Arnold Schwarzenegger
Governor

BASELINE GREENHOUSE GAS EMISSIONS AND REMOVALS FOR FOREST AND RANGELANDS IN SHASTA COUNTY, CALIFORNIA

PIER PROJECT REPORT

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Preface

The 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, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, 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
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The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

Baseline Greenhouse Gas Emissions and Removals for Forest and Rangelands in Shasta County, California is the report for the Preliminary Economic Analyses of Climate Change Impacts and Adaptation, and GHG Mitigation project, contract number 500-02-004, work authorization MR-006, Amendment 1, conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

Table of Contents

List of Figures

List of Tables

Abstract

The purpose of this report is to examine the carbon emissions and sequestration from forests and rangelands in Shasta County between 1994 and 1999. This report updates earlier work for the whole state of California (*Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands In California*),[1] with a focus on adding more detail for one county. Area of change was examined through the satellite data of the California Land Cover Mapping and Monitoring Program (LCMMP); correlated carbon stocks were derived from new field measurements taken in Shasta County. Approximately 26 square kilometers (km^2)/year of forests and rangelands showed a decrease in canopy cover caused by fire, harvesting, or development. This was equivalent to an estimated emission of 0.43 million metric tons of carbon dioxide equivalents ($MMTCO_2e$)/yr from forests and 0.026 $MMTCO_2e$/yr from rangelands. Emissions were exceeded by the estimated removals of 4.36 $MMTCO_2e$/yr from the regrowth of forests and 0.43 $MMTCO_2e$/yr from recovery of rangelands. Harvest was the dominant cause of emissions from forests while development was the most significant cause on rangelands. Fire is a less significant cause during the study period, but evidence suggests that this was a period of unusually low fire incidence, and over a longer time period (11 years) fire was the major cause of emissions.

Keywords: Carbon, sequestration, emission, forest, rangeland, Shasta County

[1] See www.energy.ca.gov/pier/final_project_reports/500-04-069.html.

Executive Summary

Introduction

This study refined an earlier analysis of greenhouse gases (GHGs) done at the state level for California (*Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands In California*).[2] The statewide analysis suggested opportunities to sequester carbon and/or reduce emissions through several classes of projects, including afforestation of rangelands, degraded forest lands, and riparian zones; changes in forest management; and improved management of hazardous fuels to reduce emissions from wildfires.

Purpose

This project's purpose was to estimate the baseline GHG emissions and removals from forests and rangelands in Shasta County, California, based on refinements to the statewide analysis. Shasta County was chosen for further analysis because it contains diverse land cover representative of areas across the state, and because all these classes of opportunities mentioned in the statewide report appear to exist in the county.

Project Objectives

Specifically, the report quantifies the baseline of changes in carbon stocks on forest and rangelands in Shasta County, using more detailed county-level data, for a five-year period 1994–2000.[3] The primary focus is on carbon stocks and CO_2 emissions/removals, but first-order estimates are also given for non-CO_2 greenhouse gases where appropriate. Baselines provide an estimate of the emissions and removals of GHGs due to changes in the use and management of land. In addition they are useful for identifying where, within Shasta County, major opportunities could exist for enhancing carbon stocks and/or reducing carbon sources to mitigate GHG emissions cost-effectively.

Two types of data were used to develop these baselines: (1) the area and condition of forest and rangeland at the start and end of the time interval, and (2) carbon stocks in each land-use type for each time. Areas and canopy cover data for forests and rangelands were derived from the California Land Cover Mapping and Monitoring Program (LCMMP). Carbon estimates for various forests and rangeland types with corresponding canopy cover measures were derived principally from field measurements in Shasta County.

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[2] See www.energy.ca.gov/pier/final_project_reports/500-04-069.html.

[3] The analysis is based on California Department of Forestry and Fire Protection LCMMP maps. Shasta County was split between the North Coast and Cascade Northeast regions, which covered two different five-year time periods between 1994 and 2000.

The satellite imagery used by the LCMMP program was used to identify measurable changes in canopy coverage of forests and rangelands that occurred in the time interval; however it does not include the continued accumulation of biomass carbon in forests with a closed canopy, a change that is undetectable from a satellite. For these reasons measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon) were tracked separately from the measurable increases in canopy cover and resulting increases in carbon stocks. For decreases in carbon stocks, both the gross and net changes were estimated, which varied by the cause of the change (e.g., fire, harvest, development). The likely magnitude of the increase in carbon stocks resulting from the non-measured change in canopy, and assumed increase in carbon stocks, was then estimated using U.S. Forest Service reports and data. In other words, the baseline includes all changes in carbon stocks, from measured and unmeasured changes in canopy coverage.

Project Outcomes

A loss in canopy cover was measured on 12,800 hectares (ha), or 31,616 acres, of forests and rangelands in the Shasta County during the approximately five-year period. This is about 1.4% of the total area of forests and rangeland in the county. For forests, a net removal of 4.36 million metric tons of carbon dioxide equivalents (MMTCO_2e)/yr and a net emission of 0.43 MMTCO_2e/yr were estimated. Rangelands were also a net sink of carbon, with a removal of 0.16 MMTCO_2e/yr exceeding a net emission of 0.026 MMTCO_2e/yr (Table S-1).

Harvest and development were the dominant causes of emissions on forestlands; these causes were responsible for 70% and 16% respectively, while fire accounted for 4% of total emissions. On rangeland, harvest was less important, accounting for only 24% of the total emissions as opposed to 52% for development on rangelands (Table S-1). Fire was a minor cause of carbon emissions in rangeland, accounting for just 7% of total emissions.

Harvest and development have little year-to-year fluctuation in impact. In contrast, fire impact can vary dramatically year to year. The years of the study (1994–2000) had an unusually low incidence of fire, with four years in which no fires were recorded at all on forestland in Shasta. Examining the 11-year period between 1990 and 2000 showed that 34,300 ha of forests and about 19,500 ha of rangeland burned in Shasta County during this period—equivalent to about 3,118 ha/yr and 1,768 ha/yr for forest and rangeland, respectively, compared to the 122 ha/yr and 36 ha/yr, respectively, derived from the shorter period of 1994–2000. Thus over a longer time frame, fire is probably a much more significant cause of change in carbon stocks in Shasta County, and may be the dominant cause of change in the county.

Table S-1. Emissions and removals by cause of change. A minus sign indicates an emission; a plus sign indicates a removal.

MMTCO₂e/yr	*FORESTS*	*RANGELANDS*
Fire	- 0.019	- 0.0018
Harvest	- 0.30	- 0.0060
Development	- 0.068	- 0.013
Other	- 0.043	- 0.0044
TOTAL	- 0.43	- 0.026
Regrowth	+ 4.36	+ 0.16

Uncertainty, based on standard deviation of the results, was estimated as +/- 15%.

The analysis suggested that forest and rangelands were responsible for a net removal of carbon dioxide from the atmosphere of 4.06 $MMTCO_2e$/yr. Non-CO_2 greenhouse gas emissions from forest and rangelands were estimated to be 0.0024 $MMTCO_2e$/yr, equivalent to about 0.06% of the removals by these systems. The overall net result was a removal of 3.93 $MMTCO_2e$/yr by forests and 0.13 $MMTCO_2e$/yr by rangelands.

The results from this analysis in Shasta County (referred here to *Phase II*) were compared with those for the same county but based on the original statewide report[4] (referred to as *Phase I*) (Table S-2). The major refinement to the Phase II analysis was the use of new county specific relationships between carbon stocks and canopy cover. These new relationships produced estimates of carbon stocks for Shasta County's forests that were considerably higher than those used in the statewide analysis—e.g., at 80% canopy cover, carbon stocks for the major forest types were from 142% to 280% higher. In a high-biomass county such as Shasta, it would be expected that the mean carbon stock per hectare is higher than the statewide average.

The use of Shasta County-specific carbon estimates resulted in higher emissions across all causes of changes in canopy coverage compared to the statewide analysis. In forests, emissions through fire were 213% higher and emissions through development were 249% higher (Table S-2). The total impact of the new carbon stock data was an increase in estimated emissions of 152%.

[4] *Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands In California.* www.energy.ca.gov/pier/final_project_reports/500-04-069.html.

Table S-2. Comparison of emissions and removals over the five-year interval for forests by cause of change for Phase I and Phase II. A minus sign indicates an emission.

	Emissions of CO_2 from: Phase I (tons CO_2e)	Phase II (tons CO_2e)	% increase
Fire	-30,769	-96,107	213
Harvest	-576,418	-1,521,397	164
Development	-97,666	-340,843	249
Other	-160,045	-216,455	35
TOTAL	-864,902	-2,174,801	152

Percentages were calculated as the difference between Phases I and II divided by the Phase I total.

For rangelands, there was no difference between Phase I and Phase II for emissions from fire, as all emissions were from shrubs and grasses. However, emissions from development in rangelands were raised by 137% and for all causes combined emissions were raised by 77% due to the new carbon stock data.

Finally, the county-level Phase II analysis produced results that were more certain than those for Phase I—uncertainty was +/-15% for Phase II versus +/-25% for Phase I.

1.0 General Approach

This project's goal was to develop a baseline of carbon emissions and/or removals in the forest and rangeland sector of Shasta County, California for a five-year period between 1994–2000,[5] including identification and quantification of the main sources or sinks of carbon. Such an analysis will aid in identifying, within the landscape of Shasta, where major opportunities exist for enhancing carbon storage and/or reducing carbon emissions. The focus of this work is carbon as carbon dioxide (CO_2), although where appropriate, first order approximations will be made of the baseline emissions for non-CO_2 gases (e.g., nitrous oxide (N_2O) and methane (CH_4)). This report complements and adds greater resolution to an earlier statewide report, *Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands in California* (Brown et al. 2004a).

To develop the baseline for a specified time period, two types of data are needed: (1) the area of forests and rangelands undergoing a change, and (2) the change in carbon stocks in the same areas. To develop a trend in the baseline, a minimum number of two time intervals (three points of time) are needed. For California, however, data for two time points with one interval only are suitable for the analysis.

The areas of forests and rangelands with a measured change in canopy coverage were available through the California Land Cover Mapping and Monitoring Program (LCMMP).[6] In the original statewide report (Brown et al. 2004a), carbon estimates for various forests and rangeland types with corresponding canopy closures were derived from: U.S. Forest Service - Forest Inventory and Analysis (FIA) data, the literature, consultations with California Department of Forestry and Fire Protection – Fire and Resource Assessment Program (CDF-FRAP) staff, and the equations of Smith et al. (2003). For the county-level baseline, field measurements in Shasta County correlating carbon stocks and canopy coverage provided an important enhancement to the carbon estimates.

Using the canopy change data alone would likely underestimate all changes in carbon stocks. When the canopy of a forest closes, trees continue accumulating biomass carbon that is undetectable from a satellite. For these reasons, measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon) were tracked separately from measurable increases in canopy cover and resulting increases in carbon stocks. For decreases in carbon stocks, both the gross and net changes, which varied by the cause of the change (e.g., fire, harvest, development) were estimated. The research team then estimated the likely magnitude of the assumed increase in carbon stocks resulting from the non-measured change in canopy. Data from the U.S. Forest Service reports (based on FIA data) on carbon stock changes

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[5] The analysis is based of CDF-LCMMP maps, in which Shasta County was split between the North Coast and Cascade Northeast regions which covered two different five-year time periods between 1994 and 2000.

[6] See www.frap.cdf.ca.gov/projects/land_cover/.

in California forests were used to estimate the likely changes in carbon stocks in the forests with no measured changes in canopy.

1.1 Classification of Forests and Woodlands

The California LCMMP uses Landsat Thematic Mapper satellite imagery to map vegetation and changes in vegetation over five-year periods. Vegetation is classified using the Wildlife Habitat Relationship (WHR) classifications. The WHR is an information system for California's wildlife; in the WHR database there are 59 wildlife habitats—27 tree, 12 shrub, 6 herbaceous, 4 aquatic, 8 agricultural, 1 developed, and 1 non-vegetated.

Vegetation classification data are verified by "ground truth" field data. The WHR classes are further classified at the individual pixel level by tree-size class and canopy crown closure. Causes of changes in vegetation distribution and/or canopy crown closure are deduced by GIS modeling, aerial photographs, and further field and site data. Causes of land-cover change include: fire, harvest, development, regrowth, seasonal (a cause used in the first phase of the LCMMP), pest-related (pest-related only in the second phase of the LCMMP), and other and unverified changes.

The California LCMMP data are divided into five regions, and Shasta County is covered partly by North Coast and partly by Cascade Northeast (Figure 1):

Figure 1. The LCMMP regions, with Shasta County superimposed in red

2.0 Area of Forests and Rangelands

2.1. Calculating Areas from Satellite Data

2.1.1 LCMMP Background

The California Department of Forestry's Fire and Resource Assessment Program (FRAP) maps land cover and tracks land-cover changes across the California landscape in a semi-automated and systematic way. This project is called the Land-Cover Mapping and Monitoring Program (LCMMP). The first task of the LCMMP was to derive a classified 30-meter (m) resolution land-cover map for each of five regions in California. The images were derived from a large archive of Landsat satellite imagery and posted on the CDF-FRAP website. Change analyses are conducted at regular intervals, about every five years but staggered across the state—i.e., different regions are analyzed for different five-year periods—and changes in land cover and changes in canopy cover are automatically incorporated into the old land-cover maps. Simultaneously, a separate map of the amount of change in canopy cover that has occurred is created. Efforts are also made by field crews and CDF-FRAP staff to determine the likely cause of this change for each of the change-areas mapped. For a large proportion of canopy changes, a cause is attributed by the LCMMP data; however, the cause is unverified for the remainder. For the analyses presented in this chapter, CDF-FRAP staff made certain assumptions, based on their experience about the likely cause of change for many of the unverified causes, to increase the accuracy and precision of this study's analyses.

The analysis of change, measured principally from satellite images, only identifies a measurable change in canopy coverage of forests and rangelands that occurred in the time interval. Other forest and rangeland habitats in California are likely to be undergoing change in carbon stocks even though a change in canopy cannot be detected. The canopy change detection method is liable to underestimate sinks of carbon because negative canopy changes (sources) are often large after fire or development but accumulation of carbon through regrowth (sinks) is gradual and in a given five-year period will often not exceed the 15% canopy change threshold necessary to be measurable. In addition, once the canopy is closed, trees continue accumulating biomass carbon that may not be detectable from a satellite. For these reasons, measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon) were tracked separately from measurable increases in canopy cover and resulting increases in carbon stocks. The likely magnitude of the increase in carbon stocks resulting from the non-measured change in canopy, and assumed increase in carbon stocks, were then estimated.

2.1.2 Methods for Baseline Analysis

Upon update of the land-cover maps, most previously existing land-cover maps of the regions are deleted from the principal archiving system of the LCMMP computer hardware. By consulting tape archives of several that were actually retained, it was evident that the updates also incorporated a number of other factors that prohibited direct comparison between previous land-cover maps from the archives and their updated versions of the same regions. Such factors as georeferencing error and refined classification due to field-crew ground-truthing made it necessary to depend on the change maps and some other source of “Time 1” land-cover data.

The “Time 1” data selected was the CDF-FRAP “Multi-Source Land-Cover Map.” This map was produced in 2003 using a variety of data inputs from several organizations and mapping projects (Figure 2). The multi-source map was transformed from the finer-scale 30-m resolution maps that were used to create it to a 100-m x 100-m grid. In a similar manner, all LCMMP data used in the analysis were also aggregated into 100-m grid cells from their original 30-m resolution. In most cases, the Multi-Source Land-Cover Map incorporated satellite data that came from the same year as had the LCMMP “Time 1” data (+/- 1–2 years in some areas).

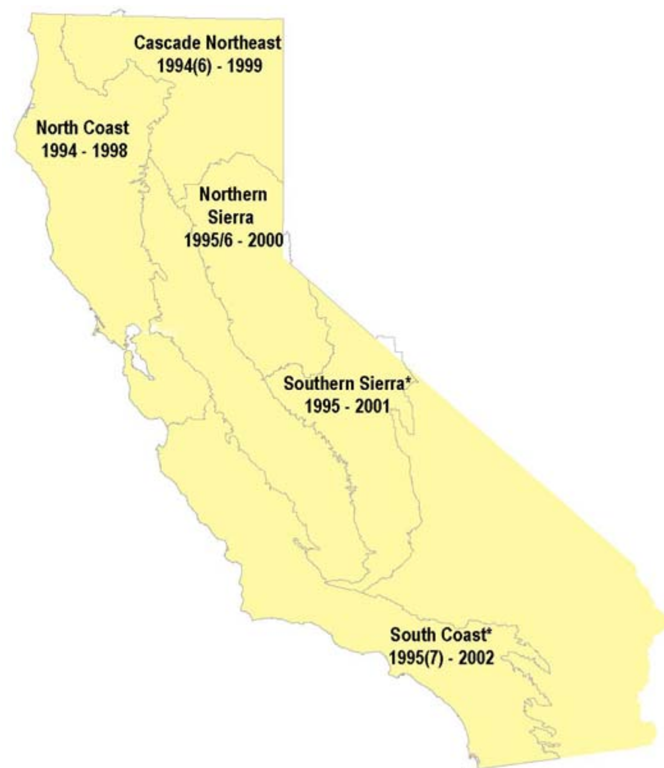

Figure 2. Satellite image dates for CDF-FRAP’s LCMMP change analysis (Time 1–Time 2). [* = Not yet completed]

The carbon emissions baseline study used **one** product from CDF-FRAP’s “Multi-source Land Cover Mapping Project” and **two** from the CDF-FRAP’s LCMMP:

I. The Multi-Source Land-Cover Map = “Time 1”;

II. The LCMMP change detection maps = the difference between LCMMP’s “Time 1” and “Time 2” land cover maps;

III. The LCMMP change cause maps = in the changed areas, what happened between LCMMP’s “Time 1” and “Time 2” to cause the detected change.

Creation of the Multi-Source Land-Cover Map involved the synthesis of a variety of different datasets into one comprehensive map. For the CDF-FRAP synthesis, it was necessary to crosswalk the various classifications present in these datasets to yield a map with a uniform habitat-type classification. The WHR classification system was chosen. The WHR-classification system includes information on many vegetation and habitat attributes that are included within the databases accompanying the GIS files. Some examples of these attributes are canopy density, tree size, and timber productivity class.

The WHR standards for canopy coverage are:

- Dense: 60%–100% (midpoint 80%)
- Moderate: 40%–59% (midpoint 50%)
- Open: 25%–39% (midpoint 32%)
- Sparse: 10%–24% (midpoint 17%)

The LCMMP change analyses are conducted by comparing the raw satellite imagery from the baseline year with other satellite imagery of the same location at another year. The LCMMP attempts to collect images with a five-year time difference for change analysis, although availability of imagery does not always allow this. The change analysis for the first LCMMP cycle presented changed grid cells along with the following qualitative degree-of-change scale:

- Large Decrease in Vegetation
- Moderate Decrease in Vegetation
- Small Decrease in Vegetation
- Little or No Change
- Small Increase in Vegetation
- Moderate Increase in Vegetation
- Large Increase in Vegetation
- Non-vegetative Change
- Terrain Shadow or Wet (or "Cloud or Cloud Shadow" in some regions)

After each region was mapped in the first cycle, a second cycle of mapping produced results classified along the following improved quantitative degree-of-change scale:

- 71% to 100% cover decrease
- 41% to 70% cover decrease
- 16% to 40% cover decrease
- +15% to -15% (Little or No Change)
- 16% to 40% cover increase
- 41% to 100% cover increase

- Shrub/Grass Decrease > 15%
- Shrub/Grass Increase > 15%
- Non-vegetative Change Including Urban (or "Change within Existing Urban Area" in some regions)
- Cloud/Shadow/Smoke (includes "fog" in some regions)

To produce the quantitative measures of changes in carbon stocks from the various change-causing agents as mapped by CDF-FRAP, it was possible to use only the second cycle of the LCMMP analysis. Additionally, the dates from the first images in the second cycle analyses were the only ones that corresponded to those of the Multi-Source Land-Cover Map. The dates of the analyses are summarized in Table 1 and Figure 2.

Table 1. Relevant California regions and dates and completion status of baselines, cause and change data

Area	Baseline years	Change data completion	Cause data completion
Cascade Northeast	1994(6)–1999	Completed	Completed
North Coast	1994–1998	Completed	Completed

Verified cause-of-change data for the different LCMMP regions were available for the identified changed cells. The causes attributed to the changes are:

- fire,
- harvest,
- development,
- regrowth,
- pest-related, and
- other and unverified.

The cause maps offered incomplete coverage of the changed areas. To assist in this analysis, CDF-FRAP conducted additional work to map the changed areas' "potential cause" by augmenting the verified cause data for the regions with other information gathered and archived, but as yet unverified by field teams. This yielded a higher proportion of change cause coverage and enabled a more realistic estimate of the effects that land-cover change had on existing carbon stocks in a given location.

The importance of knowing the cause of the change is related to the fate of carbon stocks undergoing a change. For example, when the cause of change is a wildfire, a large proportion of the biomass carbon is immediately oxidized; whereas, when the cause of change is a harvest, a large proportion of the biomass carbon will go into long-term storage in wood products. Change data without cause provides information on gross changes in carbon stocks; whereas, the addition of known cause allows for an estimation of the net change in carbon stocks.

2.2 Calculating the Change in Area

The data on changes in canopy cover between specified dates for each pixel were summarized by the use of pivot tables in Excel; producing a table of the areas of each Wildlife-Habitat Relationships (WHR) class (vegetation type) that changed, by how much (% change in canopy cover), and by which cause. The area with an increase or decrease in canopy cover was then summed across causes and vegetation types. The WHR classes were regrouped into fewer classes to match the data availability on biomass and canopy cover relationships (see next section).

3.0 Carbon Stocks in Forests and Rangelands

3.1 Aboveground Biomass

In the statewide study (Brown et al. 2004a), data on timber volume for specific WHR habitat types at different canopy coverages were used to develop the relationships between biomass and canopy crown cover that is needed to create a carbon baseline. The biomass:canopy cover relationships used in this study were enhanced by on-the-ground field measurements in Shasta County. To simplify field measurements, the species groupings from the original study were retained (see below and Table 2).

- Forests
  - Douglas fir
  - Fir-Spruce
  - Other Conifer
  - Hardwood
  - Shrubs and Grasses[7]
- Rangelands
  - Woodland Vegetation
  - Shrubs and Grasses

3.1.1 Field Measurements

To estimate the change in biomass caused by changes in crown cover, the ability to predict biomass from any given canopy crown coverage was needed. This was achieved by taking paired measurements of carbon stock and canopy crown coverage and creating a regression equation relating the two factors. A total of 62 paired canopy coverage / biomass carbon plots were measured in September 2005.

The sites for measurements were determined using the LCMMP dataset to give a full coverage of forest types and canopy coverages. The details of the field measurements are given in Appendix A.

[7] A shrub/grass category of increase or decrease in crown cover exists for each of the forest classes.

Table 2. WHR classes matched with the inferred Smith et al. (2003) classes for forests and rangelands. (Redwood is not found in Shasta County.)

<table>
<tr><th>FOREST
WHR CLASS</th><th>INFERRED CLASS</th><th>RANGELAND
WHR CLASS</th><th>INFERRED CLASS</th></tr>
<tr><td>Douglas Fir</td><td>Douglas Fir</td><td rowspan="3">Blue Oak Woodland
Valley Oak Woodland
Coastal Oak Woodland
Blue-Oak Digger Pine</td><td rowspan="3">Woodland Vegetation</td></tr>
<tr><td>Redwood</td><td>Redwood</td></tr>
<tr><td>White Fir
Red Fir</td><td>Fir-Spruce</td></tr>
<tr><td>Subalpine Conifer
Lodgepole Pine
Sierran Mixed Conifer
Klamath Mixed Conifer
Jeffrey Pine
Ponderosa Pine
Eastside Pine
Closed-Cone Pine
Cypress
Montane Hardwood-Conifer</td><td>Other Conifer</td><td>Alpine Dwarf-Shrub
Low Sage
Bitterbrush
Sagebrush
Montane Chaparral
Chemise-Redshank
Chaparral
Coastal Scrub
Desert Succulent Scrub
Juniper
Pinyon-Juniper</td><td>Shrubs</td></tr>
<tr><td>Aspen
Montane Hardwood
Montane Riparian
Valley Foothill Riparian
Desert Riparian</td><td>Hardwood</td><td>Annual Grassland
Perennial Grassland
Wet Meadow
Fresh Emergent Wetland</td><td>Grasses</td></tr>
</table>

3.1.2 Regression Equations of Canopy Coverage and Biomass

Highly significant regression equations were developed from the data on biomass stock and canopy cover (Figure 3).

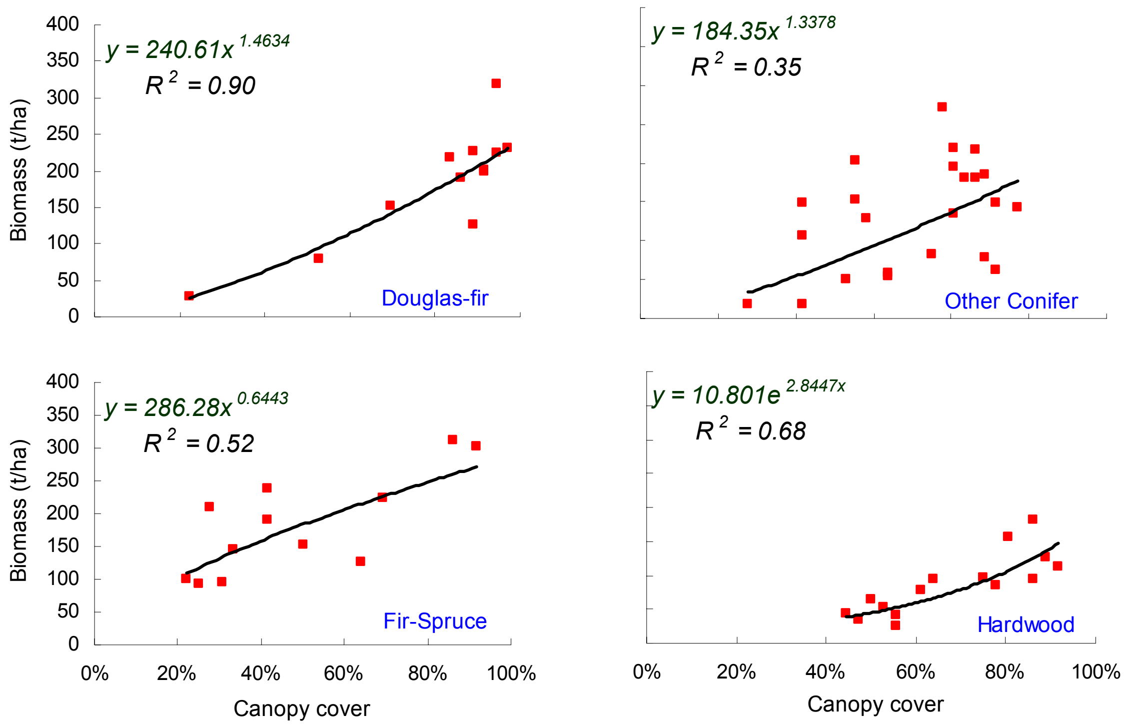

Figure 3. Relationships between biomass (tons/hectare) and canopy coverage (%) developed from field measurements in Shasta County, September 2005

Changes in canopy coverage between two points in time are recorded as percentage increases or decreases. The LCMMP incorporates a range of percentage changes into seven broad categories. Assuming an even distribution of % change within categories, the %-change midpoint can be taken as representative of the given category:

- 71% to 100% cover decrease = - 85%
- 41% to 70% cover decrease = - 55%
- 16% to 40% cover decrease = - 28%
- 16% to 40% cover increase = + 28%
- 41% to 100% cover increase = + 70%
- Shrub/Grass Decrease > 15% = - 43%
- Shrub/Grass Increase > 15% = + 43%

The application of these midpoint values to the midpoints of the WHR canopy coverage classes (see above) generates a post-change % canopy coverage, which can be used to calculate post-change biomass density using the regression equations determined in Figure 3. For example, for a "Douglas-fir" forest with a moderate coverage (40%–59%, midpoint 50%) that experiences a large decrease in canopy coverage (midpoint value, - 85%), the estimated new canopy coverage is 7.5%. Biomass carbon is estimated for the initial and final canopy cover and the difference represents the gross change in carbon from 87 tons of carbon per hectare (t C/ha) to 5 t C/ha—a net loss of 82 t C/ha.

Changes in carbon stocks for non-tree vegetation were estimated from values reported in the literature.

- For shrubs, a value of 30 t C/ha was used (Riggan and Dunn 1982; Schlesinger 1997; Harding ESE 2001; Morais 2001).
- For the grasslands, a value of 3.5 t C/ha was used (Bartolome et al. 2002; Higgins et al. 2002; Micheli and Kirchener 2002). This value is taken as 100% coverage. For grassland vegetation types where typically no coverage density is given, it was arbitrarily assumed to be 50% coverage density.
- Shrubs and grasses within forest and woodland categories are combined. Here the value of 20 t C/ha was used, which is a midpoint between the grasses and the shrubs value.
- The values above (except for grasslands) were taken as 100% coverage. Any increase or decrease in biomass is assumed to be directly proportional to the change in coverage. For the shrub/grasses within the forest and woodland categories, for which increases and decreases are in a single unit of > 15%, the midpoint was used (i.e., an increase or decrease of between 15% and 100% - midpoint = 43%).

3.2 Additional Biomass Components

Aboveground biomass of trees forms the dominant component of total biomass, but the additional components of belowground biomass, dead wood, litter, and understory vegetation may contribute significantly to carbon stocks. These additional carbon "pools" were added as follows:

- Belowground biomass was added using the temperate forests equation of Cairns et al. (1997).
- Standing dead trees were added using the equations of Smith et al. (2003).
- Understory vegetation contributes an extra 2% to biomass density (Winrock unpublished data).
- Litter and downed dead wood adds 7% (Douglas fir, redwood, other conifer), 10% (hardwoods), or 15% (fir-spruce) (from Vogt et al. 1986; Birdsey 1996).

Soil organic carbon was not included, as changes in the soil carbon pool are slow and small in magnitude (Carter et al. 2002; Laiho et al. 2002), and changes in soil carbon due to fire or harvest without a subsequent land-use change is unlikely (Binkley et al. 1992; Markewitz et al. 2002).

4.0 Carbon Stock Changes in Forests and Woodlands

As previously mentioned, here are eight causes of change in canopy cover determined by the LCCMP: fire, harvest, development, regrowth, seasonal, pest-related, other, and unverified. For the purposes of this study, the effects of these causes on biomass carbon stocks are assumed to be the following:

- Fire, harvest (commercial timber extraction) and development (construction) each reduce carbon stocks.
- The regrowth of forests and woodlands, on abandoned land or after a catastrophic event such as fire, increase carbon stocks.
- Seasonal and pest-related causes may result in a decrease in crown cover, but for "seasonal" causes this is temporary, and for "pest-related" causes potential decreases would be predominantly caused by insects and disease leaving standing dead trees which release carbon into the atmosphere very slowly. Consequently, seasonal and pest-related causes are not considered in this analysis.
- The "other" category includes both increases and decreases in canopy cover, but predominantly decreases.
- Unverified effects can both increase and decrease carbon stocks, but predominantly decrease them. The assumption is made here that most of the unverified changes are small-scale development, consequently unverified emissions are included with emissions from development.

Details of each of the causes are given in the sections below.

This report concentrates on the emissions from forests and rangelands in Shasta County. A discussion of sequestration will be included at the end of the analysis.

The *gross* change in carbon stocks would be the change that is directly proportional to the decrease or increase in canopy coverage. The *net* change deducts carbon that is not released to the atmosphere such as charcoal from fire, slash from harvesting that slowly decomposes, or long-term products from harvesting. The net deductions are detailed in the sections below.

For shrubs and grasses, the cause of the change is assumed to have no impact on the relative increase or decrease, e.g., fire will burn all vegetation; all vegetation will be cleared and destroyed by development.

Large crown change events such as fire, harvest or development are assumed to have occurred on average at the midpoint between two censuses.

4.1 Fire

The effects of fire on carbon stocks are dependent on the intensity of the fire. An intense fire will destroy biomass and release a great proportion of the carbon to the atmosphere; whereas a less intense fire will even fail to kill the majority of the trees. Here, fires are divided into three potential intensities: high, medium, and low. Based on discussions with FRAP staff, it was assumed that the three intensities are associated with the magnitude of change in crown cover, so that a large decrease in crown cover would indicate a high-intensity fire and a small decrease would indicate a low-intensity fire.

Pre-fire carbon stocks have five potential destinations during and after a fire (Figure 4). The first proportion will survive the fire to continue as live vegetation, a second proportion will be volatilized during the fire and immediately released to the atmosphere, and the remainder will be divided between the pools of dead wood, soot, and charcoal. Soot and charcoal are stable forms of carbon and can remain unchanged for very many years; however, dead wood decomposes over time.

The assumption is made that the midpoint of each decrease in canopy coverage class is the proportion of the vegetation killed by the fire. The proportion volatilized is dependent on fire intensity (Table 3; McNaughton et al. 1998; Carvalho et al. 2001). If the volatilized proportion is subtracted from the midpoint of the decrease, then the remaining fraction is the dead wood, soot, and charcoal pool.

The remaining fraction is divided using the following proportions: 22% charcoal, 44% soot, 32% dead wood (Table 3; Comery 1981; Raison et al. 1985; Fearnside et al. 1993; Neary et al. 1996). Dead wood decomposition occurs for two years from the fire occurrence, midway between the two censuses, to the endpoint at the second census. Decomposition occurs at a rate of 0.05 yr^{-1} as determined by Harmon et al. (1987) for Sequoia National Park, in California (but see Chambers et al. 2000).

As noted in Section 3.2, additional biomass components were added to the dominant biomass component of aboveground biomass in trees, based on Winrock experience across California and consulting the literature. These additional components included understory vegetation (contributing an extra 2% to biomass density, based on Winrock unpublished data), and litter and downed dead wood (contributing 7%, 10%, or 15%, depending on forest type, based on Vogt et al. 1986 and Birdsey 1996). Understory fuel loads in Shasta County may be higher than these averages, however, leading to higher overall GHG emissions due to wildfire. This would make estimates of fire emissions—based on the biomass and canopy cover relationships taken from field measurements (which included trees > 10 centimeters (cm) only; see Appendix A), then adjusted using the above percentages—a likely underestimate for Shasta County where fuel loads are higher.

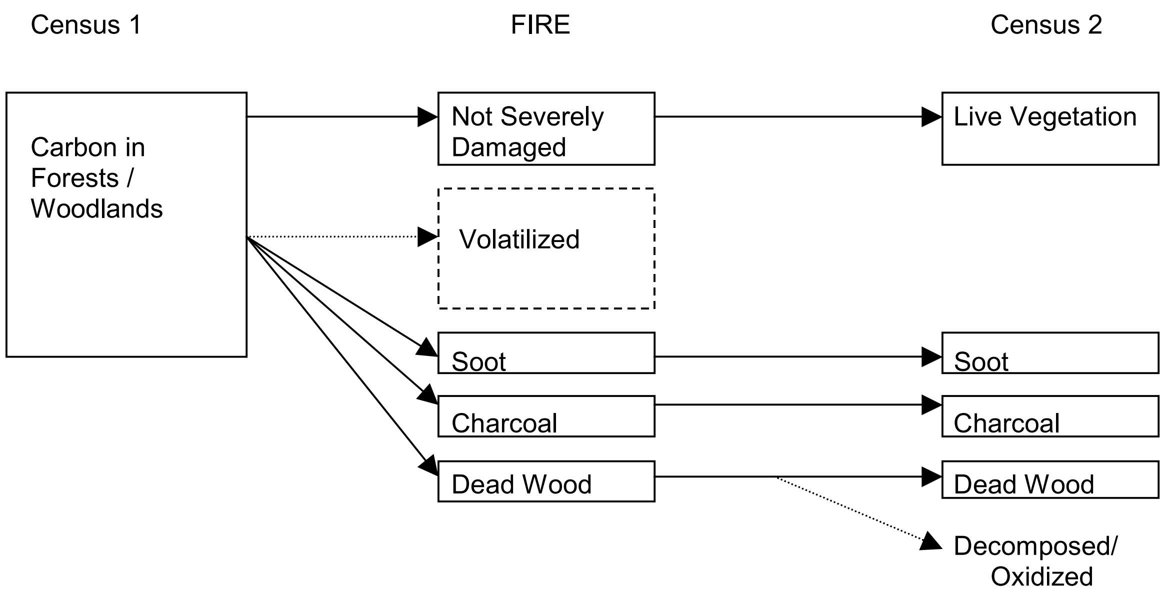

Figure 4. Flow diagram illustrating the various destinations of pre-burn carbon after a fire

Table 3. Assumptions for the fate of carbon after fire-induced decreases in canopy coverage

	Fire Intensity		
	High (%)	**Mid (%)**	**Low (%)**
Volatilized	60	40	20
Not volatilized	25	15	8
Charcoal	5.5	3.3	1.8
Soot	11	6.6	3.5
Dead wood	8.0	4.8	2.6
Surviving vegetation	15	45	72

These pools—understory fuel, lying dead wood, trees < 10 cm, and litter/duff—were also measured in Shasta County in 2005. Mean biomass in these pools was approximately 100 t/ha (n = 45, 95% CI = 27), representing an average throughout the county regardless of fuel class or forest type. If we assume that a wildfire would release to the atmosphere effectively the entire carbon stocks of these pools (a reasonable assumption for a relatively intense fire and relatively dry conditions, although wetter conditions could prevent fire from volatilizing 100% of these pools), then emissions from understory vegetation, small trees, litter, and duff would be approximately 50 t C/ha (183 t CO_2/ha or 74 t CO_2/acre) *additional to the emissions from carbon stocks in trees > 10 cm*. Table 4 shows mean biomass and estimated CO_2 emissions by pool, based on these measurements.

Table 4. Biomass and CO_2 emissions due to fire from understory vegetation, trees < 10 cm diameter at breast height (DBH), litter, and duff, additional to emissions from carbon stocks in trees > 10 cm

Pool	Mean biomass (t/ha)	Mean t C/ha	t CO_2/ha if all emitted	t CO_2/acre if all emitted
Understory vegetation	43.2	22	79	32
Trees < 10 cm	13.4	7	25	10
Litter and duff	43.3	22	79	32
All pools	100	50	183	74

Table 5 shows a comparison of mean biomass carbon in understory fuel, trees < 10 cm DBH, and litter/duff, derived from fuel measurements and Shasta County, with total mean biomass carbon for each forest type derived from biomass and canopy cover measurements.

Table 5. Mean biomass carbon in understory vegetation, trees < 10 cm DBH, litter, and duff, as compared to carbon stocks in trees, by forest type in Shasta County (total carbon stocks based on 80% canopy cover)

	Biomass carbon (t C/ha)		
Forest type	Biomass carbon, aboveground trees only, at 80% canopy cover	Mean biomass carbon in understory vegetation, trees < 10 cm, and litter/duff	Understory vegetation, trees < 10 cm, and litter/duff as a percentage of total biomass carbon
Douglas fir	173.6	n/a	n/a
Fir-Spruce	247.9	50	20.2%
Other Conifer	136.8	54	39.5%
Hardwood	105.2	39	37.1%

The percentages in Table 5 suggest that the mean biomass carbon stocks in understory vegetation, small trees, and litter/duff are generally higher for Shasta County than the overall averages assumed in Section 3.2 of 7% for Douglas fir/redwood/Other conifer, 10% for hardwoods, or 15% for Fir-spruce. This is particularly the case for the fire-prone Other Conifer forest type. Here, to be conservative, the original values are taken, but the estimates of potential carbon emissions due to fire presented in this report can be viewed as conservative.

4.2 Harvest

Figure 5 illustrates the destination of carbon after commercial harvest. Initially, at the time of harvest, trees are either cut or mortally damaged. The remaining proportion (taken here as the proportion of canopy coverage remaining after the harvest mid-point decrease) endures as live vegetation.

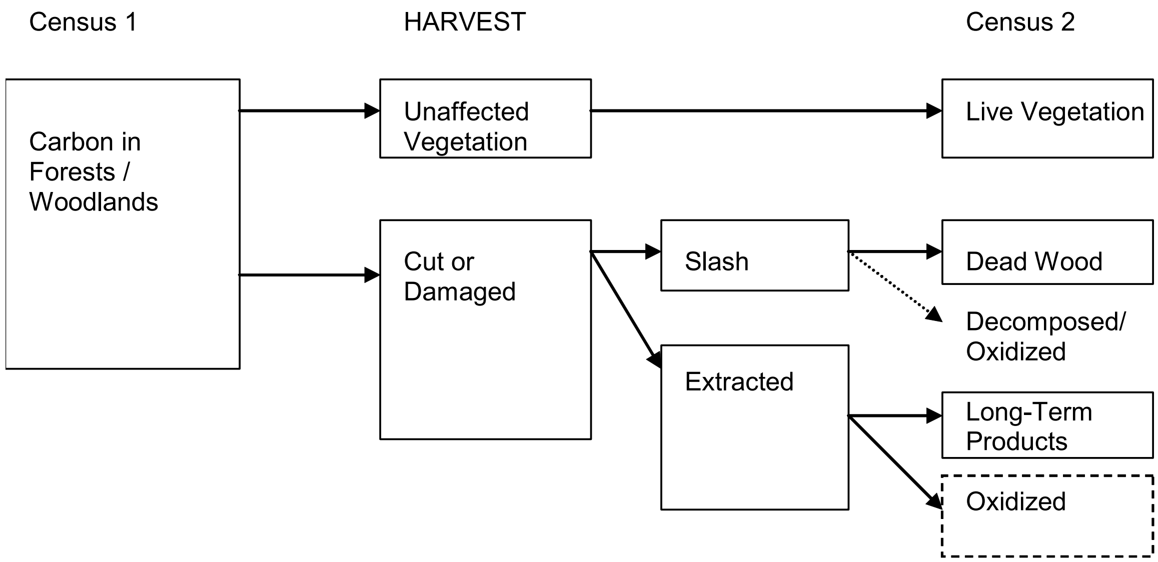

Figure 5. Flow diagram illustrating the various destinations of pre-harvest carbon after commercial harvest

The cut and damaged vegetation is divided into two pools—one of which is extracted for timber processing. The remaining fraction is either left on-site to decompose (in the wetter forest areas) or piled and burned on site (in the drier areas). For simplicity, this study assumes that all slash oxidizes for two years at 0.05/yr (Harmon et al. 1987). Finally the extracted portion is further divided into long-term products and other pools. Other pools can include waste, chips and fuel; all are assumed to release carbon rapidly to the atmosphere. The proportions extracted from the forest and transformed into long-term products are detailed for the California region by Birdsey (1996). For softwoods, 75% is extracted from the forest and 44% of the extracted volume becomes long-term products. For hardwoods 73% is extracted and 23% becomes long-term products.

4.3 Development

Developed land is typically cleared to allow for construction. Consequently it can be assumed that the mid-point decrease in canopy coverage represents vegetation that has been removed from the site.

For Douglas fir, this study assumes that the value of the timber is too high for it not to be used commercially. The research team applied the same proportions as in the harvest scenario (see Section 4.2.), except here it is assumed that slash will not be permitted to decompose onsite and instead is immediately destroyed and all carbon rapidly oxidized. The fate of carbon during development for Douglas fir is illustrated in Figure 6a.

For fir-spruce, other conifer and hardwoods it was assumed that the extracted trees are either utilized as fuel wood or are similarly destroyed and all carbon rapidly oxidized. Figure 6b illustrates the fate of carbon during development for these vegetation types.

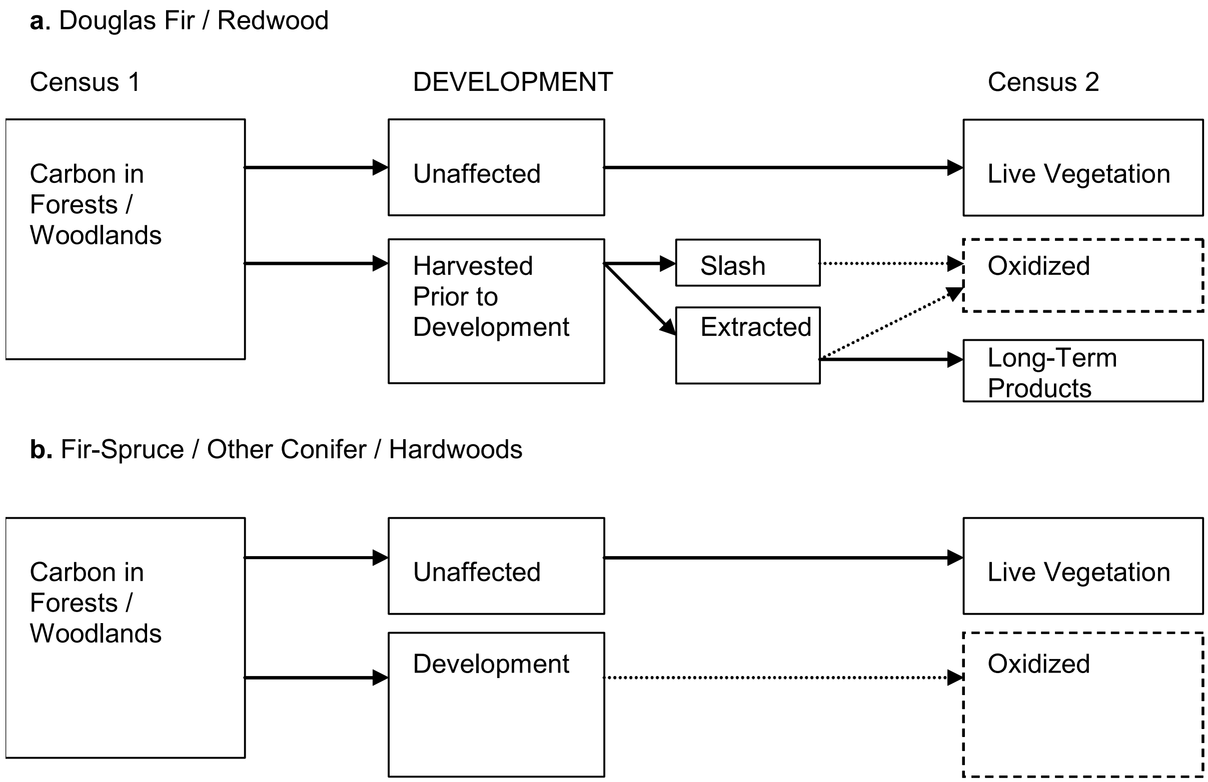

Figure 6. Flow diagram illustrating the various destinations of pre-development carbon after development has occurred

4.4 Other Changes

Decreases in canopy coverage do result from seasonal and pest-related causes; however, these causes of change are not considered in depth in this study. For seasonal causes, the area involved is small and by definition all changes will be reversed annually or semi-annually. For pest-related causes, the principal causal agent is disease, and specifically in California, Sudden Oak Death. Following onset of disease, canopy coverage declines as foliage is lost but it is unlikely that carbon stocks will be significantly affected, at least in the near to mid term. The end point of the disease will be standing dead trees, which decompose very slowly (Rizzo and Garbelotto 2003).

No pest-related changes in canopy cover were recorded in Shasta County, and the "Other" category was composed of such disparate effects as conversion to agriculture, road-related changes, and changes due to floods, landslides and avalanches. Each of these causes leads to a net change in carbon. Regarding the timber, "Other" is treated identically to development (see Section 4.3.), with Douglas fir timber converted to long-term products.

4.5 Non-CO_2 Gases

Other gases influence climate change as directly as carbon dioxide. Two gases in particular are the focus of growing attention scientifically and politically: methane (CH_4) and nitrous oxide (N_2O). Although these gases are produced in smaller quantities than carbon dioxide, their effect for a given mass on global warming is greater. This is illustrated by the calculated Global Warming Potential (GWP): over a hundred-year period methane is expected to have a GWP equal to 23 times that of CO_2, and N_2O is expected to have a GWP equal to 296 times that of CO_2 (Houghton et al. 2001). Consequently these gases need only be produced in quantities equal to 4% and 0.3% respectively of the mass of CO_2 to have an equal effect (over 100 years) with respect to climate change.

Methane and N_2O are produced mainly as the result of anthropogenic activities—for example the draining of wetland regions, the fertilization of land, and the storage and processing of livestock effluent (Houghton et al. 2001). None of these causes are of direct concern to the current study (baseline for forests and rangelands in California), because the area of wetland forest in California is minimal and fertilization of planted forests in California is rarely cost effective, and consequently is very infrequently employed (R. York, 2003, Center for Forestry, University of California, personal communication). The potential for CH_4 and N_2O release, for each of the causes of canopy coverage change discussed previously, will be examined.

4.5.1 Fire

Biomass burning is the greatest natural (or semi-natural) source of non-CO_2 gas production (IPCC 2003). The quantity released can be estimated using emission factors based on the quantity of C released (IPCC 2003).

CH_4 emissions = (carbon released) x 0.012 x 16/12 (IPCC 2003)

N_2O emissions = (carbon released) x 0.007 x 0.01 x 44/28 (Crutzen and Andreae 1990)

Fires in California are likely to be of the "flaming" rather than the "smoldering" variety; consequently it may be more appropriate to apply the lower emissions ratio: 0.009 instead of 0.012 for CH_4, and 0.005 instead of 0.007 for N_2O (IPCC 2003; Crutzen and Andreae 1990).

4.5.2 Harvest

Methane is sequestered in undisturbed forest soils at an estimated rate of 2.4 kilograms per hectare per year (kg/ha.yr) (Smith et al. 2000). Disturbance will alter this rate but it is unclear to what extent. Nitrous oxide is widely associated with fertilization (Houghton et al. 2001), but natural sequestration and release in forest environments is very poorly understood. It has been suggested that forest management activities such as clearcutting may increase emissions, but the available data are insufficient and contradictory (IPCC 2003).

In order to make an estimation of CH_4 response to harvesting, estimations of harvest-induced emissions from a single study are examined. Gasche et al. (2003) studied the flux of non-CO_2 gases from the nitrogen-saturated soils of a German spruce forest before and after clearcutting, and measured a decrease in sequestration of CH_4 from 1.46 kg CH_4/ha.yr to 0.52 kg CH_4/ha.yr spanning a clearcut. The net effect is a reduction in CH_4 sequestration of 0.94 kg/ha.yr as a consequence of clearcutting. Simultaneously in the study of Gasche et al. (2003), N_2O release increased by an order of magnitude. However, the direct relationship between fertilization and N_2O release, and the fact that these German spruce forest soils were nitrogen-saturated and Californian forests are very rarely fertilized, means that this study cannot be applied for the analysis for Californian forests.

4.5.3 Development and Other Changes

For development, the lack of information regarding subsequent land use prevents any estimation of non-CO_2 gas fluxes. For example, if development involves construction, then gradual emissions from the soil will not be possible.

For the remainder of the causes, a similar paucity of information and an entire lack of scientific consensus means that the most conservative approach is to make no estimates.

4.6 Evaluating Sources of Error

As has been described above, many steps are involved in estimating a carbon baseline for the forests and rangelands sector. As expected, each step has a degree of uncertainty (source of error) associated with it. This section describes each source of error, its likely magnitude, and an estimate of the total error for the baselines.

STEP 1: Calculating areas from satellite data

The LCMMP program reports an accuracy value for the North Coast region of 89.8%. This represents an error of 10.2%. Reported precision for the other regions is not yet available but is assumed to be equivalent.

STEP 2: Calculating carbon stocks

The Root Mean Square Error (RMSE) of the regressions between canopy cover and biomass stock are as follows: Douglas-fir – 38.5; Fir-Spruce – 48.5; Other Conifer – 64.0; Hardwood – 26.3.

STEP 3: Assumptions for calculating net emissions

For fire, altering the proportion oxidized in the fires by 10% changes the net emissions by 9%. For harvest, altering the proportion extracted by 10% changes the net emissions by 7.8% for softwoods and 8.3% for hardwoods. Altering the proportion converted to long-term products by 10% changes the net emissions by 7.5% for softwoods and 2.2% for hardwoods.

The total error was estimated using Monte Carlo simulation analysis,[8] whereby the uncertainties are summed many times each time with the uncertain inputs chosen randomly by the computer software from within the distribution of uncertainties. Uncertainties were included by assuming a normal distribution for all uncertain values.

[8] The risk analysis software package Simetar was used for this step (www.simetar.com).

The single largest source of error is derived from the regression equations used to estimate biomass from canopy coverage (Table 6). To reduce this source of error further would require additional field data.

Table 6. Sources of error and their potential magnitude in the estimated baseline for the forest and rangelands sector

	Source of Error	% Error / RMSE	Potential for Decreasing Error
1.	Image processing	10.2%	Outside the expertise or control of Winrock
2.	Regression biomass to canopy coverage		If more plots were examined in each canopy coverage class, then more precision could be attained
	a. Douglas-fir	38.5	
	b. Fir-Spruce	48.5	
	c. Other Conifer	64.0	
	d. Hardwoods	26.3	
3.	Net emission assumptions		
	a. FIRE	9.0%	Additional field work related to California needed to validate and refine the assumptions
	b. HARVEST softwoods hardwoods	 10.8% 8.6%	Detailed assessment of the forestry and milling industries to refine estimations of extracted proportion and proportion entering long-term products

No uncertainty could be added to the removals data as no uncertainty was available for the USDA Forest Service (USFS) input data.

5.0 Results

5.1 Overall Changes in Canopy Cover and Causes of Change

The area that underwent a change in canopy cover between 1994 and 1999 was 27,402 ha, or 2.8% of the land area of Shasta County. In Shasta County, fire, development and other causes are all in patches of small areal extent throughout the County (Figure 7). Harvest and regrowth (> 15% increase in canopy cover in 5 years) occur predominantly in the forested areas to the Eastern side of the county. The greatest changes in canopy cover appear to be associated with harvest (Figure 7).

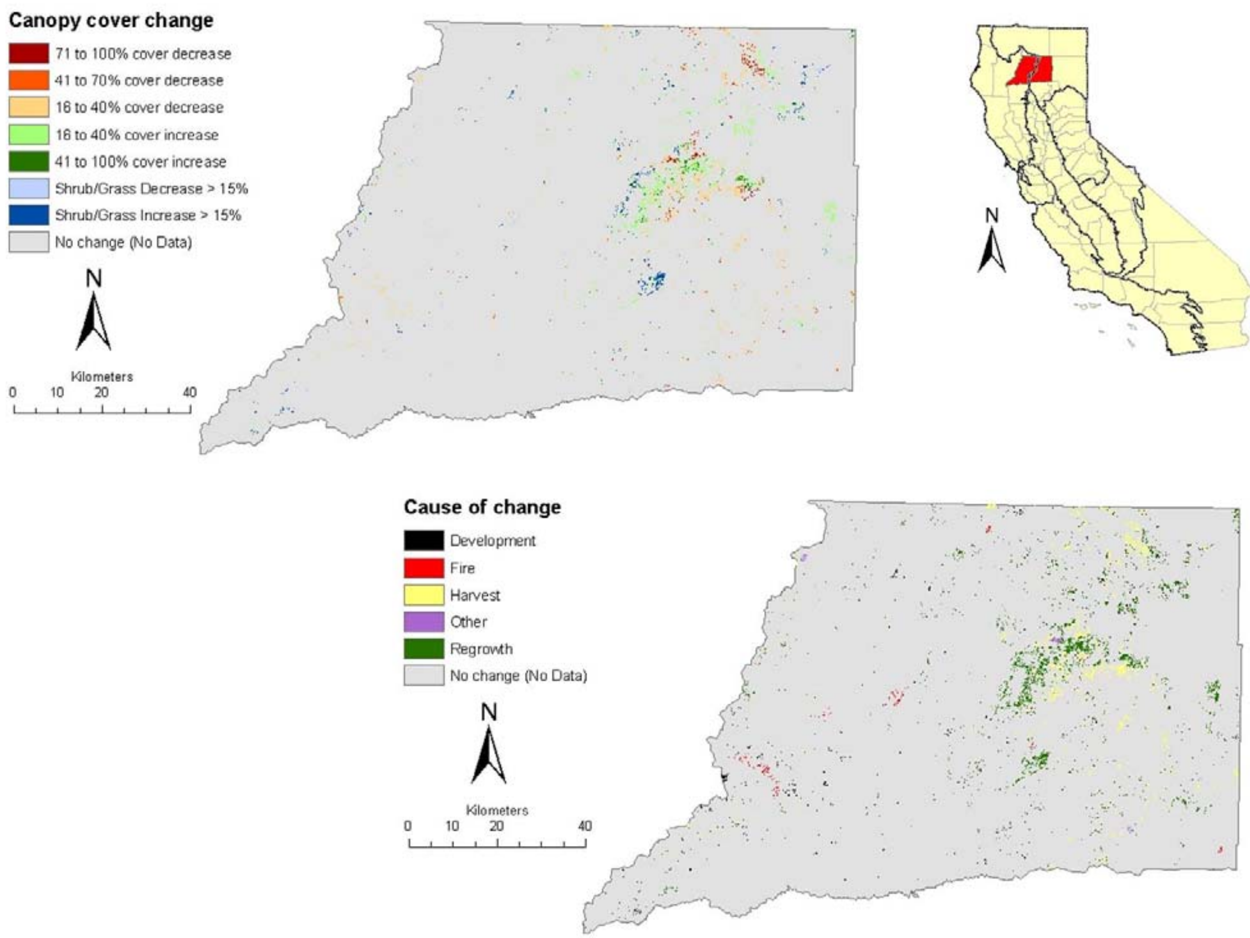

Figure 7. Areas experiencing a change in canopy by magnitude of change and by cause

5.2 CO_2 Emissions for Shasta County Forests and Rangelands

5.2.1 Rangelands

A total of 1,367 hectares of rangelands in Shasta were affected by a canopy change during the census interval. Of this total almost 20% were woodlands and the remainder were shrub/grass lands. The dominant cause of decreases in canopy coverage in rangelands was development, which accounted for 46% of the total area (Table 7).

Table 7. Change in area of Shasta County rangelands based on areas affected by a decrease in canopy cover

	Fire	Harvest	Development	Other	SUM
AREA (ha)					
Woodlands	0	46	168	39	253
Grasses / Shrubs	181	373	463	97	1,114
SUM AREA	181	419	631	136	1,367

Across Shasta County, net emissions from rangelands was estimated to be about 35 thousand t C, 52% of which was caused by development (Table 8).

Table 8. Changes in carbon stocks in Shasta County rangelands (- equals a loss in carbon stocks or a source)

EMISSIONS	Fire	Harvest	Development	Other	SUM EMISSIONS
GROSS (t C)					
Woodlands	0	-3,977	-12,966	-3,471	-20,413
Grasses / Shrubs	-2,505	-5,876	-5,150	-2,548	-16,080
SUM GROSS	-2,505	-9,853	-18,116	-6,019	-36,493
NET (t C)					
Woodlands	0	-2,340	-12,966	-3,471	-18,777
Grasses / Shrubs	-2,505	-5,876	-5,150	-2,548	-16,080
SUM NET	-2,505	-8,216	-18,116	-6,019	-34,856
+/- standard deviation	303	777	1,920	448	2,428

All values in the table are rounded to zero decimal places. Any discrepancy in totals is due to the rounding.

5.2.2 Forests

About 11,000 ha of forests lost canopy cover in Shasta County between 1994 and 1999, including about 9,000 hectares from harvest (78% of total) (Table 9). Eighty-two percent of the decreases occurred in Other Conifer (principally pine) forests.

Table 9. Area of Shasta County forests affected by a loss in canopy cover

	Fire	Harvest	Development	Other	SUM
AREA (ha)					
Douglas-fir	67	286	258	4	615
Fir-Spruce	38	760	38	24	860
Other Conifer	415	7,565	929	387	9,296
Hardwood	53	203	202	29	487
Redwood	0	0	0	0	0
Shrubs/grasses	36	31	63	24	154
SUM AREA	609	8,845	1,490	468	11,412

The net emissions from all activities is 0.59 million t C, with forest harvest accounting for 70%, development for 16% and fire for 4% of the total net emissions (Table 10). The changes in carbon stocks are clearly dominated by "other conifer" forests, which account for 74% of the total net emissions, particularly caused by harvest of these forests.

Table 10. Changes in the carbon stock of Shasta County forests (- equals a loss in carbon stocks or a source)

EMISSIONS	Fire	Harvest	Development	Other	SUM EMISSIONS
GROSS (t C)					
Douglas-fir	-5,490	-41,300	-21,832	-179	-68,802
Fir-Spruce	-3,086	-120,662	-3,324	-1,383	-128,455
Other Conifer	-21,568	-730,045	-50,725	-23,180	-825,518
Hardwood	-5,730	-31,274	-23,922	-4,151	-65,076
Shrubs/grasses	-223	-138	-359	-127	-848
SUM GROSS	-36,098	-923,419	-100,162	-29,021	-1,088,700
NET (t C)					
Douglas-fir	-3,972	-18,353	-14,628	-120	-37,073
Fir-Spruce	-2,239	-53,619	-3,324	-5,522	-64,704
Other Conifer	-15,608	-324,414	-50,725	-46,078	-436,824
Hardwood	-4,168	-18,402	-23,922	-7,186	-53,677
Shrubs/grasses	-223	-138	-359	-127	-848
SUM NET	-26,211	-414,926	-92,957	-59,033	-593,127
+/- standard deviation	6,917	85,466	20,642	7,255	92,672

All values in the table are rounded to zero decimal places. Any discrepancy in totals is due to the rounding.

To normalize the net emissions from forests as above, the average net emissions per unit area are given in Table 11 (the net emissions from Table 10 divided by the area in Table 9). For practically all forest types, except Douglas fir, mean C emissions are highest for development, followed by harvest and then by fire.

Table 11. Mean emissions per unit area (t C/ha) for fire, harvest, and development in Shasta County

t C/ha	Fire	Harvest	Development
Douglas fir	-59	-64	-57
Fir-Spruce	-59	-71	-87
Other Conifer	-38	-43	-55
Hardwood	-79	-91	-118

5.3 Non-CO_2 Gas Emissions for Shasta County Forests and Rangelands

5.3.1 Fire

Although 26,211 t C (96,107 t CO_2 e) were emitted through fire in Shasta County forests during the inter-census period, the simultaneous release of N_2O is estimated as just 3 tons. However, N_2O has 296 times the global warming potential of CO_2, so the 3 tons of N_2O translates to 853 tons of CO_2 equivalents. Yet nitrous oxide, even when converted to CO_2 equivalents, never exceeds 1% of the release of CO_2 (Table 12).

Methane emissions through fire are more significant. Methane release approximates 10% of the CO_2 release in an average fire or 8% for a fire that burns rapidly (flaming). This is equal to 9,737 tons of CO_2 equivalents for the inter-census period in Shasta County (simultaneous CO_2 releases = 105,292 tons) (Table 12).

Table 12. Estimated forest and rangelands non-CO_2 gases (methane and nitrous oxide) resulting from fire. (a) results for average fires, (b) results for flaming fires which may be more typical of fires in California

(a) Average Fire

Vegetation	Carbon emitted (t C)	Methane			Nitrous Oxide		
		t emitted	t CO2 e	(% of C) released	t emitted	t CO2 e	% of C released
Rangelands	2,505	40	922	10	0.3	82	0.9
Forests	26,211	419	9,645	10	2.9	853	0.9

b) Flaming Fire

Vegetation	Carbon emitted (t C)	Methane			Nitrous Oxide		
		t emitted	t CO2 e	% of C released	t emitted	t CO2 e	% of C released
Rangelands	2,505	30	691	8	0.2	58	0.6
Forests	26,211	315	7,234	8	2.1	610	0.6

5.3.2 Harvest

The reduction in methane sequestration caused by the disturbance of harvesting is very low, relative to the net losses of CO_2. The increase in atmospheric CH_4 CO_2 equivalents is estimated as less than one tenth of a percent of the actual increase in carbon dioxide (Table 13).

Table 13. Estimated forest and rangelands methane emissions resulting from harvest

Vegetation	Carbon emitted (t C)	Methane t emitted	Methane t CO_2 e	Methane % of C released
Rangelands	8,216	0.8	18	0.06
Forests	414,926	17	382	0.03

6.0 Forests and Rangelands as Sources and Sinks of Greenhouse Gases

6.1 Estimated Emissions over the Study Interval

Across the 9,804 square kilometers (km^2) comprising Shasta County, there are an estimated 6,302 km^2 of forest and 3,019 km^2 of rangelands. Of this area 128 km^2 of forests and rangelands had a defined decrease in canopy cover between the measurement periods (equal to 1.3% of the total area and 2.0% of the forest area). Eighty-nine percent of the changes were on forestland and 9% on rangeland.

On forestland, 78% of the area with a loss in canopy cover was caused by commercial harvest, 13% by development and 5% by fire. On rangeland, development dominated the cause of loss in canopy coverage accounting for 46% of the area. Next in significance was harvest with 31%.

In terms of carbon, 0.59 million t C were emitted from forestland in Shasta County (Table 14). On forestland, harvest emitted as much as 0.41 million t C. On rangelands, 0.034 million t C were emitted in the five-year interval from the three regions; included in this total are 0.018 million t C emitted through development (Table 14).

Table 14. Summary of the carbon emitted and removed in forests and rangelands in Shasta County during a five-year interval 1994–2000 (actual five-year periods vary by region)

	Net t C		
	Forests	Rangelands	TOTAL
EMISSIONS			
Fire	26,211	2,505	28,715
Harvest	414,926	8,216	423,142
Development	92,957	18,116	111,074
Other	59,033	6,019	65,051
EMISSIONS	593,127	34,856	627,983
Standard Deviation	*92,672*	*2,428*	*92,672*

All values in the table are rounded to zero decimal places. Any discrepancy in totals is due to the rounding.

Confidence can be had in the pattern of change, but the precise carbon values attained should be viewed as plus or minus 15% due to the limitations mentioned above.

6.1.1 Fire as a Source of Emissions in Shasta

While harvest and development are unlikely to vary greatly year from year, fire is a great deal more unpredictable. There can be years with very low fire incidence, followed by a single year with thousands of hectares burned.

To examine how typical the years of the current study are for fire incidence, this study examined fire areas for the entire period of 1990 to 2000 from the State of California's Fire Perimeters Dataset.[9] The dataset reveals that no fires were recorded on forestland in 1994, 1995, 1997, and 1998. The total area of fire over the 11 years was about 34,300 ha and 19,500 ha for forests and rangelands, respectively (Figure 8). This translates to an average annual area burned of 3,118 ha of forest and 1,768 ha rangeland during the 11-year period compared, to the 122 ha/yr for forests and 36 ha/yr for rangeland indicated for shorter period used in this study. Based on the longer time interval, it is likely that fire emissions could rival or exceed those of harvest for Shasta County.

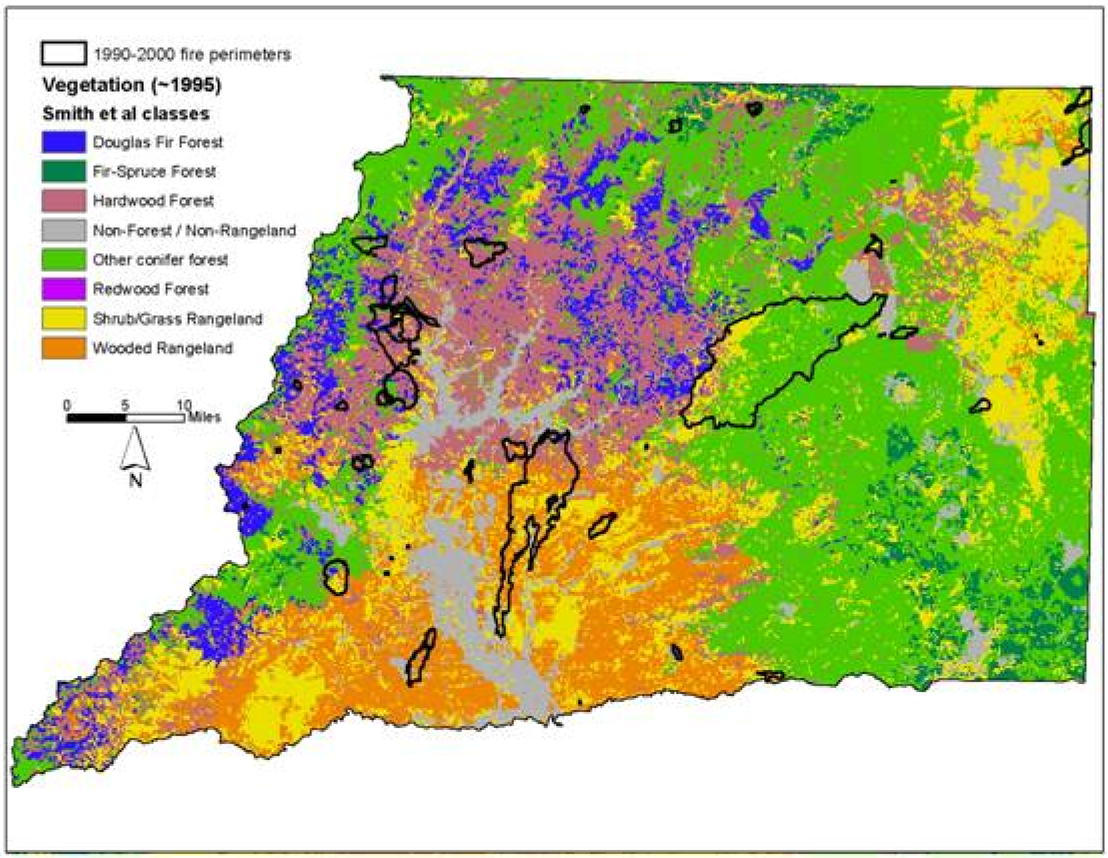

Figure 8. Areas of fires in Shasta County for the period 1990–2000

6.2 Estimated Sequestration over the Study Interval

This report focuses on emissions from forest and rangelands in Shasta County. However, a first approximation is presented here of the sequestration that occurred during the same time period and consequently the net flux of carbon from forests and rangelands in Shasta County.

[9] Available from http://frap.cdf.ca.gov/data/frapgisdata/select.asp.

Although the LCMMP database contains much additional information about the structure of forests, it is difficult to correlate these data to rates of carbon accumulation. Instead, this study used data based on the USFS FIA database (Birdsey and Lewis 2002). The Birdsey and Lewis report provides the total area of forestland for 14 different vegetation types in California in 1992 and 1997, and the total carbon stock for the same dates. The categories used by Birdsey and Lewis (2002) were combined at the area and stock stage into the Smith categories (see Table 2). The average annual change in carbon stock in t C/ha.year was determined by dividing the stock by the area at each date then subtracting 1992 from 1997 and dividing by five (the number of intervening years). Based of the USFS data, the research team's first approximation of the rate of carbon accumulation is:

- Douglas fir – 1.36 t C/ha.yr
- Fir-Spruce – 1.21 t C/ha.yr
- Other Conifer – 1.93 t C/ha.yr
- Hardwoods – 1.05 t C/ha.yr

These values are within expectations. For example, the Sierran Mixed Conifer forest at Blodgett Forest Research Station (BFRS) could be compared with the "other conifer" category, and the vegetation at Jackson State Demonstration Forest (JSDF) compared with the "redwood" category. Measurements by Winrock at BFRS for a separate study indicate the same rate of carbon accrual calculated here for other conifer forests as the rate for Sierran mixed conifer forests aged approximately 65 years, while measurements at JSDF indicate carbon accrual rate in forests at 70 years of age is equal to that calculated here for redwoods (Brown et al. 2004b).

The estimates of Birdsey and Lewis (2002) represent net changes incorporating the losses and gains that are detailed in this report through the change data. Consequently here an additional step is added to determine a sequestration for the lands that had no discernible change in canopy cover:

Net sequestration recorded by Birdsey and Lewis + the gross emissions calculated in the present study = total gross sequestration

Total gross sequestration / Total area of forests in Shasta = Mean sequestration/ha

Mean sequestration/ha x area of forests recorded as having no change or a positive change in canopy cover = sequestration in Shasta County over the study period.

Using this methodology, it was estimated that on forestland in Shasta County about 5.9 million t C were sequestered across an area of 616 thousand hectares during the five-year study period (Table 15).

Table 15. Summary of the estimated carbon removed in forests in Shasta County during a five-year interval 1994–2000 (actual five-year periods vary by region)

FORESTS	Area (ha)	Estimated Sequestration (t C)
Douglas fir	68,134	531,427
Fir-Spruce	31,833	317,624
Other Conifer	172,387	3,379,143
Hardwood	343,639	1,723,537
TOTAL	615,993	5,951,731

For rangelands, it can be assumed that shrubs and grasses are at a steady state and are not accumulating carbon biomass unless an increase in canopy coverage is recorded. In contrast trees on the wooded ranges, as long as they are alive, will be growing and accumulating biomass. There are no data on which to base an estimate of this rate, but from experience, the research team approximates an accrual of 0.3 t C/ha.yr. Where a positive change in canopy was recorded in shrubs and grasses, a proportional increase in biomass was estimated.

Using this methodology, it was estimated that on rangelands in Shasta County about 0.12 million t C were sequestered across 123.5 thousand hectares during the five-year study period (Table 16).

Table 16. Summary of the estimated carbon removed on rangelands in Shasta County during a five-year interval, 1994–2000 (actual five-year periods vary by region)

RANGELANDS	Area (ha)	Estimated Sequestration (t C)
Wooded Rangeland	119,643	179,465
Shrubs and Grasses*	3,872	33,083
TOTAL	123,515	212,548

*For shrubs and grasses, no accumulation was considered for areas with no change in canopy cover; instead a steady state was assumed.

6.3 Carbon Dioxide Equivalents

If the non-CO_2 gases are included and all values are converted to carbon dioxide equivalents, then for Shasta County as a whole, 2.2 MMTCO_2e were emitted between the census dates from forest land and 0.1 MMTCO_2e from rangelands. This converts to an annual emission of 0.43 MMTCO_2e from forests and 0.026 MMTCO_2e from rangelands (Table 17).

During the same period, 21.82 MMTCO_2e were estimated to have been removed by forestland and 0.78 MMTCO_2e on rangeland. This is equal to an annual rate of removals of 4.36 MMTCO_2e in forests and 0.16 MMTCO_2e on rangelands (Table 17).

Table 17. Summary of the emissions and removals, over the analysis period and on a per-year basis

	Forests				Rangelands			
	C	*N_2O*†	*CH_4**	**TOTAL**	*C*	*N_2O*†	*CH_4**	**TOTAL**
$MMTCO_2e$								
Emissions	2.17	0.0009	0.01	**2.18**	0.13	0.00008	0.0009	**0.13**
Removals	21.82	-	-	**21.82**	0.78	-	-	**0.78**
$MMTCO_2e$/year								
Emissions	0.43	0.0002	0.002	**0.43**	0.026	0.00002	0.0002	**0.026**
Removals	4.36	-	-	**4.36**	0.16	-	-	**0.16**

*†N_2O only calculated for fire; *CH_4 only calculated for fire and harvest.*

6.4 Comparison of the county level analysis with the statewide analysis

In this section, the current analysis is compared with the corresponding results for Shasta County from the original statewide report (Brown et al. 2004a). Hereafter Brown et al. 2004a will be referred to as *Phase I* and the current report as *Phase II.*

For the Phase II analysis, new carbon stock data were applied, derived from field measurements of carbon stocks correlated with canopy cover measurements for forest sites within Shasta County. These carbon stock estimates replaced carbon estimates in Phase I, for various forest and rangeland types and corresponding canopy closures, derived from FIA data, the literature, consultations with CDF-FRAP staff, and the equations of Smith et al. (2003). In Table 18, the increase in carbon stocks in the current analysis as opposed to the Phase I report is illustrated for the example of 80% canopy cover across the broad forest categories.

Table 18. The divergence of carbon stock data in Shasta County between Phase I And Phase II analyses. The example of 80% canopy cover is illustrated.

	Carbon stock at 80% canopy cover	
t C/ha	**Phase I**	**Phase II**
Douglas fir	196.0	279.0
Fir-Spruce	157.0	401.0
Other Conifer	140.6	228.4
Hardwood	95.7	268.5

The use of Shasta County-specific carbon numbers resulted in higher emissions across all causes of changes in canopy coverage compared to the statewide analysis. In forests, emissions through fire were 213% higher and emissions through development were 249% higher (Table 19). The total impact of the new carbon stock data was an increase in estimated emissions of 152%.

Table 19. A comparison of CO_2 emissions from forests over the five-year interval between Phase I and Phase II. The negative sign indicates emissions. The percentage is calculated as the difference between Phase I and Phase II as a proportion of the phase I value.

	Emissions of CO_2 from:		
t C	Phase I	Phase II	% increase
Fire	-30,769	-96,107	213
Harvest	-576,418	-1,521,397	164
Development	-97,666	-340,843	249
Other	-160,045	-216,455	35
TOTAL	-864,902	-2,174,801	152

For rangelands there was no divergence for emissions from fire, as all emissions were from shrubs and grasses; however, emissions from development in rangelands were raised by 137% and for all causes combined emissions were raised by 77% due to the new carbon stock data (Table 20).

Table 20. A comparison of CO_2 emissions from rangelands over the five-year interval between Phase I and Phase II. The negative sign indicates emissions.

	Emissions of CO_2 from:		
t C	Phase I	Phase II	% increase
Fire	-9,193	-9,193	0
Harvest	-23,716	-30,153	27
Development	-28,024	-66,486	137
Other	-11,531	-22,090	92
TOTAL	-72,460	-127,922	77

The uncertainty in the reported results was equal to 25% using Phase I methods and 15% using Phase II methods.

The increase in emissions in the Phase II analysis is to be expected given the region-specific carbon stock data incorporated into the study. In a high-biomass county such as Shasta, it would be expected that the mean carbon stock per hectare is higher than the statewide average. The application of these higher stocks per hectare creates higher total stocks to be affected by changes in canopy cover and these proportional changes in canopy cover will therefore lead to higher emissions.

7.0 Conclusions

A loss in canopy cover was measured on 12,800 hectares of forests and rangelands in Shasta County. This is approximately 1.4% of the total area of forests and rangeland in the county. For forests, a net removal of 4.36 MMTCO_2e/yr and a net emission of 0.43 MMTCO_2e/yr were estimated. Rangelands were a net sink, with a net removal of 0.16 MMTCO_2e/yr exceeding a net emission of 0.026 MMTCO_2e/yr.

Harvest and development were the dominant causes of emissions on forestlands; these causes were responsible for 70% and 16% respectively, while fire was responsible for 4%. However, the years of the study (1994–1999) had an unusually low incidence of fire. Examining the 11 years 1990–2000 yields annual burn areas of 3,118 ha/yr for forests and 1,768 ha/yr for rangeland, as compared with 122 ha/yr and 36 ha/yr, respectively, revealed in this study. Thus it is likely that over a longer analysis period, fire would be a more significant cause of net emissions in Shasta County—perhaps even rivaling or exceeding net emissions from harvest.

On rangeland, development was the dominant cause of emissions (52%), with harvest and fire less important (24% and 7%).

The revised baseline analysis presented here using more localized data (e.g., county-specific carbon stock data) raised the magnitude of emissions by 150% for forests and 80% for rangelands when compared to the original statewide analysis. The revised baseline was also more certain—the uncertainty based on the county level analysis was +/- 15% compared to +/- 25% for the whole state.

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Appendix A
Field Measurements

A.1 Determining Canopy Coverage in the Field

Canopy coverage was estimated using a 15 m by 15 m grid. Presence or absence of forest canopy was determined at 36 points in the grid, each point spaced 3 m apart (Figure A1). Percentage canopy coverage was estimated as % of grid points with forest canopy cover directly overhead divided by the total number of points (36).

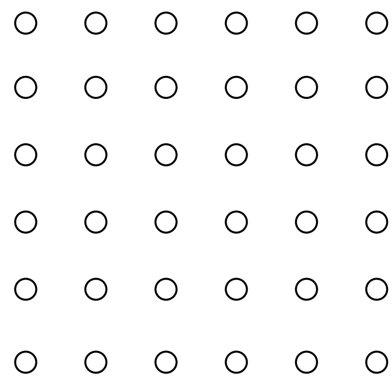

Figure A1. Example of canopy coverage measurement grid

A.2 Determining Carbon Stocks

Carbon stock was estimated using nested measurement plots in the identical location to the canopy coverage grid. The schematic diagram below represents a three-nest circular sampling plot that the research team used in Shasta County for biomass carbon stock determination (Figure A2).

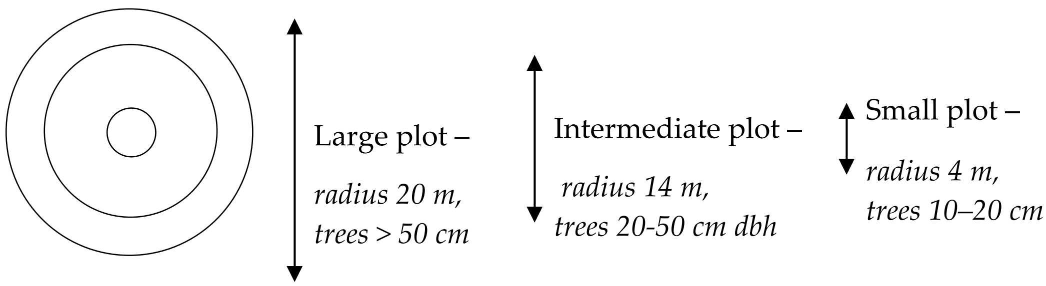

Figure A2. Example of nested measurement plots

The diameter of all trees was measured at breast height (DBH). A total of 1,267 trees were measured. Where possible the species of tree being measured was recorded. Where identification was not possible a species-group was allocated, determined by the forest type: Douglas-fir = Douglas-fir; Fir-spruce = Fir; Other conifer = pine; Hardwood = Oak.

Biomass and subsequently carbon (carbon = ½ biomass) was estimated from DBH using the biomass regression equations of Jenkins et al. (2003) (Table A1).

Table A1. The allometric regression equations of Jenkins et al. (2003) and examples of species to which they are applied

	Equation group	*Representative species*	*Regression equation*	*R^2*
Softwood	Cedar/larch	Incense cedar, Giant sequoia	Biomass (kg) = exp(-2.0336 + 2.2592 ln.*DBH*)	0.98
	Douglas-fir	Douglas fir	Bm (kg) = Exp(-2.2304 + 2.4435 ln.*DBH*)	0.99
	True fir/hemlock	White fir, Pacific yew, Nutmeg	Bm (kg) = Exp(-2.5384 + 2.4814 ln.*DBH*)	0.99
	Pine	Ponderosa pine, Sugar pine, Lodgepole pine	Bm (kg) = Exp(-2.5356 + 2.4349 ln.*DBH*)	0.99
Hardwood	Mixed Hardwood	Chinquapin, Dogwood, Tanoak, Madrone	Bm (kg) = Exp(-2.4800 + 2.4835 ln.*DBH*)	0.98
	Aspen / alder / cottonwood / willow	Alder spp.	Bm (kg) = Exp(-2.2094 + 2.3867 ln.*DBH*)	0.95
	Hard maple / oak / hickory / beech	Black oak, Live oak, Maple spp.	Bm (kg) = Exp(-2.0127 + 2.4342 ln.*DBH*)	0.99

Data and analyses at the plot level were extrapolated to the area of a full hectare to produce carbon stock estimates. Where standing dead trees (snags) were encountered in the field they were also recorded. Dead trees were divided into two categories: Trees missing just leaves or just leaves and twigs were measured at breast height and received a 6% biomass deduction (softwoods) or a 3% deduction (hardwoods) according to the proportion of aboveground biomass in leaves from Jenkins et al. (2003). The biomass of trees missing branches or represented just by the stem were conservatively estimated using volume of the stem, estimated from the diameter at the base and at the top and the height of the tree. Biomass is equal to the volume multiplied by the density. Density values were taken from Draft Technical Guidelines for Voluntary Reporting of Greenhouse Gas (1605b) Program (USDOE 2005; Appendix 4, Table 1).

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