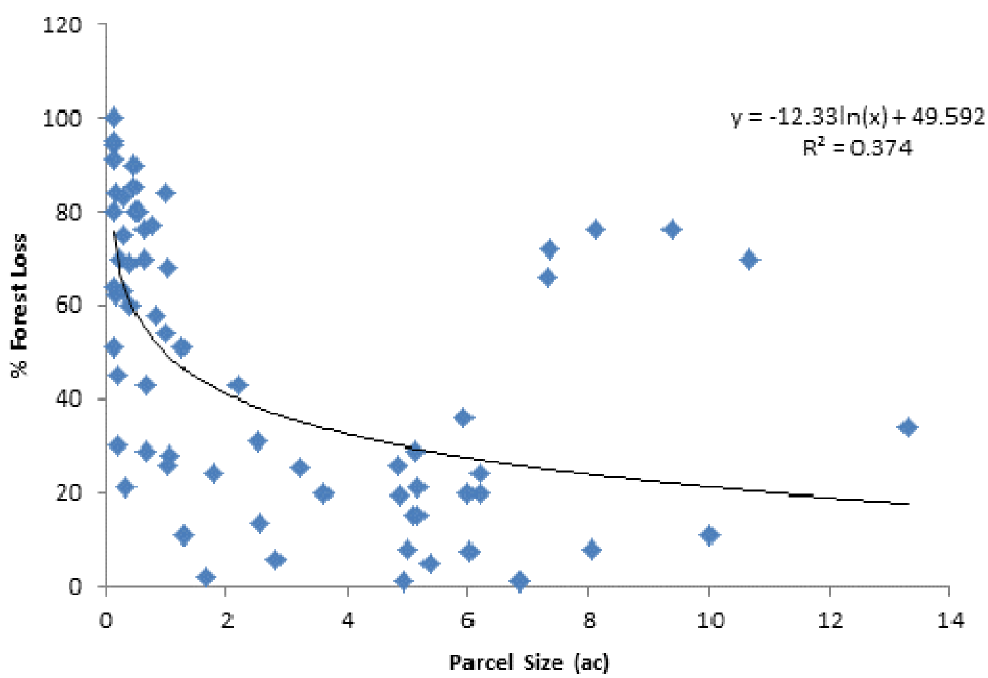


Figure 11. Correlation between parcel size and % forest loss for single house developments

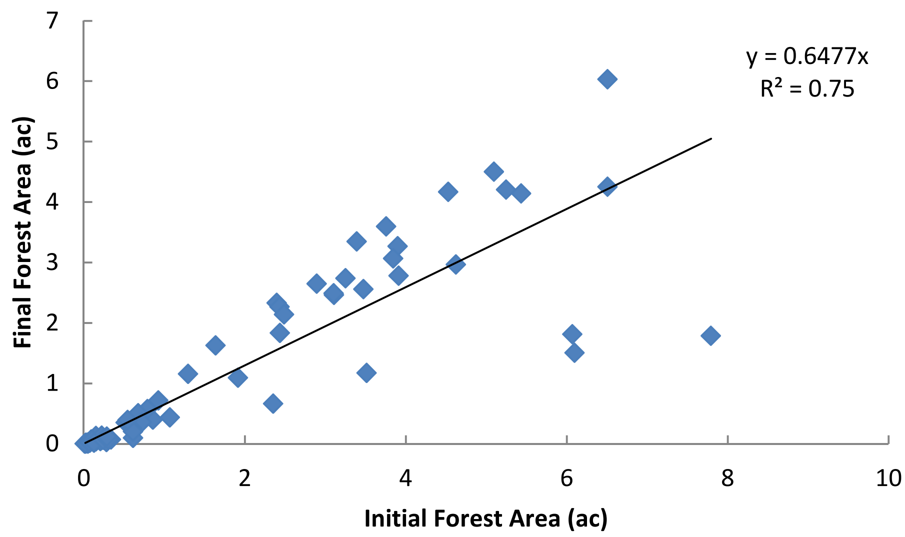


Figure 12. Correlation between initial forest area (ac) and final forest area (ac) in single house developments

4.3 Secondary development

Secondary development was only analyzed in Sonoma and Mendocino Counties, with the goal of examining the proportion of forest loss that occurs outside of new-build development. The characteristics of secondary developments for Sonoma and Mendocino County are presented in Table 10. Across the 4 sampling areas (totaling 20,270 acres), 5 instances of secondary development were recorded on 5 parcels. The average parcel size varied across the counties, ranging from 2.04 to 4.98 acres for Mendocino County and 1.3 to 49.53 acres for Sonoma County with average forest loss in these parcels ranging from 0.09 acres to 0.3 acres.

Table 10. Summary of impacts of secondary developments

County (Study Area)	Dominant Landcover Class	Number of parcels	Average Parcel Size (ac)	Average Forest Loss per Parcel (ac)	Average initial forest (ac)	Average Forest Loss per Parcel (%)
Mendocino (1)	Redwood	2	3.51	0.09	0.63	14%
Mendocino (2)	Redwood	0	-	-	-	-
Sonoma (7)	Redwood	3	17.95	0.30	17.66	2%

4.4 Forest clearing without development

Forest clearing without development, like secondary development, was only analyzed in Sonoma and Mendocino counties. The characteristics of clearing within parcels without either new or secondary development are presented in Table 11. Across the 4 sampling areas (totaling 20,270 acres), 26 instances of forest clearance without development were recorded on 26 parcels. The average parcel size varied greatly, ranging from 1.31 to 17.71 acres across both counties.

The average forest loss was the highest for redwood forest in both Sonoma County (0.76 acres) and Mendocino County (0.18 acres).

Table 11. Summary of impacts of forest clearing without developments

County (Study Area)	Dominant Landcover Class	Number of parcels	Average Parcel Size (ac)	Average Forest Loss per Parcel (ac)	Average initial forest (ac)	Average Forest Loss per Parcel (%)
Mendocino (1)	Mixed conifer	1	2.4	0.02	2.06	1%
	Redwood	14	3.12	0.19	2.16	9%
	Woodland	1	1.31	0.02	0.69	3%
Mendocino (2)	Redwood	3	4.07	0.15	3.74	4%
Sonoma	Redwood	7	17.71	0.76	17.49	4%

CHAPTER 5: Emission Results

5.1 Multi-house developments

Total CO_2 emissions in multi-house developments across the study areas ranged from 34 tons in a Shasta County development with 27 parcels averaging only 0.09 acres in size to 735 tons in another Shasta County development with 114 parcels averaging 0.39 acres. Average per parcel emissions by development ranged from 1.3 tons in the Shasta County development with small average parcel size to 21.4 tons in a development in El Dorado County with a higher average parcel size (1.2 acres), moderate forest cover loss (49%), and a moderately high emission factor (69t CO_2e/ac). (See Table 12)

Table 12. Impacts of multi-house developments by development

Development	Number of Parcels	Average Parcel Size (ac)	Initial Forest Cover (ac)	Average Forest Loss (%)	Total Development CO_2 Loss (tons)	Average Parcel CO_2 Loss (tons)
El Dorado D16	28	1.21	0.59	49	600	21.4
Los Angeles D17	32	1.55	0.42	91	352	11.0
Los Angeles D18	17	2.37	0.63	84	244	14.3
Napa D3	18	0.23	0.15	79	90	5.0
Nevada D15	19	0.91	0.22	16	49	2.6
Shasta D10	27	0.09	0.03	93	34	1.3
Shasta D11	6	0.72	0.15	95	41	6.9
Shasta D13	114	0.39	0.29	47	735	6.5
Shasta D14	4	0.49	0.43	54	39	9.6
Shasta D19	35	0.38	0.24	96	398	11.4
Shasta D6	57	0.29	0.23	94	554	9.7
Shasta D7	63	0.35	0.18	93	528	8.4
Sonoma D1	22	0.20	0.09	76	136	6.2
Sonoma D2	16	0.13	0.09	80	98	6.1

The average within-county CO_2 loss ranged from 2.6 tons per parcel in Nevada County to 21.4 tons in El Dorado County (See Table 133). El Dorado County has somewhat low average forest cover loss, but has high per acre carbon stocks and somewhat large parcels. Los Angeles County, on the other hand, has low per acre carbon stocks and emission factors (Table 3 and 4), so the relatively high average CO_2 loss per parcel in the county is a function of larger parcels and a high percent of forest cover removed.

Table 13. Impacts of multi-house developments by county (±90% confidence interval)

County	Average Parcel Size (ac)	Initial Forest Cover (ac)	Average Forest Loss (%)	Sum CO_2 Loss (tons)	Average Parcel CO_2 Loss (tons)	*90% CI, avg CO_2 loss*
El Dorado	1.21	0.59	49	600	21.4	*5.7*
Los Angeles	1.83	0.49	88	596	12.6	*5.3*
Napa	0.23	0.15	79	106	5.0	*0.7*
Nevada	0.91	0.22	16	49	2.6	*1.5*
Shasta	0.34	0.23	76	2,327	7.6	*0.9*
Sonoma	0.17	0.09	78	234	6.2	*3.0*

5.2 Single house developments

Total emissions from single house developments range widely, from 1 t CO_2 in Napa County to 287 t CO_2 in Shasta County (Table 14). Because gross emissions are a function of parcel size, percent of parcel in forest cover, and percent of forest cover lost to development, it is somewhat more useful to look at the per acre emissions based on parcel size. This ranges from 0.2 t CO_2/ac on a parcel in El Dorado County which had only 1% of forest cover removed to 45 t CO_2/ac on a parcel in Sonoma County which had 80% of forest cover lost.

Table 14. Impacts of single house developments by development

Development	Parcel Size (ac)	Initial Forest Cover (ac)	Forest Loss (%)	Total CO_2 Emission (tons)	Emissions per acre (tCO_2/ac)*
El Dorado S41	6.86	2.40	1	2	0.2
El Dorado S42	10	5.10	11	38	3.8
Los Angeles S43	2.5	0.53	31	5	1.8
Los Angeles S44	0.98	0.62	84	15	15.3
Mendocino S62	1.79	0.93	24	48	26.6
Napa S50	0.12	0.03	51	1	6.5
Napa S51	0.12	0.05	94	2	20.3
Napa S52	0.15	0.11	62	3	20.8
Napa S53	0.14	0.06	64	2	13.1
Napa S54	0.12	0.05	91	2	17.0
Napa S55	0.12	0.02	95	1	6.4
Napa S56	0.14	0.03	100	1	9.2
Napa S8	0.22	0.12	70	4	17.7
Nevada S63	3.62	3.10	20	65	18.0
Nevada S64	4.88	3.90	19	79	16.1
Nevada S65	2.56	1.07	14	15	5.9
Nevada S66	3.21	2.44	25	46	14.2
Shasta S9	0.99	0.86	54	22	22.5

Development	Parcel Size (ac)	Initial Forest Cover (ac)	Forest Loss (%)	Total CO_2 Emission (tons)	Emissions per acre (tCO_2/ac)*
Shasta S10	2.8	2.44	6	7	2.5
Shasta S11	1.06	0.80	28	11	10.1
Shasta S12	0.34	0.16	21	2	4.7
Shasta S13	1.03	0.68	26	8	8.1
Shasta S14	1.27	0.72	51	18	13.9
Shasta S15	0.14	0.08	80	3	21.6
Shasta S16	0.15	0.08	84	3	21.7
Shasta S17	0.84	0.60	58	17	20.0
Shasta S18	0.4	0.12	69	4	10.4
Shasta S19	0.64	0.08	70	3	4.0
Shasta S20	0.47	0.29	90	12	26.6
Shasta S21	2.18	1.92	43	39	18.0
Shasta S22	5.37	3.76	5	8	1.6
Shasta S23	4.83	3.48	26	43	8.9
Shasta S24	6.18	5.25	20	50	8.1
Shasta S25	5.09	2.49	15	18	3.5
Shasta S26	8.04	6.51	8	24	3.0
Shasta S27	4.92	3.39	1	2	0.5
Shasta S28	5.17	3.26	15	24	4.7
Shasta S29	5.18	3.11	21	31	5.9
Shasta S30	6.01	3.85	20	38	6.3
Shasta S31	5.93	4.63	36	81	13.6
Shasta S32	6.18	5.44	24	62	10.0
Shasta S33	5	2.90	8	11	2.1
Shasta S34	5.15	3.91	29	54	10.5
Shasta S35	7.37	2.36	72	82	11.1
Shasta S36	9.39	6.10	76	224	23.8
Shasta S37	13.29	6.51	34	107	8.0
Shasta S38	10.66	6.08	70	205	19.2
Shasta S39	7.33	3.52	66	112	15.2
Shasta S40	0.28	0.16	75	6	20.0
Shasta S45	8.12	7.80	76	287	35.3
Shasta S46	0.3	0.19	63	6	19.2
Shasta S47	0.3	0.14	83	5	17.8
Shasta S48	0.19	0.10	30	1	7.7
Shasta S49	0.18	0.11	45	2	13.3
Shasta S57	0.51	0.21	80	8	15.7
Shasta S58	0.65	0.23	43	5	7.2
Sonoma S1	0.54	0.34	80	24	44.7
Sonoma S2	0.46	0.13	85	10	22.0
Sonoma S3	0.62	0.24	76	16	26.5
Sonoma S4	1.01	0.62	68	38	37.0
Sonoma S5	0.75	0.31	77	21	28.2
Sonoma S6	0.66	0.55	29	14	20.9
Sonoma S7	0.4	0.29	60	16	39.3
Sonoma S59	1.3	1.30	11	30.32	23.3
Sonoma S60	1.66	1.64	2	6.50	3.9
Sonoma S61	6.04	4.53	8	73.63	12.2

* Per acre emissions based on total parcel size, rather than acres of forest cover.

For single house developments, the average CO_2 loss for single house parcels ranged from 2.0 tons in Napa County to 42 tons per development in Shasta County (Table 155). It is important to note, however, that there was wide range in the emissions within each county, and all have a high confidence interval. Shasta County, in fact has the lowest confidence interval as a percent of the mean, although it is still fairly high at 18%. The average emissions per acre also ranged widely, with a low of 2.0 t CO_2/ac in El Dorado County, which has a relatively large average parcel size, and a high of 27 in Mendocino County, though this is based on only one development. Sonoma County, which has smaller parcels, relatively high percent forest loss, and high carbon stocks, had the second highest emissions per acre at 22 t CO_2/ac.

Table 15. Impacts of single house developments by county (±90% confidence interval)

County	Average Parcel Size (ac)	Initial Forest Cover (ac)	Average Forest Loss (%)	Sum CO_2 Loss (tons)	Average Parcel CO_2 Loss (tons)	*90% CI*	Average Emissions per acre (tCO_2/ac)**	*90% CI*
El Dorado	8.43	3.8	6	40	20.0	*53.5*	2.0	*5.2*
Los Angeles	1.74	0.6	58	20	9.8	*15.1*	8.6	*19.6*
Mendocino*	1.79	0.9	24	48	48	*NA*	26.6	*NA*
Napa	0.14	0.1	78	16	2.0	*0.7*	13.9	*3.9*
Nevada	3.6	2.6	20	205	51	*29.4*	13.6	*5.7*
Shasta	3.69	2.4	44	1,644	42.1	*17.5*	12.2	*2.2*
Sonoma	1.35	1.0	49	250	25.0	*11.2*	22.0	*7.9*

*Only one development found in study area in Mendocino County.

** Per acre emissions based on total parcel size, rather than acres of forest cover.

5.3 Total Development Analysis

The total development approach was designed for very limited sample areas (primarily redwood dominated areas) to test whether a significant proportion of deforestation associated with development, and resulting emissions, occurs in areas that were not new builds.

5.3.1 Secondary Development

Table 16 presents the emissions from secondary developments in Mendocino and Sonoma Counties. Because secondary development was only analyzed in four study areas, and so few instances were found in those areas, it is not possible to draw firm conclusions regarding secondary development, although in Sonoma County per acre emissions do not appear to be substantially higher or lower than those from single house developments, while in Mendocino County, they are lower.

Table 16. Impacts of secondary development by county (±90% confidence interval)

County (Study Area)	Average Parcel Size (ac)	Average Forest Loss (%)	Sum CO_2 Loss (tons)	Average Parcel CO_2 Loss w/90% CI (tons)	Average Emissions per acre w/90% CI (tCO_2/ac)*	*Comparison Average Emissions for New Development (tCO_2/ac)*
Mendocino (1)	2.04	0.21	30	30.3 (NA)	**14.9 (NA)**	*26.6*
Mendocino (2)	-	-	-	-	-	-
Sonoma	14.14	0.09	217	54.1 (32.2)	**16.7 (18.6)**	*13.14*

* Per acre emissions based on total parcel size, rather than acres of forest cover.

5.3.2 Forest Clearing without Development

Table 17 presents the emissions from forest clearing without development in Mendocino and Sonoma Counties. Because forest clearing without development was only analyzed in four study areas, and so few instances were found in those areas, it is not possible to draw firm conclusions regarding forest clearance on residential parcels without development, although per parcel emissions appear to be substantially lower than those from single house developments.

Table 17. Impacts of forest clearing without development by county (±90% confidence interval)

County (Study Area)	Average Parcel Size (ac)	Average Forest Loss (%)	Sum CO_2 Loss (tons)	Average Parcel CO_2 Loss w/90% CI (tons)	Average Emissions per acre w/90% CI (tCO_2/ac)*	*Comparison Average Emissions for New Development (tCO_2/ac)*
Mendocino (1)	2.96	0.07	583	36.5 (24.2)	**9.4 (3.7)**	*26.6*
Mendocino (2)	4.07	0.05	130	43.3 (25.7)	**12.8 (14.1)**	-
Sonoma	20.21	0.04	1,128	188.1 (243.5)	**8.51 (2.1)**	*13.14*

* Per acre emissions based on total parcel size, rather than acres of forest cover.

This type of clearing shows that deforestation occurred for reasons other than immediate development. These clearings may have occurred for a variety of reasons, including planned development that was cancelled or postponed, removal of hazard trees, or landscaping. The scale of these clearings indicates that they were not done for purposes of commercial timber harvest. They are included in this study, however, because they account for sizeable total acreage and of forest loss and carbon emissions relative. Forest clearing without subsequent development would have been included in the spatial analysis conducted by Pearson et al (2009) and could account for a proportion of total deforestation.

5.3.3 Comparison with New Builds

Comparing the forest loss and emissions from secondary development to those from new developments within these study areas provides an initial estimate of what proportion of deforestation and resulting emissions is overlooked when only new builds are considered. In both Mendocino and Sonoma Counties, new developments accounted for less than 10% of total acres of forest loss and net emissions. In Mendocino new development emissions exceed those from secondary development (6% versus 4% of the total) but in Sonoma the opposite is recorded with 15% of total recorded emissions from secondary development but only 8% from new builds. The dominant source of emissions in the given study areas in these counties is therefore clearing with no observed development. In Mendocino County, forest clearing with no development was responsible for nearly 90% of the impact across all categories, while in Sonoma County, it accounted for 78% of forest loss and total emissions. (See Table 18)

Table 18. Percent of total impact by type of forest clearing

County	Type of Clearing	Number of Parcels	Forest loss	Total CO_2 emissions
		Percent of total		
Mendocino	New development	4%	6%	6%
	Secondary development	8%	5%	4%
	Clearing w/no development	88%	90%	91%
Sonoma	New development	23%	8%	8%
	Secondary development	31%	15%	15%
	Clearing w/no development	46%	78%	78%

The sample area for consideration of development emissions outside of new builds was on the north coast and was redwood dominated. Additional work would be needed to see if this pattern is replicated in other areas and other forest types, or whether significant forest loss with no recorded immediate development is particular to redwood-dominated areas.

CHAPTER 6: Discussion

Across the seventeen sampling areas analyzed, the majority of developments occurred on woodland or urban forests, including all of the multi-house developments. Little deforestation of redwood and mixed conifer forests was observed. This echoes conversations with county planners from the counties studied, all of whom stated that nearly all development occurs as infill or on woodland areas.

The results of the previous spatial analysis by Pearson et al (2009) indicated that while most deforestation is in woodlands and urban areas, 25% of small scale deforestation occurs in redwood and mixed conifer forests. Based on the current analysis, however, it appears that little of that deforestation, especially on redwood forests, actually occurs for the purpose of new development. It likely, therefore, that small scale forest clearing in redwood and mixed conifer forests is secondary development within developed parcels, clearing without development, or timber harvest. The small sample of redwood study areas that were analyzed using the total development method indicates that focusing solely on forest clearing due to new builds overlooks a significant proportion of deforestation and emissions that occur.

While it might be expected that larger parcels would have a higher percent of forest cover removed, there is no clear correlation between parcel size and percent forest loss from multi-house developments. This is likely due to differences in topography and forest cover across developments, as there is also no clear correlation between parcel size and percent forest cover. There was a correlation between parcel size and percent forest loss on the single house developments, and the average percent forest loss for both multi-house and single-house developments had a low confidence interval.

Because carbon emissions are linked directly with the acreage deforested, the carbon impact of the multi-housing developments varies greatly from county to county. It is not possible to make a generalization of the impacts of either multi-housing or single house developments that is applicable across the state. However, emission factors could be developed for areas of specific interest throughout the state, and applied to the relevant average percent forest loss to estimate total emissions.

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APPENDIX D:
Economic Analysis

Sohngen, B., D. Hite, and L. Marzen. 2012. Economic Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity. California Energy Commission. Publication number: CEC-PIR-08-008.

Public Interest Energy Research (PIER) Program
INTERIM PROJECT REPORT

Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity

Value of Trees to Homes in California

Prepared for: California Energy Commission
Prepared by: Winrock International

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
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- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

"Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity: Emissions Analysis" is an interim report for the project Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity, grant number PIR-08-008 conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

For this study, we develop a hedonic pricing model to assess the influence of trees on house values in California. A literature review and benefit transfer exercise provide useful information on the potential scale of the effects of tree cover on home value and indicate the need to conduct primary data analyses on this issue for California. To assess the effect of tree cover on house values in California, we have linked information on house sales over the period 2002-2009 in several regions of California with data on tree canopy cover. Based on our results, we estimate that an acre of deforestation loss is worth from $4,806 to over $146,000 per acre in California. The highest loss estimate occurs in the North Coast region and is heavily influenced by estimates from Sonoma County.

Keywords: greenhouse gas, development, deforestation, carbon stock, urban, forest, valuation, hedonic pricing, home value, tree cover, quantile regression

Please use the following citation for this report:

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EXECUTIVE SUMMARY

This report analyzes the effect of tree cover on home value and the benefits to homeowners. The study reviews the literature on economic analyses conducted since the 1980s. These analyses relate various characterizations of trees on or near a home to the value of the home sale. Many of the studies were conducted in the US, although a number of the studies have been conducted in Canada and Europe. The studies indicate that home value largely increases due to nearby tree cover, although there is some evidence of satiation. Based on the results in the literature review, the presence of trees adds 4% to 19% to the value of a home.

The existing studies are highly informative, but of potentially limited use in California given the very different conditions there. Therefore, for this study, we conducted a hedonic pricing analysis for home sales in California. The hedonic pricing method proposes that houses are bundled goods with the total house value being the sum of implicit expenditures on various characteristics. We conducted the analysis across two different time periods and we relate the proportion of tree canopy of house parcels to house sale values. We find that home values are positively influenced by tree canopy cover in California, but that the benefits of increased tree canopy vary depending on location. Specifically, in one area we analyze in LA county, the value of additional tree cover is very small (only around $175 per house per 1% increase in tree cover), while in one area in Sonoma county the value is very large (over $2400 per house per 1% increase in tree cover).

An earlier study by Pearson et al. (2011) indicated that around 15,904 acres of land is deforested each year in California, or around 0.09% of the total forestland area. We apply this estimate of annual loss to the data in our sample to calculate the value of losses on a per hectare basis and to calculate the aggregate losses. The resulting estimates indicate that for the 7,025 observations in our dataset, 10.6 acres could be deforested each year, and a loss of this scale would be worth $446,000 per year. We use these data to calculate a statewide estimate that each acre of forestland lost would be worth $21,003. Thus, if just 10% of the total annual statewide deforestation occurred on homesites, the value of the externality could be around $33 million per year. Further analysis will be undertaken to determine the amount of deforestation that occurs when houses are built and these estimates will be developed for a case study in one of the study areas for this analysis.

These estimates of loss in value with deforestation (or alternatively gain in value with tree growth) incorporate the effects not only of the aesthetic value of the trees, but also the implications of the trees for insurance rates and energy consumption. Hedonic models capture all relevant components of house value, or at least those that can be measured. Thus, it is not necessary to separately measure the value of gains in heating and cooling or insurance rates with additional trees.

CHAPTER 1: Introduction

There has been much concern in California and elsewhere that as development occurs, trees are removed from development sites, and carbon is lost. This carbon loss could have important implications for climate change, but also the loss of tree cover could have important consequences for home value. There are now a large number of studies suggesting that trees influence home value, and many of these studies suggest that additional trees have a positive influence on home value. This study examines the potential influence of trees on homes and assesses the potential externality that arises when deforestation occurs as home-sites are developed.

Many different factors ultimately influence the value of trees on homes, including the aesthetic effects of trees, the influence of trees on energy consumption, and the influence of trees on insurance rates. Within housing markets, however, one would expect that each of these would ultimately be capitalized into the value of the house itself. For instance, a well-insulated home with trees on the west side to shade it from summer sun would likely use less energy for cooling than a similar house with less efficient insulation and no trees. Home purchasers will factor these components into their pricing decisions when offering to purchase a home. Similarly, trees will influence home maintenance costs, which homeowners will factor into their decisions. Insurance rates also influence home values. Most purchasers for example, get estimates of insurance rates from their agents before ultimately purchasing a home, and most real estate agents will help purchasers calculate ownership costs which include mortgage payments, insurance payments, and real estate taxes. Although insurance is paid separately, all else equal, higher insurance rates to account for potential damages from nearby trees (e.g., from fire) will be offset by a lower house value of equal proportion.

For this study, we develop a hedonic pricing model to assess the influence of trees on house values in California. The hedonic pricing model, developed by Rosen (1974), proposes that houses are bundled goods, with the total house value being the sum of implicit expenditures on various characteristics. These characteristics include size and quality of the structure itself (e.g., square footage, number of rooms, presence of a fireplace), the quality of the neighborhood (e.g., school quality, crime statistics), and environmental characteristics like air pollution, views, wetlands, or trees. The hedonic pricing model allows us to estimate the effects of environmental amenities on home values using statistical techniques, and it has been used widely over the years (e.g., Cavailhes, 2009; Nelson, 2010; Tapsuwan, Ingram, Burton and Brennan, 2009).

While it is tempting to think of the influence of trees on energy use or insurance rates as having a different impact on house value than the estimates calculated by the hedonic model, hedonic estimates of the effects of trees on house values will encompass all potential values that can be capitalized into the value of a home. Of course, the influence of trees on energy use, for example, can be separately calculated (e.g., McPherson and Rowntree, 1993 or Donovan and Butry, 2009), but hedonic estimates will include the influence of each of the other potential effects. Thus, while it is useful to review the potential effects of trees on energy use, we will only calculate hedonic values in this study.

The study began with a thorough literature review of economic analyses that have estimated the effect of tree cover on home values. Studies are drawn mostly from the United States, but some have been conducted in Europe and Canada. The first part of the review details information provided directly in each of the studies reviewed. The literature review illustrates that there are no studies available on the effect of tree cover on home values in California, the region of interest for our analysis. In addition to reviewing the literature on hedonic studies, we also examine the literature assessing the effects of trees on energy consumption. Unlike the hedonic literature, there have been many studies of this sort in California.

Armed with the many studies on the effects of trees on home values, we undertake a benefit transfer exercise to estimate the value of tree cover on homes in California. The benefit transfer uses existing studies from other regions to provide an estimate of the influence of tree cover on home value. Although this function is generated from data outside of California, the benefit transfer exercise provides preliminary estimates for California. It also provides a baseline for comparison against our later estimates of a hedonic model for California itself.

The literature review and benefit transfer exercise provide useful information on the potential scale of the effects of tree cover on home value. They also suggest the importance of conducting primary data analyses on this issue for California. The results of the literature review suggest that the effects of trees are influenced by many factors, including neighborhood characteristics, types of trees, climatic conditions, etc. It is thus important to conduct specific analysis for California, given the wide variety of tree cover in that state.

To assess the effect of tree cover on house values in California, we have linked information on house sales over the period 2002-2009 in several regions of California with data on tree canopy cover. Previous research by Winrock International examined tree cover changes in several study areas of California (Pearson et al., 2011). For this study, we have taken maps for a number of these study areas in the state and calculated contemporaneous tree canopy cover for parcels with home sales. These data are then linked to information on home sale prices (for homes which had a sale) for the year in which the mapped image is available.

The earlier analysis by Winrock (Pearson et al., 2011) considered 28 different study areas in the state to assess tree cover change. That earlier study, however, did not calculate actual tree cover in each time period. For this hedonic analysis, our goal was to link house sale value to tree cover, so we needed actual tree cover for the period when the sale occurred. We therefore limited our analysis to six of Winrock's original study areas. These six study areas were selected in conjunction with Winrock personnel to cover a range of California tree types and market locations. In addition, they were selected to be in regions with a sufficient number of house transactions to conduct a statistical hedonic analysis.

This report is structured as follows. The first section is a literature review of the hedonic literature on the effects of trees on home values. Then these data are used to develop a benefit transfer function to provide information on the value of tree cover in California. The third section contains a literature review of the effect of trees on home energy use and insurance rates. The fourth section describes the hedonic analysis we conducted. The final section is a policy analysis with the data and a discussion of the results.

CHAPTER 2: Literature Review

One of the earliest studies assessing the implications of trees on home values, by Anderson and Cordell (1988), was done in Athens, Georgia. They considered 844 sales of single family residences from 1978-1980. They used photographs from the Multiple Listing Service (MLS) books for the area to determine the number of trees on the property. They classified trees into evergreen and deciduous and into three size classes (small, medium and large). They conducted several regression analyses. Their results suggest that the average tree cover at the time would benefit home value by 3.9-4.6%, with different results for hardwoods versus softwoods. They also found a slight preference for larger trees by home buyers.

Two studies reviewed used non-hedonic methods to develop estimates. One study by Morales et al. (1983) considered the city of Greece, New York, and compared the tree valuation methods of the International Society for Arboriculture to methods using sales data from the region. They did make comparisons across house sales, but they did not use hedonic methods. They considered relatively few homes in their analysis. They found that the price difference between homes with trees on the lot and homes without trees on the lot was $9500. With an average value of a non-treed lot of $51,108 and the average value of the treed lot of $60,614, the presence of trees added around 17% to home value. One major problem with this analysis is that the houses with trees were also larger on average, and the size difference can explain most of the difference in value. Using the tree valuation guide, they found an average value of the trees on the lots of $6,000.

Martin et al. (1989) did a study similar to that of Morales et al. in Austin Texas. One additional problem with their study, however, is that they used appraised values and not sales values when making their comparisons. Using the appraised values of houses, they found that trees add $18,000 to the value of houses, or around 19% to the value. Using the tree valuation guide, they found similar results.

Powe et al. (1995) conducted a hedonic study in Newcastle Upon Tyne, England for the period 1990-1992, considering 519 transactions. They used a number of environmental amenities, but these data were collected at a fairly aggregate level. They used a dummy variable (i.e., a variable that is 1 if the amenity exists and 0 if not) for whether or not tree cover exists within 500 meters of a house sale. Their estimates were conducted in British Pounds, so only the percentage is provided. They found that the presence of deciduous trees would enhance house value by 8%. They did suggest a note of caution interpreting the results on this variable, however, because it interacted with the area of the home.

Geoghegen et al. (1997) considered residential sales from 1990 in the Patuxent river watershed between Baltimore MD and Washington, DC. They included both agriculture and forestry in their measure of open space, so it is impossible in their study to separate the two land uses. They found that open space within 0.1 km had a positive effect on house value (0.0189%) and open space within 1 km had a negative effect (-0.034%). Both of these effects were significant, but they do not provide average house value so we are unable to determine the value of the effect.

Tyrvainen (1997) examined the value of recreational and wooded areas to homes in Joensu, Finland based on data from 1,006 real estate deals in the period 1984-1986, although all prices were deflated to 1983 values. Three variables were chosen for analysis: distance to nearest wooded recreational area, distance to nearest forested area, and the relative amount of forested area in the houses' district. The results indicated that increasing the distance to wooded recreation areas reduced the value of the property, as expected, and percentage forest cover in the housing district increased values, but increasing distance to the nearest forested area also increased values. This last result was contradictory to what the author expected to find. The authors suggested that perhaps most of the homes in the region have substantial forest around them, so proximity to forest does not necessarily provide additional value.

Tyrvainen and Miettenen (2000) conduct a follow-on study to Tyrvainen (1997) in Salo, Finland. They used 590 transactions from the mid-1980s for the analysis. Their results indicate that distance to a forested recreational area has little impact on house value, but increasing distance to nearest forested area reduced value. This is the reverse of the result found in Tyrvainen (1997). They also find that a higher proportion of forest in the housing district increased value. Having a view of forest also increased value. They found that distance to the wooded park has an effect only within the first 300 meters of the home. Further distances had little effect. Residents in Salo are found to pay a 4.9% premium for a house with a view of forest.

The study by Mahan et al. (2000) used 14,485 market-based residential sales for Multnomah County, Oregon (suburb of Portland) that occurred between June 1992 and May 1994. They adjusted sales prices to a May 1994 price level. The average sales price for a residence was $123,109 and the median price was $104,240. Their primary focus was on the value of wetlands to nearby homes, but they did specifically examine forested wetlands. Wetlands were determined to have a positive, significant effect on homes, but forested wetlands were not found to be distinguishable from other types of wetlands. Increasing wetlands size by one acre increased the residence's value by $24, thus increasing forested wetland area by 1 acre would have the same effect. Similarly, reducing the distance to the nearest wetland by 1,000 feet increased home value by $436.

A study by Lutzenhiser and Netusil (2001) examined the effect of various amenities on house sales in Portland, OR using a dataset of 16,636 house sales from 1990-1992. The authors did not look at trees specifically but looked at parks and open space. They considered several types of parks. Natural parks, or those with more than 50% of the land devoted to natural land cover, were found to have a positive effect on house values if located within 1.5 kilometers of the house. A park of this type located within 1.5 km of the home increased house value by $10,648, or 16% of the average house value. They found that a natural park of 258 acres would maximize value. In addition, the authors examined whether distance to the park would influence value; they found that natural parks at all distances less than 1.5 km would increase value, but the maximum value would occur at 400-600 feet. Urban parks (those with less than 50% of the park in natural cover) or specialty parks had positive effects on house value, but the effects were smaller.

Netusil (2005) used 30,015 property transactions in the year 2001 to assess the effect of tree canopy on home value in Oregon. In that study, tree canopy is defined as more than one continuous acre of tree cover. The author assessed the effect of tree canopy on house prices in different zones around a property (on the property, within 200 feet, within 0.25 miles, between 0.25 and 0.5 miles). The study showed that tree canopy on the property had no statistically significant effect on the house value, although tree canopy combined with a stream on the property enhanced property value by 12.2%. At greater distances, tree canopy had a larger, positive effect on home value. If there is tree canopy within 200 feet, the value of the house rises by 2%, or $3,503 given the average house value of $175,160 in the study. If there is tree canopy within 200 feet to 0.25 miles (1300 feet), house value increases by 1.13%, or $1,980. Beyond 0.25 miles, trees have little additional effect.

A more recent study by Netusil et al. (2010) used the same data from Portland, Oregon for the year 2001 as the study by Netusil (2005). They examined the effect of the percent of tree canopy within 0.25 mile of the properties that sold. All transactions were used to calculate the first stage analysis and to determine the marginal effects. They conducted a second stage analysis using survey data on 440 property owners to derive a demand function for tree cover proportion. Of the 30,015 observations in the dataset, there are 9,353 observations with no tree canopy within 0.25 miles of the property and 27,583 properties with no tree canopy on the property. They conducted two sets of first stage estimates. A model with a quadratic functional form (i.e., a variable for % tree cover and a separate variable for % of tree cover squared) indicated that the proportion of tree cover has a positive and significant effect on house value on average. Further, they found that the optimal canopy cover was 18%. A model using log transformed data, however, found that the optimal tree cover was 0%. Their results were heavily influenced by sales occurring in the Northwest and Southwestern part of Portland. These regions already have heavy tree cover so additional tree cover is not necessarily a desired amenity because it possibly will reduce views and sunlight exposure.

Summary results from the second stage estimates extracted directly from Table 10 in Netusil's paper are presented in Table 1. The estimates indicate that at the low end, 2.5% tree canopy cover within 0.25 miles would enhance house value by $548 to $1,672. The average tree canopy for the study is 7.2%, and this would provide benefits of $1,310 to $4,416, or 0.7% to 2.5% of the total value of the house. They also calculated that at the sample average, each additional acre of tree canopy cover within 0.25 miles of a house would benefit the house by $111 to $350 per acre of tree cover.

A study by Kadish and Netusil (2012) uses the same housing dataset as described in the two other papers by Netusil, but they use substantially more detailed land cover data. They also calculate the value of tree cover, both on the property and in nearby areas. They find that tree cover on the property has a positive effect on house value, although the effect is relatively small. They also find that tree cover within 200' to ½ mile have positive effects on home values, although they do not calculate the implications of changing these for home value.

Table 1. Reproduction of Table 10 from Netusil et al. (2010). Per property benefit estimates for alternative canopy cover and 95% confidence intervals.

Percentage of Tree Canopy within 0.25 miles	Results using quadratic first stage and linear second stage regressions	Results using quadratic first stage and log second stage regressions
2.53%	$1,672 +/- $15	$548 +/- $1
7.21%	$4,416 +/- $42	$1,310 +/- $5
8.21%	$4,944 +/- $47	$1,459 +/- $5
15%	$7,988 +/- $87	$2,409 +/- $8
25%	$10,747 +/- $144	$3,685 +/- $14
35%	$11,453 +/- $202	$4,874 +/- $18
40%	$11,037 +/- $231	$5,447 +/- $20

Kestens et al. (2004) examined the effects of trees on house sales in Quebec City, Quebec using two datasets from two different time periods. They used a variety of different tree measures and thus provided information on how to integrate satellite data or images and aerial photographs into a hedonic analysis. The first dataset was for 724 houses that sold in the period 1986-87, and used aerial photographs to determine tree characteristics. The second dataset was for 2,278 houses sold between 1993-1996. This dataset was linked with a Landsat TM 5 image from 1999.

Kestens et al. (2004) found that for both datasets, woodlands in the neighborhood had a negative effect on house value. These woodlands were essentially public parks with woody plant cover. They were measured within 1 km of the house, so not necessarily within the immediate neighborhood. They found that tree cover on residential properties within 100m and 500m would have a positive effect on house value. A 10% increase in the proportion of tree cover within 100 meters would increase house value by 0.7 to 1.0%, or $1,237 to $1,978. A 10% increase in the proportion of tree cover within 100 meters would increase house value by 2.5%, or $3,089. They also found that lower tree density would reduce house value.

Des Rosiers et al. (2007) considered 598 properties that sold at least once in Quebec City, Canada between 1993 and 2000. Interestingly, they found that young trees had a negative effect on house values. They did not find that other tree variables had a significant effect, but they did find a number of interaction variables (e.g. tree variables times income) were significant. These findings suggest that landscaping variables interact with the demographics of the homeowner and thus it is important to account for demographic variables when estimating models. Therriault et al. (2002) used the same dataset and found that, not surprisingly, landowners who have an appreciation of trees on site were willing to pay a 4% premium for a house with trees. For families with children, trees on site have a negative effect on house value (-9%) if the households are in a low income status, to a positive 10% benefit for house value if they are in a high income category. Given the average selling price of around $114,000, the value of mature trees on site could be worth up to $11,400, although it could also be a detriment in some instances.

Discussion and Summary of the Studies

The studies above provide a wide range of estimates about whether trees enhance the value of a house. These values range from negative, where proximity to trees or density of nearby trees reduces home value, to positive. Table 2 presents a summary of estimates from the various studies. For example, Tyrvainen (1997) and Kestens et al. (2004), both find that trees have a negative effect on home value, but in the study by Tyrvainen (1997) the results appear mostly to have to do with the large density of tree cover in the region. Hedonic studies calculate marginal values, and at the margin, additional trees may not increase home value if there is already significant tree cover nearby or on the property. This result is clearest in the study by Netusil et al. (2005), who found that increasing tree canopy enhances house value in regions with lower canopy initially, but in regions with high levels of existing tree canopy, additional tree canopy does not improve home value.

Most of the studies find that trees enhance the value of homes in some way, but each study measures tree density in a slightly different way (see Table 2). One of the earliest studies, by Anderson and Cordell (1988) considered the number of trees on the individual plot. They used photographs of each of the plots and counted the trees. They also differentiated between hardwoods and softwoods and tried to index for tree size. They did not find a significant preference for one type of tree or another. Over time, studies have used mapping techniques, first aerial photography, as in Tyrvainen (1997), and later satellite imagery. These data have not so far allowed for consideration of the number of trees on each parcel or the type of trees (e.g., hardwood or softwood). Typically, the more recent studies have focused on using distance variables to parks, whether the homes view a forest, and the proportion of cover.

For studies that consider the number of trees on a site, the effect of the average number of trees ranged from around 4% to 19%. Additional trees provide additional value, at least to a point. Most of these studies have been conducted in the eastern US. The study by Cordell and Anderson (1988) used legitimate hedonic techniques, and thus is the most appropriate for consideration. The estimate by Cordell and Anderson (1988), that the average number of trees enhanced house value by 4% to 4.6%, is actually fairly close to the estimate by Tyrvainen and Miettinen (2000) who examined the impact of a forest view, even though their study occurred in a different country. Tyrvainen and Miettinen (2000) found that a view of a forest increased home value by 4.9%.

Netusil (2005) suggested that tree cover has modest impacts on house value. In fact, Netusil (2005) found that having tree canopy physically on a property would have no significant impact on house value. This contradicts the results in Anderson and Cordell (1988), although there is likely a large difference in their definition of tree cover. Anderson and Cordell (1988) just counted number of trees, and Netusil (2005) used a variable called "tree canopy", which would be positive if there is more than 1 continuous acre of closed tree canopy. Netusil (2005) did find that tree canopy within a radius of 200 feet to 0.25 miles would have a positive impact of 1.1% to 2%. Thus, trees nearby provide benefits, but trees on an individual property are less likely to provide benefits.

Table 2. Summary of results from studies examined in this review.

Study	Measure	% of home value	Value in nominal terms (year)	Value in 2010$
Anderson and Cordell (1988) – Athens, Georgia	number of trees	3.9% to 4.6% at sample average # of trees (5.1)	$1,480 to $1,750 (1979)	$4,445 - $5,256
	average tree		$290 to $344/tree	$871 - $1,033
	hardwood tree		$257 to $376/tree	$772 - $1,129
	softwood tree		$319 to $333/tree	$958 - $1,000
Morales et al. (1983) – Greece, New York	number and type of trees	17%	$9,500 (1983)	$20,799
Martin et al. (1989) – Austin, Texas	number of trees	19%	$18,000 (1989)	$31,653
Powe et al. (1995) – Newcastle Upon Tyne, England.	dummy variable for tree cover within 500 meters.	8%	£32,000 (1991)	$8,539
Geoghegan et al (1997) – Baltimore Maryland	area of open space, which includes forest and agriculture	0.0189% if within 0.1 km -0.034% if within 1.0 km.	No house value provided	
Tyrvainen (1997) – Joensu, Finland	distance to nearest wooded recreation area	-1.4% for each additional 100 meters	-42 FIM per m^2 for each 100 meters (1985)	-$13
	distance to nearest forest area	+15.6% for each additional 100 meters	+471 FIM per m^2 for each 100 meters (1985)	$145
	relative amount of forested area in housing district	+0.2% per % change in cover in district	+7.36 FIM per m^2 for each percent change in cover (1985)	$2
Tyrvainen and Miettinen (2000) – Salo, Finland	distance to nearest forest area	-5.9% for each additional kilometer	-249 FIM per additional kilometer (1996)	-$53
	view onto forests	+4.9% for view.	+207 FIM for view (1996)	$44
Lutzenhiser and Netusil (2001) – Portland Oregon	presence of natural park within 1.5 kilometers	+16%	10,648 (1991)	$17,047
Netusil (2005) – Portland, Oregon	tree canopy (more than 1 continuous acre of tree cover) on the property	not significant		
	tree canopy within 200 feet	+2%	$3,503 (2001)	$4,313
	tree canopy 200 feet to 0.25 miles	+1.1%	$1,980 (2001)	$2,438
	Beyond 0.25 miles	not significant		
Netusil et al. (2010)	2.5% of tree canopy within 0.25 miles		$548-$1,672	$675 – $2,059
	7.2% of tree canopy within 0.25 miles	+0.7% to +2.5%	$1,310 to $4,416	$1,613 - $5,437
	each additional acre of tree canopy within 0.25 miles		$111-$350 per acre (2001)	$137 - $431
Kadish and Netusil (2012)	Increase tree cover from 26% to 37%	0.1422	452 (2007)	$475

The study by Netusil et al. (2010) expanded this earlier work, and this most recent study is the most germane for the present analysis. The authors of this study directly measured tree canopy cover on the property and in nearby zones. They found that the sample average proportion of tree canopy cover within 0.25 miles of the property (7.21%) would benefit home values by 0.7% to 2.5%. They also calculated a downward sloping demand function for tree canopy cover, showing in the linear case that the value of additional tree cover would become negative beyond 35% tree canopy cover.

Kadish and Netusil (2012) find that tree cover on the parcel has a positive effect on house value, however, the effect is relatively small. The current average tree cover for parcels in their sample in Portland is 26%, but they also calculate that the optimal is 37%. The increase from 26 to 37% would increase house value by around $452, or about 0.14%. They also found that trees in the neighborhood would enhance value, but there is not enough information in the published study to determine the size of this effect.

A general trend cannot be observed across the results of the studies examined in this report, a result that likely relates to the large climatic gradient spanned by the various studies. In the Oregon studies, the trees are generally conifers that provide shade in both summer and winter. With the exception of the summer months, which tend to be dry and sunny, the rest of the year in the Portland area is cloudy and rainy and presence of trees close to a home could reduce the natural light to the home and make them appear darker. The study in Georgia did not find a significant preference for evergreen or deciduous tree type—this part of the country experiences a lot of sunny weather all year round and with a long warm spring to fall period. In such a situation, evergreen and deciduous trees will play their role of keeping the house cooler in the summer and probably have little to no effect on the internal home climate in the winter. In addition, lots with higher percentages of tree cover may well be located in areas further from employment centers, which also has a negative impact on house values.

CHAPTER 3: Benefit Transfer: A Tree Cover Canopy Value Function

In recent years, a number of economists have used a method called "Benefits Transfer" to use results from existing studies undertaken on specific sites, for new study areas. For this analysis, benefits transfer will be used because none of the existing studies reviewed in this paper were conducted in California. The most recent estimates for a region most similar to California are those by Netusil et al. (2010) from Portland, Oregon. Obviously, California is very diverse and locations in California are substantially different than the conditions in Portland, Oregon, although the native tree species types tend to be similar in the two regions (native forests dominated by conifers). The study in Portland, Oregon, however, is the most complete and it provides the most comprehensive information for producing a benefit transfer study. Furthermore, the study provides a per property benefit estimate, which is a more comprehensive calculation of the benefit provided by tree canopy than the marginal effects from a hedonic model.

For the benefit transfer exercise, we developed a transfer function that calculates the percentage of home value contributed by tree cover in the home's neighborhood. Based on the data provided in Table 1 above (taken from Netusil et al., 2010), the functions in equations (1) and (2) below were developed. These functions relate the proportion of tree canopy cover in the area up to 0.25 miles of the property to the per property benefit estimate as a proportion of home value. Equation (1) below is derived from a linear function and equation (2) is derived from a log-log function.

(1) % of Home Value = 0.392*(% tree cover) – 0.006*(% tree cover)^2

(2) % of Home Value = 0.1907 + 0.0782*(% tree cover) – 0.0001*(% tree cover)^2

The use of these two equations produces wide variation in value, depending on which functional form is chosen (Figure 1). Importantly, both are derived from exactly the same data, and the same first stage hedonic function. Up to about 50% tree canopy cover, the linear demand function predicts more value associated with trees than the log-log function, but the linear demand function also suggests that beyond around 35% tree cover, additional trees do not provide additional value.

Based on other studies examined above, it appears most realistic that the marginal value of additional tree cover becomes zero, or negative, if tree cover is high enough. Other studies do not provide enough information to determine the level at which this change occurs, whereas the study by Netusil et al. (2010) indicates that it occurs at around 35% tree canopy cover. Thus, using equation (1) above is recommended, the linear demand function, to determine the value of tree canopy. With this function, tree canopy can obviously lead to negative value. Negative value occurs at about 65% tree cover. We recommend setting the proportion to zero when the equation turns negative.

Table 3 provides recommended values from using equation (1) above. The estimates provided by the transfer equation (1) and shown in Table 3 are well within the range of estimates provided by the literature (that benefits of trees on homes may range from 4-19%). The estimates in our benefit function and Table 3 are at the lower end of this range, but it is important to note that the estimates at the upper end of this range tend to be from non-economic studies. The economic studies, e.g., the ones that use statistical techniques and data from actual house sales, are at the lower end of the range.

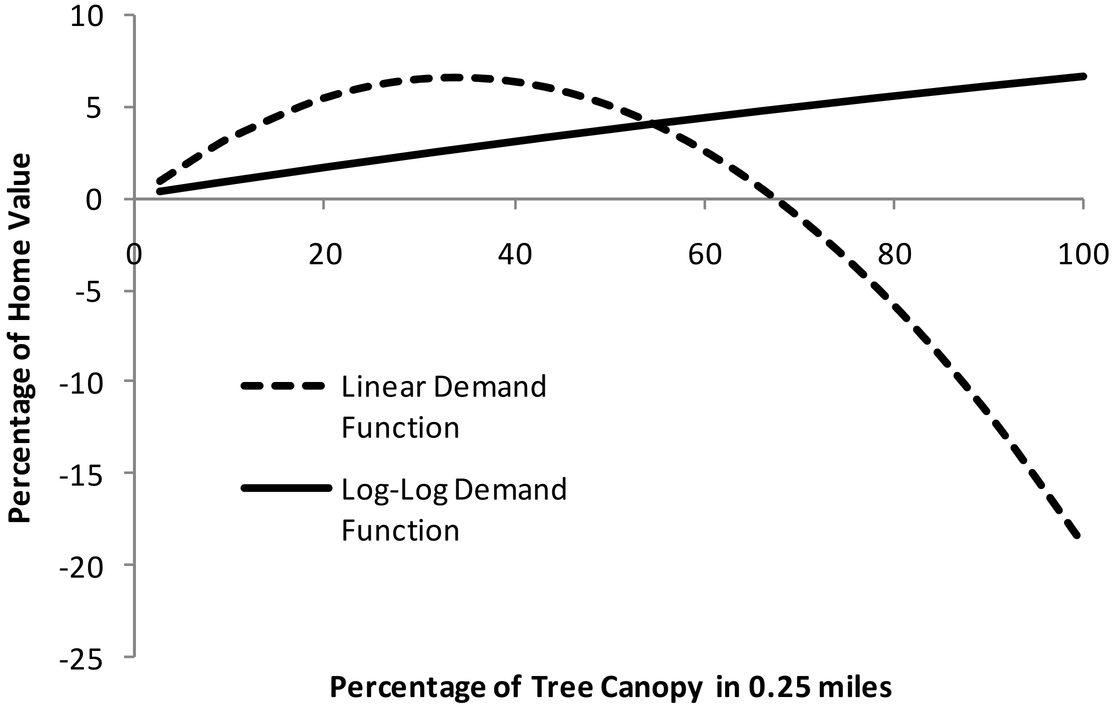

Figure 1. Estimated benefit functions for tree value as a percentage of home value, derived from Netusil et al. (2010).

Table 3. Benefit of tree cover on house value based on estimates from equation 1.

% Tree Cover w/in 0.25 miles	% of House Value
Up to 10%	3.3
10-20	5.5
20-30	6.5
30-40	6.4
40-50	5.1
50-60	2.6
60-100	0.0

CHAPTER 4:
Effect of Tree Cover on Energy Use and Insurance Rates

Within California, there long have been programs aimed at increasing the number of trees planted in urban areas around homes to help reduce energy consumption, in particular during summer. As a result, a number of studies have now examined how tree cover influences energy costs, in particular in California (e.g., Donovan and Butry, 2009; McPherson and Simpson, 2003; Simpson and McPherson, 1996; and McPherson and Rowntree, 1993).

McPherson and Rowntree (1993) review a large range of studies across the US and conclude that a single tree can reduce residential energy costs by 8-12%. They then analyze the potential savings of one tree in a yard in Fresno, California, and find that the energy savings annually would be 347 Kilowatt-hours. Simpson and McPherson (1996) found that for Sacramento, a single tree on the western side of a home could reduce energy use by 180 Kilowatt-hours. For their analysis, Simpson and McPherson (1996) considered a single type of deciduous tree, and conducted analysis across a range of climatic conditions in California. They found that trees were especially effective in cooler climates, providing energy savings of up to 50% annually. However, because cooling loads overall are greater in warmer climates, the actual amount of energy saved in warmer climates is greater with the addition of trees on the western side of a home. Donovan and Butry (2009) conducted empirical analysis based on actual energy expenditures in the peak cooling season for the city of Sacramento and found that a single tree would reduce energy use by 82 Kilowatt hours.

McPherson and Simpson (2003) conduct a statewide simulation analysis of the effects of existing trees on energy consumption and the potential for increased tree cover. They estimate an average savings of 4-5 Kilowatt-hours per tree in Mountainous regions to 160-170 Kilowatt hours per tree in the desert areas. At current prices of $0.14 per Kilowatt hour, this amounts to a savings of around $0.70 per tree per year to $23 per tree per year, depending on the region. This amounts to a reduction of 0.9% to 6.5% at maximum in energy costs per tree. The average effect across California of current trees is a savings of 36 Kilowatt hours per tree year, or $5.04 per tree per year. If one calculated the present value effect of this for a house over a 30 year period at 5% interest, the value is around $77 per tree per house.

An extensive review of the literature found little evidence that insurers account for trees around homes when setting rates. Shafran (2008) discussed the possibility that homeowners could generate credits or discounts by removing trees if they are in fire prone areas, but that study also illustrates the difficulty of pricing such a policy given the externalities and spillovers generated within the entire neighborhood. Shafran (2008) claims that insurance companies currently do not incorporate trees into their pricing policies.

The California Department of Insurance conducts a homeowner premium survey every year (California Department of Insurance, 2011). A review of the data in this survey indicates differences in insurance premiums across California (higher rates in more fire prone regions), but it does not indicate that rates depend on trees near a home. Further, a list of discounts available for homeowners indicates that there are no applicable discounts associated with tree removal or maintenance. Insurance in some cases may actually pay for the loss of a tree. California law stipulates that trees may be covered for up to 5% of the value of the liability coverage on the property or $250-$500 per tree (see California Department of Insurance, 2011). Thus, trees are in many circumstances recognized as adding value to a home rather than detracting from the value of a home.

As discussed above, the value of trees in reducing energy expenditures and in influencing insurance rates are interesting areas of research, but they do not constitute value beyond estimates generated by the hedonic methods undertaken below. The value of trees in providing energy benefits is probably fairly small. Table 3 for instance illustrates that 10% tree cover could provide up to 3.3% of the value of a home. For a home worth $200,000, this would amount to a value of $6,600. A single tree would likely fit within this 10% tree cover category, and thus could provide benefits of up to $6,600 per house. In comparison, the energy savings were calculated to be around $77 (above). Energy savings thus are a small part of the overall value of trees to homes.

CHAPTER 5: Econometric Analysis

The goal of econometric analysis is to determine the value of tree cover on homes in California. Estimates from other states, as described above, suggest that the value can be substantial, but that it potentially varies by tree type, regional tree density, and other factors. Given the great variety of tree types and life zones across California, as well as the diversity of home markets, it is important to conduct primary analysis in California.

To accomplish primary analysis, we started with the earlier Winrock work that considered tree cover change in 28 locations in California (Pearson et al., 2011). For each location, two satellite images of tree cover for two different time periods and at two different resolutions were obtained. The focus of the work by Pearson et al. was on detecting change in forest cover in relation to development and to demonstrate that use of Landsat type imagery underestimated deforestation due to development. Although the study included a large number of locations, it did not originally measure actual tree canopy cover in each of those locations.

Because of the importance of tree canopy cover for use in our hedonic analysis, we needed to measure tree canopy cover on each parcel. This was impractical for all of the Winrock study sites. We thus used six of their original locations for the hedonic analysis (Table 4). The six we chose had a relatively large number of houses in them and therefore had a sufficient number of house transactions for statistical analysis. Further, the six were chosen to be in different regions, and thus different markets and climate conditions. The characteristics of houses differ substantially over the various study areas, although we should caution that the characteristics we examine in this analysis apply to the houses that sold not to the entire population of houses.

Table 4. Study areas for hedonic analysis

Study Area Number	County	Years for tree cover maps
8	Sonoma	2004, 2009
9	Napa	2004, 2009
12	Shasta	2003, 2008
17	Placer	2006, 2009
26	Los Angeles	2005, 2008
28	Los Angeles	2004, 2008

The first step in developing our model was to collect parcel data for the study areas we were going to use. Parcel data were purchased from ParcelQuest, a California based firm that collects and consolidates parcel data, including house sales and physical characteristics of homes, from all counties in that state. The purchased parcel data included shape files and other files with house transaction prices and characteristics. Specifically, we obtained data for the transactions in the counties and time periods listed in Table 4. For the final analysis, we use 7025 observations of sales taking place in two time periods for each study area. There were 3,839 houses in the earlier time period and 3,186 in the second. All house prices are deflated to 2003 US dollars. Definitions and descriptive statistics for the variables used in the econometric models are found in Tables 5, 6 and 7.

The next step was to calculate tree canopy for each parcel with a dwelling from the parcel data. The tree canopy cover for the study areas was calculated using a program called *eCognition*[1]. To calculate tree canopy percentage, multispectral satellite imagery ranging from 60cm – 1m in spatial resolution and using blue, green, red, and near-infrared reflectance bands were analyzed. Traditional remote sensing (RS) classification methods are analyzed on a pixel by pixel basis and are limited to using spectral signatures to separate land cover classes, which causes problems when classes share a similar reflectance curve.

In this study, traditional RS methods were first tested and were unsuccessful in separating lawns from trees as both reflected highly in green and especially in near-infrared. Therefore, methods were explored using eCognition 8.0 software which incorporates Geographic Object Based Image Analysis (GeOBIA) methods. In GeOBIA, image pixels are grouped into vector polygons or objects by segmenting the image first. In this study the images were first segmented using eCognition's MultiResolution segmentation algorithm with equal weight assigned to each

[1] This program and calculation was led by Luke Marzen at Auburn University

band, a scale parameter of 30, shape factor of 0.1, and a compactness factor of 0.5. By grouping pixels into objects, other factors than spectral signature can be examined, such as texture. For instance an object that covers a lawn is likely to be more smooth on the image and therefore has a lower standard deviation than an object covering a tree canopy which will have a more coarse texture and likely a higher standard deviation of reflectance values from any given color band in that object.

Once the images were segmented, rule-sets were developed to group the objects into classes. We used a classification system grouping the image objects into five classes including impervious, open, lawn, water, and finally tree canopy cover. Hundreds to thousands of training samples were then selected for each class for each image, which enabled a supervised classification of the objects. The process was repeated until accuracy of tree cover polygons clearly matched when overlain on the false color composite imagery. The tree layer was then intersected with parcel layer in a GIS to produce a layer that yielded the area of tree cover for each parcel analyzed. Figure 2 shows a neighborhood in study 12 with tree cover polygons intersected with parcels.

Figure 2. Tree cover in parcels with homes for study area 8, 2009

Other variables have been added to the dataset. Fire hazard data --is the SRA, or State Responsibility Area data, originally from the State of California (see their website: http://frap.fire.ca.gov/projects/hazard/hazard.html). For these data, there are three levels of fire hazard, which increase hazard risk. In addition, year 2000 US Census socioeconomic data at census block group level (http://www2.census.gov/census_2000/datasets/), and 2005 USEPA National-Scale Air Toxics assessments for environmental risk data at census tract level (http://www.epa.gov/nata/) were also obtained and merged into the dataset.

Table 5. Definition and source of data used in models

Variable Name	Variable Definition	Source
Log(PRICE)	Natural logarithm of house price after prices adjusted for inflation (in 2003 dollars)	Constructed from parcel and US consumer price index
Lot size (10000 m^2)	Size of house lot in 10,000s of square meters	Parcel data
Area of House (1000 ft^2)	Size of the house structure in thousands of square feet	Parcel data
Fire place (1, 0)	Number of fire places	Parcel data
Year House Built	Year that the house was built	Parcel data
Condition	Auditor's assessment of the condition and upkeep of a house	Parcel data
Pool (1,0)	House has a pool	Parcel data
CBG % Black	Percentage of black population in a Census Block Group	2000 decennial census current population statistics
CBG % Hispanic	Percentage of Hispanic population in a Census Block Group	2000 decennial census current population statistics
CBG % Vacant Property	Percentage of vacant single family dwellings in a Census Block Group; measures excess housin supply	2000 decennial census current population statistics
Average slope	Steepness of the lot on which a house is built. Higher number = higher slope.	Calculated using GIS from USGS data
Total Respiratory Risk	Total respiratory risk measured by toxic air releases. Higher number = more risk.	2005 USEPA National-Scale Air Toxics
Fire Hazard Code	Fire hazard code for parcel on which house is built	California department of Forestry and Fire Protection
Tree %	% of parcel covered by trees	Calculated (Area tree cover /lot area)
Time	dummy variable = 1 if second time period.	Calculated
Study Area 8	dummy variable = 1 if observation in Study Area 8 (Sonoma County)	Calculated
Study Area 9	dummy variable = 1 if observation in Study Area 9 (Napa County)	Calculated
Study Area 12	dummy variable = 1 if observation in Study Area 12 (Shasta County)	Calculated
Study Area 17	dummy variable = 1 if observation in Study Area 17 (Placer County)	Calculated
Study Area 28	dummy variable = 1 if observation in Study Area 17 (Los Angeles County)	Calculated
Tree% x Study Area 8	dummy variable =Tree%*1 if obs in Study Area 8 (Sonoma county)	Calculated
Tree% x Study Area 28	dummy variable =Tree%*1 if obs in Study Area 28 (LA county)	Calculated

A number of the variables used in our regression model have been calculated. Because the Study Areas are substantially different, we have included dummy variables for each of the Study Areas in the model. These dummy variables shift the intercept term up or down depending on the average difference for results within the specific areas. Note that a dummy variable for one area must be excluded from the analysis to avoid multi-collinearity, so we have excluded the dummy for Study Area 26. In addition to these dummy variables, we also include several interaction terms which multiply the area dummy variables by the tree %. This tests whether the coefficient on tree % differs across the Study Areas. For our model, we only find that the results on this interaction term are significant for Study Area 8 (Sonoma County). The interaction term for Study Area 28 is included as well because it is close to significant and it improves the fit of the model.

The counties and Study Areas analyzed in this dataset differ substantially (Table 7). For our analysis, house values are highest in Study Areas 9 (Napa) and 17 (Placer), although the driving factor in house value in Study Area 17 is likely house size. The data generally make sense in that cooler regions are more likely to have fire places (e.g., there are not many homes with fireplaces in LA county, Study Areas 26 and 28). Conversely there are more pools in Study Area 28 than in the other Study Areas. Respiratory risk is greatest in LA county.

Table 6. Descriptive statistics for data used in models (number of observations = 7205). See Table 5 for additional information on variables.

	25th Percentile	Median	75th Percentile	Mean
Lot Size (10,000 m^2)	0.55	0.71	1.18	1.75
Area of house (1,000 ft^2)	1.18	1.51	1.99	1.72
Fireplace (1=yes; 0 = no)	0.00	1.00	1.00	0.56
Year Built	1955	1975	1990	1972
Condition[a]	6.00	6.50	7.00	6.38
Pool (1=yes; 0 = no)	0.00	0.00	0.00	0.10
% Black	0.42	0.88	2.24	1.61
% Hispanic	5.68	14.08	30.15	20.29
% Vacant	0.48	1.07	1.68	1.32
Average slope	0.63	1.82	6.63	4.90
Total Respiratory Risk	3.82	4.44	6.56	5.80
Fire Hazard Code	0.00	0.00	0.00	0.11
Tree %	21.34	37.10	53.20	38.24

[a]Condition is a subjective value of the structural quality of houses, assigned by appraisers.

Table 7. Descriptive statistics for data used in the model by study area. See Table 5 for additional information on variables.

	Average for Study Area					
	8	9	12	17	26	28
N	1816	2341	150	250	42	1070
House Value	$396,024	$432,614	$242,087	$446,341	$192,951	$382,841
Lot Size (10,000 m^2)	0.7	0.9	1.4	8.4	13.6	3.9
Area of House (1000 ft^2)	1.7	1.5	1.7	2.6	2.1	2.0
Fireplace (1=yes)	0.9	0.6	0.6	0.4	0.0	0.0
Year Built	1980	1959	1973	1986	1978	1976
Condition	6.4	6.1	6.2	6.9	6.7	6.9
Pool (1=yes)	0.0	0.1	0.2	0.2	0.0	0.3
% Black	2.4	0.5	1.1	0.5	2.9	3.6
% Hispanic	17.4	29.2	5.7	4.2	15.4	30.2
% Vacant	1.0	1.0	2.5	1.1	9.6	0.6
Average slope	3.9	0.0	6.7	13.3	5.8	8.5
Total Resp. Risk	5.4	4.4	4.5	4.0	3.3	11.8
Fire Hazard Code	0.0	0.0	0.0	1.3	1.6	0.3
Tree %	42.3	38.8	37.5	62.6	11.5	26.5

Quantile Regression Models

Quantile regression models allow us to examine how houses in different parts of the house price distribution react to changes in tree canopy cover. Thus, for example, the 25th percentile represents the results of the regression analysis applied to houses in the lowest 25% of the distribution of house sales. For this analysis, we estimate parameters for the 25th, 50th, and 75th quantiles. In addition, we have pooled the data for the two house sales, although as noted earlier we use real values deflated to 2003 $. Because there were potentially large structural differences in housing markets between the two time periods, we use a dummy variable to distinguish sales that occurred in the second time period.

The results of the regression are shown in Table 8, with the parameters for each of the quantiles. The regression model is estimated in semi-log form, and thus is written as:

$$\ln(y_t) = \beta X_t + e_t$$

For a quantile regression model, however, we solve the following problem (Koenker and Hallock, 2001):

$$\min_{\beta \in R} \sum \rho_\tau (\ln(y_t) - f(X_t, \beta)).$$

For this analysis, we use quartiles, thus estimating parameters of the model (β) for $\rho_\tau = 0.25$, 0.50, and 0.75. Standard errors for the parameter estimates are calculated with bootstrapping techniques. The model and the standard errors are estimated using SAS version 9.

It is important to recognize when interpreting the results of quantile regression that all of the parameters are estimated for all of the data. The data are not segmented into different pieces (e.g., house values up to the 25th percentile; house values from the 25th to the 50th percentile). All the data are used for each set of regression results for each of the percentiles shown in Table 8. The difference in each regression, shown in each column, is that the weighting factor ρ_τ differs. Quantile regression thus provides parameter estimates that are weighted towards specific segments of the sample population.

To interpret the results, consider the column for 25th percentile in Table 8. These results are fitted assuming that conditional median of the sample lies at the 25th percentile. Thus the regression prediction will yield results such that 75% of the actual sale values will be above the predicted sale value based on the regression model. The set of regression results for the 25th percentile is weighted more heavily towards observations with lower house values. In contrast, for the column for the 75th percentile, the regression results are weighted towards high value homes. For this set of results, the parameters are estimated using weights such that only 25% of the actual sale values will be above the predicted sale value.

As noted above, we have included dummy variables for each of the Study Areas given they differ by a number of ecological and demographic factors. The dummy variable for Study Area 26 in LA County is left out of the regression to avoid multi-collinearity, so all dummy variables indicate the shift in the model relative to that study area. The parameters for the dummy variables for Study Area 8 to Study Area 28 (excluding Study Area 26) are positive, and mostly significant. This indicates that house values in general are higher in Study Areas other than 26. Study Area 26 is relatively rural, and has relatively few houses, and house sales, compared to the other Study Areas.

The parameter for lot size is positive and significant for the first two quantiles, although the parameter estimate is smaller for the 50th quantile than the 25th. The parameter estimate is insignificant for the 75th quantile. In general, this suggests that increased land area enhances house value, although lot size has the largest marginal effect on lower value homes. The parameter on house size (square footage) is positive and significant for each of the quantiles. Fire places have a positive effect on less valuable homes, but have a smaller impact as house values increase. For larger, more valuable homes, fireplaces are likely a more common, and thus, less distinguishing feature. Year built has a negative parameter indicating that more recently built homes are worth less than older homes. The impact of year built is smaller for higher value homes.

Condition class and pool both have expected signs. The census parameters follow expected signs, although it is interesting that the effect of vacant homes on values becomes insignificant for higher value homes. Higher value homes located in higher value neighborhoods are likely more resilient to the impacts of vacancy rates than lower value homes. Greater respiratory risk reduces house value, although respiratory risk has the greatest effect on the lower value homes The time variable is negative, as expected, indicating that house values declined over time on average. The effect is smaller for larger, more valuable homes.

Table 8. Quantile Regression Results (Dependent variable = ln(sale price in 2003 USD) [Standard errors are presented below the regression coefficients. ***indicates significance at the 0.001 level, **

indicates significance at the 0.05 level, and * indicates significance at the 0.1 level.

Variable Name	25th Percentile		50th Percentile		75th Percentile	
Intercept	13.3808		13.2689		13.2714	
	0.7657	***	0.4767	***	0.5199	***
Study Area 8 dummy	0.8748		0.5892		0.584	
	0.1684	***	0.1023	***	0.094	***
Study Area 9 dummy	1.2041		0.8997		0.8365	
	0.1663	***	0.1049	***	0.0892	***
Study Area 12 dummy	0.3928		0.1403		0.1302	
	0.1634	**	0.0999		0.0865	
Study Area 17 dummy	0.5749		0.4554		0.3912	
	0.1645	***	0.1069	***	0.0844	***
Study Area 28 dummy	0.9415		0.8772		0.7717	
	0.1896	***	0.1135	***	0.0947	***
Lot Size (1000 m^2)	0.0077		0.0051		0.0062	
	0.0023	***	0.0022	**	0.0038	
Area of House (1000 ft^2)	0.2760		0.3107		0.3451	
	0.0148	***	0.014	***	0.0116	***
Fireplace (1,0)	0.0891		0.0507		0.0222	
	0.0112	***	0.0101	***	0.0085	***
Year Built	-0.0012		-0.0009		-0.0008	
	0.0004	***	0.0002	***	0.0003	***
Condition	0.0943		0.081		0.0519	
	0.0124	***	0.0096	***	0.0078	***
Pool (1,0)	0.1498		0.0812		0.072	
	0.0208	***	0.0176	***	0.0161	***
% Black	-0.005		-0.0082		-0.006	
	0.0035		0.0036	**	0.003	*
% Hispanic	-0.0068		-0.0047		-0.003	
	0.0005	***	0.0004	***	0.0004	***
% Vacant	-0.0341		-0.0025		-0.0084	
	0.0089	***	0.0062		0.0061	
Average slope	0.0000		0.0012		0.0019	
	0.0011		0.0008		0.0009	**
Total Resp. Risk	-0.0254		-0.0179		-0.0072	
	0.006	***	0.0052	***	0.0032	**
Time	-0.3656		-0.2875		-0.1894	
	0.0116	***	0.0095	***	0.0101	***
Tree %	0.0015		0.0007		0.0006	
	0.0004	***	0.0003	**	0.0003	**
Tree % X Study Area 8	0.0037		0.0035		0.0025	

	0.0006 ***	0.0005 ***	0.0005 ***
Tree % X Study Area 28	0.0008	0.0002	0.0004
	0.0019	0.0012	0.0008
Hazard Code	0.0625	0.0083	0.0254
	0.042	0.0159	0.0175

Tree canopy cover (tree %) has a positive effect on home value, as expected. The impact, however, is strongest for lower value homes. We have interacted tree canopy with the dummy for observations in Study Areas 8 (Sonoma county) and 28 (Los Angeles county). Other study areas were considered, but the parameter estimates were not significant and did not enhance the overall model. For Sonoma County, tree canopy has a larger and stronger effect than the other Study Areas on average, while for LA county tree canopy has a smaller effect. Thus, tree canopy benefits all homes in the sample on average, but it has a larger effect in Sonoma County and a smaller effect in LA County. The effects are of different magnitude, but they are consistent in direction across the quantiles. It should be noted that as house price increases, unobservable quality characteristics become more important; for example, even the condition variable cannot capture characteristics such as architectural style or high-end kitchen appliances that are likely capitalized into house price.

We calculate the average effect of a 1% change in tree canopy cover, e.g., the marginal implicit price, and report it in Table 9[2]. The effect in Study Areas 9, 12, 17, and 26 is indistinguishable statistically, but the implicit prices differ due to differences in house size and quality, and so are reported separately. The effect in Study Areas 8 and 28 differ statistically from the others. Study Area 8 has the highest implicit prices in general. In general, marginal implicit prices fall moving from lower to higher quantiles, indicating that tree canopy is important, but less important for higher value houses.

2 The original regression equation is $\ln(P) = \beta X + \varepsilon$, so the marginal implicit prices are found as $dP/dX = \beta \exp(\beta X)$. Using this equation, one can see that β = $\frac{dP/dX}{P}$, or the proportional effect of a one unit change in X on the house value.

Table 9. Marginal Implicit Prices for a 1% increase in tree canopy for the Study Areas examined

	Quantiles		
Study Area	0.25	0.5	0.75
8	$2,414	$1,958	$1,460
9	$752	$329	$304
12	$453	$198	$183
17	$781	$342	$316
26	$433	$189	$175
28	$1,167	$453	$517

Marginal implicit prices are calculated for the current level of tree canopy cover for each home. For example, tree canopy cover in Study Area 8 averages 42%. For the median house, these marginal implicit prices indicate that the value of increasing tree canopy from 42% to 43% is $1,958. To determine the aggregate value of trees to home values, we use the model to predict the value of homes without trees and compare it to the predicted value of trees. The total value of tree canopy, expressed as a proportion of house value, for the median house in each Study Area is given in Table 10. These results account both for the marginal value of tree canopy cover to homes as well as the total tree cover. That is, regions with higher tree cover will have higher proportional values.

Tree canopy has a wide range of impacts on house values across the state. Tree canopy is a highly valued commodity in Sonoma county (Study Area 8), amounting to around 12.7% of the value of homes at the sample average. A large part of this value arises from the relatively high proportion of tree cover for homes. Study Area 17 has more tree cover for home sales, but trees do not provide as much value. In contrast, in Study Areas 26 and 28 in LA County, the total value of trees to homes is substantially less, owing partly to the lower quantity of tree cover, but also a lower marginal effect of tree canopy. Across Study Areas 9-26, the marginal value of tree canopy to home value is the same, but the total value in table 10 differs due to the difference in average tree canopy.

Table 10. Estimated value of trees to homes in the study area

Study Area	Average % Trees	Average Value House Sale	Value of trees as a % of Home value
8	42.3	$467,658	12.7%
9	38.8	$504,264	3.6%
12	37.5	$304,135	3.3%
17	62.6	$523,730	5.2%
26	11.5	$290,279	1.0%
28	26.5	$511,771	3.9%

CHAPTER 6: Valuing Losses from Deforestation

The results can be used to assess the value of the potential tree cover losses in California. The earlier analysis by Pearson et al. (2011) calculated deforestation in four regions in the state that are consistent with our empirical estimates of value. The areas of deforestation they estimate occur as development occurs, e.g., when houses, shopping malls, or roads get built. Obviously, when development occurs, substantial value is created, but tree losses are an externality, reducing this value. It is worth reiterating that the values we capture in this analysis cannot fully estimate tree values such as ecosystem services, and therefore our calculations reflect mostly private benefit to homeowners.

For any particular house, we can calculate the value of this externality by estimating a value lost per acre of deforestation. To do this, we start with the estimates of deforestation by Pearson et al. (2011). They estimate that there are about 4100 acres of deforestation per year in the four regions they analyze, and this amounts to a rate of loss of 0.09% per year. We use the region specific estimates of deforestation from Pearson et al, and assume that amount of deforestation for all the parcels in our sample of home sales. We use that change to re-predict house values and to determine the marginal loss per acre with deforestation (Table 11).

The estimated value of losses range from $146,570 per acre in the North Coast region to $4,806 per acre in the Northern Sierra. We then use these estimates to value the total potential annual loss in value for the homes in just our sample (7,025 sales) if these homes experienced the regional average forest loss (i.e. 0.09% of their tree cover per home per year). We estimate a total forest loss of 10.6 acres of land across these homes, and a total value loss of $446,753 per year.

It is much more difficult to aggregate these estimates beyond our sample. Much of the deforestation that occurs may not occur in homesites, but instead on commercial sites, or in the process of building roads for homes. These losses in value would not be counted in our estimates. However, if one took the total forest loss for California of 15,904 acres, and assumes that only 10% of this occurred on homesites, the potential annual economic loss is $33.4 million per year for the state. We use a statewide average of $21,003 per acre in economic loss for deforestation that occurs on a homesite. This state-wide estimate is substantially less than the estimate in table 11 because it accounts for the fact that the North Coast is only about 6% of statewide total deforestation.

Table 11. Estimate of value loss for the area of forestland in the sample use for the estimates in this paper.

		Estimates for Houses in Sample		
Region	$/Acre	Total Forest Acre	Deforestation Acres/yr.	Value Lost/yr. (Million $)
North Coast	$146,570	3,905	2.3	$343,440
Shasta	$12,042	2,158	2.4	$28,584
Northern Sierra	$4,806	3,190	2.9	$13,798
South Coast	$20,016	3,044	3.0	$60,930
Total	$42,018	12,298	10.6	$446,753

CHAPTER 7: Conclusion

This study assesses the economic implications of deforestation in California on homeowners. As development has occurred in California over the preceding decades, large areas of forests have been removed as land has been converted to residential uses. An earlier study (Pearson et al. 2010)suggests that up to 15,904 acres per year are deforested in the development process. There is substantial evidence indicating that forest cover has an important positive impact on home value. Thus, the loss of forest cover as development occurs likely has a large negative effect on home value.

To assess the potential implications of forest loss for home value in California, we conduct a literature review on studies that examine the impact of trees on home values in the United States and globally. Our review of many of these studies indicates that trees provide benefits to homes, although some of the results suggest that, at the margin, additional trees would lower the value of homes. For those studies indicating that trees have a negative effect, one important factor is the existing density of trees. In regions that have large existing tree cover density, there is little impact associated with tree cover loss around homes. Another factor is views, in that trees can reduce the value of the view-shed around a home. Overall, estimates in the literature suggest that trees provide value to homes amounting to around 4-19%.

One of the studies is used to provide information for a benefit transfer exercise (Netusil et al. 2010). Two functions were created that can be used to relate the proportion of tree canopy cover within a 0.25 mile radius of homes to the benefits that homeowners get from these homes. Based on these functions, homeowners get benefits in the range of 2.6-6.5% of the value of the home, depending on the density of trees.

In addition to considering the effects of trees on home values, we also review the literature assessing the effects of trees on energy use and insurance rates. The literature on the effects of trees on energy use is fairly robust, but the effects are relatively small compared to the overall effects of trees on homes. Theoretically, the value of trees to home energy use should be capitalized into the value of the home and therefore captured by the hedonic estimates. Thus, we do not pursue the use of these energy values in terms of our overall economic valuation. Similarly, there is little evidence that trees influence insurance rates, in California or anywhere else.

We analyzed the effect of changes on forest canopy cover on home values in California. To accomplish this, we used an earlier study that compared highly detailed satellite maps at two different time periods to determine what change in forest cover occurred when development occurred in those regions (Pearson et al., 2011). . This earlier study did not actually calculate tree canopy cover for each of the study areas, so we conducted spatial imagery analysis as part of this study. Because of the complexity of calculating tree canopy cover for each area, and the complexity of obtaining house sale data for all 28 study areas, we limited our analysis to 6 of study areas in the study by Pearson et al. (2011) with the most house parcels.

For these 6 areas, we linked house sales in two time periods with tree canopy cover and estimate a regression model that predicts house value as a function of house amenities, where the one of the amenities is tree canopy cover. The models suggest that tree canopy cover enhances house value by $175 per 1% increase in tree canopy to over $2,414 per 1% increase in tree canopy cover, depending on the area. The large range of results makes sense given the large diversity of ecological and economic conditions in California. The lowest value, for instance, occurs in areas of LA County with little possibility of tree cover, while the highest value occurs in Sonoma County (one of richer areas of the state). For the areas we analyze, we find that trees account for 1.0% to 12.7% of the total value of homes. This is consistent with the existing literature, although the higher end estimate is larger than more recent studies. The high estimate results from the relatively high total level of average forest canopy cover on house sites in the North Coast region of California, and the high marginal value.

We then use the model to calculate the potential loss in $ per acre of forest. We begin by assessing the potential value of loss on the hectares in our sample. The study by Pearson et al. (2011) suggests that the rate of deforestation in California due to development is about 0.09% per year. We use estimates for the four regions they assess to determine the lost value associated with potential deforestation for homes in our dataset. For our dataset, there would be around 10.6 acres of deforestation per year and it would be worth $446,753 per year, or $63 per household.

Based on our results, we also estimate that an acre of deforestation loss is worth from $4,806 to over $146,000 per acre in California. The highest loss estimate occurs in the North Coast region and is heavily influenced by estimates from Sonoma County. Estimates for the more sparsely populated Northern Sierra region are the lower estimate. Given that relatively little of the total deforestation in the state occurs in this high value North Coast region, we estimate an average loss for the state of California of $12,003 per acre. Thus, if just 10% of the total 15,904 acres of deforestation occurs on homesites, then deforestation losses in California could be worth over $33.4 million per year. These aggregate estimates could be more precisely estimated by determining the amount of deforestation in the state attributed to homesites.

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Netusil, N. 2005. The Effect of Environmental Zoning and Amenities on Property Values: Portland, Oregon. Land Economics. 81 (2): 227-246.

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Theriault M, Kestens Y, Des Rosiers F, 2002, ``The impact of mature trees on house values and on residential location choices in Quebec City'', in Meeting of the IEMSs Society Lugano, Switzerland, pp. 478-483, International Environmental Modelling and Software Society, http://www.iemss.org/iemss2002/

Tyrvainen, Liisa. 1997. "The Amenity Value of the Urban Forest: An Application of the Hedonic Pricing Method." Landscape and Urban Planning 37 (3-4): 211-22.

Tyrvainen, Liisa. and Antti Miettinen. 2000. "Property Prices and Urban Forest Amenities." Journal of Environmental Economics and Management. 39 (2): 205-23.

APPENDIX:
Additional data and information from studies considered for the analysis

Netusil, NR, S. Chattopadhyay, and KF Kovacs. 2010. "Estimating the Demand for Tree Canopy: A Second-Stage Hedonic Price Analysis in Portland, Oregon" Land Economics.86 (2): 281 293

Examined % of tree canopy within 0.25 mile of property in Portland, Oregon from 30,015 property transactions in 2001. Marginal effects for all transactions used for first stage analysis, however, used survey data on 440 property owners for second stage demand function analysis. Of the 30,015 observations in the data set, there are 9,353 observations with no tree canopy within 0.25 miles of the property and 27,583 properties with no tree canopy on the property. The first stage estimates indicate that 18% tree cover has the maximum effect on house value and it is positive. Their results do show that in some parts of the city, tree canopy can have a negative marginal effect, namely in the SW and NW regions. They explain these negative values with views, suggesting that these regions already have extensive tree coverage and additional trees may reduce views. Summary results from the second stage estimates are presented in table 10 below, extracted directly from their paper. They also provide a per acre benefit estimate in their Table 11. The change from 7.21% to 8.21% represents a 1.35 acre increase.

TABLE 10

PER PROPERTY BENEFIT ESTIMATES FOR ALTERNATIVE CANOPY COVER AND 95% CONFIDENCE INTERVALS

Percentage of Tree Canopy	Quadratic First Stage, Linear Second Stage	Quadratic First Stage, Log Second Stage
2.53	\$1,671 ± \$15	\$548 ± \$2
7.21	\$4,416 ± \$42	\$1,310 ± \$5
8.21	\$4,944 ± \$47	\$1,459 ± \$5
15	\$7,988 ± \$87	\$2,409 ± \$8
25	\$10,747 ± \$144	\$3,684 ± \$14
35	\$11,453 ± \$202	\$4,874 ± \$18
40	\$11,037 ± \$231	\$5,447 ± \$20

TABLE 11

PER-PROPERTY AND PER-ACRE BENEFIT ESTIMATES FROM PERCENTAGE CHANGES IN CANOPY COVERAGE AND 95% CONFIDENCE INTERVALS

Change in Percentage of Tree Canopy	Quadratic First Stage, Linear Second Stage	Quadratic First Stage, Log Second Stage
2.53 to 7.21	\$2,745 ± \$27	\$762 ± \$3
7.21 to 8.21	\$528 ± \$6	\$149 ± \$ 1
7.21 to 15	\$3,572 ± \$45	\$1,099 ± \$4
Per acre benefit from 7.21 to 8.21 increase	\$391	\$111

TABLE 2

SUMMARY STATISTICS (STANDARD DEVIATIONS IN PARENTHESES)

	Combined	NW	SW	SE	NE	N
Mean real sale price (2000)	$175,160	$443,588	$255,965	$152,679	$168,894	$125,090
Mean median income (census tract 2000)	$45,985	$84,834	$63,790	$41,145	$45,216	$37,148
Mean lot size (ft^2)	7,043	13,626	10,022	6,788	6,310	5,327
Mean percentage of tree canopy on the property	3.48 (14.44)	21.64 (31.26)	16.02 (28.56)	1.22 (7.89)	1.00 (7.22)	0.40 (4.67)
Mean percentage tree canopy within 1/4 mile of properties	7.21 (13.29)	40.26 (20.12) Max: 90	27.03 (17.83) Max: 86	3.86 (7.62) Max: 85	2.53 (4.80) Max: 68	2.66 (3.76) Max: 29
Observations	30,015	767	3,879	11,980	9,597	3,792

Netusil, N. 2005. The Effect of Environmental Zoning and Amenities on Property Values: Portland, Oregon. Land Economics. 81 (2): 227-246.

Same dataset from Portland, Oregon as 2010 study. Consider only the first stage estimates. Tree canopy used to assess the value of trees. Tree canopy described as more than 1 continuous acre of tree cover. Consider the effect of tree canopy within different zones (on property, within 200 feet, within 0.25 miles, between 0.25 and 0.5 miles).

Effects on the property:

Tree canopy has no statistically significant effect

Trees and streams have a positive effect, their presence increases sale value 12.18%.

Effects at greater distances

Within 200 ft, tree canopy increases value by 2% and from 200 ft to 0.25 miles it increases value by 1.13%. Beyond 0.25 miles trees appear to have little additional effect.

The average house value was $175,160, so the effects are as follows:

Distance	%	Value
On property	0.00	$0
200 ft	2.00%	$3503
200 ft to 0.25 miles	1.13%	$1979
0.25 to 0.50 miles	0.00%	$0

Geoghegan. J., LA. Wainger. and NE Bockslael. 1997. "Spatial Landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS." Ecological Economics 23 (3): 251-64.

Patuxent river watershed between Baltimore MD and Washington, DC. Residential sales from 1990. Open space includes agriculture and forestry surrounding a property that sales. Most sales are suburban. Found that open space within 0.1 km had a positive effect (0.0189%) and open space within 1 km had a negative effect (-0.034%). Both significant. Do not provide average house value so unable to determine $ effect.

Lutzenhiser. Margot, and Noelwah R. Netusil. 2001. "The Effect of Open Space Type on a Home's Sale Price: Portland. Oregon." Contemporary Economic Policy 19(1): 291-98.

This study analyzed the effect of various amenities on house sales in Portland, OR using a dataset of 16636 house sales from 1990-1992. The authors did not look at trees specifically but looked at parks and open space. They considered several types of parks. Natural parks, or those with more than 50% of the land devoted to natural land cover, were found to have a positive effect on house values if located within 1.5 kilometers of the house. A park of this type located within 1.5 km of the home increased house value by $10648, or 16% of the average house value. They found that a natural park of 258 acres would maximize value. In addition, the authors examined whether distance to the park would influence value; they found that natural parks at all distances less than 1.5 km would increase value, but the maximum value would occur at 400-600 feet. Urban parks (those with less than 50% of the park in natural cover) or specialty parks had positive effects on house value, but the effects were smaller.

Tyrvainen, Liisa. 1997. "The Amenity Value of the Urban Forest: An Application of the Hedonic Pricing Method." Landscape and Urban Planning 37 (3-4): 211-22.

Estimates the value of recreational and wooded areas to homes in Joensuu Finland. Finds that distance to forest cover increases property value, while distance to a forest recreation area reduces house value. Thus, local forests were not found to improve value, although local parks were.

Tyrvainen, Liisa. and Antti Miettinen. 2000. "Property Prices and Urban Forest Amenities." *Journal of Environmental Economics and Management.* 39 (2): 205-23.

Estimate the value of forests on properties in Salo Finland. According to the estimation results a one kilometer increase in the distance to the nearest forested area leads to an average 5.9 percent decrease in the market price of the dwelling. Dwellings with a view onto forests are on average 4.9 percent more expensive than dwellings with otherwise similar characteristics. The average value of an apartment in a terraced house in Salo was 4225 FIM per square meter in 1996.

Mahan, Brent L.. Stephen Polasky. and Richard M. Adams. 2000. "Valuing Urban Wetlands: A Property Price Approach." Land Economics 76 (1): 100-13.

Hedonic study in Portland Oregon. Look at the value of wetlands on houses. Considered forested wetlands. Wetlands are determined to have a positive, significant effect on homes, but forested wetlands are indistinguishable from other types of wetlands. Increasing wetlands size by one acre increased the residence's value by $24. Similarly, reducing the distance to the nearest wetland by 1,000 feet increased home value by $436.

A total of 14,485 market-based residential sales for Multnomah County occurred between June 1992 and May 1994. Sales prices were adjusted by a price index for the Multnomah County residential housing market to a May 1994 price level. The average sales price for a residence was $123,109; the median price was $104,240. The most expensive home sold for $1,913,814, while the least expensive sold for $9,656. Ninety percent of the residences had market values between $55,000 and $250,000.

Martin, CW, RC Maggio, and DN Appel. 1989. The contributory value of trees to the residential property in Austin, Texas Metropolitan Area. Journal of Arboriculture 15(3):72-76.

Compared hedonic valuation techniques to formulaic techniques from the International Society of Aboriculture. Found that the formulas suggest that tree cover adds around 13% to the value of a property while the hedonic techniques suggest that tree cover adds around 19%. Some issues with the study are that they use appraised values for the hedonic techniques not actual sales data. The formulaic approach however uses a formula which must be estimated with actual information on the trees.

Des Rosiers, F., M Theriault, Y. Kestens, and P. Villeneuve. 2007. "Landscaping Attributes and Property Buyers' Profiles: Their Joint Effect on House Prices", Housing Studies, 22: 6, 945 — 964

They make the following claim:

> "Following the pioneer work by Payne (1973) and Payne & Strom (1975) on the impact of tree cover as measured by traditional valuation techniques, Morales et al. (1976), Seila & Anderson (1982) and Anderson & Cordell (1985, 1988) conducted hedonic analyses which led to the conclusion that the presence of trees adds a 3 to 9 per cent premium to the sale price of a house. Perception studies by Orland et al.(1992) and Kuo et al. (1998) corroborate the positive effects of tree planting on residents'
>
> preference ratings, especially for upper-price houses and provided trees are not too large."

Examined 598 properties that sold at least once in Quebec city between 1993 and 2000. They found that young trees had a negative effect on house values. They did not find that other tree variables had a significant effect, but they did find a number of interaction variables (e.g. tree variables times income) were significant, but they are not direct so not discussed here.

Kestens. Yan. Marius Theriault, and Francois Des Rosiers. 2004. "The Impact of Surrounding Land Use and Vegetation on Single-Family House Prices," Environment and Planning B: Planning and Design 31 (4): 539-67.

Quotes from literature review:

> Vegetation attributes, principally trees, have often been studied, with a positive contribution to property values associated with tree presence generally ranging from 3% to 8% (Anderson and Cordell, 1985; 1988; Luttik, 2000; Morales et al, 1976; Seila and Anderson, 1982; Tyrvainen and Miettinen, 2000) and specific landscaping attributes deserving an additional premium (Des Rosiers et al, 2002). The overall quality of the view is sometimes integrated, showing positive premiums (Do and Sirmans, 1994; Rodriguez and Sirmans, 1994). Specific elements of the view have also been studied, such as a view of a forest, mountain, lake, river, ocean, or open space (Benson et al, 1998; 2000; Luttik, 2000; McLeod, 1984; Powe et al, 1995).

The paper examines house sales in Quebec City, Quebec. Two datasets are used. The first is for 1986-87 and uses aerial photographs. The second dataset is for 2278 houses sold between 1993-1996. This dataset is linked with a Landsat TM 5 image from 1999.

They found for the 1986-87 dataset that the percentage of woodlands within 1 km had a negative effect on house values. A 10% increase in woodland % would reduce house values by 1.0-1.3%.

For the later dataset, they found that the proportion of mature trees on residential property within 100 and 500 meters would increase property value. Increasing the proportion 10% within 100 meters would increase value by 0.7 – 1.0%. Increasing the proportion 10% within 500 meters would increase value by around 2.5%. Increasing the proportion of residential property with low density of trees would conversely reduce value of the property. However, increasing the proportion of woodlands (i.e., parks) within 500 meters reduces value. Thus, their results point to the value of maintaining tree cover on residential land and not necessarily having tree cover on public land.

Average house value was 86155 for the 1986-87 sample, and 123657 for the 1993-1996 sample. Thus, a 10% increase in proportion of mature trees on residential property within 100 meters would lead to an increase in value of $865-1237. This effect is still positive for a larger area, with a gain of up to $3,091.

Summary on the effects of trees on house values

	Dataset 1	**Regression 2**
Increase woodlands within 1 km by 10%	- 1.0 to -1.3%	-1.0 to -1.6%
Increase proportion of mature trees on residential property within 100 meters by 10%	NA	+0.7 to +1.0%
Increase proportion of mature trees on residential property within 100 meters by 10%	NA	+2.5%
Increase proportion of residential property with low density of trees by 10%		-1.9 to -2.1%
Average house value	$86155	$123657
Increase woodlands within 1 km by 10%	-$861 to -$1120	-$1237 to - $1978
Increase proportion of mature trees on residential property within 100 meters by 10%	NA	+ $865 to + $1237
Increase proportion of mature trees on residential property within 100 meters by 10%	NA	+ $3089

Theriault M, KestensY, Des Rosiers F, 2002, ``The impact of mature trees on house values and on residential location choices in Quebec City'', in Meeting of the IEMSs Society Lugano, Switzerland, pp. 478-483, International Environmental Modelling and Software Society, http://www.iemss.org/iemss2002/

This research is based on a detailed field survey of 640 single-family homes transacted between 1993 and 2000 on the territory of Quebec City. It integrates various data sets: an opinion poll of recent home buyers; a summary of their transactions (sale price); in-site visits of properties to assess vegetation status; socio-economic attributes of families; and full description of their homes (property specifics). These data are located using a geographical information system (GIS).

The survey of actual homeowners provides the researchers with an opportunity to compare specific data with information about the house. For instance, they ask homeowners about their appreciation of trees on site, finding that having an appreciation of trees on sits leads homeowners to be willing to pay a 4% premium for a house. For families with children, trees on site have a negative effect on house value (-9%) if the households are in a low income stratus, to a positive 10% benefit for house value if they are in a high income category. These estimates are in-line with some of the earlier estimates.

Anderson L M, Cordell H K, 1988, ``Influence of trees on residential property values in Athens, Georgia (USA): a survey based on actual sales prices'' Landscape and Urban Planning 15: 153-64

From their abstract:

A survey of the sales of 844 single family residential properties in Athens, Georgia, U.S.A., indicated that landscaping with trees was associated with 3.5%-4.5% increase in sales prices. During the 1978-I 980 study period, the average house sold for about $38 100 (in I978 constant dollars) and had five trees in its front yard. The average sales price increase due to trees was between $1475 and $17.50 ($2869 and $3073 in 1985 dollars) and was largely due to trees in the intermediate and large size classes, regardless of species. This increase in property value results in an estimated increase of $100 000 (1978 dollars) in the city's property tax revenues.

Effects of trees on house values (1978-1980 nominal $)

	Regression 1	**Regression 2**
Average tree	$344/tree	$290/tree
Hardwood Tree	$376/tree	$257/tree
Softwood Tree	$319/tree	$333/tree
Intermediate/large trees	$382/tree	$336/tree
Value of average number of trees (5.1)	$1750/house	$1479/house
Average house value	$38102	$38102
Tree value %	4.6%	$3.9%

Table 1 below is taken directly from their paper.

TABLE 1

Descriptive statistics for house, lot, and sale variables used in regressions[1]

Variable	Average	Standard deviation	80% of cases fall between (low)	(high)
Price for which house sold[2]	$38 102.80	$13 155.60	$23 860.30	$55 710.30
Price per square foot[2]	$ 22.41	$ 4.22	$ 17.21	$ 27.35
Size of house[3] (square feet)	1718	580	1100	2458
Size of lot (acres)	0.7	0.9	0.3	1.0
Age of house (years)	11.1	13.0	New	23
Number of rooms	9.4	1.8	7	11
Number of baths	2.0	0.6	1	2
Covered car storage (vehicles)	1.3	0.8	0	2
Amenities[4]	3.4	1.4	1	5
Fireplaces	0.6	0.5	0	1
Central air	(73% of houses had central air conditioning)			
Number of trees in front yard	5.1	4.7	0	12
Small trees	1.0	1.5	0	3
Large trees	4.1	4.4	0	10
Pines	2.8	3.6	0	7
Hardwoods	2.3	3.2	0	6

[1]For 844 houses where lot size, house age and floorplan were known.
[2]In 1978-constant dollars.
[3]Interior heated space.
[4]Number of fireplaces, plus one for each of the following, if present: dishwasher, disposal, stove, refrigerator, or deck.

APPENDIX E: Economic Case Study

Sohngen, B., S. Petrova, and D. Hite. 2012. The Impact of Tree Loss During Development on House Values and Carbon Storage: A Case Study from Two Counties in California. California Energy Commission. Publication number: CEC-PIR-08-008.

Public Interest Energy Research (PIER) Program

PROJECT REPORT

Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity

The Impact of tree loss during development on house values and carbon storage: a case study from two counties in California

Prepared for: California Energy Commission

Prepared by: Winrock International

JULY 2012

CEC-PIR-08-008

WINRROCK INTERNATIONAL
Putting Ideas to Work

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

"Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity: Emissions Analysis" is an interim report for the project Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity, grant number PIR-08-008 conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

This report examines the effect of development on tree canopy cover change in two regions in California. One region is in Shasta County and another is in Placer County. For each region, we have data on the tree cover canopy for two time periods, and we have data on the parcels, such as information on when houses were built, their size, and other characteristics. These regions were selected as part of a larger project to assess the implications of development on deforestation, and the resulting economic effects. An earlier study by Sohngen et al. (2012) describes the economic model used in this case.

The two areas have differing trends in overall tree canopy cover. In the Shasta county site, the trend in tree canopy cover was towards less cover over the observation period of 2003 to 2008. These losses amounted to a reduction in tree canopy cover of 0.02 acres per house, or about 13%. The economic value of this loss was $1,416 per house. In Placer County, the trend was towards more cover over the observation period of 2006 to 2009. These gains in tree canopy cover amounted to 0.15 acres per house, or about 10%. The economic value of this gain was $3,996 per house.

The case study reveals that development leads to losses in tree canopy cover regardless of the overall trend. In Shasta County, development appears to cause a loss of around 0.08 acres of tree canopy cover. This loss in tree canopy cover in turn causes a $4,923 loss in average house value and an estimated loss of about 5.0 tons of CO_2. In Placer County, development appears to cause a loss of about 0.06 acres of tree canopy cover. This loss in tree canopy cover causes a $3,127 loss in house value and an estimated loss of about 5.6 tons of carbon. The case study also suggests that tree canopy cover rebounds anywhere from 2 to 7 years after development occurs, depending on the location.

Keywords: greenhouse gas, development, deforestation, carbon stock, urban, forest, house values

Please use the following citation for this report:

Sohngen, Brent, Silvia Petrova, and Diane Hite. 2012. ***The Impact of Tree Loss During Development on House Values and Carbon Storage: A Case Study from Two Counties in California.*** California Energy Commission. Publication number: CEC-PIR-08-008.

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EXECUTIVE SUMMARY

This report examines the effect of development on tree canopy cover change in two regions in California. One region is in Shasta County and another is in Placer County. For each region, we have data on the tree cover canopy for two time periods, and we have data on the parcels, such as information on when houses were built, their size, and other characteristics. These regions were selected as part of a larger project to assess the implications of development on deforestation, and the resulting economic effects.

An earlier study by Sohngen et al. (2012) describes the economic model used in this case. That study used hedonic pricing analysis of over 7000 parcels in five areas of interest in California to estimate the value of tree canopy cover on house sites. The results suggest that the value of forest cover for homes in Shasta and Placer county ranges from $4,806 per acre to $12,032 per acre of trees. Given the level of tree cover, tree canopy cover could provide 2.5-6.5% of the total value of homes.

The Shasta county site examined in this study experienced a decline in tree canopy cover over the observation period of 2003 to 2008. These losses amounted to a reduction in tree canopy cover of 0.02 acres per house, or about 13%. The economic value of this loss to homeowners was $1,416 per house.

When considering just sites in Shasta County that developed over the 5 year time period of analysis (2003-08), the case study reveals a loss of around 0.08 acres of tree canopy cover on sites that developed. This loss in tree canopy cover in turn causes a $4,923 loss in average house value on sites where development occurred, and an estimated loss of about 5.0 tons of CO_2 per house.

In Placer County, the trend was towards more cover on average over the observation period of 2006 to 2009. These gains in tree canopy cover amounted to 0.15 acres per house, or about 10%. The economic value of this gain was $3,996 per house. Although tree cover was increasing in Placer County on average, development appears to cause a loss of about 0.06 acres of tree canopy cover there. This loss in tree canopy cover causes a $3,127 loss in house value and an estimated loss of about 5.6 tons of carbon.

The results suggest that development causes tree canopy cover losses from 0.06 to 0.08 acres per house. This causes homeowners economic loss of around $4000 - $5000 per house. Carbon losses are in excess of 5 tons of carbon per house. The case study does suggest that these losses are temporary, with tree canopy cover rebounding on developed sites anywhere from 2 to 7 years after development occurs. The rebound does not offset earlier losses however.

CHAPTER 1: Introduction

This case study examines the influence of alternative tree canopy cover on housing values in two areas of interest in California. In many cases, when development occurs, tree canopy cover is removed in order to build the houses and associated infrastructure. While some of the loss of tree canopy cover is unavoidable, some of it could be avoided. Based on our earlier estimates (see Sohngen et al., 2012), tree canopy cover around homes has significant value in California, so losses in tree canopy cover when development occurs could imply significant losses in value for homeowners. These losses when development occurs could also have important implications for carbon storage. By maintaining additional tree canopy cover on their properties, landowners may enhance the value of their home and they may provide a global public good in terms of carbon storage.

In addition to the change in tree canopy cover when development occurs, tree canopy cover is changing around existing homes in numerous ways. Landowners change tree canopy cover by planting and removing trees depending on their objectives for their landscape. These changes will have economic implications for homes by increasing or reducing house value, and will influence the amount and value of carbon stored on house sites. It is important to carefully assess both the losses that occur during development, and the potential gains that occur over time after sites have been developed.

For this analysis, we examine development that occurred in two regions in California in the 2003-2009 period. These two regions were included in an earlier hedonic study assessing the effect of tree canopy cover on house value (Sohngen et al., 2012). This earlier model will be used to calculate the value of changes in tree canopy cover over a 3-5 year time period on all houses in two areas of interest in California, namely in Shasta county (Study Area 12) and Placer county (Study Area 17). In addition to assessing what happens to all houses in the Study Areas, we look specifically at the houses that were built during the same 3-5 year period of time.

CHAPTER 2: Methods

For this report, we analyze Study Area 12 in Shasta County and Study Area 17 in Placer County. These areas were earlier described in the reports by Pearson et al. (2011) and Sohngen et al. (2012). For Study Area 12, we have land cover maps and house sales for 2003 and 2008, and for Study Area 17 we have land cover maps and house sales for 2006 and 2009. Using the parcel data for each of these Study Areas, we begin by predicting the value of each house using the hedonic equation estimated in Sohngen et al. (2012). The hedonic equation is given as:

$$\ln(y_i) = \beta X_i + e_i$$

In the equation above, y_i is home value, and X_i is a variable that explains home value; e_i is an error term in the regression equation that estimates parameters β. The methods for estimating these parameters are described in Sohngen et al. (2012). The estimation technique employed in the analysis was a quantile regression, so the parameter estimates for the median quantile are used to make the predictions for this analysis. These parameters are shown in table 1.

Table 1. Parameters β used in the model to predict the value of homes (from Sohngen et al., 2012)

Variable Name	Parameters
Intercept	13.2689
Study Area 8 dummy (0,1)	0.5892
Study Area 9 dummy (0,1)	0.8997
Study Area 12 dummy (0,1)	0.1403
Study Area 17 dummy (0,1)	0.4554
Study Area28 dummy (0,10	0.8772
Lot Size (1000 m^2)	0.0051
Area of House (1000 ft^2)	0.3107
Fireplace (1,0)	0.0507
Year Built	-0.0009
Condition	0.081
Pool (1,0)	0.0812
% Black	-0.0082
% Hispanic	-0.0047
% Vacant	-0.0025
Average slope	0.0012
Total Respiratory. Risk	-0.0179
Time (0 if first period)	-0.2875
Tree Canopy Cover (%)	0.0007
Tree % X Study Area 8	0.0035
Tree % X Study Area 28	0.0002
Fire Hazard Code	0.0083

One of the variables in the regression equation is tree canopy cover for the parcel. We calculate change in house value from the first time period to the second time period by varying the tree canopy cover according to our estimates for each parcel. The first time period for which we have tree canopy cover for each parcel is 2003 for Study Area 12 and 2006 for Study Area 17, and the final time period is 2008 for Study Area 12 and 2009 for Study Area 17. Once we have a prediction of house value for the first and second time period, we can calculate the impact of the change on house value. We filter the results so that only parcels with buildings smaller than 10,000 square feet and greater than 500 square feet were included.

As noted in the original report, this analysis was conducted during a time period when housing values were generally declining due to deteriorating economic conditions. Thus, the original hedonic estimates included a time dummy variable which represented whether the sale occurred in the initial or later period. We did detect in our analysis a substantial reduction in house value over the time period. For this analysis of the effect in tree canopy cover, we hold this dummy variable constant at "0", representing the initial conditions. This allows us to measure the effect of the change in tree canopy cover independently from the effect of change in general economic conditions.

In addition to examining the value of trees on the landscape, we also examine the impact of tree gains or losses on carbon storage. Since we cannot measure carbon specifically, we use estimates of carbon density from Winrock International (Goslee et al., 2012), and from Smith et al. (2005). Estimates from Winrock for Shasta County indicate carbon values of 61 tons of CO_2 per acre for areas of woodlands. This is consistent with estimates of live tree carbon in a 40-50 year stand in California. For Placer County, Winrock estimates more carbon per acre, 94 tons CO_2 per acre for woodlands. For our analysis we multiply the net change in acres of land in forests by these numbers. This potentially overestimates carbon gain when parcels are increasing forest cover, particularly if the reason for the increase is a newly planted tree and not growth of existing trees.

CHAPTER 3: Results

Study Area 12 – Shasta County

We begin by assessing the implications of development on tree canopy cover. To determine development, we filter the results by the year the houses were built. Table 1 presents some summary statistics for houses that were built between 2003 and 2008. Over this time period, 356 houses were built in this Study Area in Shasta County. The difference in house value represents the change associated with a gain or loss in tree canopy cover. For Study Area 12, between 2003 and 2008, 356 parcels fitting our filtering criteria were developed (Table 2). The number of parcels developed dropped after 2005, as expected, due to the downturn in economic conditions. Note that because economic conditions changed so dramatically over the time period, we held our time variable constant at the initial value for the analysis. This ensures that we isolate the value of the tree canopy cover change relative to the impact of the change in economic conditions.

For parcels that were built in the period 2003 and 2004, tree canopy cover increased on average between 2003 and 2008, suggesting that enough trees were left on site to contribute positive value to homes and that the growth of the trees over the five year period enhanced house value. Development that occurred in 2005 to 2008 caused more loss of tree canopy cover. During this period, tree canopy cover declined by about 0.08 acres per house after the development occurred. On average, the loss in tree canopy cover over the period 2003 to 2008 caused a $3,180 loss to homeowner, however if we isolate houses that were built in the 2005 to 2008 period, when most tree canopy cover loss occurred, the effect of tree canopy cover loss is $4,923 per house.

Table 2. Estimates of economic gains and losses for parcels that were developed during the 2003 to 2008 period in Study Area 12, Shasta County

Year	Number of Parcels	Average Lot Area (acres)	2003 Average Tree Area (acres)	2008 Average Tree Area (acres)	Average Change in Tree Area (acres)	Total Value of Tree Area Change	Average Loss Per House
2003	65	0.53	0.14	0.14	0.00	$43,709	$672
2004	61	0.57	0.19	0.19	-0.01	$48,476	$795
2005	98	0.28	0.13	0.06	-0.06	-$525,036	-$5,358
2006	52	0.35	0.16	0.10	-0.07	-$264,667	-$5,090
2007	46	0.31	0.12	0.04	-0.08	-$212,230	-$4,614
2008	34	0.93	0.62	0.46	-0.16	-$222,510	-$6,544
Total	356	0.45	0.19	0.14	-0.05	-$1,132,258	-$3,180
Avg. 2005-08	230	0.40	0.21	0.13	-0.08	-$1,132,258	-$4,923

To get a sense for the implications of our estimates on individual homes, data for several representative parcels from Study Area 12 are shown in Table 3. We pick one parcel for each year of our analysis from 2003 to 2007. The first two years, 2003 and 2004, include parcels with an increase in tree canopy cover. In those two years, the average lot size is relatively large compared to development that occurred in later years, and the average area of trees initially is relatively low. We calculate that for the parcel developed in 2003, house value was increased $2,109 by 2008 with a modest increase in tree canopy cover, and for the parcel developed in 2004 house value increased by $3,651 by 2008. To get a sense for the changes represented by these values, the change in tree cover over the five year period for the 2004 parcel is shown in figure 1. This is an important value improvement, which offsets to some extent at least, the losses that occurred with the economic downturn in the housing market that started in 2005. We calculate that the 2003 and 2004 parcels lost around $85,000 in value by 2008, 20-30% of their value.

Figure 1. Tree cover for parcel 203470011000 in 2003 and 2008

The results for 2005 to 2007 show losses in tree canopy cover on average, so we have picked representative parcels that have losses. For 2005, one can see the typical type of development which involved tree canopy cover of near 100% before the parcel was developed, with nearly no tree canopy cover remaining after development. The house on the site is a relatively modest size house of 2027 square feet, worth around $339,000. The reduction in tree canopy cover to nearly 0 causes a loss in value of the house of around $15,000, or about 4.5% of the value of the house. Of course, it may not be possible, given the footprint of the house and the driveway to maintain the original tree canopy cover, but it is possible to maintain more tree canopy cover than the 0.06 acres currently.

Table 3. Data for representative parcels in each year from 2003 to 2007 for Study Area 12, Placer County

Year	Parcel Number	Lot Size Acres	Tree Area 2003 Acres	Tree Area 2008 Acres	House Size ft2	Tree Area Change Acres	Tree Area Change ($)	House Value ($)
2003	203480002000	0.61	0.03	0.08	2,118	0.06	$2,109	$354,609
2004	203470011000	0.34	0.01	0.06	2,628	0.05	$3,651	$413,207
2005	204620001000	0.23	0.22	0.06	2,027	-0.16	-$15,277	$339,147
2006	103750013000	0.84	0.61	0.32	2,631	-0.29	-$9,800	$429,549
2007	104240012000	0.86	0.21	0.20	3,146	-0.01	-$514	$493,635

The parcels chosen for 2006 and 2007 represent other types of changes evident in the data. The 2006 parcel is a fairly large lot with a moderately sized house. The lot did not start out with full tree canopy cover, but about 50% of existing tree canopy cover was lost with the development. In this case, much of this could have been avoided. As a result, the house experienced a $9,800 loss in value, or about 2.3%. Alternatively, for the

2007 plot, the lot is also fairly big, but the owners have preserved most of the initial tree canopy cover. Thus, they experience a very small loss in house value when the development occurs.

We calculate that the net carbon loss on parcels that developed between 2003 and 2008 in Shasta county was 1,158 tons CO_2 (Table 4). Across the 356 parcels this amounts to an average loss of 3.3 tons per parcel. As noted above, parcels that were developed in the period 2003 and 2004 had much smaller carbon losses by 2008 than those parcels that converted later. This results from regrowth in carbon on those parcels. Evidence of regrowth can be seen through the change per house estimates in Table 3, which are larger for later time periods.

Table 4. Carbon losses for sites developed between 2003 and 2008 in Study Area 12, Shasta County

Year	Total C Change	Change per house
	tons CO2	
2003	(12.1)	(0.2)
2004	(21.1)	(0.3)
2005	(368.1)	(3.8)
2006	(206.4)	(4.0)
2007	(212.7)	(4.6)
2008	(337.2)	(9.9)
Total	(1,157.6)	(3.3)

Table 5. Change in tree canopy cover and value for parcels developed between 1980 and the present, and the total average across all houses for all years (pre- and post-1980) for Study Area 12, Shasta County

Year	Number of Parcels	Average Lot Area (acres)	2003 Average Tree Area (acres)	2008 Average Tree Area (acres)	Change in Tree Area (acres)	Value of Tree Area Change	Average Loss Per House
1980	116	0.30	0.15	0.12	-0.02	-$201,841	-$1,740
1981	26	0.30	0.12	0.11	-0.02	-$25,232	-$970
1982	17	0.28	0.11	0.09	-0.02	-$29,482	-$1,734
1983	48	0.28	0.13	0.10	-0.02	-$72,338	-$1,507
1984	46	0.31	0.15	0.12	-0.03	-$112,914	-$2,455
1985	82	0.30	0.13	0.11	-0.02	-$174,121	-$2,123
1986	75	0.28	0.14	0.12	-0.02	-$127,761	-$1,703
1987	56	0.33	0.17	0.13	-0.04	-$88,189	-$1,575
1988	52	0.51	0.26	0.25	-0.01	-$48,088	-$925

1989	171	0.39	0.17	0.16	-0.01	-$130,501	-$763
1990	225	0.45	0.21	0.20	-0.01	-$145,710	-$648
1991	161	0.45	0.17	0.17	0.00	-$58,651	-$364
1992	117	0.56	0.29	0.28	-0.01	-$59,421	-$508
1993	97	0.56	0.23	0.22	-0.01	-$17,931	-$185
1994	85	0.55	0.22	0.22	0.00	-$16,578	-$195
1995	69	0.43	0.16	0.17	0.00	-$12,208	-$177
1996	51	0.47	0.19	0.20	0.01	$6,824	$134
1997	65	0.51	0.21	0.22	0.01	$19,897	$306
1998	76	0.58	0.27	0.28	0.00	$12,409	$163
1999	95	0.58	0.24	0.24	0.00	$9,903	$104
2000	97	0.52	0.16	0.18	0.02	$44,453	$458
2001	51	0.47	0.15	0.14	-0.01	$3,578	$70
2002	75	0.74	0.31	0.30	-0.01	$56,731	$756
2003	65	0.53	0.14	0.14	0.00	$43,709	$672
2004	61	0.57	0.19	0.19	-0.01	$48,476	$795
2005	98	0.28	0.13	0.06	-0.06	-$525,036	-$5,358
2006	52	0.35	0.16	0.10	-0.07	-$264,667	-$5,090
2007	44	0.31	0.12	0.04	-0.08	-$210,049	-$4,774
2008	33	0.95	0.64	0.48	-0.17	-$221,788	-$6,721
Average 1980-2008	2,306	0.45	0.20	0.18	-0.02	-$2,296,523	-$996
Average from all years built	5,597	0.34	0.15	0.13	-0.02	-$7,924,976	-$1,416

Considering the results from 2003 to 2008, one explanation for the smaller changes for earlier time periods in Table 4 is that after several years, enough tree growth has occurred to surpass the losses that occurred when the site was being developed. To assess the potential for regrowth after development, we expand our carbon analysis to houses that were developed from 1980 to the present (Table 5). These results show that from 1994 to 2004, the net change in tree area was positive or modestly negative (in only two years). Prior to 1994, the changes are all negative and near the sample average for the entire sample of houses. After 2004, the changes are all negative, but substantially larger in absolute terms than the sample average. The losses are largest for the most recent developments.

These results indicate that when development occurs, it appears to have an immediate impact on carbon, causing carbon losses of 3.8 to 10 tons CO_2 per house. The losses last for 3-5 years, but then there are net gains in carbon. The gains, however, appear to be fairly modest. Based on our estimates, they average about 0.01 to 0.02 ton CO_2 per year for about 10 years. Despite the potential regrowth, for Shasta county at least, our results indicate that any net gains are relatively modest compared to the overall losses that occur during development.

Study Area 17 – Placer County

For the site examined in Placer County, Study Area 17, the two years with tree canopy cover data are 2006 and 2009. In this Study Area there are fewer houses than Study Area 12 discussed above. For the period over which we have data on tree canopy cover change, 2006 to 2009, there were 95 parcels that were developed (Table 6). For Placer County we do not break out the years 2006 to 2009 separately and instead examine all years from 1980 to 2009 in table 6. During the period 2006 to 2009, the number of houses built fell after 2007. As with the analysis for Shasta county, we have held our time variable constant at the initial value for the analysis due to the large change in economic conditions. This ensures that we isolate the value of the tree canopy cover change rather than the impact of the change in economic conditions.

The net change in tree canopy cover during the period 2006 to 2009 for parcels in Placer County that were built between 1980 and the present is positive. For all houses built between 1980 and the present the average change in tree canopy cover was 0.2 acres, and the average value of the gain per house is $1,298. This is consistent with our analysis of the entire Study Area, where tree canopy cover increased by nearly 10% during this time period. Parcels converted in 2008 and 2009, however, lost forest cover. On average, these parcels lost 0.06 acres of tree canopy cover when development occurred (Table 6). This loss reduced house value by $3,127 on average. These results are consistent with our finding from Shasta County, where more recently developed parcels lost cover over the analysis period. The parcels in Placer County have slightly less overall tree canopy cover loss than those in Shasta County, but they also start from a higher tree canopy cover base and are in a region where the trends are positive anyhow.

Table 6. Estimates for Study Area 17, Placer County, from 1980 to 2009

Year	Number of Parcels	Average Lot Area (acres)	2006 Average Tree Area (acres)	2009 Average Tree Area (acres)	Change in Tree Area (acres)	Value of Tree Area Change	Average Loss Per House
1980	38	2.47	1.70	1.83	0.13	$49,710	$1,308
1981	24	2.49	1.53	1.69	0.16	$62,798	$2,617
1982	26	2.74	1.77	1.94	0.17	$56,117	$2,158
1983	13	2.44	1.74	1.86	0.12	$20,029	$1,541
1984	42	2.74	1.75	1.95	0.20	$102,847	$2,449
1985	23	2.62	1.79	1.97	0.18	$52,684	$2,291
1986	31	4.10	2.31	2.62	0.30	$91,250	$2,944
1987	16	3.45	2.48	2.77	0.30	$23,535	$1,471
1988	32	2.81	1.46	1.67	0.20	$89,441	$2,795
1989	44	3.14	1.96	2.11	0.15	$66,408	$1,509
1990	34	3.75	1.63	1.86	0.23	$121,879	$3,585
1991	40	3.20	2.09	2.26	0.17	$87,253	$2,181
1992	21	2.35	1.51	1.66	0.15	$64,680	$3,080
1993	30	2.85	1.63	1.77	0.13	$94,987	$3,166
1994	13	3.96	2.37	2.63	0.26	$26,767	$2,059
1995	10	3.79	2.67	2.92	0.25	$32,594	$3,259
1996	16	3.26	2.10	2.35	0.24	$54,562	$3,410
1997	6	2.25	1.58	1.65	0.08	$13,266	$2,211
1998	15	5.98	4.29	4.61	0.32	$36,883	$2,459
1999	18	3.16	1.58	1.71	0.12	$26,836	$1,491
2000	20	2.37	1.38	1.65	0.27	$92,297	$4,615
2001	31	2.13	1.08	1.22	0.14	$78,986	$2,548
2002	25	2.82	1.51	1.77	0.26	$140,265	$5,611
2003	32	2.46	1.24	1.44	0.20	$172,619	$5,394
2004	32	1.81	0.93	1.10	0.17	$202,204	$6,319
2005	37	2.06	1.00	1.22	0.22	$318,402	$8,605
2006	39	2.57	1.29	1.54	0.25	$356,390	$9,138
2007	30	2.25	1.22	1.40	0.18	$329,457	$10,982
2008	16	1.72	0.90	0.81	-0.08	-$69,698	-$4,356
2009	10	1.91	1.28	1.26	-0.02	-$11,600	-$1,160
Average all yrs	1,508	2.43	1.51	1.66	0.15	$6,025,968	$3,996
Average 1980-2009	764	2.81	1.65	1.84	0.19	$2,783,848	$3,644
Average 2008-09	26	1.79	1.04	0.99	-0.06	-$81,298	-$3,127

Table 7. Carbon losses for parcels developed between 2006 and 2009 in Study Area 17, Placer County

	Total C Change	Change per house
Year	tons CO2	
2006	913.5	23.4
2007	499.3	16.6
2008	(126.9)	(7.9)
2009	(14.6)	(1.5)
	1,271.3	13.4

We use an estimate of 94 tons of CO_2 per acre to calculate carbon gains and losses. For the parcels developed between 2006 and 2009, CO_2 increased by an estimated 1,271.3 tons, or 13.4 tons CO_2 per house (Table 7). There was a loss in carbon for parcels developed in the period 2008 and 2009 of around 127 total tons CO_2, or 5.4 tons CO_2 per house. In Placer County, as in Shasta County, there is a loss of carbon associated with the development process. The overall trend in Placer County, however, is towards an increase in carbon on parcels with houses.

CHAPTER 4: Discussion

The two regions examined for this case study analysis, Study Area 12 in Shasta County and Study Area 17 in Placer County exhibit different trends in overall land use over the time period for which we assess land cover. For the Shasta County Study Area, tree canopy cover on all parcels declined by 13% over the period of analysis 2003 to 2008. For all houses in the Study Area, the average value of the loss associated with the reduction in tree canopy cover for single family homes is $1,416 per house. The average carbon loss for all houses over a 5 year period is 1.2 tons CO_2, or 0.2 tons CO_2 per year.

The results for Shasta County indicate that tree canopy cover is reduced by about 0.08 acres when development occurs. We calculate that this loss causes a carbon emission of about 3.3 tons CO_2 per house. The results also indicate that tree canopy cover expansion occurs after development, although it takes 5-7 years to start to show gains in tree canopy cover.

Placer County experienced a 10% increase in tree canopy cover over the 2006 to 2009 period. The increase in tree canopy cover enhanced house value by $3,996 per house on average. Houses that were built in 2008 and 2009, however, experienced a 0.06 acre reduction in tree canopy cover on average. This loss of trees reduced house value by $3,126 on average. We estimate that this tree canopy cover loss led to a carbon emission of 4.6 tons CO_2 per house. These losses for recently built houses, however, were more than offset by the gains that occurred across the entire Study Area of 0.15 acres of trees per house, or 13.7 tons CO_2 per house (3.4 tons per house per year).

One concern with the carbon calculations in this analysis is that we are using estimates for the carbon contained in mature woodlands to assess carbon changes during development and over time. This may over-estimate the total carbon on a site if the trees on the parcels we are examining are mainly ornamental trees. In addition, when we see increases in tree canopy cover on a given parcel, the increase could be generated by newly planted trees, or it could be generated by growth of existing trees. We treat the carbon changes in both cases the same because we cannot distinguish between them. To improve on this, we would need to visit the sites and conduct sampling, something we are unable to do in the context of this analysis.

CHAPTER 5: Conclusions

This analysis examines the impact of tree canopy cover change on house values and carbon storage on plots with houses. In particular, we examine the effect of development on tree canopy cover. To conduct the analysis we used maps of tree canopy cover for two regions in California for two time periods generated in earlier analysis (Sohngen et al., 2012). These maps were generated for Study Area 12 in Shasta County and Study Area 17 in Placer County. For each Study Area, we have two sets of maps, each for a different time period, and have linked this to data on parcels described in Sohngen et al. (2012).

To estimate the value of change in tree canopy cover over two time periods we use the hedonic model estimated in Sohngen et al. (2012). We first estimate the impact of tree canopy cover change for all parcels with houses in each of the Study Areas. We then select this data to assess changes that occurred on parcels that were developed in different time periods.

The underlying trends in tree canopy cover differed in the two Study Areas. In Shasta County (Study Area 12), the overall trend is towards less tree canopy cover. For the entire Study Area, tree canopy cover declined about 13% from 2003 to 2008. Our analysis, however, indicates a dynamic process on developed parcels in Shasta County. When development occurs, deforestation occurs, averaging 0.08 acres per development. Subsequently, it appears that regrowth occurs, where tree canopy expands. Thus, for the Shasta County site, even though average tree canopy cover was declining, tree canopy cover was expanding on parcels that were developed from 1994 to 2000.

In summary, for the Shasta County site (Study Area 12), the average tree canopy cover loss when development occurs is 0.08 acres, which causes a loss in house value of $4,923 per house, and a loss of about 5 tons of CO_2. While regrowth does occur subsequently, this regrowth does not appear to be enough to make up for the losses that occurred during development.

For the Placer County site (Study Area 17), overall tree canopy cover was increasing, by around 10%, over the observation period of 2006 to 2009. Over the 4 year period, this increase amounted to 0.15 acres per house, an increase in value of $3996 per house, and an increase in carbon of 14.l tons of CO_2 per house. We did detect a difference among more recently developed sites, such that for sites that were developed in 2008 and 2009, tree canopy cover was lost, while for other sites tree canopy cover increased on average. The overall trend towards increasing tree canopy cover, however, was very strong during the 2006 to 2009 time period, and parcels developed in 2006 and 2007 appear to behave similarly to the average for the entire Study Area.

The results of this case study illustrate that development does affect tree canopy cover in California, likely reducing it. The results suggest that there is likely a dynamic process that occurs after development in that tree canopy cover starts to rebound, and after about 5 – 7 years is increasing. The gains, however, do not offset the losses that occurred during development. The results also illustrate large differences across California. In Placer County the overall trends are towards greater tree canopy cover on all parcels, even fairly recently developed parcels.

CHAPTER 8: References

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APPENDIX F: Indirect Emissions Analysis

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Public Interest Energy Research (PIER) Program

INTERIM PROJECT REPORT

Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity

Indirect Emissions

Prepared for: California Energy Commission

Prepared by: Winrock International

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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"Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity: Emissions Analysis" is an interim report for the project Deforestation in California – a poorly understood greenhouse gas emission source and emission reduction opportunity, grant number PIR-08-008 conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

This report aims to expand the analysis done to date by addressing the climate implications of development beyond carbon emissions that result from the removal of existing trees. Trees in urban and developed rural settings can reduce greenhouse gas emissions and increase carbon sequestration in additional ways than the carbon sequestration in tree growth and emissions when trees are cut down. The shade provided by trees may decrease the need for summer cooling, and the windbreak formed by conifers in the winter may decrease heating costs. Retaining at least some of the trees at development sites and planting trees post development can lead to ongoing reductions in energy emissions. Additionally, retained trees continue to grow and provide future sequestration benefits, which are lost when trees are removed during development. This report addresses the implications of deforestation on indirect emissions from energy use and foregone future sequestration.

Keywords:

Greenhouse gas emissions, Energy use, Forestry, Urban forests

Please use the following citation for this report:

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EXECUTIVE SUMMARY

This report expands the analysis done to date by addressing the climate implications of development beyond carbon emissions that result from the removal of existing trees. Trees in urban and developed rural settings can reduce greenhouse gas emissions and increase carbon sequestration in additional ways than the carbon sequestration in tree growth and emissions when trees are cut down. This report addresses the implications of deforestation on indirect emissions from energy use and foregone future sequestration.

Estimations of indirect emissions and emission reductions were developed using a modeling approach. The US Forest Service Center for Urban Forest Research has developed a tree carbon calculator (CTCC) that models the effects of tree shade on residential energy use from heating and cooling systems. For this project, CTCC was used to determine indirect emission reductions from trees adjacent to residential buildings.

Both CTCC and the Forest Vegetation Simulator (FVS) were used to estimate the annual amount of CO_2 sequestered in tree biomass, and the total CO_2 stored over time. CTCC models growth and future sequestration of individual trees, while FVS models growth and sequestration of entire forest stands.

The average net emission reduction from energy use was 82.7 kg CO_2e per tree per year. This ranged from increased emissions of 35 kg CO_2e per tree per year for 13″ adjacent south-side ponderosa pine in the Mountain climate zone to emission reductions of 201 kg CO_2e per tree per year for 23″ near west-side water oak in the Mountain climate zone.

Total CO_2e stored annually in trees modeled with CTCC ranged from 383 kg per tree for a 13″ blue spruce in the Mountain climate zone, to 4,829 kg per tree for a coast live oak in the North Coast climate zone. The annual CO_2e sequestered ranged from 37 kg per tree per year for a 13″ ponderosa pine to 340 kg per tree per year for a 23″ water oak. Over a 10-year period, this results in 370-3,400 kg CO_2e additional carbon sequestered per tree, although it is important to note that CTCC does not account for growth, so this is likely to be an underestimate. The annual increases projected by FVS range from 1.0 metric tons CO_2e per acre for oak woodlands in Shasta County to 8.6 metric tons CO_2e per acre for mixed conifer in Mendocino County. These stands represent hypothetical forests that are nearly fully stocked.

Combining annual net emission reductions from energy consumption with annual sequestered carbon yields total emission reductions per tree retained. The highest reductions result from trees located on the west side of houses, with a range from 99 kg CO_2e per tree per year for a 13″ ponderosa pine in the Mountain climate zone to 541 kg CO_2e per tree per year for a 23″ water oak also in the Mountain climate zone. The total CO_2e stored in these trees is 403 kg and 4,663 kg, respectively.

CHAPTER 1: Introduction

In a poll in 2000, urban sprawl was classified, along with crime, as the leading local concern in the US. Across the country, urban area has doubled over the past 40 years. In California during the same period there was a 252% increase in the urban area. Among regions in the US, California has the lowest current number of developed acres per capita, but the second highest population growth rate and an average income growth rate that outstrips population growth (cf. Swails et al 2009). This trend in population and income growth rates makes one question whether the area of development is captured correctly in California. Thus the purpose of this project is to improve the assessment of forest conversion to development.

Deforestation events occurring daily around California are poorly accounted under current greenhouse gas emission monitoring systems and there is no standard methodology for tracking these emissions. Therefore, the significance of small-scale development as a source of greenhouse gases is currently unknown.

Assessments of deforestation for development do exist but no confident emission estimates can be paired with the estimates of rates of deforestation. In addition, deforestation is monitored using coarse scale imagery which can only poorly track the most common form of urban development – scattered development. It is therefore likely that deforestation rates are underestimated and actual emissions are entirely unknown. For these reasons, Winrock International, under funding and guidance from CA PIER, is conducting a multi-year study of small-scale development and its impacts on greenhouse gas emissions and reductions.

Project Findings to Date

Desk Study

The project began with a desk study (Swails et al, 2009[1]), which described development and associated deforestation in California, including the laws and regulations that govern development and the forest ecosystems in which development is most likely to occur. Based on recent development pressures and forest cover, this study identified these four geographic target areas on which to focus further analysis (see Figure 1):

1. **The Sierra Mountain counties of El Dorado, Placer and Nevada**
2. **The counties of Marin, Sonoma, Napa and Mendocino (north of the San Francisco Bay Area)**
3. **Los Angeles and Ventura Counties in Southern California**
4. **Shasta County in Northern California**

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[1] Swails, E, Pearson, T, Goslee, K, Petrova, S, and Brown S, 2009. Desk Study: Deforestation in California: a poorly understood GHG emission source and emission reduction opportunity. Report to PIER under #PIR-08-008

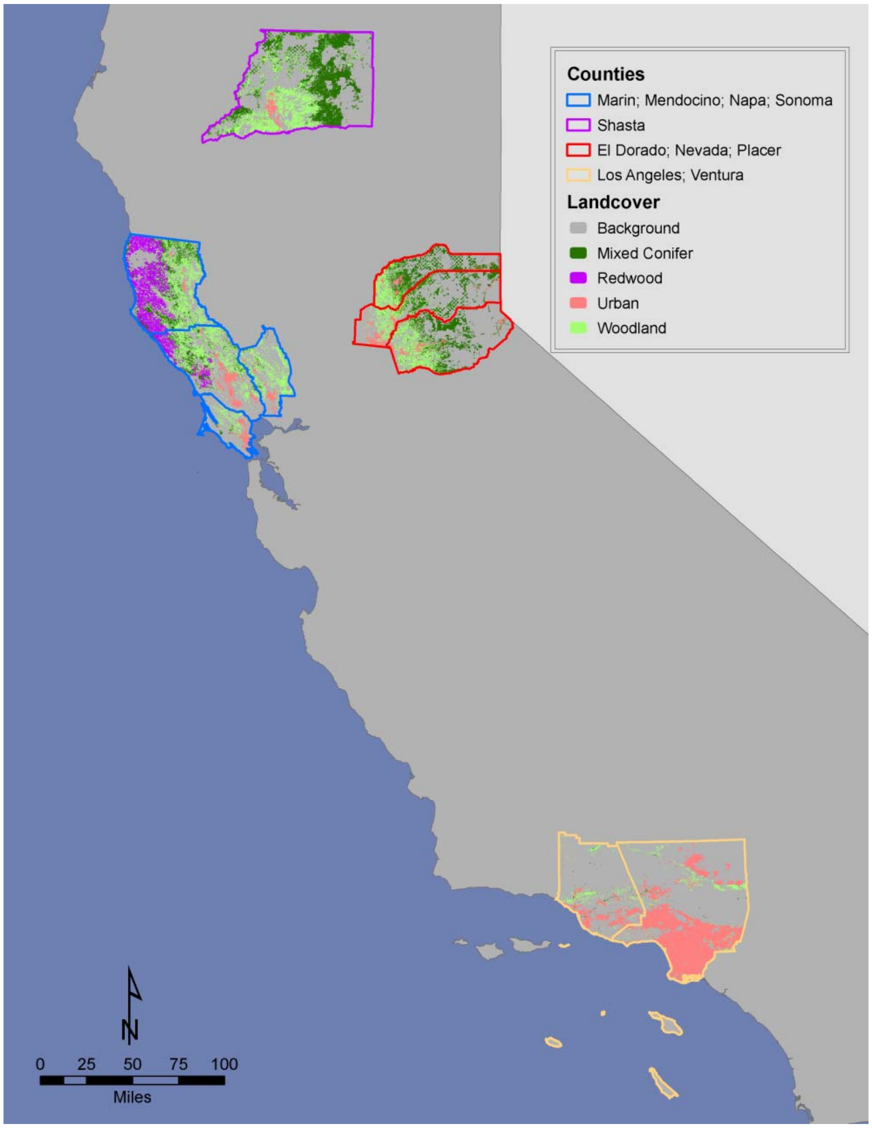

Figure 1. Sites chosen for in-depth study

Spatial Analysis

Following the desk study, a spatial analysis study was conducted to assess deforestation resulting from development, by using a sampling of deforested areas to assess actual acreage of deforestation. This study showed that interpretation of very high resolution remote sensing imagery results in higher estimates of deforestation due to development in comparison to the results from interpreting the commonly used Landsat imagery (Pearson et al. 2011[2]).

[2] Pearson, Timothy, Grimland, Sean, Goslee, Katie and Brown, Sandra. (Winrock International). 2011. Spatial Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity. California Energy Commission. Report to PIER under #PIR-08-008.

For the spatial analysis study, twenty-eight sampling areas totaling 123,630 acres were sampled at two points in time, 3-7 years apart, and change in forest cover was analyzed using both high resolution imagery (60 cm pixels) and medium resolution imagery (Landsat 30 m pixels). The high resolution imagery indicated that 569 acres (0.46%) were deforested, while the medium resolution imagery indicated that 220 acres were deforested (0.09%). According to the high resolution imagery, this was an average of 110 acres deforested annually, with 42% occurring on woodland and hardwood forests, 31% on urban landscapes, 17% on other conifer forests, and 9% on redwood forests. Thirty-six percent of this deforestation occurred in Shasta County, 30% on the North Coast, 22% in the North Sierra region, and 12% on the South Coast.

Emissions Analysis

Following the spatial study, an emissions analysis was conducted to determine the common practice for conversion of forest land to residential development and create emission factors that can be paired with areas of deforestation to give associated greenhouse gas emissions that result from tree removal. An analysis was conducted of the emissions associated with tree canopy loss/deforestation for urban development. The majority of deforestation for development occurred on areas of woodland forest cover, which have lower carbon stocks than redwood or mixed conifer forests. The development that was seen in redwood and mixed conifer forests was single home developments or clearing within existing developments. In all of the study areas, there appears to be little correlation between parcel size and the percent of forest cover loss in multi-parcel developments, though there is some correlation for single house developments.

Across the seventeen 9.7 square mile sampling areas analyzed, a total of 80 new developments, 5 secondary developments, and 26 forest clearings were identified (Table A)[3]. The developments included a total of 557 developed parcels within 14 multi-house developments and 66 single house developments, as well as 5 parcels with secondary development and 26 parcels with clearing.

Across counties, the average size of a parcel in a multi-housing development ranged from 0.17 acres in Sonoma to 1.83 acres in Los Angeles. The average forest loss ranged from 16% in Nevada to 88% in Los Angeles. For single house developments, the average size of a parcel ranges from 0.14 acres in Napa to 8 acres in El Dorado. The average forest losses range from 6% in El Dorado to 78% in Napa.

Total CO_2 emissions in multi-house developments across the study areas ranged from 34 tons in a Shasta County development with 27 parcels averaging only 0.09 acres in size to 735 tons in another Shasta County development with 114 parcels averaging 0.39 acres. Average per parcel emissions by development ranged from 1.3 tons in the Shasta County development with small average parcel size to 21.4 tons in a development in El Dorado County with a higher average parcel size, moderate forest cover loss, and a moderately high emission factor.

[3] In one of the sampling sites in Mendocino County and two in Nevada County no forest loss was identified within the analyzed time period.

For single house developments, the average CO_2 loss for single house parcels ranged from 2.0 tons in Napa County to 42 tons per development in Shasta County. It is important to note, however, that there was wide range in the emissions within each county, and all have a large confidence interval. Shasta County, in fact has the smallest confidence interval as a percent of the mean, although it is still fairly high at 18%. The average emissions per acre also ranged widely, with a low of 2.0 t CO_2/ac in El Dorado County, which has a relatively large average parcel size, and a high of 27 in Mendocino County, though this is based on only one development. Sonoma County, which has smaller parcels, relatively high percent forest loss, and high carbon stocks, had the second highest emissions per acre at 22 t CO_2/ac.

Purpose of this Report

This report aims to expand the analysis done to date by addressing the climate implications of development beyond carbon emissions that result from the removal of existing trees. Trees in urban and developed rural settings can reduce greenhouse gas emissions and increase carbon sequestration in additional ways than the carbon sequestration in tree growth and emissions when trees are cut down. The shade provided by trees may decrease the need for summer cooling, and the windbreak formed by conifers in the winter may decrease heating costs. Retaining at least some of the trees at development sites and planting trees post development can lead to ongoing reductions in energy emissions. Additionally, retained trees continue to grow and provide future sequestration benefits, which are lost when trees are removed during development. This report will address the implications of deforestation on indirect emissions from energy use and foregone future sequestration.

Section 2 describes the CTCC model, which is used to estimate emission reductions and sequestration. Section 3 describes emission reductions from energy use and Section 4 describes emission reductions from future sequestration. Section 5 describes total estimated emissions that can result from homes, and potential for these emissions to be reduced.

CHAPTER 2:
Indirect Emissions Analysis Approach

Energy Emissions

Estimations of indirect emissions and emission reductions were developed using a modeling approach. The US Forest Service Center for Urban Forest Research has developed a tree carbon calculator (CTCC) that models the effects of tree shade on residential energy use from heating and cooling systems. It is programmed into an Excel spreadsheet and is currently considered "proof of concept" software[4].

The model provides carbon-related information for a single tree within one of sixteen U.S. climate zones (Figure 2). Users are required to provide:

- The geographic location of the project,
- The species and size or age of a tree,
- The location of the tree relative to a building,
- The age of the building, and
- The type of heating and cooling system used.

The model uses growth curves, developed from 650-1000 sampled street trees across 20 common species in each of 16 regional reference cities, to calculate total tree size over time. The effects that tree shade has on energy performance are modeled based on 12,000 simulations which were conducted for each reference city, with different combinations of tree size and location and building.

The model output includes projections of:

- Energy reduction,
- Emission reduction, and
- Carbon sequestration for individual trees.

For this project, CTCC was used to determine indirect emission reductions from trees adjacent to residential buildings.

[4] CUFR Tree Carbon Calculator – Help Manual, available for download from http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/.

Figure 2. Climate Zone Map used by CTCC

While the CTCC seems to be the best available method of modeling the energy impacts of individual trees on individual residential buildings, there are some shortcomings. First, only certain species are available for each climate zone, and in many cases, those species do not include the most common species in the area. For instance, Douglas-fir was not among the listed species in the mountain climate zone in California. Similarly, there are no oaks included that are native to the counties in this study.

Future Sequestration

In addition to calculating emission reductions from energy conservation, CTCC also calculates the annual amount of CO_2 sequestered in tree biomass, and the total CO_2 stored over time. Tree biomass and carbon storage are calculated in CTCC using volumetric equations in a two-step process. First, green volume is calculated, using appropriate allometric equations based on DBH and height. Green volume is then converted to dry weight biomass and subsequently carbon and CO_2e. This process is further described in section 4.1 and the equations in tables 4 & 5 of the CTCC help manual[5].

[5] Available for download from http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/.

Many of the development projects identified in Goslee et al (2012[6]) occurred in more rural areas, with dense, non-urban forest cover. For this reason, it is useful to model the future sequestration of whole forest stands, rather than simply individual trees. This was done using the Forest Vegetation Simulator (FVS). FVS is also a product of the US Forest Service, although it is a much more complex model than CTCC. FVS is a semi-distant-independent individual tree growth and yield model that projects tree growth based on management activity and geographic location. Geographic variants are used, which apply regional characteristics and growth rates are used, and unlike CTCC, the population unit is the stand, so growth is projected for a stand rather than for a single tree, and the effects of competition are addressed by the model. Regional Forest Service biomass equations were used to calculate carbon.

[6] Goslee, Katherine, Pearson, Timothy, Petrova, Silvia, and Brown, Sandra. (Winrock International). 2012. *Emissions Analysis: Deforestation in California - a poorly understood GHG emission source and emission reduction opportunity.* California Energy Commission. Publication number: CEC-PIR-08-008.

CHAPTER 3:
Estimation of Indirect Emissions from Energy Use for New Development in California

Here we conduct assessments of indirect emissions from hypothetical new developments in two regions of California. We examine the implications of retaining or planting trees of various sizes and species on both winter heating and summer cooling energy use.

Methods

The variables that affect the impact tree shade has on energy use include:

- Size of tree
- Distance from the building
- Azimuth (compass bearing) from the building (Figure 3)
- Species of tree
- Climate zone

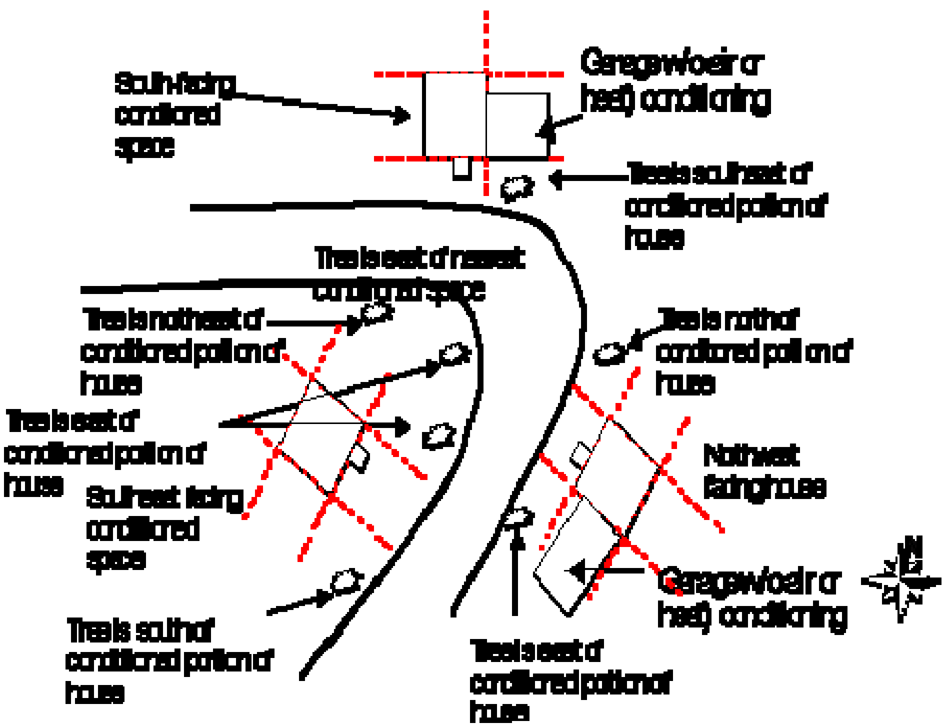

Figure 3. Diagram showing trees at a variety of compass bearings (azimuth) from a building, taken from CUFR Tree Carbon Calculator – Help Manual

Numerous scenarios were modeled, to calculate the energy impact of several tree species in various locations, at a range of distances from the residential building. The calculator was used to determine the impact of the following species, by climate zone:

- North Coast climate zone, which includes Mendocino, Napa, and Sonoma counties
  - redwood (*Sequoia sempervirens*)
  - coast live oak (*Quercus agrifolia*)
- Mountain climate zone, including El Dorado, Nevada, and Shasta counties
  - ponderosa pine (*Pinus ponderosa*)
  - blue spruce (*Picea pungens*)
  - water oak (*Quercus nigra*)

In each case, the trees were modeled with each combination of the following variables:

- Size:
  - 13” dbh
  - 23” dbh[7]
- Distance from building:
  - Adjacent (within 20 feet)
  - near (20-40 feet)
  - far (40-60 feet)
- Azimuth from building:
  - North
  - South
  - East
  - West

Other variables that have an impact include the type of heating and cooling equipment used in the home and the respective emission factors of each. These were held constant for this exercise, because this research is addressing new developments, which are all likely to use the most modern heating and cooling equipment available.

Results

CTCC calculates the impact of only one tree at a time, so it is necessary to sum output from individual trees in order to find the benefits of multiple trees. For this exercise the impact of only one tree was determined, although these results can be summed to obtain an estimate of the impact of multiple trees. For small residential buildings, it is assumed that in comparison to the first tree, additional trees have a reduced impact on energy use, and in many cases the

[7] The CTCC calculates height as a function of species and diameter.

impact of additional trees is likely negligible. For large buildings, or for multi-house developments, however, multiple trees are likely to increase the energy benefit.

CTCC projects the energy reductions and emission reductions from energy for cooling and heating systems separately.

Emission reductions for cooling systems

The lowest emission reductions from cooling systems for all species in all climate zones resulted from 13″ trees on the north side of the house, where there is less need to block the sun. These reductions ranged from 12.6 kg CO_2e per tree per year for ponderosa pine in the mountain zone to 64.7 kg for coast live oaks in the north coast zone.

The highest emission reductions from cooling resulted from larger trees, usually on the west side of the house (afternoon sun). The exception was for north coast redwoods, which yielded the highest reductions on the south side (direct sun throughout the year). Reductions ranged from 83 kg CO_2e per tree per year for 23″ adjacent, west side ponderosa pines in the mountain zone to 138.2 kg for 23″ adjacent coast live oaks on the west side of houses in the north coast zone.

The average emission reduction from cooling systems was 58.3 kg CO_2e per tree per year. This ranged from emission reductions of 13 kg CO_2e per tree per year for 13″ far south-side ponderosa pine in the Mountain climate zone to emission reductions of 138 kg CO_2e per tree per year for 23″ adjacent west-side coast live oak in the North Coast climate zone.

Figure 4 shows the lowest and highest emission reductions from cooling systems for each species in each climate zone.

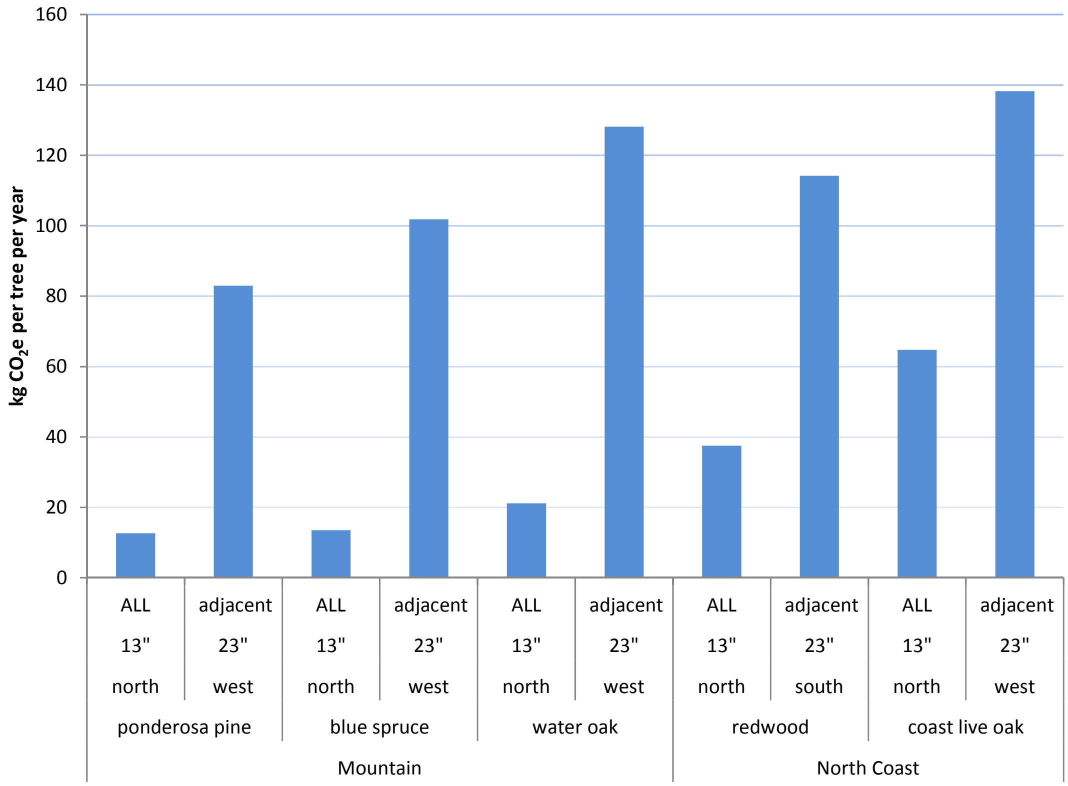

Figure 4. Lowest and highest emission reductions from cooling systems

Emissions/reductions for heating systems

In a number of cases, emissions from heating systems increased with the retention of a tree. In the mountain climate zone, a 23″ ponderosa pine on the south side of a house increased emissions by 73 kg CO_2e per tree per year – due to blocking winter sun and associated warmth by the constant canopy of a coniferous tree.

All of the highest emission reductions were from 23″ trees on the north side of the house, regardless of species, climate zone, or proximity to the house. On the north side there will be no blocking of sunlight while winds will be blocked. The greatest emission reductions were in the mountain climate zone, where a 23″ water oak on the north side of the house reduced emissions by 101 kg CO_2e per tree per year.

The average emission reduction from heating systems was 24.4 kg CO_2e per tree per year. This ranged from increased emissions of 73 kg CO_2e per tree per year for 23″ adjacent south-side ponderosa pine in the Mountain climate zone to emission reductions of 101 kg CO_2e per tree per year for 23″ near west-side water oak in the Mountain climate zone.

Figure 5 shows the lowest and highest emission reductions from heating systems for each species in each climate zone.

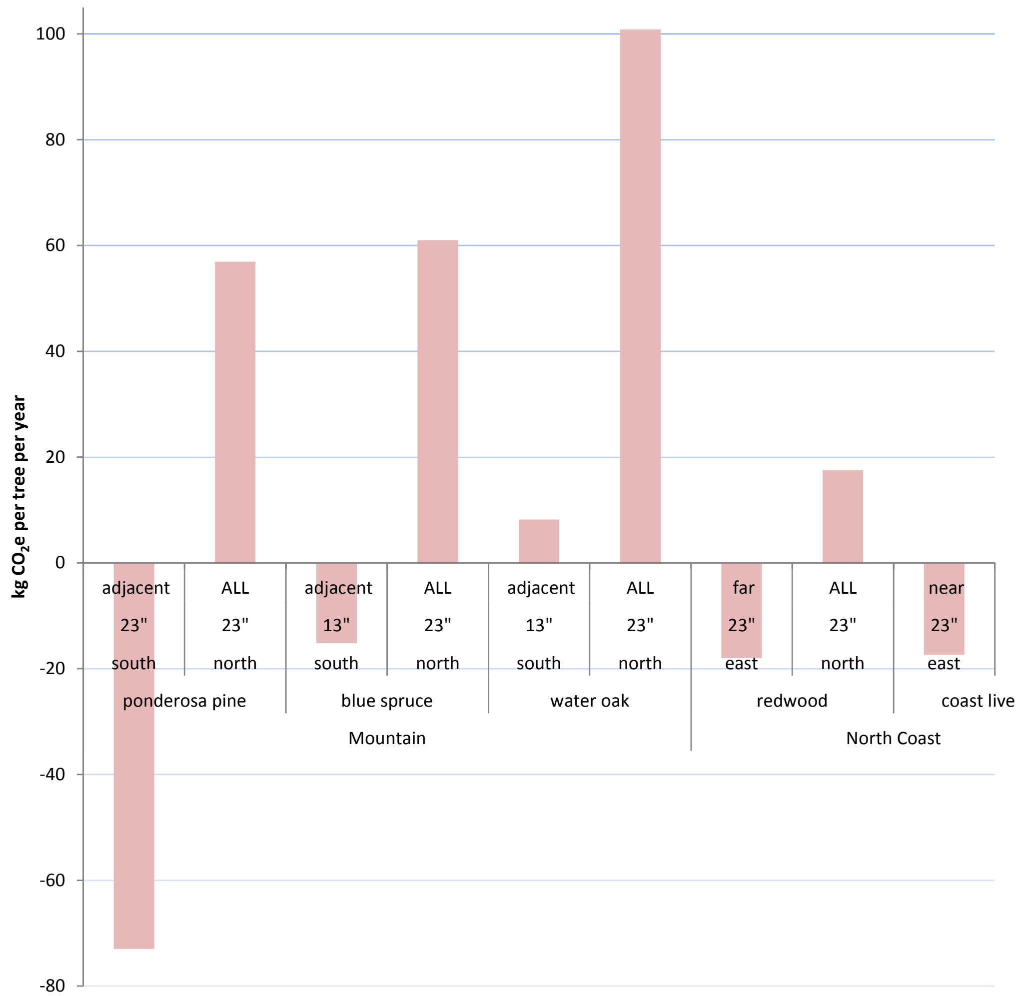

Figure 5. Lowest and highest emissions from heating systems

Net emissions/reductions

In some cases, while the reductions from cooling were sizeable, there was an increase in emissions from heating, and the net reductions were low or even negative. This was most often the case with coniferous trees on the south facing side of the residence. Figure 4 shows the three highest emission reductions for each species in each climate zone and Figure 5 shows the three lowest emission reductions for each species in each climate zone.

As would be expected, the greatest emission reductions are seen from the larger trees. Trees planted on the west-facing side of the building result in the highest emission reductions, regardless of size. In a few instances 23” trees result in low emission reductions, and in the case of ponderosa pine on the south-facing side in the Mountain climate zone, a 23” tree results in increased net emissions. The trees which were either within 20 feet or between 20 and 40 feet of the building resulted in the highest emission reductions, though in a few cases, trees that were between 40 and 60 feet of the building also had high reductions.

The average net emission reduction was 82.7 kg CO_2e per tree per year. This ranged from increased emissions of 35 kg CO_2e per tree per year for 13″ adjacent south-side ponderosa pine in the Mountain climate zone to emission reductions of 201 kg CO_2e per tree per year for 23″ near west-side water oak in the Mountain climate zone.

The highest emission reductions for 13″ trees ranged from 62 kg CO_2e per tree per year for a west-side ponderosa pine in the Mountain climate zone to 134.7 kg CO_2e per tree per year for a west side coast live oak in the North Coast climate zone.

Appendix A shows all of the modeled results.

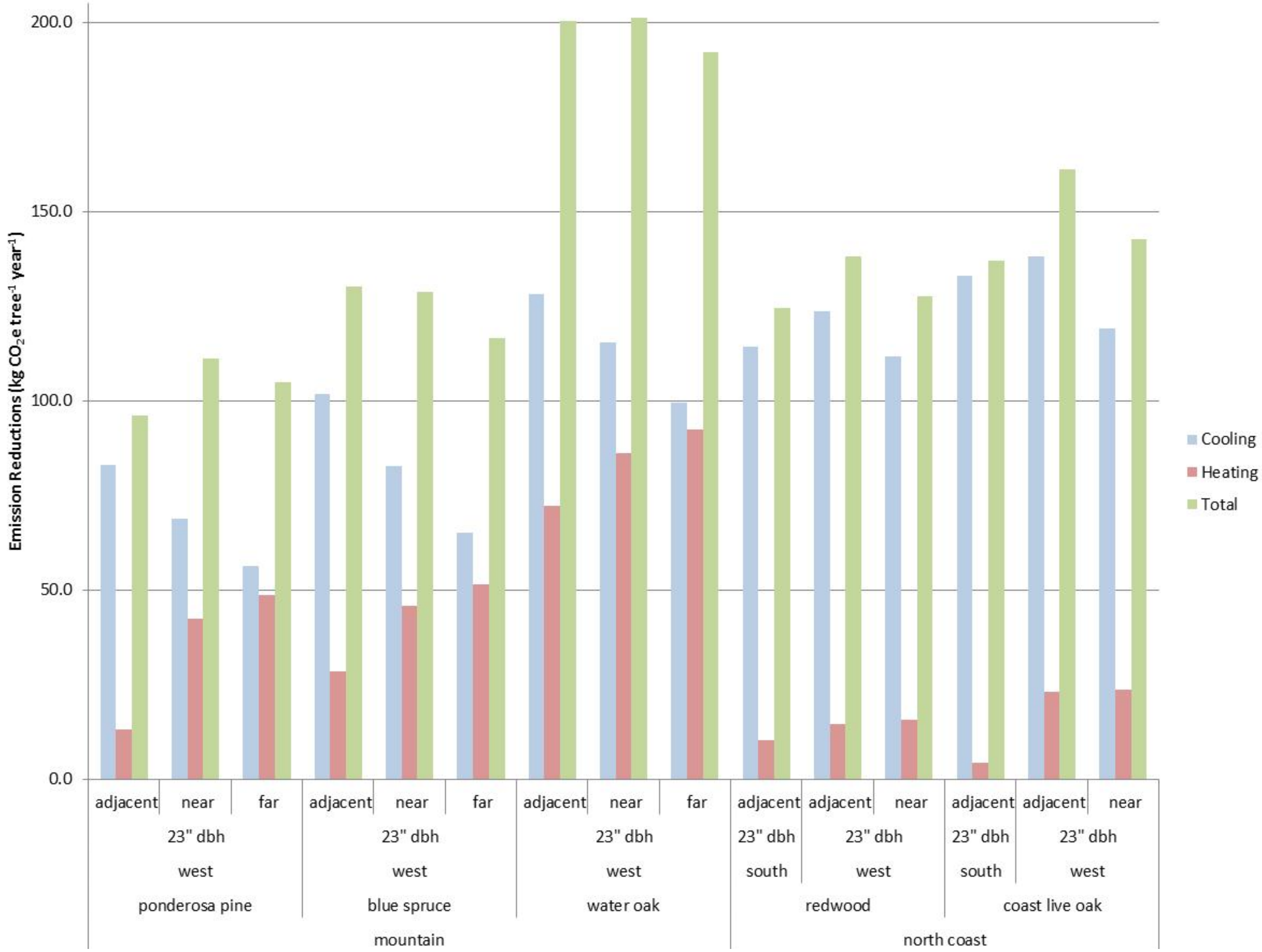

Figure 6. Highest emission reductions resulting from the impact of a single tree on energy use, as calculated using CTCC.

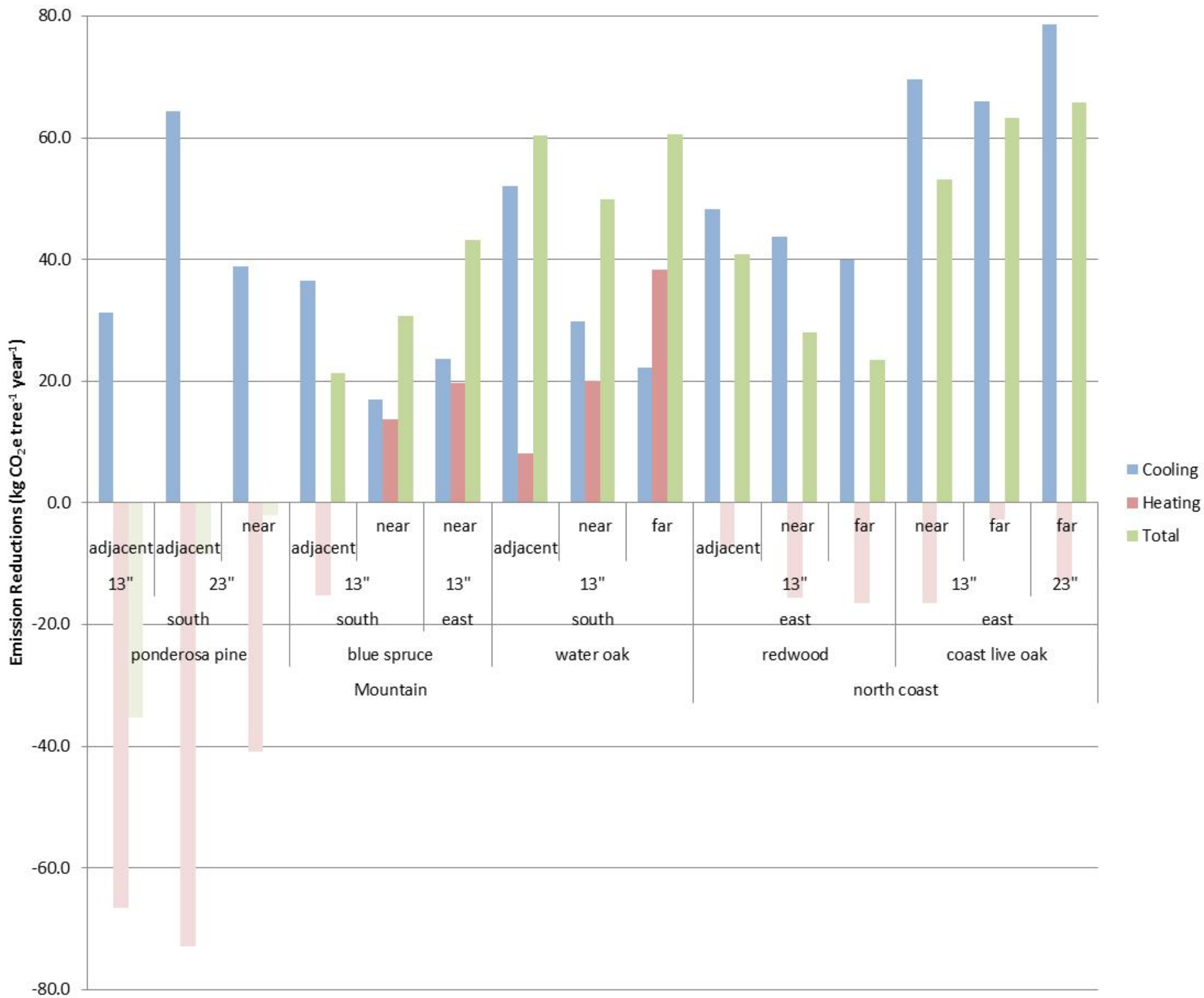

Figure 7. Lowest emission reductions resulting from the impact of a single tree on energy use, as calculated using CTCC.

Discussion

Overall, the modeled results suggest that keeping nearly any tree within 60 feet of a newly developed residential building will result in some level of emission reductions from reduced energy consumption. The exception to this is south-side ponderosa pine in the Mountain climate zone. While these trees provide some emission reductions from cooling systems, they result in a larger increase in emissions from heating systems, due to south-side winter shade leading to greater heating requirements. In addition, keeping any large tree on the west facing side of the building will result in somewhat sizeable net emission reductions. This is due to high emission reductions from cooling systems combined with moderate reductions from heating systems. West-side trees block direct sunlight, reducing cooling needs in summer, but can also reduce heating needs by blocking winter winds.

The highest benefit of all is likely to be gained from retaining large south-side deciduous trees (which block summer but not winter sun) and any large north-side tree. Conversely, removing these trees will result in increased emissions from increased energy consumption. In many cases, the indirect emission reductions from energy use are on the order of the annual CO_2e sequestration of the tree itself.

The projections from CTCC are in keeping with Heisler (1986[8]) who found that deciduous trees near west-facing walls are liable to provide the greatest energy reductions. He concluded that well-positioned trees reduce energy consumption 20-25% for detached houses, relative to the same house with no surrounding trees.

[8] Heisler, G.M. 1986. Energy savings with trees. J. Arboric. 12(5), 113-125.

CHAPTER 4: Indirect Emission Reductions from Growth and Future Sequestration

Methods

Foregone future sequestration was estimated for individual trees using CTCC and for whole forest stands using the Forest Vegetation Simulator (FVS).

<u>CTCC & individual trees</u>

As with emission reduction from energy use, CTCC calculates carbon sequestration only for individual trees. While it is possible to add the results across multiple trees to determine the carbon sequestered by more than one tree, the model does not account for how trees influence one another's growth. In the case of urban or exurban trees, however, this is not a significant issue as such trees are generally growing in more open conditions than are trees in non-urban forests.

Sample tree data input into CTCC included various species of 13" and 23" diameter trees:

- Mountain Climate zone
  - Ponderosa pine
  - Blue spruce
  - Water oak
- North Coast Climate zone
  - Redwood
  - Coast live oak

<u>FVS & forest stands</u>

Sample stand data were developed for two forest types at two locations, based on approximate stand characteristics, and input into FVS using the appropriate variant. This included:

- Shasta County, Inland California variant
  - Mixed conifer forest
  - Oak woodland
- Northern California/Mendocino County, Klamath Mountains variant
  - Mixed conifer forest
  - Oak woodland

Results

CTCC & individual trees

Total CO_2e stored in modeled trees ranged from 383 kg per tree for a 13" blue spruce in the Mountain climate zone, to 4,829 kg per tree for a coast live oak in the North Coast climate zone. The annual CO_2e sequestered ranged from 37 kg per tree per year for a 13" ponderosa pine to 340 kg per tree per year for a 23" water oak. Over a 10-year period, this results in 370-3,400 kg CO_2e additional carbon sequestered per tree, although it is important to note that CTCC does not account for growth, so this is likely to be an underestimate.

Table 1 shows the annual carbon sequestered by single trees of different species and sizes, as calculated by CTCC.

Table 1. Annual sequestration by individual trees, as calculated by CTCC.

Climate zone	Species	DBH	Total CO_2e stored (kg tree^{-1})	CO_2e sequestration (kg tree^{-1} yr^{-1})	Additional CO_2e sequestered over 10 years (kg tree^{-1})
Mountain	Ponderosa pine	13"	403	37	370
		23"	2,375	75	750
	blue spruce	13"	383	39	390
		23"	2,026	82	820
	water oak	13"	1,149	157	1,570
		23"	4,663	340	3,400
North coast	redwood	13"	436	71	710
		23"	1,937	176	1,760
	coast live oak	13"	1,291	132	1,320
		23"	4,829	271	2,710

FVS & forest stands

The annual increases projected by FVS range from 1.0 metric tons CO_2e per acre for oak woodlands in Shasta County to 8.6 metric tons CO_2e per acre for mixed conifer in Mendocino County (Table 2). These stands represent hypothetical forests that are nearly fully stocked. The differences are based on different growth rates as well as species composition and stocking level, which is lower for oak woodlands than for mixed conifer forests. It is important to note that this rate of increase will slow as the forest continues to mature, although it is not advisable to project much further than 10 years into the future regardless.

Table 2. FVS outputs for total stand carbon and annual increase in carbon for modeled forests

County	Forest type	Total stand carbon ($tCO_2e\ ac^{-1}$)	Annual increase* ($tCO_2e\ ac^{-1}$)
Shasta	Mixed conifer	164	5.3
	Oak woodland	86	1.0
Mendocino	Mixed conifer	155	8.6
	Oak woodland	76	2.8

*Annual increase represents first 10 years after development.

Discussion

As described in Goslee et al (2012), developments did not result in 100% forest loss. The average loss for single house developments was 48% of forest cover, which equates to an annual loss of 0.48-4.1 metric tons CO_2e per acre from foregone sequestration. This corresponds to the removal of ten trees per acre based on the CTCC results, which would lead to an annual loss of 0.37-3.4 metric tons CO_2e per acre. For multi-house developments, the average loss of forest cover was 76%, or 0.76-6.6 metric tons of CO_2e per acre based on results from FVS modeling. Based on CTCC results, this suggests the removal of twenty trees per acre.

These estimates given here for annual sequestration rates are slightly higher than those in a report by Nowak and Crane (2002[9]), which found that gross annual sequestration rates in California are 0.45 tons of CO_2e per acre. This figure, however, is based solely on urban forests in densely populate areas. Nowak and Crane note that this compares with sequestration rates of 3.9 tons of CO_2e per acre for a 25-year old genetically improved loblolly pine plantation and 1.5 tons of CO_2e per acre for a 25-year old naturally regenerated spruce-fir forest on an average site. These rates indicate that those projected by FVS may be an overestimate, although they are likely based on younger forests on lower quality sites.

[9] Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution 116, 381-389.

CHAPTER 5:
Total Indirect Emissions and Potential for Emission Reductions

In a development project it is likely not possible to retain all existing trees. However, locating new buildings in a manner that allows retention of some well-place trees can reduce project emissions from tree removal, energy consumption, and future tree growth.

Combining annual net emission reductions from energy consumption with annual sequestered carbon yields total emission reductions per tree retained. The highest reductions result from trees located on the west side of houses, with a range from 99 kg CO_2e per tree per year for a 13″ ponderosa pine in the Mountain climate zone to 541 kg CO_2e per tree per year for a 23″ water oak also in the Mountain climate zone. The total CO_2e stored in these trees is 403 kg and 4,663 kg, respectively.

Table 3 shows the highest estimated emission reductions for retained trees across all species in all climate zones. To estimate the result for more than one retained tree, these values can be multiplied by the appropriate number.

Table 3. Total estimated emission reductions from retained trees on west-facing side of building. Trees located on the west side yielded the highest reductions regardless of species or climate zone.

Climate zone	Species	DBH	Distance	Total energy emission reductions (kg CO_2e tree^{-1} year^{-1})	CO_2 sequestration (kg CO_2e tree^{-1} year^{-1})	Total emission reductions (kg CO_2e tree^{-1} year^{-1})	Total CO_2 stored (kg/tree)
Mountain	**ponderosa pine**	13"	near	62	37	99	403
		23"	near	111	75	186	2,375
	blue spruce	13"	adjacent	84	39	123	383
		23"	adjacent	130	82	212	2,026
	water oak	13"	adjacent	106	157	264	1,149
		23"	near	201	340	541	4,663
North Coast	**redwood**	13"	adjacent	94	71	165	436
		23"	adjacent	138	176	314	1,937
	coast live oak	13"	adjacent	135	132	267	1,291
		23"	adjacent	161	271	432	4,829

APPENDIX A:

All emission reduction resulting from the impact of a single tree on energy use, as calculated using CTCC

Climate zone	Species	Azimuth	DBH	Distance	Emission reductions (kg* CO_2e/tree)		
					Cooling	Heating	Total
Mountain	ponderosa pine	south	13"	adjacent	31.3	-66.6	-35.3
				near	16.0	-16.8	-0.8
				far	12.6	21.3	33.9
			23"	adjacent	64.4	-73.0	-8.5
				near	38.9	-40.8	-2.0
				far	27.8	-2.9	24.9
		north	13"	adjacent	12.6	34.1	46.7
				near	12.6	34.1	46.7
				far	12.6	34.1	46.7
			23"	adjacent	22.6	56.9	79.6
				near	22.6	56.9	79.6
				far	22.6	56.9	79.6
		east	13"	adjacent	27.1	13.4	40.6
				near	20.7	19.7	40.4
				far	16.2	26.1	42.3
			23"	adjacent	50.8	27.2	78.0
				near	44.8	30.6	75.4
				far	39.0	34.8	73.7
		west	13"	adjacent	54.5	4.7	59.1
				near	36.6	25.6	62.2
				far	23.5	30.6	54.2
			23"	adjacent	83.0	13.0	96.0
				near	68.9	42.3	111.1
				far	56.4	48.5	104.9

*To convert kilograms to tons, multiply by 0.001.

Climate zone	Species	Azimuth	DBH	Distance	Emission reductions (kg* CO_2e/tree)		
					Cooling	Heating	Total
Mountain	blue spruce	south	13"	adjacent	36.5	-15.2	21.3
				near	17.0	13.7	30.7
				far	13.5	32.2	45.7
			23"	adjacent	75.0	-8.6	66.4
				near	42.3	13.6	55.9
				far	29.2	35.0	64.2
		north	13"	adjacent	13.5	37.6	51.1
				near	13.5	37.6	51.1
				far	13.5	37.6	51.1
			23"	adjacent	25.2	61.0	86.2
				near	25.2	61.0	86.2
				far	25.2	61.0	86.2
		east	13"	adjacent	32.4	12.1	44.5
				near	23.6	19.7	43.3
				far	18.1	27.7	45.8
			23"	adjacent	59.8	25.7	85.5
				near	51.4	28.7	80.1
				far	42.6	34.3	77.0
		west	13"	adjacent	70.0	14.3	84.3
				near	45.4	28.8	74.2
				far	28.9	33.6	62.5
			23"	adjacent	101.8	28.5	130.3
				near	82.7	45.9	128.6
				far	65.0	51.4	116.4

*To convert kilograms to tons, multiply by 0.001.

Climate zone	Species	Azimuth	DBH	Distance	Emission reductions (kg* CO_2e/tree)		
					Cooling	Heating	Total
Mountain	water oak	south	13"	adjacent	52.1	8.2	60.4
				near	29.8	20.1	49.9
				far	22.2	38.2	60.5
			23"	adjacent	109.2	45.5	154.7
				near	81.1	48.5	129.6
				far	62.1	65.8	127.9
		north	13"	adjacent	21.1	52.6	73.7
				near	21.1	52.6	73.7
				far	21.1	52.6	73.7
			23"	adjacent	55.9	100.8	156.8
				near	55.9	100.8	156.8
				far	55.9	100.8	156.8
		east	13"	adjacent	43.4	35.0	78.3
				near	36.8	36.7	73.5
				far	29.8	41.4	71.2
			23"	adjacent	90.5	76.2	166.7
				near	83.5	77.1	160.7
				far	75.2	79.4	154.6
		west	13"	adjacent	70.6	35.8	106.4
				near	56.9	45.3	102.2
				far	42.6	48.5	91.2
			23"	adjacent	128.1	72.2	200.3
				near	115.3	86.0	201.3
				far	99.6	92.4	191.9

*To convert kilograms to tons, multiply by 0.001.

Climate zone	Species	Azimuth	DBH	Distance	Emission reductions (kg* CO_2e/tree)		
					Cooling	Heating	Total
north coast	redwood	south	13"	adjacent	73.7	3.6	77.3
				near	53.6	4.8	58.4
				far	42.6	7.7	50.3
			23"	adjacent	114.2	10.3	124.5
				near	92.6	9.9	102.5
				far	76.0	13.0	89.0
		north	13"	adjacent	37.5	10.1	47.6
				near	37.5	10.1	47.6
				far	37.5	10.1	47.6
			23"	adjacent	64.5	17.5	82.1
				near	64.5	17.5	82.1
				far	64.5	17.5	82.1
		east	13"	adjacent	48.2	-7.4	40.8
				near	43.7	-15.6	28.0
				far	40.0	-16.5	23.5
			23"	adjacent	81.6	-0.4	81.2
				near	76.7	-12.6	64.1
				far	70.0	-18.0	52.0
		west	13"	adjacent	86.8	7.5	94.2
				near	72.5	8.7	81.3
				far	57.6	9.4	67.0
			23"	adjacent	123.7	14.4	138.1
				near	111.8	15.7	127.5
				far	96.6	16.3	112.9

*To convert kilograms to tons, multiply by 0.001.

Climate zone	Species	Azimuth	DBH	Distance	Emission reductions (kg* CO_2e/tree)		
					Cooling	Heating	Total
north coast	coast live oak	south	13"	adjacent	104.9	3.0	107.8
				near	75.1	8.5	83.6
				far	65.1	16.4	81.4
			23"	adjacent	132.9	4.2	137.1
				near	101.2	7.2	108.4
				far	82.7	24.8	107.5
		north	13"	adjacent	64.7	17.1	81.8
				near	64.7	17.1	81.8
				far	64.7	17.1	81.8
			23"	adjacent	75.9	30.5	106.4
				near	75.9	30.5	106.4
				far	75.9	30.5	106.4
		east	13"	adjacent	78.7	-11.2	67.5
				near	69.7	-16.5	53.2
				far	66.0	-2.8	63.2
			23"	adjacent	92.8	-7.7	85.1
				near	84.6	-17.3	67.3
				far	78.7	-12.9	65.9
		west	13"	adjacent	121.8	12.8	134.7
				near	95.2	14.7	109.9
				far	75.4	16.3	91.7
			23"	adjacent	138.2	23.1	161.2
				near	119.0	23.6	142.6
				far	93.0	26.6	119.7

*To convert kilograms to tons, multiply by 0.001.