Arnold Schwarzenegger
Governor

BASELINE GREENHOUSE GAS EMISSIONS FOR FOREST, RANGE, AND AGRICULTURAL LANDS IN CALIFORNIA

PIER FINAL 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 (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
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

What follows is the final report for the Measurement, Classification, and Quantification of Carbon Market Opportunities in the U.S.: California Component project, contract number 100-98-001, conducted by Winrock International. The report is entitled *Baseline Greenhouse Gas Emissions and Removals for Forest, Range, and Agricultural Lands in California.* This project contributes to the PIER Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-4628.

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Abstract

The project described in *Baseline Greenhouse Gas Emissions and Removals for Forest, Range, and Agricultural Lands in California* sought to quantify the baseline of changes in carbon stocks on forest, range, and agricultural lands in California for the 1990s—filling the gaps for those sectors that existed in the 2002 California Energy Commission report, *Inventory of California Greenhouse Gas Emissions and Sinks: 1990–1999*. These baselines provide an estimate of the emissions and removals of GHGs attributable to changes in the use and management of land, and are useful for identifying where major opportunities could exist in California for enhancing carbon stocks and/or reducing carbon sources to potentially mitigate GHG emissions.

The analysis revealed that forests and rangelands were responsible for a net removal of carbon dioxide from the atmosphere of 7.55 million metric tons of carbon dioxide per year ($MMTCO_2eq/yr$), and that agricultural lands were responsible for a net emission of 0.35 $MMTCO_2eq/yr$. Non-CO_2 GHG emissions from forest and range lands were estimated to be 0.16 $MMTCO_2eq/yr$, or equivalent to about 2% of the removals by these systems. Nitrous oxide (N_2O) emissions (in CO_2 eq) from agricultural lands are more than 40 times higher than carbon emission due to land use change. The overall net result was a removal of 7.20 $MMTCO_2eq/yr$ by forests and 0.18 $MMTCO_2eq/yr$ by rangelands, and an emission of 14.19 $MMTCO_2eq/yr$ by agricultural land.

Executive Summary

Objectives

This report's goal is to quantify the baseline of changes in carbon stocks on forest, range and agricultural lands in California for the decade of the 1990s. The focus here is on carbon but first approximation estimates are also given for non-CO_2 greenhouse gases (GHGs) where appropriate.

Baselines provide an estimate of the emissions and removals of greenhouse gases due to changes in the use and management of land. In addition they are useful for identifying where, within the landscape of California, major opportunities could exist for enhancing carbon stocks and/or reducing carbon sources to potentially mitigate greenhouse gas emissions.

The 2002 California Energy Commission report[1] estimated the emissions and removals of GHGs from all economic sectors of the State for the period 1990–1999, generally at one-year intervals. However, the sections of the Energy Commission's 2002 report on the forest, rangelands and agriculture sectors were incomplete and did not include all the changes taking place on these lands.

Outcomes

In this report, methods for estimating baseline carbon emissions and removals from forests, rangelands and agriculture are presented with corresponding results. Thus this report will fill the gap in the existing Energy Commission 2002 report. However, given the nature of the databases used in this analysis, the time periods encompassed by the baselines vary by sector. One 5-year time interval during the period 1994-2000 was used for forest and range lands with the exact five-year time interval varying slightly from region to region within the state. For agricultural lands, the period of analysis was 1987-1997, and it encompassed two 5-year intervals to develop a trend.

To develop the baselines, two types of data were used: (1) the area of the forest, rangeland and agricultural land at the start and end of the time interval, and (2) the carbon stocks in each land-use type for each time. For the forests and rangelands, areas were derived from the California Land Cover Mapping and Monitoring Program (LCMMP). Carbon estimates for various forests and rangeland types with corresponding canopy closures were derived from Forest Inventory and Analysis (FIA) data, the literature and California Department of Forestry's Fire and Resource Assessment Program (FRAP)staff. The areas of agricultural lands are based primarily on the National Resource Inventory (NRI) database for the period 1987-1997, in five-year intervals. Carbon estimates of various agricultural land-use types are derived from the literature in combination with standard methods.

1 California Energy Commission. November 2002. *Inventory of California Greenhouse Gas Emissions and Sinks: 1990–1999.* Staff Report. 600-02-001F.

Conclusions

The analysis revealed that forests and rangelands were responsible for a net removal of carbon dioxide from the atmosphere of 7.55 MMTCO_2eq/yr , and that agricultural lands were responsible for a net emission of 0.35 MMTCO_2eq/yr (Table S-1). Non-CO2 GHG emissions from forest and range lands were estimated to be 0.16 MMTCO_2eq/yr, or equivalent to about 2% of the removals by these systems. Nitrous oxide emissions (in CO_2 eq) from agricultural lands are more than 40 times higher than carbon emission due to land use change. The overall net result was a removal of 7.20 MMTCO_2eq/yr by forests and 0.18 MMTCO_2eq/yr by rangelands and an emission of 14.19 MMTCO_2eq/yr by agricultural land.

Table S-1. Emissions and Removals of Greenhouse Gases by Land-use Sector. – Indicates an Emission, + Indicates a Removal

	C	*N_2O*	*CH_4*
		MMTCO_2eq/yr	
***Forests*[1]**	**+ 7.35**	**- 0.01**[4]	**- 0.14**[5]
***Rangelands*[1]**	**+ 0.20**	**- 0.001**[4]	**- 0.01**[5]
***Agriculture*[2]**	**- 0.35**	**- 14.54**[3]	**-0.51**[3]

[1] Five-year interval between 1994-2000 (actual five-year period varies slightly by region; includes three regions encompassing 84% of forests and 42% of the rangelands in California.

[2] Period 1987-1997; all of California.

[3] California Energy Commission. November 2002. *Inventory of California Greenhouse Gas Emissions and Sinks: 1990–1999.* Staff Report. 600-02-001F.

[4] Calculated only for fire

[5] Calculated only for fire and harvest

Forests and Rangelands

Due to limitations in data availability only three of the five regions in California have been analyzed to date. These three regions, however, account for 84% of the forests and only 42% of the rangelands in the state.

The baseline for forests was estimated by combining two approaches. The areas of satellite-detectable change in forests and rangelands, with a measured change in canopy coverage, were available through the California Land Cover Mapping and Monitoring Program (LCMMP). Carbon estimates for various forests and rangeland types with corresponding canopy closures were derived principally from Forest Inventory and Analysis (FIA) data. The analysis of change, measured from satellite images, only identifies a measurable change in canopy coverage of forests and rangelands that occurred in the time interval, and does not include those forests with a closed canopy that continue accumulating biomass carbon that is undetectable from a satellite. For these reasons we tracked measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon) separately from the measurable increases in canopy cover and resulting increases in carbon stocks. For decreases in carbon stocks, we estimated both the gross and net changes, which varied by the cause of the change (e.g., fire, harvest, development). We then estimate the likely magnitude of the increase in carbon stocks resulting from the non-measured change in canopy and assumed increase in carbon stocks using U.S. Forest Service reports and data. In other word, the baseline includes all changes in carbon stocks, from measured and unmeasured changes in canopy coverage.

A change in canopy cover was measured on 3,452 km^2 of forests and rangelands in the North Coast, Cascade Northeast and North Sierra regions. This is approximately 2.5% of the total area of forests and rangeland in the regions. For 82% of the changed area, the cause of change was verified.

For forests, a net removal of 10.96 $MMTCO_2eq/yr$ and a net emission of 3.76 $MMTCO_2eq/yr$ were estimated (Table S-2). The greatest emissions were found in the North Sierra region with its dry conditions and resultant fires. The greatest removal was found in the forests of the North Coast with its dominance by fast-growing redwoods and Douglas-fir.

Rangelands were a net sink of carbon with a net removal of 0.46 $MMTCO_2eq/yr$ exceeding a net emission of 0.27 $MMTCO_2eq/yr$ (Table S-2).

Table S-2. Emissions and Removals by Forests and Rangelands by Region

$MMTCO_2eq/yr$	*FORESTS*		*RANGELANDS*	
	Emissions	*Removals*	*Emissions*	*Removals*
North Coast	1.39	4.95	0.07	0.23
Cascade Northeast	0.88	3.19	0.08	0.16
North Sierra	1.49	2.82	0.12	0.07
TOTAL	**3.76**	**10.96**	**0.27**	**0.46**

Fire and harvest were the dominant causes of emissions on forestlands; these causes were responsible for 1.55 $MMTCO_2eq/yr$ and 1.40 $MMTCO_2eq/yr$ respectively. On rangeland, harvest was less important, accounting for only 11% of the total emissions as opposed to 52% for fire on rangelands (Table S-3). Development is a minor cause of carbon emissions through land-use change in both forest- and range-land in the three studied regions of California. However, some of the unverified change could include development that tends to occur in smaller patches as the pattern of verified changes were in the three-region area.

Table S-3. Emissions and Removals by Cause of Change.
– Indicates an Emission; + Indicates a Removal

$MMTCO_2eq/yr$	*FORESTS*	*RANGELANDS*
Fire	- 1.55	- 0.14
Harvest	- 1.40	- 0.03
Development	- 0.01	- 0.004
Other/Unverified	- 0.79	- 0.10
Regrowth	+ 10.96	+ 0.46

The counties with the largest decrease in carbon stocks (largest emissions) were located in areas affected by fire especially in North Sierra and parts of Cascade Northeast (Figure S-1). The largest increases in carbon stocks (measured and unmeasured canopy change) are in the high volume fast-growing conifer forests of the North Coast and Cascades Northeast.

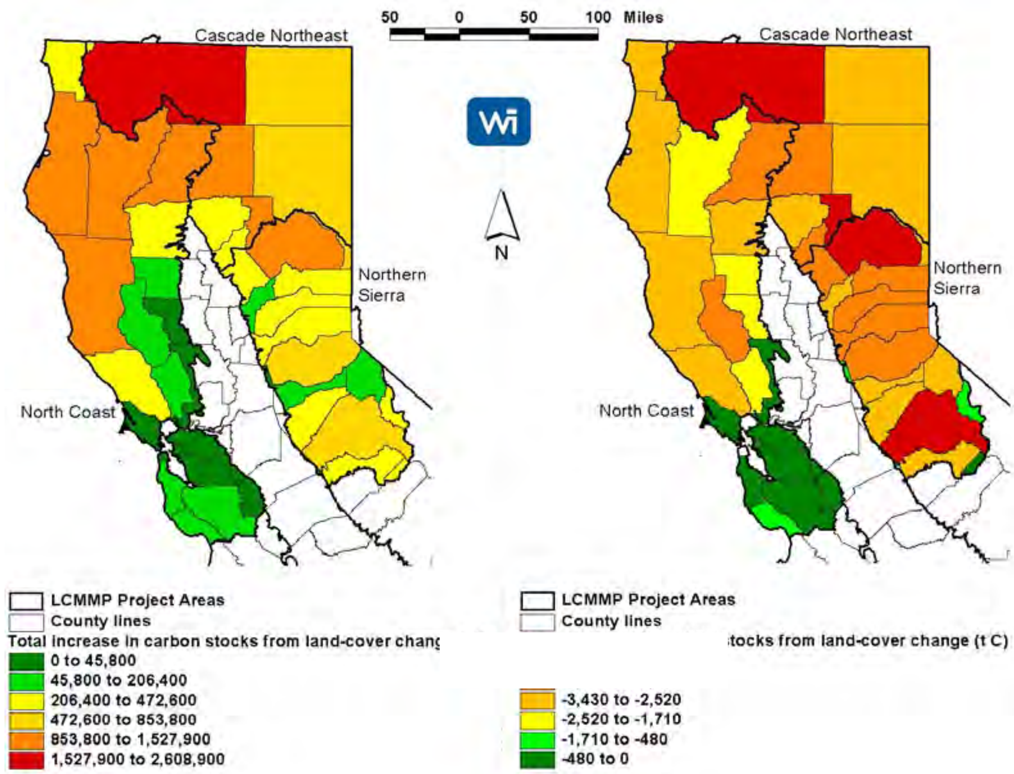

Figure S-1. County Level Summary of the Increases (Left figure), and Decreases (right figure) in Carbon Stocks on Forests and Rangelands in the North Coast (1994-1998), the Cascades Northeast (1994-1999) and the North Sierra (1995-2000) (Note that the values for the increases in carbon stocks are several orders of magnitude higher than the decreases)

The calculated removals of 10.96 MMTCO_2eq/yr and emissions of 3.76 MMTCO_2eq/yr for the forest sector differ markedly from the reported removal of 17.3 MMTCO_2eq/yr in the California Energy Commission's report (CEC, 2002). Although our analysis does not include the whole state of California; the results are based on 84% of the forestlands and include an estimate of the uncertainty in the estimates (±38%). We conclude that despite the relatively high uncertainty, the finer detail, and inclusion of areas with measured changes in canopy, and thus carbon stocks, our estimate should be considered to be representative of the real changes occurring on forest and range lands during the period of 1994/1995-2000.

Agricultural Land

Agriculture is an important economic sector in the State of California. Agricultural lands cover up to 10% (excluding grazing lands) of the Californian land area. The way these lands are used and managed impacts the amount of emissions and removals of greenhouse gases (GHGs) generated by the State.

In 1997, agriculture in California (excluding livestock grazing lands dealt with in the rangelands sector) covered about 4 million hectares (9.9 million acres). Of this area, 74% was in non-woody crops (annual crops such as grains, vegetables, cotton, etc.) and 26% were in woody crops (orchards, vineyards, etc.). The total carbon stock was estimated to be 74.5 $MMTCO_2eq$, of which 42% was in non-woody crops and 58% in woody crops.

Between 1987 and 1997, 232,000 ha of agricultural land were converted to non-agricultural uses. Eighty-eight percent of this change was in non-woody crops. The change in area was estimated to equal a net loss of 3.5 $MMTCO_2eq$ over the 10-year period, of which 63% was due to the decrease in non-woody croplands.

At a county scale the changes were more significant (Figure S-2) with, for example, losses in woody crop biomass of 1.5 $MMTCO_2eq$ in Kings or a gain of 0.92 million t CO_2eq in Humboldt between the same dates (1987 and 1997).

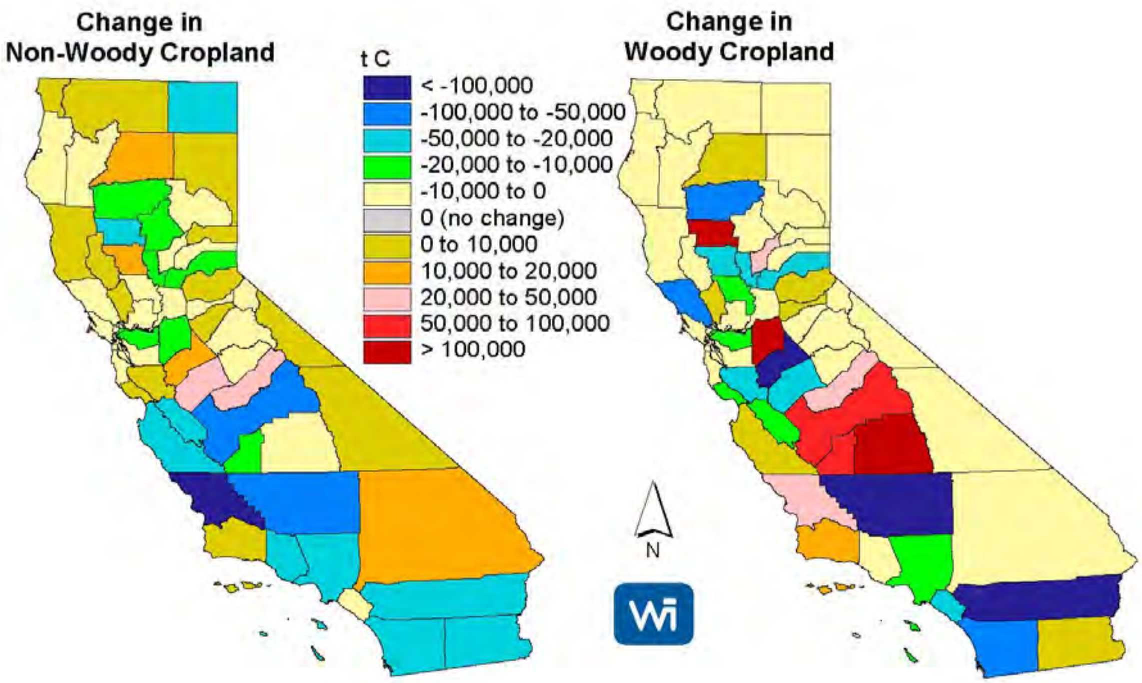

Figure S- 2. County Level Summary of the Change in Carbon Stocks on Agricultural Land for the Period 1992-1997. Changes in Both Non-woody and Woody Cropland are Illustrated

Uncertainty is high (31%), mainly caused by uncertainty in the carbon densities of croplands. Future studies could employ field measurements to greatly decrease this uncertainty.

The overwhelmingly dominant non-CO_2 gas emitted from non-livestock agriculture in California is nitrous oxide (N_2O). The California Energy Commission reported that between 1990 and 1999 the mean annual source was 14.54 $MMTCO_2eq$. In comparison the annual source in the form of carbon is here calculated as 0.35 $MMTCO_2eq$. Therefore the total annual source of greenhouse gases from agricultural lands (except grazing lands) in California was 14.89 $MMTCO_2eq$ of which only 2% was from reduction in carbon stocks caused by changes in land use.

1.0 Baselines for Forest and Range Lands in California

1.1. General Approach

The goal of this section is to develop a baseline of carbon emissions and/or removals in the forest and rangeland sector of California for the period of the 1990s, including identification and quantification of the main sources or sinks of carbon. Such an analysis will aid in identifying within the landscape of California where major opportunities exist for enhancing carbon storage and/or reducing carbon emissions. The focus of this work is carbon, as carbon dioxide, although where appropriate, first order approximations will be made of the baseline emissions for non-CO_2 gases (N_2O and CH_4).

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 change in forests and rangelands, with a measured change in canopy coverage, were available through the California Land Cover Mapping and Monitoring Program (LCMMP). Carbon estimates for various forests and rangeland types with corresponding canopy closures were derived from Forest Inventory and Analysis (FIA) data, the literature, California Department of Forestry's Fire and Resource Assessment Program (FRAP) staff, and the equations of Smith et al. (2003). Using the canopy change data only 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 this reasons we tracked measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon) separately from the measurable increases in canopy cover and resulting increases in carbon stocks. For decreases in carbon stocks, we estimated both the gross and net changes, which varied by the cause of the change (e.g., fire, harvest, development). We then estimated the likely magnitude of the increase in carbon stocks resulting from the non-measured change in canopy but assumed increase in carbon stocks. We use data from the U.S. Forest Service reports (based on FIA data) on carbon stock changes in Californian forests to estimate the likely changes in carbon stocks in the forests with no measured changes in canopy. The details of all these steps are given in the next section.

1.1.1. Classification of Forests and Woodlands

The California Land Cover Mapping and Monitoring Program (LCMMP) uses Landsat Thematic Mapper satellite imagery to map vegetation and changes in vegetation over 5 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 (Figure 1-1):

- North Coast
- Cascade Northeast
- North Sierra
- South Sierra
- South Coast

The Central Valley and South Interior regions are not included in the analysis, as these areas are not covered by the CDF-FRAP data.

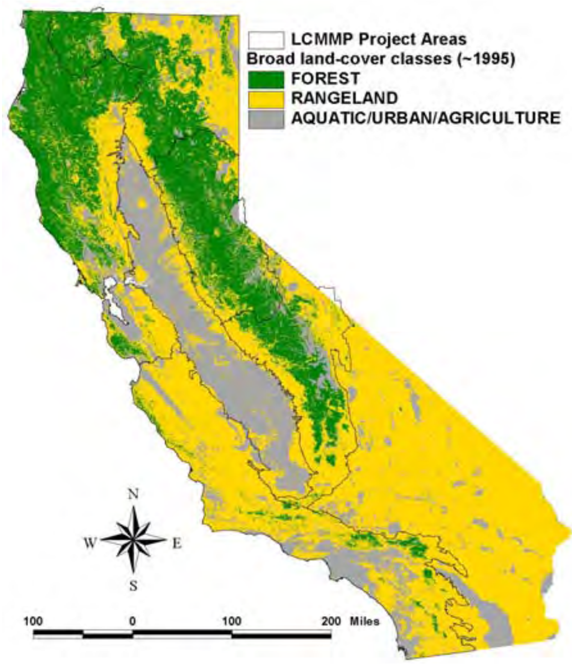

Figure 1-1. The CDF-FRAP Multi-source Land-cover Map Reclassified into Three Broad Classes with the LCMMP Regions Superimposed on Top in Black

1.2. Area of Forests and Rangelands

1.2.1. Calculating Areas from Satellite Data

1.2.1.1. LCMMP Background

The FRAP has embarked on a comprehensive effort to map land cover and track 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 LCMMP was to derive a classified 30-meter 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 in files reduced to the county-level. 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) whereby the changes in land cover are automatically incorporated into the old land-cover maps. Simultaneously, a separate map of the amount of change that occurred is created. Efforts are made by field crews and CDF-FRAP staff to also 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, for the remainder, the cause is unverified. For the analyses presented in this section, 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 our 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. For example, 97.8% of the vegetated land area in the North Coast region had no discernable change between 1994 and 1998. 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 5 year period will often not exceed the 15% canopy change threshold necessary to be measurable. In addition even when the canopy is closed, trees keep accumulating biomass carbon that may not be detectable from a satellite. For these reasons we track measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon) separately from the measurable increases in canopy cover and resulting increases in carbon stocks. We then estimate the likely magnitude of the increase in carbon stocks resulting from the non-measured change in canopy but assumed increase in carbon stocks.

1.2.1.2. 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 that we 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 1-2). To encompass all of California in one manageable grid, the multi-source map was transformed, from the finer-scale maps that were used to create it (generally 30m x 30m imagery), to a 100mx100m grid. In a similar manner, all LCMMP data used in the analysis were also aggregated into 100-meter grid cells from their original 30-meter 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).

Thus, the carbon emissions baseline study used **two** products from the CDF-FRAP's LCMMP and **one** from CDF-FRAP's "Multi-source Land Cover Mapping Project":

- The Multi-source Land-cover map = "Time 1"
- The LCMMP change detection maps = the difference between LCMMP's "Time 1" and "Time 2" land cover maps
- 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%)

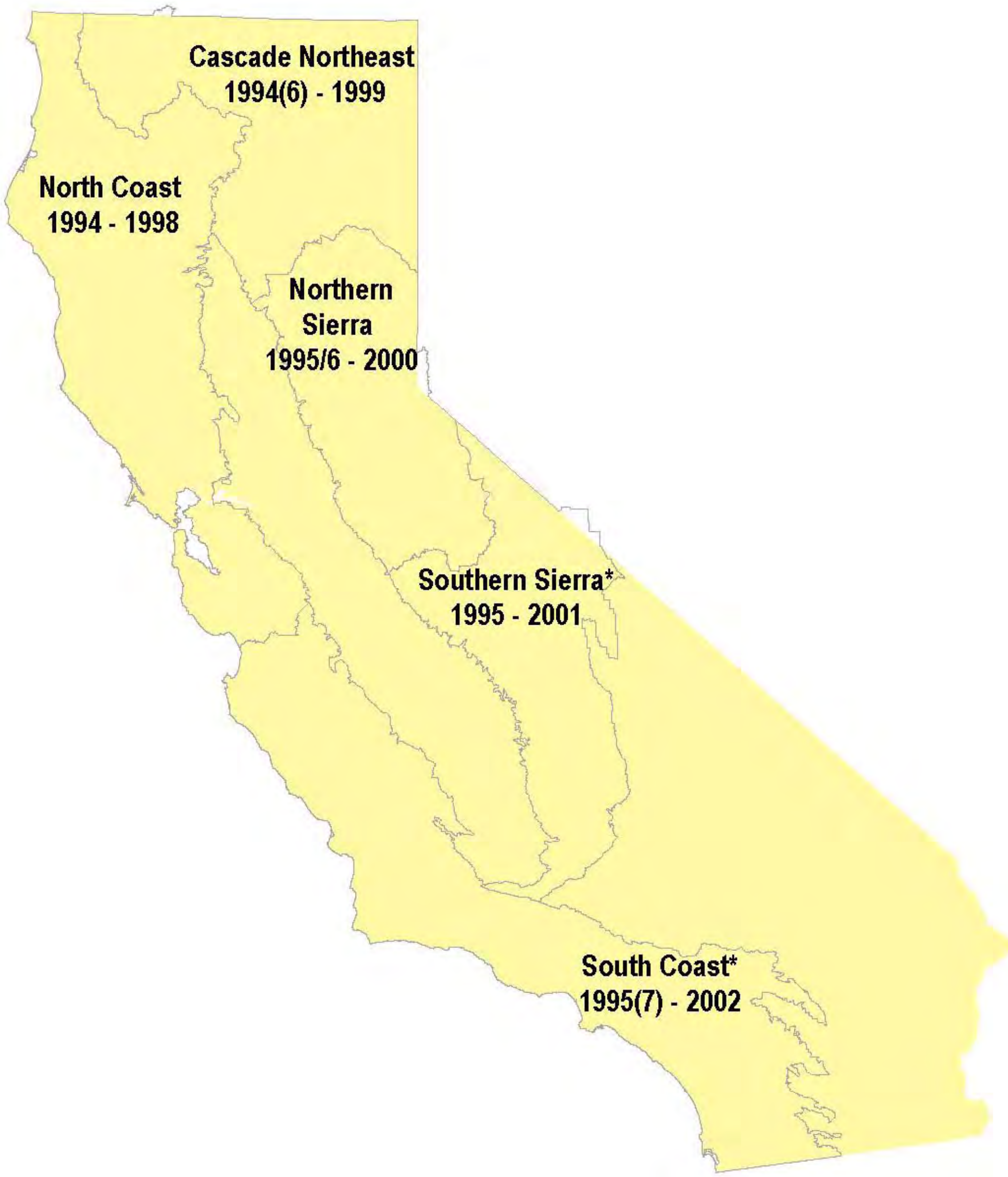

Figure 1-2. Satellite Image Dates for CDF-FRAP's LCMMP Change Analysis (Time 1–Time 2). [* = Not yet completed]

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 1-1 and Figure 1-2.

Table 1-1. 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
North Sierra	1995/6 - 2000	Completed	Completed
South Coast	1995(7) - 2002	End of 2004	Spring 2005
South Sierra	1995 - 2001	March 2004	Fall 2004

Verified cause of change data for the different LCMMP regions were available for the identified changed cells. These data are available on the CDF-FRAP website along with all of the LCMMP data and the multi-source Land-cover Map. 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 our 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, 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 the change in carbon stocks. For example, the fate of the change in biomass carbon stocks from fire versus logging is different—a large proportion of the biomass carbon is immediately oxidized from a wildfire, whereas a large proportion of the biomass carbon can go into long term storage from logging. The change without cause provides information on the gross changes in carbon stocks, whereas the addition of known cause allows for an estimation of the net change in carbon stocks.

1.2.2. 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 WHR class (vegetation type) that changed and by how much (% change in canopy cover) and the by which cause. The number of hectares 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).

1.3. Carbon Stocks in Forests and Rangelands

1.3.1. Above- and Below-ground Biomass

Two additional databases are needed for use with the area change data: relationships between biomass of forests and canopy crown cover and the allocation or fate of the biomass resulting from different causes of land-use change. To develop the relationships between biomass and canopy crown cover, data on timber volume for specific WHR habitat types at different canopy crown coverages were used (T. Shih, FRAP, personal communication). To convert timber volume to above- and belowground biomass, five equations that relate volume to biomass for five forest types across the Pacific Northwest were used (from Smith et al., 2003) to produce biomass estimates across canopy crown coverage classes (Figure 1-3). As only equations were available that represented five general forest types in California, the WHR forest and woodland types were reclassed as follows (decisions on the classifications are based on a division between rangelands and forests, divisions implied by the use of the Smith et al. (2003) equations and the division between tree and non-tree vegetation) (Table 1-2):

- Forests
  - Douglas fir
  - Fir-Spruce
  - Redwood
  - Other Conifer
  - Hardwood
  - Shrubs and Grasses[2]
- Rangelands
  - Woodland Vegetation
  - Shrubs and Grasses

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

Table 1-2. WHR Classes Matched with the Inferred Smith et al. (2003) Classes for Forests and Rangelands

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

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 developing a regression equation that related the midpoints of the given crown cover classes against the biomasses calculated using the equations of Smith et al. (2003). The resultant regression equations can be used to make the desired estimates (Figure1-4).

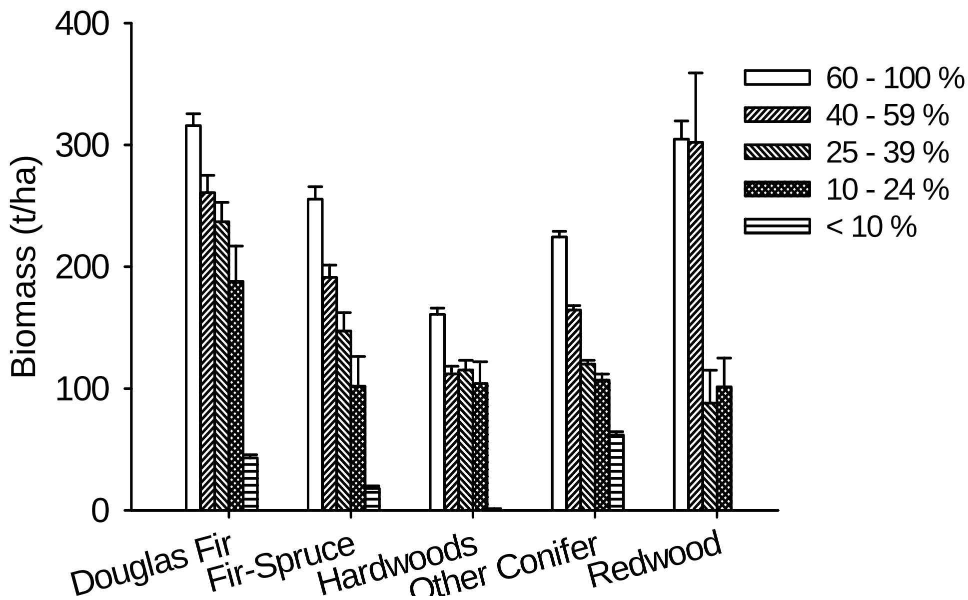

Figure 1-3. Mean Above- and Below-ground Biomass Estimates (± 1 SE) Calculated for Each Canopy Crown Coverage Class (in %)

Significant regression equations were obtained for the Douglas fir, fir-spruce, other conifer and hardwood classes. The shape of the relationships for these species is logical given established patterns of tree growth (Richards, 1959, Pienaar and Turnbull, 1973). For other conifer, however, a more significant relationship between the data is obtained if a linear relationship is applied. There was no significant equation for redwood largely because very few data were recorded for any but the most dense canopy crown coverage.

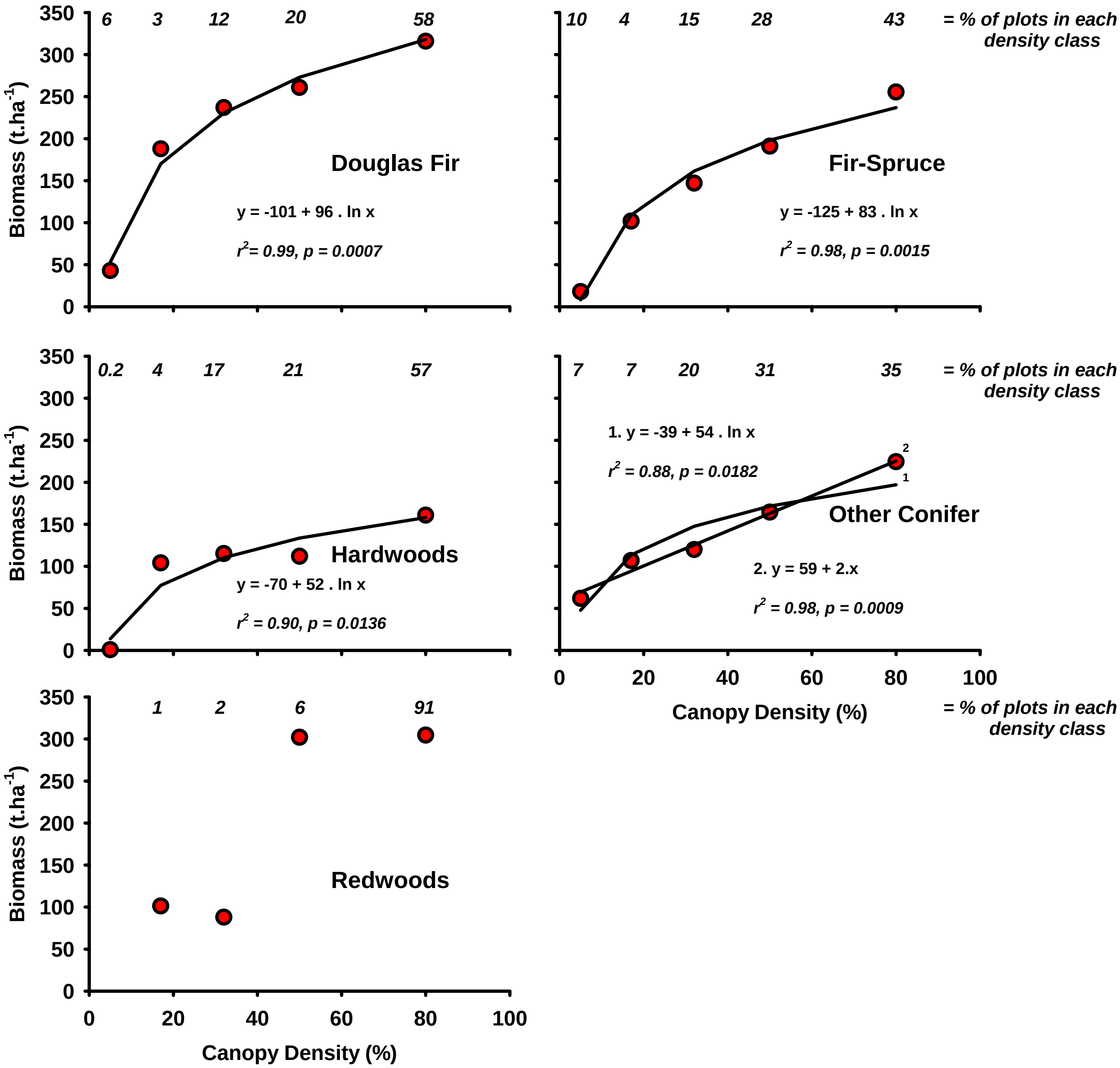

Figure 1- 4. Relationships between Biomass (t/ha) and Canopy Coverage (%). Regression Equations, r^2 and p Values are Indicated. For Each Species the Percentage of Individual Plot Data Recorded in Each Density Class is Indicated above the Graphs

For redwood it is apparent that one biomass value can be given to canopy coverages in excess of 40% and a second value for coverages of less than this density.

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 4. For example, for an "Other Conifer" forest with a moderate coverage (40-59%, midpoint 50%) that experiences a large decrease in canopy coverage (midpoint value, - 85%) gives a new canopy coverage of 7.5%. Biomass carbon is estimated for the initial and final canopy cover and the difference represents the gross change in carbon from 80 t C/ha to 37 t C/ha, a net loss of 43 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 for all regions except the North Coast region where the higher biomass of 40 t C/ha is more appropriate (Riggan and Dunn 1982, Schlesinger 1997, Pierce et al. 2000, 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 assume 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) will be 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 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%).

1.3.2. Additional Biomass Components

Above- and belowground biomass of trees form the dominant components of total biomass but the additional components of dead wood, litter and understory vegetation may contribute significantly to carbon stocks.

- Standing dead trees are added using additional equations from Smith et al. (2003).
- Understory vegetation contributes an extra 2% to the biomass density (Winrock unpublished data).
- Litter and downed dead wood adds either 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 of a small magnitude (Carter et al. 2002, Laiho et al. 2002), and the occurrence of any change in soil carbon due to fire or harvest without a subsequent land-use change is unlikely (Binkley et al. 1992, Markewitz et al. 2002).

1.3.3. Above- and Below-ground Biomass for Unmeasured Forests

As described above (Section 1.1.1), we provide estimates of the likely magnitude of the increase in carbon stocks resulting from the non-measured change in canopy. Although the LCMP database contains much additional information about the structure of the forests it is difficult to correlate these to rates of carbon accumulation. Instead we use 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 1-2). We assume that these forests are at the stage where no further change in canopy coverage can be detected from the satellite imagery, that is they are at least 60% canopy closure or more (see Figure 1-3). 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 our 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
- Redwood: 2.59 t C/ha.yr

These values are within expectations. This can be illustrated by comparing with field estimates determined during the measuring and monitoring component of this project. For example, the Sierran Mixed Conifer forest at Blodgett Forest Research Station (BFRS) could be compared with the “other conifer” category, and “redwood” category could be compared with the vegetation at Jackson State Demonstration Forest (JSDF). The BFRS measurements 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, and the JSDF measurements indicate carbon accrual rate in forests at 70 years of age is equal to that calculated here for redwoods.

For the rangelands it can be assumed that the 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 using experience and knowledge the approximate accrual is 0.3 t C/ha.yr.

1.4. Carbon Stock Changes in Forests and Woodlands

There are eight causes for changes in canopy cover (Table 1-3) determined by the LCCMP separately from this study. 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 a fire increase carbon stocks. In cycle one (north coast) the "other" category is dominated by pest-related factors and it is assumed that there is no net effect on carbon stocks. By cycle two (all other regions) "pest-related" becomes its own category and the diminished "other" category is dominated by reductions in canopy coverage. Unverified effects can both increase and decrease carbon stocks but are predominantly a decrease. Details of each of the causes are given in the sections below.

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.

Table 1-3. Causes of Changes in Canopy Crown Coverage and Effect on Carbon Stocks

Cause	Increase in Carbon Stocks	No Change in Carbon Stocks	Decrease in Carbon Stocks
FIRE			X
HARVEST			X
DEVELOPMENT			X
UNVERIFIED	(X)		X
OTHER	(X)	X †	X
PEST-RELATED		X †	
SEASONAL		X †	
REGROWTH	X		

† "Seasonal," "pest-related," and "other" (in cycle one) may result in a decrease in crown cover but for "seasonal" this is temporary and for "pest-related" and "other" (in cycle one) this is predominantly caused by insects and disease leaving standing dead trees which release carbon into the atmosphere very slowly.

1.4.1. 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, while 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, we assumed that the three intensities are associated with the magnitude of change in crown cover, so that a large decrease in crown cover would be due to a high intensity fire or a small decrease is caused by a low intensity fire.

Pre-fire carbon has five potential destinations during and after a fire (Figure 1-5). 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; in contrast dead wood decomposes over time.

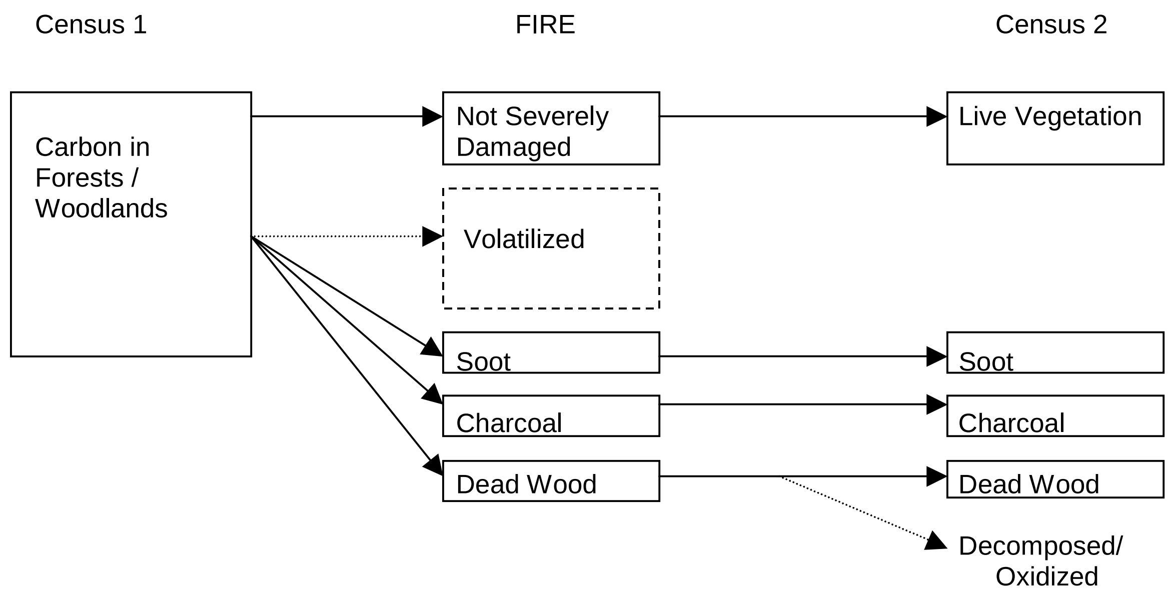

Figure 1-5. Flow Diagram Illustrating the Various Destinations of Pre-burn Carbon after a Fire

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 1-4, 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 1-4; 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 the Sequoia National Park in California (but see Chambers et al. 2000).

Table 1-4. 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

1.4.2. Harvest

The net destination of carbon after commercial harvest is illustrated in Figure 1-6. 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.

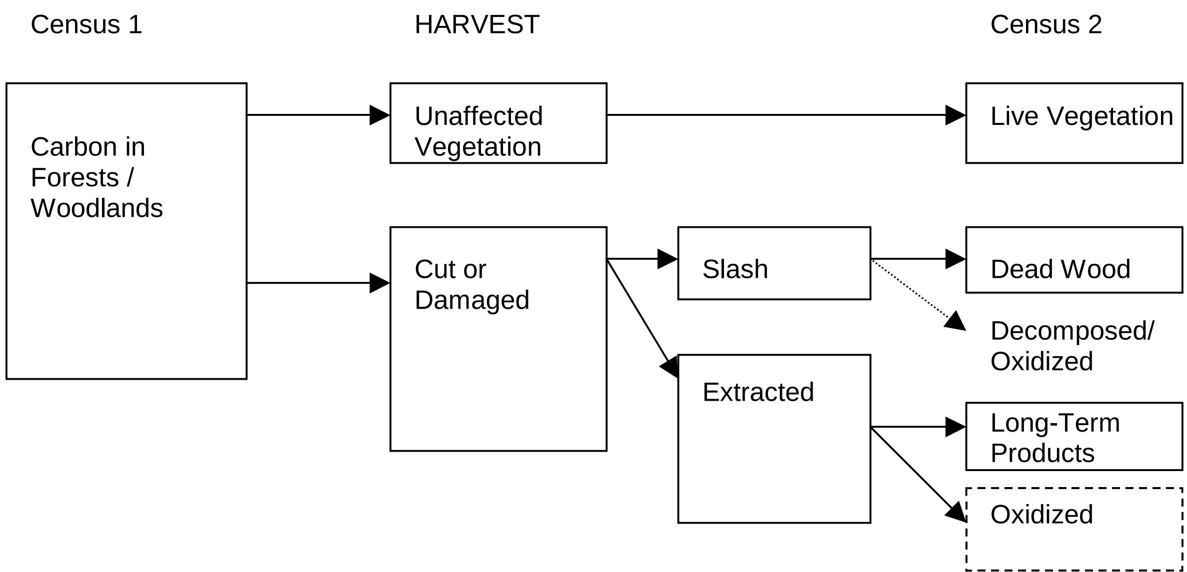

Figure 1-6. Flow Diagram Illustrating the Various Destinations of Pre-harvest Carbon after Commercial Harvest

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, we assume 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, chipping and fuel; all are assumed to rapidly release carbon 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.

1.4.3. 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 and redwood it was assumed that the value of the timber is too high for it not to be used commercially. We apply 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 and redwood is illustrated in Figure 1-7a.

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. The fate of carbon during development for these vegetation types is illustrated in Figure 1-7b.

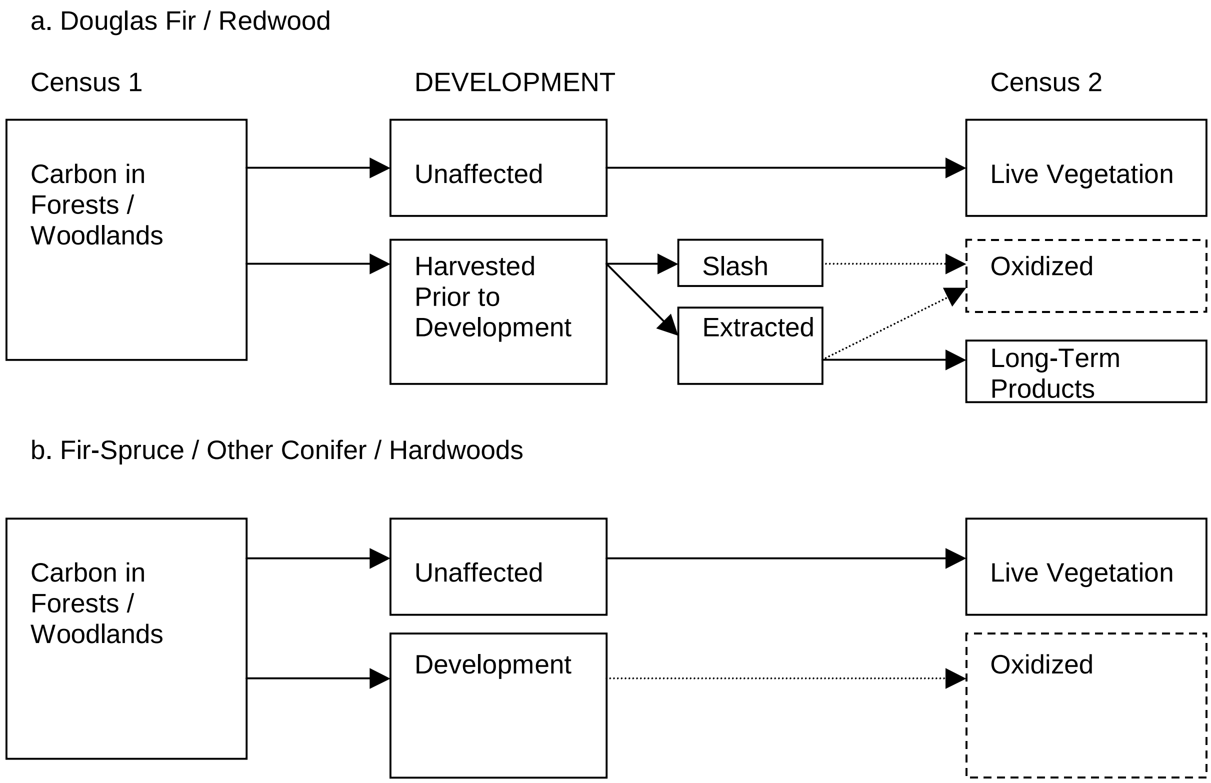

Figure 1-7. Flow Diagram Illustrating the Various Destinations of Pre-development Carbon after Development has Occurred

1.4.4. Regrowth

Ostensibly regrowth represents the simplest scenario. An increase in canopy coverage represents a net increase in biomass. Complications are introduced, however, as trees keep growing even when the canopy is closed, and at the other extreme tree growth often may be insufficient to reach the change-detection threshold. Consequently it is possible that the potential biomass accrual is underestimated.

Support for the strength and sensitivity of these data comes from the fact that substantial areas in the highest density class report a large increase in canopy coverage. This translates to areas of forest with an initial canopy coverage of between 60 and 100% reporting an increase in coverage of between 40 and 100%. For example, in the North Coast region 402 hectares of Douglas fir and 827 hectares of redwood fall into this category. A second, and potentially a greater, weakness is the threshold of 15% for change detection. Decreases in vegetative land cover are typically large (e.g., fire or development). Regrowth is gradual, and it is a fair assumption that areas exist which did not achieve the 15% threshold, and so are not included leading to an underestimation of sink size. In order to include these unmeasured changes, standard factors are applied. These factors are discussed in detail in Section 1.3.3.

1.4.5. Seasonal and Pest-related Changes

While decreases in canopy coverage do result from seasonal and pest-related causes, these causes of change are not considered in depth in this study. For seasonal, the area involved is small and by definition all changes will be reversed annually or semi-annually. For pest-related, 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).

1.4.6. Other Changes

The pest-related category only exists in the Cascades Northeast region. In the other regions, pest effects therefore dominate the "other" category resulting in no net effects on carbon. In the Cascades, "pest-related" was separated into its own category and "other" was composed of such disparate effects as conversion to agriculture, road-related changes and changes due to floods, land-slides and avalanches. Each of these causes leads to a net change in carbon. Regarding the timber, "other" is treated identically to development (see Section 1.4.3.), with redwood and Douglas fir timber converted to long-term products.

1.4.7. Unverified Changes

A large proportion of the measured changes in canopy coverage have causes that remain unverified. Some assumptions, however, can be made with regard to the likely causes to increase the precision of our final estimates of net carbon stocks.

Fire as a cause is carefully traced by the California Department of Forestry and Fire Protection and it can safely be assumed none of the unverified area of change is caused by fire damage.

Instead it is likely that all decreases in canopy coverage are caused by small-scale harvesting and development operations. Again due to the value of Douglas fir and redwood timber it is assumed that these forest types are harvested and arbitrarily is assumed that the other forest types are subject to development.

Increases in canopy coverage are caused by regrowth and all decreases in carbon stock values are reported net of the gains through regrowth.

1.4.8. 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 and nitrous oxide. 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. Over a hundred year period methane is expected to have a global warming potential equal to 23 times that of carbon dioxide and nitrous oxide has a potential 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 nitrous oxide 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 section (baseline for forests and rangelands in California) as 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 in this section, will be examined.

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

CH_4 emissions = (carbon released) x 0.012 x 16/12 (IPCC GPG 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_20 [IPCC GPG 2003; Crutzen and Andreae 1990]).

Harvest—Methane is sequestered in undisturbed forest soils at an estimated rate of 2.4 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 clear cutting may increase emissions but the available data are insufficient and is contradictory (IPCC GPG 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 clear-cutting. Gasche et al. (2003) 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 clear cutting. 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 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.

Development, regrowth, seasonal, pest-related changes, other changes and unverified 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.

1.4.9. Evaluating Sources of Error

As has been described above, many steps are involved in estimating the baseline for the forests and rangelands sector. As expected, each step has a degree of uncertainty (source of error) associated with it. Here we describe each source of error, its likely magnitude, and an estimate of the total error for the baselines. The magnitude of the error for each source is expressed as the percent of the average value represented by the 95% confidence interval.

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

A: FIA data–

The FIA program determines a maximum allowable sampling error of 9.5% at the county scale at the 67% confidence level.

Using - t = 1.036 @ 67%; t = 1.960 @ 95% - the equivalent error at the 95% confidence level is 18%.

B: FIA data to canopy coverage classes–

Excluding Redwood (for which 91% of the measurements were in only one of the four > 10% canopy coverage classes), the 95% confidence interval around the coverage averages 15.1%.

STEP 3: Creating a regression for biomass to canopy coverage

The 95% confidence prediction interval was calculated around each of the regressions of canopy coverage to biomass. The mean deviation of the confidence intervals from the original curves was 27.3%.

STEP 4: Assumptions for calculating net emissions

Fire:

Altering the proportion oxidized in the fires by 10% changes the net emissions by 9%.

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.

ESTIMATED TOTAL ERROR

The total error is estimated as equal to the square root of the sum of the squares of the component errors (we assume that each source of error is independent).

Fire = 38.5%

Harvest (softwood) = 39.0%

Harvest (hardwood) = 38.4%

All other causes = 37.4%

The single largest source of error is derived from the regression equations used to estimate biomass from canopy coverage (Table 1-5). Reducing this error may be one of the more difficult steps as it is related to the initial remote sensing interpretation of canopy coverage classes. To reduce most of the other sources of error would require additional field data, but the potential to significantly reduce the error would be worth the effort.

Table 1-5. Sources of Errors and their Potential Magnitude in the Estimated Baseline for the Forest and Rangelands Sector

	Source of Error	% Error	Potential for Decreasing Error
1.	Image processing	10.2	Outside the expertise or control of Winrock (but see Step 4)
2.	a. FIA	18	Outside the control of Winrock. More plots could be used to increase precision.
	b. FIA to canopy coverage	15.1	If more plots were examined in each canopy coverage class then more precision could be attained.
3.	Regression biomass to canopy coverage	27.3	To increase precision more canopy coverage classes would be required (remote sensing step). Four or five classes are not sufficient to create a tight regression.
4.	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
	TOTAL Fire Harvest-softwood Harvest-hardwood All other causes	 38.5 39.0 38.4 37.4	

As the carbon values applied to regrowth that was not measured by the LCMMP resulted directly from FIA data the FIA error of 18% will be used.

1.5. Results

Here we report on the North Coast, Cascades Northeast and North Sierra regions. These regions account for more than 84% of the forests in California. The imagery for the analysis of the South Sierra and South Coast regions is not currently available; these two regions will be completed later in 2004 (see Table 1-1).

Each of the following sections will include data tables by area as well as gross and net changes in carbon stocks.

1.5.1. North Coast

The area experiencing a change in canopy cover between 1994-1998 was only 124,000 ha which is just 1.8% of the land area of the north coast region. All causes are limited to small patches except for a single area with a large extent of fire damage in Lake County (Figure 1-8). Harvest is a significant cause, albeit in small patches, through the redwood and Douglas fir forests of Humboldt and Mendocino Counties.

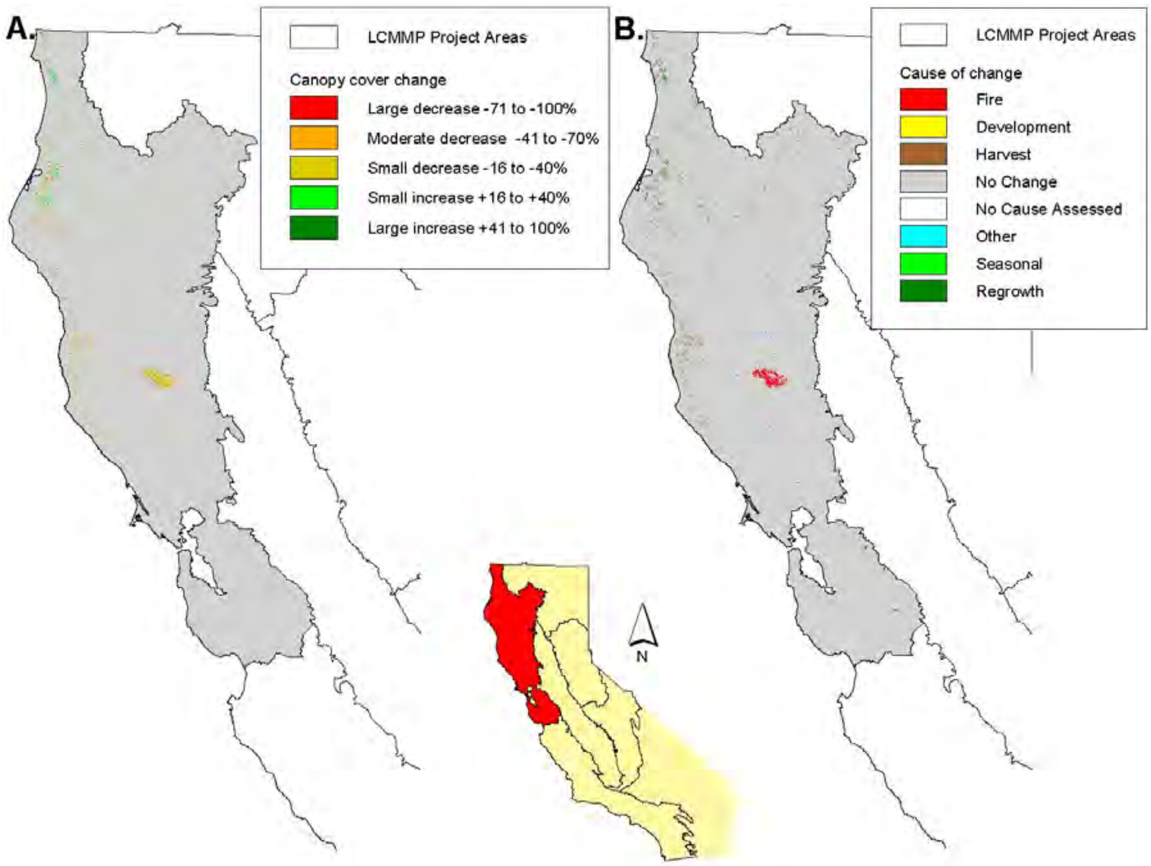

Figure 1-8. Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B) for the North Coast region

1.5.1.1. Rangelands

The total area of rangelands in the North Coast region affected by a canopy change (decrease and increase) was about 24,000 hectares. The greatest cause of changes for the north coast rangelands was regrowth that was responsible for 41% of the total recorded canopy crown changes (with 98% of this total in shrubs and grasses). The greatest source of decreases in canopy cover was fire with 4,063 ha affected (Table 1-6).

Table 1-6. Change in Area of North Coast Rangelands Based on Areas Affected by Canopy Cover Change (- Equals a Decrease in Canopy Cover, + Equals an Increase) between 1994–1998.

	Fire	Harvest	Development	Regrowth	Other		Unverified		SUM
					-	+	-	+	
AREA (ha)									
Woodlands	511	152	16	189	60	0	429	79	**1,436**
Grasses / Shrubs	3,552	620	1,033	9,498	889	6	2,364	4,335	**22,297**
SUM AREA	**4,063**	**772**	**1,049**	**9,687**	**949**	**6**	**2,793**	**4,414**	**23,733**

In terms of carbon stocks, carbon removals dominate, accounting for almost 250,000 tons of carbon (Table 1-7). Fire is the largest source of carbon emissions with a net total of about 35,000 tons emitted between 1994 and 1998. There is a net loss in the tree-covered rangelands (woodlands) of 16,000 t C and a net loss of about 60,000 t C in the shrub and grass covered rangelands mostly caused by fire. Across the rangelands in north coast California it is calculated that the net change between 1994 and 1998 was a gain of about 174,000 t C (Table 1-7).

Table 1-7. Changes in the Carbon Stock of North Coast Rangelands. (- Equals a Loss in Carbon Stocks [a Source] and + Equals a Gain in Stocks [a Sink])

EMISSIONS						REMOVALS		
	Fire	Harvest	Develop-ment	Other/ Unverified	SUM EMISSIONS	Measured Removals	Unmeasured Regrowth	SUM REMOVALS
GROSS – t C								
Woodlands	-6,842	-4,586	-159	-8,258	**-19,844**	2,023	162,442	**164,465**
Grasses / Shrubs	-29,717	-7,456	-1,100	-21,765	**-60,038**	85,148	-	**85,148**
SUM GROSS	**-36,559**	**-12,041**	**-1,259**	**-30,023**	**-79,883**	**87,171**	**162,442**	**249,613**
NET – t C								
Woodlands	-4,983	-2,698	-159	-8,258	**-16,098**	2,023	162,442	**164,465**
Grasses / Shrubs	-29,717	-7,456	-1,100	-21,765	**-60,038**	85,148	-	**85,148**
SUM NET	**-34,700**	**-10,154**	**-1,259**	**-30,023**	**-76,137**	**87,171**	**162,442**	**249,613**
+/- uncertainty	*13,360*	*3,825*	*471*	*11,229*	***17,872***	*32,602*	*29,240*	***38,862***

1.5.1.2. Forests

A total area of about 96,000 hectares of North Coast forest were affected by canopy crown change between 1994 and 1998 (Table 1-8). The dominant influence on the North Coast forest in terms of area is commercial harvest, accounting for 42% of the total change. Between 1994 and 1998 at least 40,000 hectares were affected by harvesting, especially in Douglas-fir and redwood forests. In contrast only 107 ha of the verified causes were altered by development.

Table 1- 8. Change in Area of North Coast Forests Based on Areas Affected by Canopy Cover Change. (- Equals a Decrease in Canopy Cover, + Equals an Increase)

	Fire	Harvest	Development	Regrowth	Other		Unverified		SUM
					-	+	-	+	
AREA (ha)									
Douglas-fir	4,828	9,879	29	6,279	499	0	2,166	462	**24,142**
Fir-Spruce	96	777	0	689	23	7	567	67	**2,226**
Other Conifer	5,091	2,728	0	2,273	221	7	1,688	70	**12,078**
Hardwood	7,176	7,040	65	5,797	728	7	2,784	1,478	**25,075**
Redwood	17	19,553	9	6,649	172	0	1,613	978	**28,991**
Shrubs/grasses	242	100	4	1,904	90	2	209	1,232	**3,783**
SUM AREA	**17,450**	**40,077**	**107**	**23,591**	**1,733**	**23**	**9,027**	**4,287**	**96,295**

Total net emissions by all activities were 1.48 million t C (Table 1-9). Harvest was responsible for 58% of the net emissions, followed by fire for another 23% of the total. Harvest of redwood forests accounted for most of the net emission from harvest (64%). The sum of the removals was 5.4 million t C, more than 90% of which was from the estimated unmeasured increases in canopy coverage. Overall for the North Coast, removals exceeded emissions by 3.92 million t C (Table 1-9). Accounting for the uncertainties, the North Coast net removals could range between 4.5 to 6.3 million t C.

During the five-year interval (1994-98), the average net emissions per unit area for forest harvest are (the net emissions from Table 1-9 divided by the area in Table 1-8):

- Douglas fir—21.5 t C/ha
- Fir-spruce—11.0 t C/ha
- Other conifer –13.5 t C/ha
- Hardwoods—18.0 t C/ha
- Redwoods—35.5 t C/ha

As these estimated annual net emissions (keeping in mind the uncertainty range around these estimates, see Table 1-5) represent area-weighted averages and practices for a five-year period, it is possible that they could serve as a benchmark against which future activities could be compared. These net emissions per unit area also serve as a way to normalize the data for future comparisons when the area being harvested and the practice used could be different. Although we recognize that there are large uncertainties around these estimates, it does point towards the use of an indicator against which future activities, for example forest harvesting, could be measured against to show either reductions or increases in carbon emissions.

Table 1-9. Changes in the Carbon Stock of North Coast Forests. (- Equals a Loss in Carbon Stocks [a Source] and + Equals a Gain in Stocks [a Sink])

EMISSIONS						REMOVALS		
	Fire	Harvest	Develop-ment	Other / Unverified	SUM EMISSIONS	Measured Removals	Unmeasured Regrowth	SUM REMOVALS
GROSS – t C								
Douglas-fir	-175,410	-385,778	-686	-78,115	**-639,990**	95,893	1,320,759	**1,416,652**
Fir-Spruce	-3,053	-15,417	0	-13,141	**-31,611**	9,460	155,012	**164,472**
Other Conifer	-148,453	-66,521	0	-47,433	**-262,407**	44,587	965,336	**1,009,923**
Hardwood	-130,274	-171,688	-1,379	-68,823	**-372,164**	60,226	1,332,064	**1,392,290**
Redwood	0	-1,252,205	-506	-91,846	**-1,344,558**	139,668	1,269,587	**1,409,255**
Shrubs / grasses	-1,417	-607	-23	-1,764	**-3,812**	11,926	-	**11,926**
SUM GROSS	**-458,607**	**-1,892,215**	**-2,594**	**-301,125**	**-2,654,541**	**361,760**	**5,042,758**	**5,404,518**
NET – t C								
Douglas-fir	-127,146	-171,430	-460	-38,755	**-337,792**	95,893	1,320,759	**1,416,652**
Fir-Spruce	-2,211	-6,851	0	-15,552	**-24,615**	9,460	155,012	**164,472**
Other Conifer	-107,919	-29,560	0	-66,963	**-204,442**	44,587	965,336	**1,009,923**
Hardwood	-94,693	-101,025	-1,379	-116,180	**-313,278**	60,226	1,332,064	**1,392,290**
Redwood	0	-556,449	-339	-43,469	**-600,257**	139,668	1,269,587	**1,409,255**
Shrubs / grasses	-1,417	-607	-23	-1,764	**-3,812**	11,926	-	**11,926**
SUM NET	**-333,386**	**-865,922**	**-2,201**	**-282,686**	**-1,484,195**	**361,760**	**5,042,758**	**5,404,518**
+/- uncertainty	*128,354*	*337,474*	*823*	*105,724*	***376,220***	*-135,298*	*907,696*	***917,725***

1.5.2. Cascade Northeast

The area that underwent a change in canopy cover between 1994-1999 was 141,500 ha which is 1.9% of the land area of the Cascades Northeast region. In the Cascade Northeast region, development, harvest, pest-related and other causes are all in small patches of small area extent (Figure 1-9). Fire and regrowth occur over units of a larger area, especially fire where wide areas are affected in Modoc and Siskiyou Counties.

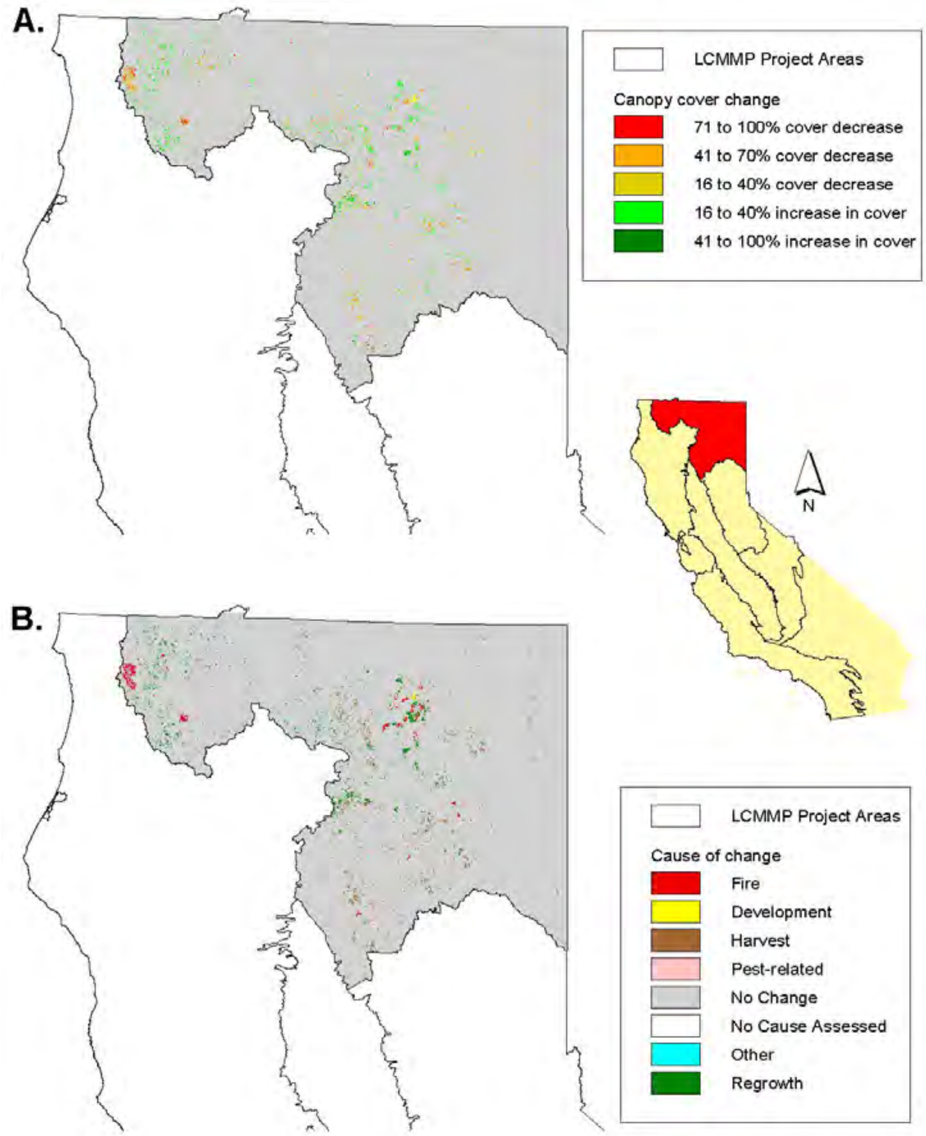

Figure 1-9. Illustration of Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B)

1.5.2.1. Rangelands

A total of 22 thousand hectares of rangelands in the Cascade Northeast region were affected by a canopy change during the census interval. Of this total about 3,000 ha were woodlands and 19,000 ha were shrub/grass lands. The dominant influences were regrowth affecting 11,676 ha and fire affecting about 5,600 ha (Table 1-10).

Table 1-10. Change in Area of Cascade Northeast Rangelands based on Areas Affected by Canopy Cover Change. (- Equals a Decrease in Canopy Cover, + Equals an Increase)

	Fire	Harvest	Development	Regrowth	Pest-related	Other		Unverified		SUM
						-	+	-	+	
AREA (ha)										
Woodlands	1272	238	0	683	7	476	1	47	172	**2,896**
Grasses / Shrubs	4,336	2056	9	10,993	140	579	96	343	751	**19,303**
SUM AREA	**5,608**	**2,294**	**9**	**11,676**	**147**	**1,055**	**97**	**390**	**923**	**22,199**

Across the Cascade Northeast, net emissions from rangelands was estimated to be about 108,00 t C, 53% of which was caused by fire (Table 1-11). Total removals were estimated to be about 218,600 t C. Removals exceeded emissions by 110,600 t C during the period 1994-1999.

Table 1-11. Changes in the Carbon Stock of Cascade Northeast Rangelands. (- Equals a Loss in Carbon Stocks [a Source] and + Equals a Gain in Stocks [a Sink])

EMISSIONS							**REMOVALS**		
	Fire	Harvest	Develop-ment	Pest-related	Other/ Unverified	**SUM EMISSIONS**	Measured Removals	Unmeasured Regrowth	**SUM REMOVALS**
GROSS – t C									
Woodlands	-16,377	-4,039	0	-70	-12,612	**-33,099**	6,328	132,699	**139,027**
Grasses / Shrubs	-45,121	-21,662	-72	-1,382	-12,785	**-81,022**	79,609	-	**79,609**
SUM GROSS	**-61,499**	**-25,701**	**-72**	**-1,453**	**-25,397**	**-114,121**	**85,937**	**132,699**	**218,636**
NET – t C									
Woodlands	-11,893	-2,377	0	-70	-12,612	**-26,952**	6,328	132,699	**139,027**
Grasses / Shrubs	-45,121	-21,662	-72	-1,382	-12,785	**-81,022**	79,609	-	**79,609**
SUM NET	**-57,014**	**-24,038**	**-72**	**-1,453**	**-25,397**	**-107,974**	**85,937**	**132,699**	**218,636**
+/- *uncertainty*	*21,950*	*9,014*	*27*	*543*	*9,498*	***25,565***	*32,140*	*23,886*	***40,044***

1.5.2.2. Forests

About 113,000 ha of forests were affected by a canopy change in the Cascades Northeast between 1994-1999, including about 49,000 hectares of regrowth, about 41,000 hectares of harvest, and about 13,000 hectares of fire damage (Table 1-12). Considerably more than half of the affected area occurred in the "other conifer" forests.

Table 1-12. Change in Area of Cascade Northeast Forests based on Areas Affected by Canopy Cover Change. (- Equals a Decrease in Canopy Cover, + Equals an Increase)

	Fire	Harvest	Development	Regrowth	Pest-related	Other		Unverified		SUM
						-	+	-	+	
AREA (ha)										
Douglas-fir	3,899	1,619	0	9,820	163	242	0	103	176	**16,022**
Fir-Spruce	340	4114	0	2683	421	424	25	107	179	**8,293**
Other Conifer	6,732	33,425	228	30,728	628	1,413	147	1,431	1,967	**76,699**
Hardwood	2,115	1,509	1	5,267	133	469	8	158	598	**10,258**
Redwood	0	0	0	0	0	0	0	0	0	**0**
Shrubs/grasses	225	257	1	889	16	70	26	24	69	**1,577**
SUM AREA	**13,311**	**40,924**	**230**	**49,387**	**1,361**	**2,618**	**206**	**1,823**	**2,989**	**112,849**

The net emissions from all activities is 1.16 million t C, with forest harvest accounting for 52% and fire for an additional 34% of the total net emissions (Table 1-13). The changes in carbon stocks are clearly dominated by "other conifer" forests which account for 66% of the total net emissions, particularly caused by harvest and regrowth of these forests. Total removals from all causes are estimated to be 4.35 million t C, 77% of which is caused by other conifers. The net balance for the region is a removal of 3.19 million t C, with a range of 2.20-4.18 million t C.

To normalize the net emissions from forests as above, the average net emissions per unit area for forest harvest are (the net emissions from Table 1-13 divided by the area in Table 1-12):

- Douglas fir —18.5 t C/ha
- Fir-spruce—18.0 t C/ha
- Other conifer — 14.0 t C/ha
- Hardwoods —15.5 t C/ha

Table 1-13. Changes in the Carbon Stock of Cascade Northeast Forests. (- Equals a Loss in Carbon Stocks [a Source] and + Equals a Gain in Stocks [a Sink])

EMISSIONS							REMOVALS		
	Fire	Harvest	Develop-ment	Pest-related	Other/ Unverified	SUM EMISSIONS	Measured Removals	Unmeasured Regrowth	SUM REMOVALS
GROSS – t C									
Douglas-fir	-202,832	-66,550	0	-5,289	-12,553	**-287,224**	136,529	250,811	**387,340**
Fir-Spruce	-14,599	-164,708	0	-11,752	-17,527	**-208,586**	38,227	304,366	**342,593**
Other Conifer	-263,104	-1,066,273	-4,630	-20,031	-81,042	**-1,435,079**	565,461	2,775,178	**3,340,639**
Hardwood	-55,199	-40,197	-58	-2,658	-17,136	**-115,248**	42,895	229,818	**272,713**
Redwood	0	0	0	0	0	**0**	0	0	**0**
Shrubs / grasses	-998	-1,323	-4	-106	-429	**-2,861**	3,405	-	**3,405**
SUM GROSS	**-536,732**	**-1,339,050**	**-4,692**	**-39,836**	**-128,688**	**-2,048,998**	**786,516**	**3,560,173**	**4,346,689**
NET – t C									
Douglas-fir	-146,109	-29,573	0	-5,289	-7,675	**-188,646**	136,529	250,811	**387,340**
Fir-Spruce	-10,553	-73,192	0	-11,752	-17,527	**-113,025**	38,227	304,366	**342,593**
Other Conifer	-190,128	-473,825	-4,630	-20,031	-81,042	**-769,656**	565,461	2,775,178	**3,340,639**
Hardwood	-39,789	-23,653	-58	-2,658	-17,136	**-83,294**	42,895	229,818	**272,713**
Redwood	0	0	0	0	0	**0**	0	0	**0**
Shrubs / grasses	-998	-1,323	-4	-106	-429	**-2,861**	3,405	-	**3,405**
SUM NET	**-387,577**	**-601,566**	**-4,692**	**-39,836**	**-123,810**	**-1,157,481**	**786,516**	**3,560,173**	**4,346,689**
+/- uncertainty	*149,217*	*235,276*	*1,755*	*14,899*	*46,305*	***282,825***	*294,157*	*640,831*	***705,119***

1.5.3. North Sierra

The area that underwent a measured change in canopy cover between 1995-2000 was approximately 90,200 ha, which is 2.5% of the total land area or 2.8% of the area of forests and rangelands. In the North Sierra region, fire and regrowth with moderate to large decreases in canopy are the most obvious causes of change, with scattered areas of harvest and other causes (Figure 1-10). Large patches of fire damage can be seen in Plumas, Yuba, Tuolumne, and Butte counties.

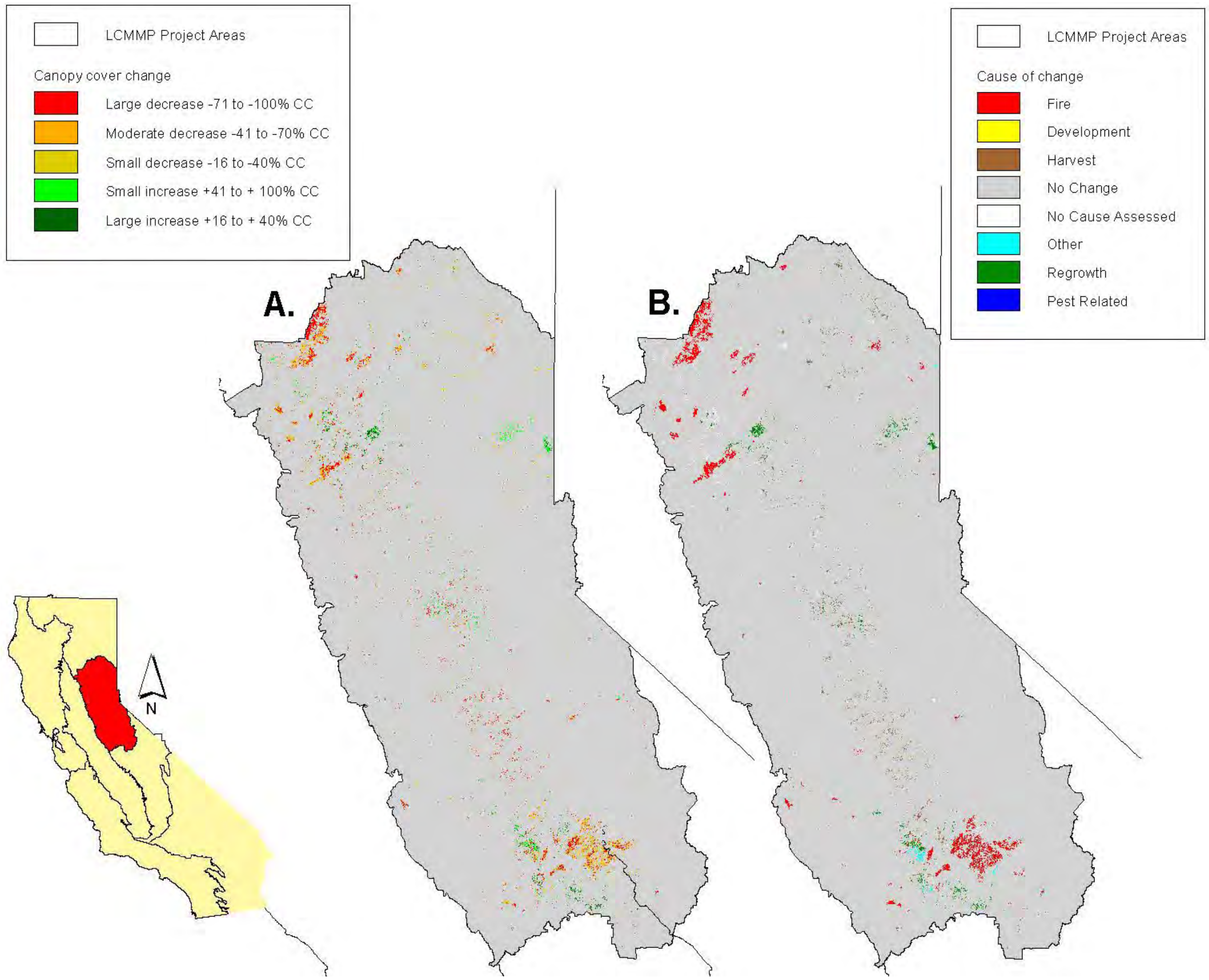

Figure 1-10. Illustration of Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B)

1.5.3.1. Rangelands

The area of rangelands affected by canopy change between 1995-2000 was 17.6 thousand hectares. The dominant causes were fire and regrowth each responsible for over 5 thousand hectares (Table 1-14). Ninety percent of the area affected was in the shrub/grass classes as opposed to woodland.

Table 1-14. Change in Area of North Sierra Rangelands based on Areas Affected by Canopy Cover Change. (- Equals a Decrease in Canopy Cover, + Equals an Increase)

	Fire	Harvest	Development	Regrowth	Pest-related	Other		Unverified		SUM
						-	+	-	+	
AREA (ha)										
Woodlands	883	0	47	12	0	10	0	684	93	**1,729**
Grasses / Shrubs	4,139	381	96	5,976	0	1,040	135	2,728	1,376	**15,871**
SUM AREA	**5,022**	**381**	**143**	**5,988**	**0**	**1,050**	**135**	**3,412**	**1,469**	**17,600**

Overall, the rangelands emit a net of about 153,300 t C, most of which is due to unverified causes (50%) and fire (44%) (Table 1-15). Total removals are estimated to be about 94,300 t C. Overall, the rangelands of this region are a net source of carbon emissions of about 59,000 t C (Table 1-15).

Table 1-15. Changes in the Carbon Stock of North Sierra Rangelands. (- Equals a Loss in Carbon Stocks [a Source] and + Equals a Gain in Stocks [a Sink])

EMISSIONS						**REMOVALS**		
	Fire	Harvest	Develop-ment	Other/ Unverified	SUM EMISSIONS	Measured Removals	Unmeasured Regrowth	**SUM REMOVALS**
GROSS – t C								
Woodlands	-28,706	0	-2,374	-31,363	**-62,443**	1,135	52,056	**53,191**
Grasses / Shrubs	-46,365	-5,595	-905	-45,960	**-98,825**	41,106	-	**41,106**
SUM GROSS	**-75,071**	**-5,595**	**-3,279**	**-77,323**	**-161,268**	**42,241**	**52,056**	**94,297**
NET – t C								
Woodlands	-20,701	0	-2,374	-31,363	**-54,437**	1,135	52,056	**53,191**
Grasses / Shrubs	-46,365	-5,595	-905	-45,960	**-98,825**	41,106	-	**41,106**
SUM NET	**-67,066**	**-5,595**	**-3,279**	**-77,323**	**-153,262**	**42,241**	**52,056**	**94,297**
+/- uncertainty	*25,820*	*2,093*	*1,226*	*28,919*	***38,844***	*15,798*	*9,370*	***22,713***

1.5.3.2. Forests

The total area of measured change in forests is about 72,600 hectares (Table 1-16). Fire is the dominant cause of change in canopy cover in the forests of the North Sierra region, accounting for 47% of the total measured change. This differs from the North Coast and the Cascade Northeast where harvest and regrowth dominated. This could be expected from the dry fire-prone conditions in the Sierras. The "other conifer" class is the dominant forest type reflecting the coverage by ponderosa pine and lodgepole pine.

Table 1-16. Change in Area of North Sierra Forests based on Areas Affected by Canopy Cover Change. (- Equals a Decrease in Canopy Cover, + Equals an Increase)

	Fire	Harvest	Development	Regrowth	Pest-related	Other		Unverified		SUM
						-	+	-	+	
AREA (ha)										
Douglas-fir	2,379	409	0	955	0	40	0	1,428	626	**5,837**
Fir-Spruce	4661	528	36	145	0	183	0	671	207	**6,431**
Other Conifer	16,006	10,401	37	5,004	0	659	166	7,981	2,925	**43,179**
Hardwood	10,928	502	64	798	0	93	0	3,346	1,331	**17,062**
Redwood	0	0	0	0	0	0	0	0	0	**0**
Shrubs/grasses	17	7	1	10	0	0	0	31	27	**93**
SUM AREA	**33,991**	**11,847**	**138**	**6,912**	**0**	**975**	**166**	**13,457**	**5,116**	**72,602**

In terms of carbon in the North Sierra region, the net emissions from all measured changes is 1.90 million t C, of which is 58% is caused by fire (Table 1-17). The North Sierras produce a greater source of CO_2 than either the North Coast (Table 1-9) or the Cascade Northeast (Table 1-13). Total removals by forests in the North Sierra region are 3.85 million t C. Overall, the region is a net remover (sink) of carbon of about 1.94 million t C, with a range of 0.8 – 3.08 million t C.

To normalize the net emissions from dominant cause in changes in forest carbon stocks, the average net emissions per unit area for forest fires are (the net emissions from Table 1-17 divided by the area in Table 1-16):

- Douglas fir —51.0 t C/ha
- Fir-spruce —44.5 t C/ha
- Other conifer —32.0 t C/ha
- Hardwoods—24.5 t C/ha

Douglas fir forests have the highest emissions per unit area from fire and these are the least fire tolerant forests. In contrast, the other conifer forests, such as ponderosa pine and lodgepole pine, have the lowest emissions per unit area and these forest types are purported to be some of the more fire tolerant species. The emissions from fire certainly seem to support the fire tolerance of the different forest types in this region. Harvesting of the other conifer forests produces a net emission of 92 t C/ha or more than from fire, most likely due to the general practice of clearcutting these forest types. On the other hand, harvesting Douglas fir forests produces a net emission of 35 t C/ha or somewhat less than that from fire.

Table 1-17. Changes in the Carbon Stock of North Sierra Forests. (- Equals a Loss in Carbon Stocks [a Source] and + Equals a Gain in Stocks [a Sink])

EMISSIONS						REMOVALS		
	Fire	Harvest	Develop-ment	Other/ Unverified	**SUM EMISSIONS**	Measured Removals	Unmeasured Regrowth	**SUM REMOVALS**
GROSS – t C								
Douglas-fir	-169,086	-31,997	0	-79,855	**-280,939**	29,053	201,334	**230,387**
Fir-Spruce	-288,736	-25,893	-2,249	-41,604	**-358,482**	7,086	368,383	**375,469**
Other Conifer	-706,206	-429,818	-1,117	-362,987	**-1,500,127**	166,703	2,498,111	**2,664,814**
Hardwood	-370,156	-21,032	-3,019	-122,319	**-516,526**	22,288	552,474	**574,762**
Redwood	0	0	0	0	**0**	0	0	**0**
Shrubs / grasses	-74	-27	-7	-177	**-285**	138	-	**138**
SUM GROSS	**-1,534,257**	**-508,768**	**-6,392**	**-606,942**	**-2,656,359**	**225,267**	**3,620,302**	**3,845,569**
NET – t C								
Douglas-fir	-121,514	-14,219	0	-35,845	**-171,578**	29,053	201,334	**230,387**
Fir-Spruce	-208,255	-11,506	-2,249	-41,604	**-263,614**	7,086	368,383	**375,469**
Other Conifer	-510,106	-191,000	-1,117	-362,987	**-1,065,209**	166,703	2,498,111	**2,664,814**
Hardwood	-266,521	-12,376	-3,019	-122,319	**-404,235**	22,288	552,474	**574,762**
Redwood	0	0	0	0	**0**	0	0	**0**
Shrubs / grasses	-74	-27	-7	-177	**-285**	138	-	**138**
SUM NET	**-1,106,470**	**-229,128**	**-6,392**	**-562,932**	**-1,904,923**	**225,267**	**3,620,302**	**3,845,569**
+/- uncertainty	*425,991*	*89,302*	*2,391*	*210,537*	***483,502***	*84,250*	*651,654*	***657,078***

1.5.4. Non-CO_2 Gases for California Forests and Rangelands

Fire

Although 333,386 t C (1,222,415 t CO_2 eq) were emitted through fire in the North Coast forests during the inter census period the simultaneous release of N_2O is estimated as just 37 tons. However, N_2O has 296 times the global warming potential of CO_2 so the 37 tons of N_2O translates to almost 11,000 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 18).

Methane emissions through the actions of 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 more than 100 thousand tons of CO_2 equivalents for the inter census period for the cascades northeast (simultaneous CO_2 releases = 1,421,115 tons) (Table 1-18).

Table 1-18. 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

Region	Vegetation	Carbon emitted t C	Methane			Nitrous Oxide		
			t emitted	t CO_2 eq	% of C released	t emitted	t CO_2 eq	% of C released
North Coast	rangelands	34,700	555	12,769	10	4	1,130	0.9
	forests	333,386	5,334	122,686	10	37	10,855	0.9
Northeast Cascades	rangelands	57,014	912	20,981	10	6	1,856	0.9
	forests	387,577	6,201	142,628	10	43	12,620	0.9
North Sierra	rangelands	67,066	1,073	24,680	10	7	2,184	0.9
	forests	1,106,470	17,704	407,181	10	122	36,027	0.9

b) Flaming Fire

Region	Vegetation	Carbon emitted t C	Methane			Nitrous Oxide		
			t emitted	t CO_2 eq	% of C released	t emitted	t CO_2 eq	% of C released
North Coast	rangelands	34,700	416	9,577	8	3	807	0.6
	forests	333,386	4,001	92,015	8	26	7,754	0.6
Northeast Cascades	rangelands	57,014	684	15,736	8	4	1,326	0.6
	forests	387,577	4,651	106,971	8	30	9,014	0.6
North Sierra	rangelands	67,066	805	18,510	8	5	1,560	0.6
	forests	1,106,470	13,278	305,386	8	87	25,733	0.6

Harvest

The reduction in methane sequestration caused by the disturbance of harvesting is very low relative to the net losses of CO_2. Here we estimate the increase in atmospheric CH_4 CO_2 equivalents as less than one tenth of a percent of the actual increase in carbon dioxide (Table 1-19).

Table 1-19. Estimated Forest and Rangelands Methane Emissions Resulting from Harvest

Region	Vegetation	Carbon emitted	Methane		
		t C	t emitted	t CO_2 eq	% of C released
North Coast	rangelands	10,154	1	33	0.09
	forests	865,922	75	1,733	0.05
Northeast Cascades	rangelands	24,038	4	99	0.11
	forests	601,566	77	1,770	0.08
North Sierra	rangelands	5,595	1	16	0.08
	forests	229,128	22	512	0.06

1.6. Forests and Rangelands of California as Sources and Sinks of Greenhouse Gases

Across the 260,236 km^2 comprising the North Coast, Cascade Northeast and North Sierra, there are an estimated 80,020 km^2 of forest and 53,718 km^2 of rangelands. Of this area 3,453 km^2 of forests and rangelands had a change in canopy cover between the measurement periods (equal to 2.5% of the total area). Of this area of change 85% had a verified cause. Eighty-two percent of the changes were on forestland and 18% on rangeland.

On forestland, 33% of the area with a canopy change was affected by commercial harvest, 28% by measured forest regrowth and 23% by fire. Development was only responsible for 0.2% of the verified change, but it could be higher when and if the cause of the unverified changes was confirmed. The distribution of causes, however, varied by region. In the North Coast 42% of the change area was caused by commercial harvest, in the Cascade Northeast 44% of the change area was undergoing forest regrowth and in the North Sierra 47% was caused by fire.

On rangeland, measured regrowth dominated the cause of changed area accounting for 43%. Next in significance was fire with 23%.

In terms of carbon, 4.55 million t C were emitted from forestland in the three regions (Table 1-20). On forestland, fires emitted as much as 1.8 million t C, however, 61% of this total came from the North Sierra alone. During the same period, approximately 13.6 million t C were removed.

On rangelands, 0.34 million t C were emitted between the 5-yr intervals from the three regions, included in this total are 0.16 million t C emitted through fire (Table 1-20). During the same period it is estimated that 0.56 million t C were removed through rangeland regrowth and natural tree growth.

Table 1-20. Summary of the Carbon Emitted and Removed in Forests and Rangelands of Three Regions of California between a 5-yearInterval during 1994-2000 (Actual 5-yr Periods Vary by Region)

Forests	Net t C			
	North Coast	Cascades Northeast	North Sierra	TOTAL
EMISSIONS				
Fire	-333,386	-387,577	-1,106,470	-1,827,433
Harvest	-865,922	-601,566	-229,128	-1,696,617
Development	-2,201	-4,692	-6,392	-13,285
Other/Unverified	-282,686	-163,646	-562,932	-1,009,264
EMISSIONS TOTAL	-1,484,195	-1,157,481	-1,904,923	-4,546,599
Estimated error	*376,220*	*282,825*	*483,502*	*674,764*
REMOVALS TOTAL	5,404,518	4,346,689	3,845,569	13,596,776
Estimated error +/-	*917,725*	*705,119*	*657,078*	*1,330,850*

Rangelands	Net t C			
	North Coast	Cascades Northeast	North Sierra	TOTAL
EMISSIONS				
Fire	-34,700	-57,014	-67,066	**-158,780**
Harvest	-10,154	-24,038	-5,595	**-39,788**
Development	-1,259	-72	-3,279	**-4,610**
Other/Unverified	-30,023	-26,850	-77,323	**-134,196**
EMISSIONS TOTAL	**-76,137**	**-107,974**	**-153,262**	**-337,373**
Estimated error	*17,872*	*25,565*	*38,844*	*49,818*
REMOVALS TOTAL	**249,613**	**218,636**	**94,297**	**562,546**
Estimated error +/-	*38,862*	*40,044*	*22,713*	*60,247*

Uncertainty in the estimated carbon totals is high. Confidence can be had in the pattern of change but the precise carbon values attained should be viewed as plus or minus 38% due to the limitations mentioned above (principally in the imagery).

1.6.1. Summary at the County Level

In general the areas with the largest emissions are not necessarily those with the largest removals, either due to a disconnection between the factors leading to the high values of each (e.g., fire principally in the North Sierra and fast forest growth rates principally in the North Coast), or due to a lag in the regrowth response (Figure 1-11). The areas with low emissions and low removals do coincide with the highly developed Bay Area around the city of San Francisco.

The counties with the highest emissions are Siskiyou, Plumas and Tuolumne each affected by fire damage during the investigation period. Counties with high removals include Trinity, Humboldt, and Mendocino where the fast growing, high biomass Douglas fir and redwood forests are located.

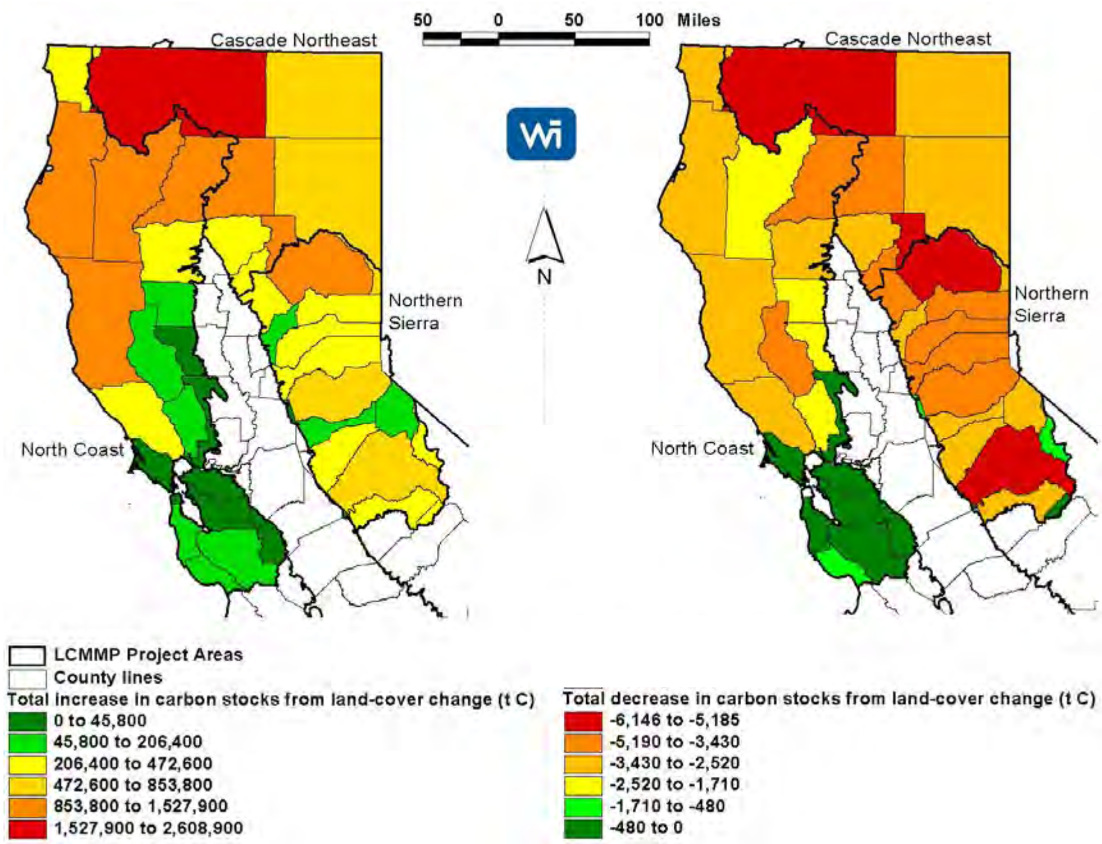

Figure 1-11. County Level Summary of the Increases (left), and Decreases (right) in Carbon Stocks in the North Coast (1994-1998), the Cascades Northeast (1994-1999) and the North Sierra (1995-2000)

1.6.2. Carbon Dioxide Equivalents

If the non-CO_2 gases are included and all values are converted to carbon dioxide equivalents, across the three regions 16.67 million metric tons of carbon dioxide equivalents ($MMTCO_2eq$) were emitted between the census dates from forest land and 1.24 $MMTCO_2eq$ from rangelands. This converts to an annual emission of 3.76 $MMTCO_2eq$ from forests and 0.27 $MMTCO_2eq$ from rangelands (Table 1-21).

During the same periods 49.85 $MMTCO_2eq$ were estimated to have been removed by forestland and 2.06 $MMTCO_2eq$ on rangeland. This is equal to an annual rate of removals of 10.96 $MMTCO_2eq$ in forests and 0.46 $MMTCO_2eq$ on rangelands (Table 1-21).

Table 1-21. Summary of the Emissions and Removals both over the Analysis Period and on a Per Year Basis

	Forests				Rangelands			
	C	*N_2O†*	*CH_4**	**TOTAL**	*C*	*N_2O†*	*CH_4**	**TOTAL**
$MMTCO_2eq$								
Emissions	16.67	0.06	0.68	**17.41**	1.24	0.005	0.06	**1.30**
Removals	49.84	-	-	**49.84**	2.06	-	-	**2.06**
$MMTCO_2eq$/year								
Emissions	3.61	0.01	0.14	**3.76**	0.26	0.001	0.01	**0.27**
Removals	10.96	-	-	**10.96**	0.46	-	-	**0.46**

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

1.6.3. Comparison with Other Studies for California

The California Energy Commission published a report in 2002 summarizing all estimated emissions and removals of CO_2 and CO_2 equivalents in California during the 1990s. For the forest sector, the data come directly from the publication of Birdsey and Lewis (2001). In turn Birdsey and Lewis (2001) based their reporting on the U.S. Forest Service's FIA data. It is significant that the last re-measurement of the FIA plots for California was completed in 1994. The data reported by Birdsey and Lewis is modeled through 1997 from the 1994 inventory. The Energy Commission makes a further extrapolation to include values through 1999. The reported data for the forest sector represent net changes with no separate consideration of emissions and removals and no consideration of non-CO_2 gases nor non-woody rangeland vegetation.

In contrast, the values reported in our analyses are based on measured changes in canopy cover for emissions and removals, and estimates of unmeasured changes. It must be acknowledged that the flux from unmeasured changes exceeded that from measured changes, and that the estimated rates of carbon accumulation used for the unmeasured changes were equally derived from Birdsey and Lewis (2001). However, these rates were independently calculated and were independently verified for selected areas by Winrock field measurements.

The Energy Commission (2002) reports a net removal from Californian forestland of 17.3 $MMTCO_2eq$/yr for each of the years examined in the study. In contrast, here the annual removal (examining just carbon) is reported as 10.96 $MMTCO_2eq$/yr or if net of emissions the removal falls to 7.35 $MMTCO_2eq$/yr for forestland. The Energy Commission reports for the entire state as opposed to the three regions in this study, yet the three regions in this study represent 84% of the forests in California. Extrapolating the emissions and removals to be equivalent to the full 100% of forests produces estimates of 13.05 $MMTCO_2eq$/yr for removals or 8.76 $MMTCO_2eq$/yr for removals net of emissions, still considerably lower than the estimates in the Energy Commission report. We also note that no measure of uncertainty is included in the Energy Commission report in contrast to our analyses.

The estimates from the Energy Commission report and those resulting from our analysis represent a significant disparity. Reasons for the disparity may include errors implicit in the modeling and extrapolation approach employed by Birdsey and Lewis (2001)/CEC (2002). The results reported by the Energy Commission (2002) are also at a scale whereby individual emissions are overlooked. Instead species-group growth rates are applied across extents including areas that rather than accumulating biomass actually had a net emission due, for example, to fire.

Additionally, the details of the sources of emissions and removal given in Birdsey and Lewis (2001) are confusing. For example, the report estimates a net removal of 18.7 MMTCO_2eq/yr between 1992 and 1997 by live biomass (net growth in biomass of forests) and a further removal of 7.4 MMTCO_2eq/yr in wood products and landfill (amount going into long term storage after harvest of wood) to give a total removal of 26.1 MMTCO_2eq/yr. This value is then reduced by estimated emissions from dead wood (5.8 MMTCO_2eq/yr) and soil (3.0 MMTCO_2eq/yr). Field measurements by Winrock in the North Sierra and North Coast as well as literature sources show no change in soil carbon with land use/land management except perhaps for conversion to some forms of agriculture. So this emission is appears to be an over estimate. Also it is counter-intuitive that there would be an accumulation of carbon in live biomass but a net emission from dead wood. Most of these net emissions are assumed to represents the decomposition of slash left behind after commercial harvest. But if decomposition is occurring at 5% per year then this represents an enormous quantity of dead wood standing on the land (about 116 MMTCO_2eq) with diminishing annual additions of new dead wood.

We conclude that, despite the relatively high uncertainty associated with our analyses, because of the finer detail and inclusion of areas with measured changes in canopy, and thus carbon stocks, our estimate should be considered to be representative of the real changes occurring on forest and range lands during the period of 1994/5-2000.

1.7. Conclusions

- Data on change in vegetation coverage from the California Land Cover Mapping and Monitoring Program (LCMMP) was combined with carbon estimates derived principally from Forest Inventory and Analysis (FIA) data. The baseline includes all changes in carbon stocks, from measured and un-measured changes in canopy coverage.
- A change in canopy cover was measured on 3,452 km^2 of forests and rangelands in the North Coast, Cascade Northeast and North Sierra regions. This is approximately 2.5% of the total area of forests and rangeland in the regions. For 82% of the changed area, the cause of change was verified.
- For forests, a net removal of 10.96 MMTCO_2eq/yr and a net emission of 3.76 MMTCO_2eq/yr were estimated (Table S-2). The greatest emissions were found in the North Sierra region with its dry conditions and resultant fires. The greatest removal was found in the forests of the North Coast with its dominance by fast-growing redwoods and Douglas-fir.
- Rangelands were a net sink of carbon with a net removal of 0.46 MMTCO_2eq/yr exceeding a net emission of 0.27 MMTCO_2eq/yr (Table S-2).
- Fire and harvest were the dominant causes of emissions on forestlands; these causes were responsible for 1.55 MMTCO_2eq/yr and 1.40 MMTCO_2eq/yr respectively. On rangeland, harvest was less important, accounting for only 11% of the total emissions as opposed to 52% for fire on rangelands (Table S-3). Development is a minor cause of carbon emissions through land-use change in both forest- and range-land in the three studied regions of California. However, some of the unverified change could include

development that tends to occur in smaller patches as the pattern of verified changes were in the three-region area.

- The counties with the largest decrease in carbon stocks (largest emissions) were located in areas affected by fire especially in North Sierra and parts of Cascade Northeast (Figure S-1). The largest increases in carbon stocks (measured and unmeasured canopy change) are in the high volume fast-growing conifer forests of the North Coast and Cascades Northeast.
- The calculated removals of 10.96 $MMTCO_2eq/yr$ and emissions of 3.76 $MMTCO_2eq/yr$ for the forest sector differ markedly from the reported removal of 17.3 $MMTCO_2eq/yr$ in the California Energy Commission's report (CEC, 2002). Although our analysis does not include the whole state of California; the results are based on 84% of the forestlands and include an estimate of the uncertainty in the estimates (±38%). We conclude that despite the relatively high uncertainty, the finer detail, and inclusion of areas with measured changes in canopy, and thus carbon stocks, our estimate should be considered to be representative of the real changes occurring on forest and range lands during the period of 1994/1995–2000.

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2.0 Baselines for Agriculture in California

2.1. Purpose and Background

Forestry and agriculture are important economic sectors in the State of California. The way forest and agricultural lands within California are used and managed impacts the amount of emissions and removals of greenhouse gases (GHGs) generated by the State. The 2002 California Energy Commission's report[3] estimated the emissions and removals of GHGs from all economic sectors of the State for the period 1990-1999, generally at one-year intervals. These GHG emissions and removals can serve as a baseline for California for the 1990s against which future trends can be compared, and to assess where opportunities exist for reducing emissions and enhancing sinks. However, the sections of the Energy Commission 2002 report on the forestry and agriculture sectors were incomplete and did not include all the changes taking place on these lands.

The goal of this section is to quantify the baseline of changes in carbon stocks in the agricultural sector of California for the decade of the 1990s. The focus here is on carbon and not on non-CO_2 greenhouse gases that are covered in other Californian reports (CEC, 2000) and by other ongoing work (W. Salas, 2003, pers. comm.).

2.1.1. General Approach

To develop the baseline, two types of data are needed: (1) the total area of agricultural land and of each of the major agricultural land-use types through time, and (2) the carbon stocks in each land-use type. The areas of agricultural lands are based primarily on the National Resource Inventory (NRI) database for the period 1987-1997, in five-year intervals. Carbon estimates of various agricultural land-use types are derived from the literature in combination with standard methods. The analysis is conducted for the entire State of California at the county scale of resolution.

2.1.1.1. Classification of Agricultural Land

The National Resources Inventory (NRI) is a scientifically-designed, longitudinal survey of the nation's soil, water, and other related resources designed to assess conditions and trends every five years. The 1997 NRI contains data only on non-federal lands and water bodies. As noted in the Users' Manual (NRI 2001), the NRI data are useful in developing estimates of natural resource conditions, and in conducting geospatial and temporal analyses of these conditions (however, the location of the survey plots is not given in the database).

In this study, NRI data were used for estimates of area because of its relative strength in agricultural surveys compared with the LCMMP data (land cover mapping and monitoring program). The coverage of NRI data is wider and is available across the state for multiple points in time for multiple classes of agriculture. Neither of these conditions are met by the LCMMP database. However, no cause of changes are given in the NRI data.

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3 California Energy Commission, 2002. *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999.* Publication #600-02-001F. Sacramento, California.

Because NRI data come from a sample survey, it is important to have sufficient sample size for a reliable estimate. The users manual for the NRI does not recommended that the data be used for county level analysis because of sample size issues. However, we argue that it is statistically appropriate for county level analysis for the State of California. The nationwide average number of sampling points is about 270 per county, while the California average is 800 points per county, three times the national average.

In this analysis, agricultural land is equated to cropland as defined in the NRI (2001). The NRI recognizes two categories of cropland: cultivated and non-cultivated. Cultivated cropland includes small grains and row crops, hay and pasture with cropping history, and horticulture with double cropping (meaning horticulture with crops planted under the trees). Non-cultivated cropland includes horticulture without double cropping, and hay without cropping history. Pastureland was excluded from this analysis because pastureland is included in rangelands (see Section 1).

The distinction between cultivated and non-cultivated crops is not convenient for the purpose of carbon analysis. The specific land-use categories, therefore, were grouped by the growth form of the crop. All horticulture lands, with or without double cropping, are reclassified as woody cropland. The rest of the croplands, including hay, row crops and small grains, are considered to be non-woody crops (Table 2-1).

Table 2-1. Agricultural Land and its Categories and Subcategories in California, Reclassified as Woody vs. Non-woody Croplands

Broad land cover/use	Specific land cover/use
Annual non-woody crops	Row/Corn
	Row/Sorghum
	Row/Soybean
	Row/Cotton
	Row/Sugar beet
	Row/Potato
	Row/other Vegetable/truck
	Row/others
	Row/Sunflower
	Close/Wheat
	Close/Oats
	Close/Rice
	Close/Barley
	Close/all other close grown
	Hay/Grass
	Hay/Legume
	Hay/Legume-Grass
	Other crop/Summer fallow
	Other crop/other set aside, etc.
Perennial woody crops	Horticulture/Fruit
	Horticulture/Nut
	Horticulture/Vineyard
	Horticulture/Berry
	Horticulture/other

2.1.1.2. Limitations of the NRI database

The baseline analysis for the agricultural sector is based primarily on NRI data. Despite the general acceptance of NRI as a quality source of data for agricultural resource analysis, it is important to note its limitations. First, the samples were taken from non-federal lands only. In California, federal land occupies about half of the total area of the State. Second, the data are not from a complete census, but rather from a statistical sound sampling design. Finally, classification of land cover/use types may not be consistent with other classification schemes commonly used in land cover/use analysis, e.g., the classification in USGS National Land Cover Classification system. However, for the purposes of this report, practically all of these limitations are non-issues as the data are only being used for the agricultural sector, where lands are privately owned, easy to classify, and statistically well reported.

The NRI reports a margin of error (equivalent to a 95% confidence interval) of ±9% for its sampling of areas of cropland for the 1997 reporting.

2.1.1.3. Carbon Density of Agricultural Land

The baseline analysis for the agricultural sector focuses on carbon in vegetation only, including above- and belowground (roots) components. Carbon in vegetation is estimated as 50% of the biomass of the vegetation.

A difficulty in estimating the biomass of crops is caused by the seasonal change of the vegetation. During the non-growing season, there is little biomass in annual crops, while at the peak of the growing season biomass can be high. Considering that litter production is usually low in annual crops, the peak biomass of annual crops is assumed to be equivalent to the annual primary production of the crops on the land. In many cases the majority of the biomass (or production) is removed from the field at harvest. An approximate temporal average of the biomass was used to derive the carbon stock. The biomass in cultivated non-woody crops was estimated based on three sources of data: maximum crop biomass from the Food and Agriculture Organization (FAO), length and timing of harvest cycles and the relative abundance of each crop type.

Data on the carbon stock of horticultural crops are scarce. The estimates here were based on consulting the literature, principally to determine the stocking densities (number of trees per unit area) and tree heights. The stocking densities were combined with maximum and average diameters to produce estimates of biomass per plant that were then multiplied by the stocking densities to arrive at an estimate of biomass carbon density (metric t C/ha).

Changes in soil carbon are not included in this report because it is likely that most of the agricultural land has been under cultivation long enough that changes in soil carbon stocks are minimal to non-existent under current practices. This no change in soil carbon on cultivated land was confirmed by the study of DeClerk and Singer (2003) who showed that the percent change in soil carbon under row crops remained constant over an approximate period of 50 years. Interestingly, they also found the same trend for tree crops. However, the study by DeClerk and Singer did show an increase in soil carbon over the past 50 years for soils under viticulture (about a 1.7-fold increase) and pasture (about a 1.6-fold increase). These reported results are not too useful for the baseline work because the authors give results as an increase in % carbon with no indication of changes in soil bulk density. To calculate changes in carbon stocks require not only the change in % carbon but also the change in soil bulk density. Furthermore, the use of NRI data for estimating changes in area are non-spatial and as such the dynamics of the change are unable to be tracked, or in other words unable to know what type of land an increase in, say, viticulture originated from. Soil carbon can, however, increase through changes in agricultural practices, such as reduced tillage in row crops; this topic will be examined in Volume 2 of this report.

2.2. Area of Agricultural Land

2.2.1. State Level Estimate of Agricultural Land Area

The area of agricultural land in the State of California, including both the perennial woody and the annual non-woody lands, was estimated for 1987, 1992, and 1997 (Table 2-2). Agricultural lands account for about 4 million hectares, or 10% of the land area of the State. The area of non-woody crop land is about three times that of perennial woody crops.

Table 2-2. Agricultural Land Area in California (x1000 hectares) (NRI Database)

Year	Agricultural land	Woody Crops	Non-woody Crops
1987	4,115	1,040	3,075
1992	4,063	1,008	3,055
1997	3,883	1,013	2,870

Overall, agricultural land in California experienced a 5.6% (232,000 ha) loss in area during the 10-year period from 1987 to 1997. The loss was primarily caused by the conversion of non-woody cropland (204,000 ha) into built-up areas. Woody cropland had a relatively small overall decrease during the period (27,000 hectares, or 2.6%). However, the pattern of change in woody cropland varied by period. The area of this category of land decreased by 32,000 hectares from 1987 to 1992, but increased by 5,000 hectares during the period 1992 to 1997. Most of the loss in agricultural land area was caused by conversion to the urban and built-up categories, which have low carbon contents. The estimate of land conversion in this analysis is about twice as high as in Kuminoff et al. (2001), who estimated a loss of 80,693 hectares for cropland from 1988 to 1998 based on the data from the Farmland Mapping and Monitoring Program (FMMP) of the California Department of Conservation. The FMMP data is a great deal coarser than NRI data based on aerial photographs with few agricultural categories and the state is never mapped in its entirety in a single year. Consequently greater confidence should lie with the NRI results.

2.2.2. Changes in Specific Land-use Type

To develop the carbon baseline for agricultural land there was a need to consider specific land uses in the analysis. Agricultural land was separated into 10 categories: horticulture/fruit, horticulture/nut, horticulture/vineyard, horticulture/berry/other, row crop/corn, row crop/cotton, row crop/vegetable/truck crops, other row crops, small grains, and hay.

In the non-woody category, the areas of small grains and hay showed the largest differences among the three inventories, with most of this difference occurring between the 1987 and 1992 inventories (Figure 2-1). The largest overall increase was in the area of hay at 233,000 hectares. The area of cotton increased slightly at each census. All other specific land-use types decreased in area (Figure 2-1). Corn, vegetables and small grains had nearly a 30% loss in area. In fact, the loss of land areas in these three types (494,000 hectares) was more than double the total decrease (232,000 hectares) across all agricultural land.

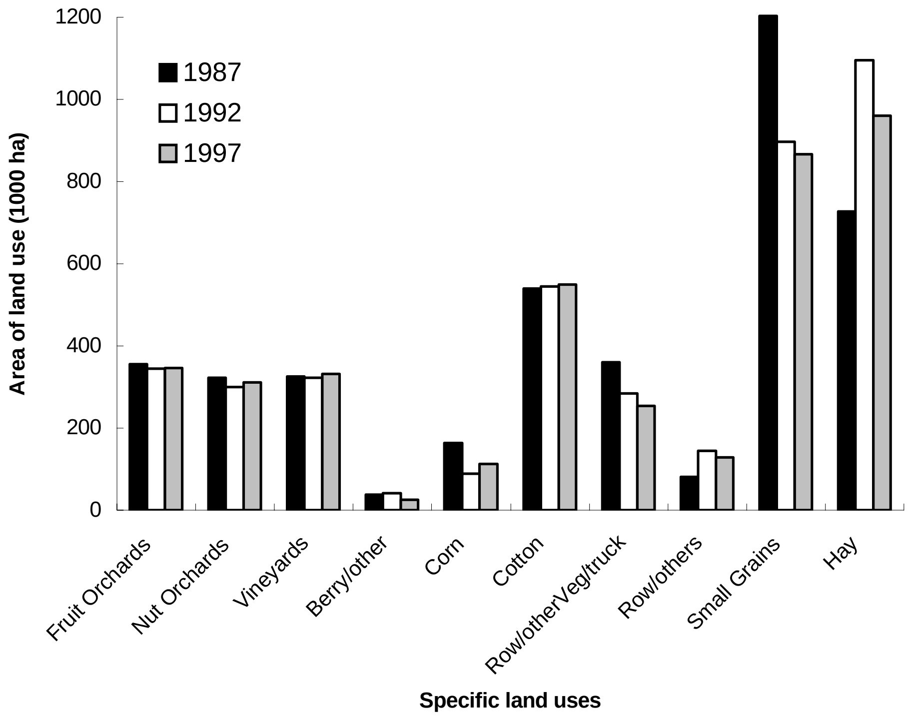

Figure 2-1. Area of Specific Agricultural Land-use Types for 1987, 1992, and 1997

Both woody and non-woody crops decreased in area over the 10-year period (Table 2-3). However, all woody crops decreased in area during the first five-year period, except for berry/other type. For the second five-year period, the reverse trend was observed, where all woody crops increased in area with the exception of berry/other which decreased. Only the area of vineyards showed a net increase in area over the total time period of about 6,000 ha.

The area of non-woody cropland decreased slightly during 1987 to 1992 (less than 1% loss), but during 1992-1997 the area decreased by 6% (Table 2-3).

Table 2-3. Change in Area of Specific Agricultural land-use Types in 1987, 1992 and 1997. (x 1000 ha, Negative Values Indicate Decreases in Land Areas)

Specific Land Use	1987	1992	1997	1987-1992	1992-1997	1987-1997
Fruit Orchards	356	344	346	-12	2	-10
Nut Orchards	322	300	311	-21	11	-11
Vineyards	325	322	331	-3	9	6
Berry/other	37	41	25	4	-16	-12
Woody Croplands	1,040	1,008	1,013	-32	5	-27
Non-Woody Cropland	3,074	3,055	2,870	-20	-185	-205

2.2.3. County Level Estimate of Agricultural Land Area

Due to the spatial heterogeneity of the California landscape, the geographic distribution of agricultural land is uneven among counties. For example, there is no agricultural land in San Francisco County, Nevada County and Mariposa County as sampled in NRI, while in Kings, Yolo and Sutter Counties more than 60% of the non-federal land is agricultural land. The central valley counties have the greatest proportion of agricultural land as expected, and the Sierra Nevada and the north coast counties have the smallest proportion of agricultural land (Figures 2-2 and 2-3, and Table 2-4). Although Imperial County is a major agricultural county in the State, the percentage of agricultural land is low due to the large area of desert in the county.

There is a distinct difference between the pattern of change for woody and non woody croplands between 1987 to 1997 (Figures 2-4 and 2-5). For the woody cropland (Figure 2-4), the majority of the counties remained more or less unchanged during the 10-year period and for those counties where change occurred, the changes were smaller than for the non-woody cropland. Only a few counties experienced significant loss in area of woody cropland. These counties include Riverside (-16,633 ha), San Diego, (-9,470 ha), Stanislaus (-7,851 ha), Tehama (-5,504 ha), and Orange County (-3,764 ha). The counties that had large increases in areas of woody cropland are Tulare (12,384 ha), Glenn (8,863 ha), and Fresno (7,851 ha).

The pattern of change is very different for the non-woody cropland (Figure 2-5). Firstly, 20 counties had more than 3,000 ha of loss in non-woody cropland area (left hand column of Table 2-5). The right hand column of Table 6 also shows the 20 counties with the greatest losses of all agricultural land. Eighteen of the counties in Table 2-5 are common to both columns. Comparing the results in Table 2-5 with those in Figures 2-2 and 2-3, it is clear that the spatial change across all agricultural land resembles that in non-woody cropland.

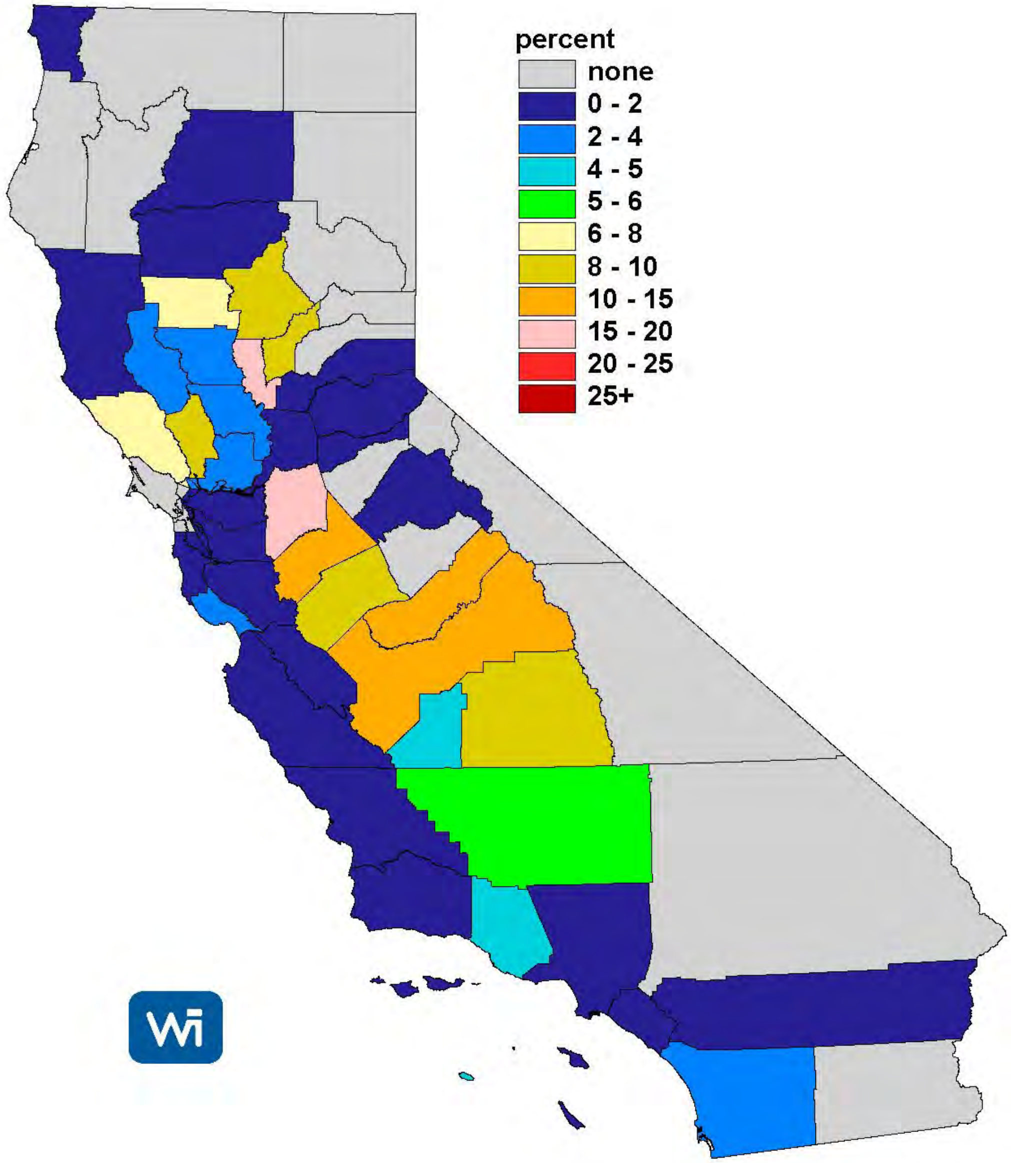

Figure 2-2. Distribution of Woody Cropland by County in 1997. Values Indicate the Percentage of Total Land Area in Each County Occupied by Agricultural Land

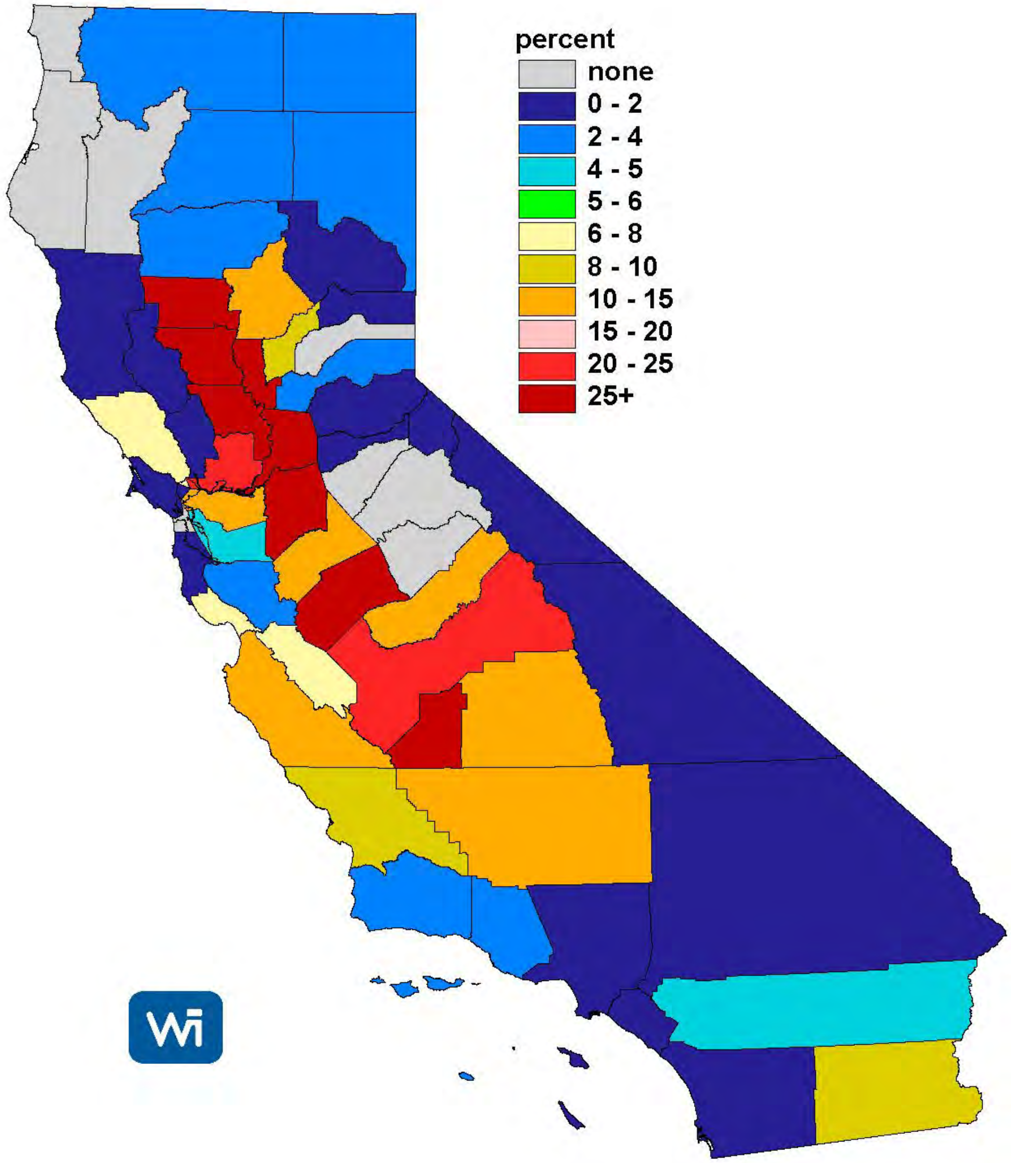

Figure 2-3. Distribution of Non-woody Cropland by County in 1997. Values Indicate the Percentage of Total Land Area in Each County Occupied by Agricultural Land

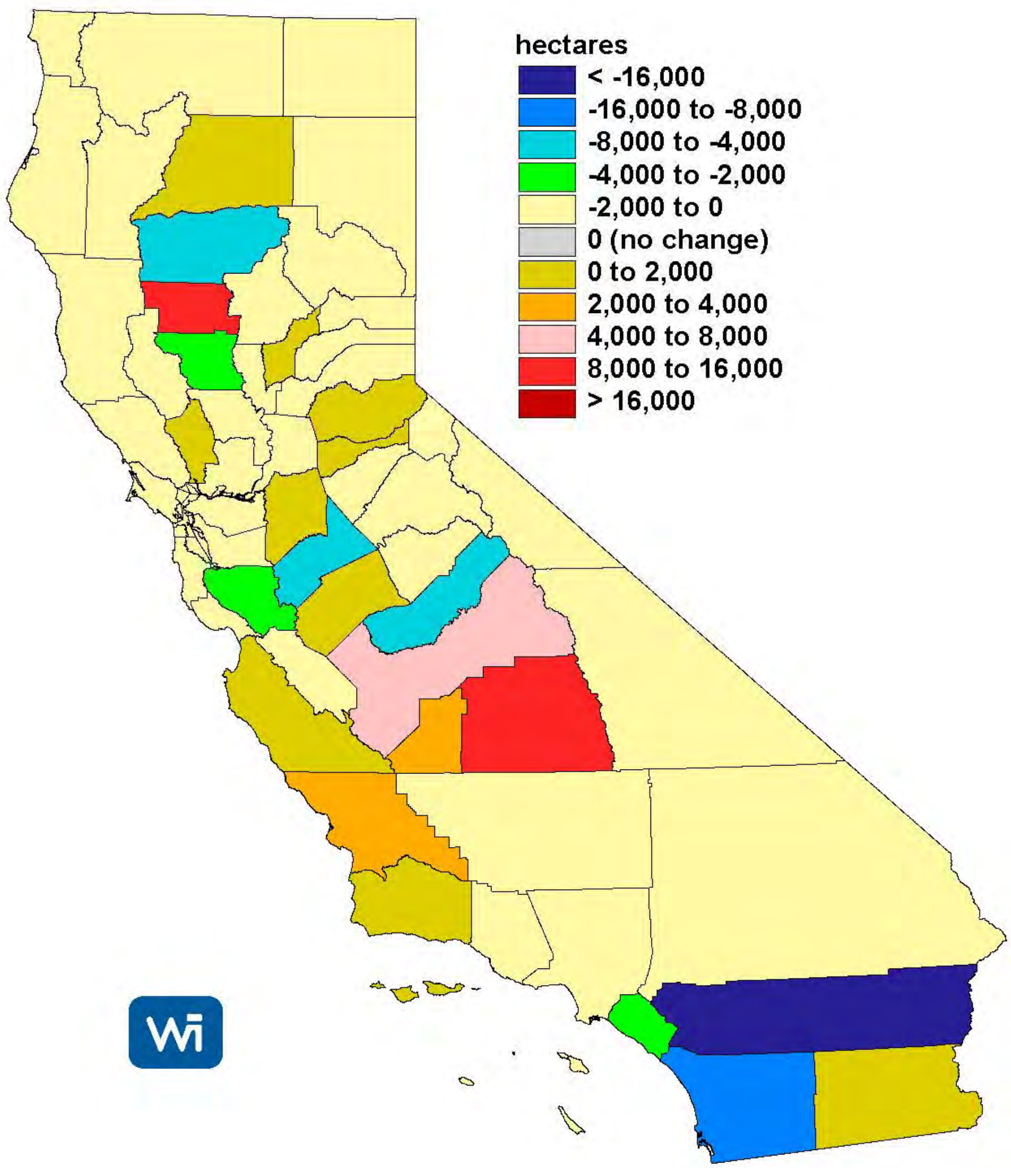

Figure 2-4. Distribution of Change in Area in Woody Cropland by County. Values Indicate Change in Hectares, Minus Sign Indicates a Loss in Area from 1987 to 1997 and Plus Sign Indicates a Gain in Area in the Same Period

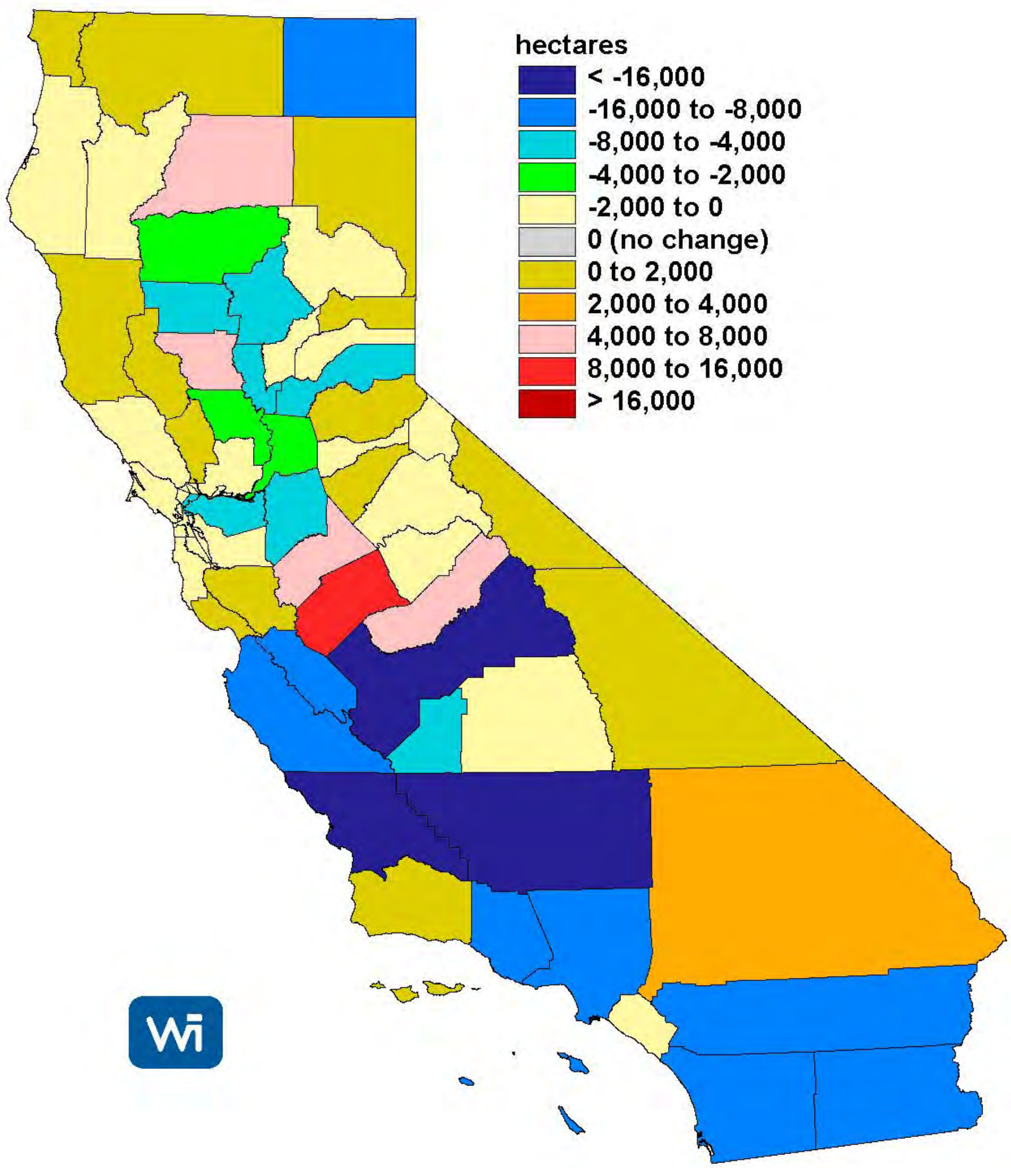

Figure 2-5. Distribution of Area Change in Non-woody Cropland by County. Values Indicate Change in Hectares, Minus Sign Indicates a Loss in Area from 1987 to 1997 and Plus Sign Indicates a Gain in Area in the Same Period

Table 2-4. Agricultural Land Area by County in 1987, 1992, and 1997 (x1000 ha)

COUNTY	1987 Woody	1987 Non-woody	1987 Agricultural Land	1992 Woody	1992 Non-woody	1992 Agricultural Land	1997 Woody	1997 Non-woody	1997 Agricultural Land
Alameda	0.6	9.7	10.3	0.6	8.2	8.8	0.6	9.4	10.0
Alpine	0	0.2	0.2	0	0.2	0.2	0	0.2	0.2
Amador	1.0	1.1	2.1	1.2	0.8	2.0	1.4	0.8	2.2
Butte	36.1	70.2	106.4	34.4	69.3	103.7	36.1	64.8	100.9
Calaveras	0	0	0	0	0	0	0	0.1	0.1
Colusa	13.2	111.4	124.6	11.0	116.4	127.4	10.3	116.0	126.3
Contra Costa	4.2	26.3	30.5	3.7	23.5	27.2	3.4	21.3	24.6
Del Norte	0.9	0	0.9	0.9	0	0.9	0.2	0	0.2
El Dorado	1.1	0	1.1	1.1	0.3	1.4	1.7	0.3	2.0
Fresno	166.5	395.5	562.0	174.9	396.5	571.4	174.4	370.4	544.8
Glenn	16.1	93.0	109.1	12.5	98.5	111.0	24.9	86.3	111.2
Humboldt	0	0.3	0.3	0	0.3	0.3	0	0.1	0.1
Imperial	0	108.4	108.4	0.2	103.0	103.2	0.2	94.9	95.1
Inyo	0	2.8	2.8	0	2.8	2.8	0	4.0	4.0
Kern	111.0	328.6	439.5	110.6	304.1	414.7	110.1	310.4	420.5
Kings	13.2	209.5	222.7	5.6	216.1	221.7	15.9	204.6	220.4
Lake	10.0	2.1	12.1	9.6	2.1	11.7	9.3	2.3	11.6
Lassen	0	26.0	26.0	0	25.3	25.3	0	26.4	26.4
Los Angeles	7.2	25.0	32.2	7.9	14.1	22.0	5.9	11.3	17.2
Madera	65.5	74.9	140.4	65.6	83.1	148.7	60.9	81.6	142.5
Marin	0	1.6	1.6	0	1.6	1.6	0	1.6	1.6
Mendocino	5.3	2.3	7.6	5.3	2.3	7.5	4.4	2.8	7.2
Merced	47.3	152.8	200.1	43.8	165.8	209.6	48.8	161.2	209.9
Modoc	0	53.9	53.9	0	50.1	50.1	0	40.3	40.3
Mono	0	3.8	3.8	0	3.8	3.8	0	4.7	4.7
Monterey	11.9	101.1	113.0	9.9	100.2	110.1	13.2	86.3	99.6
Napa	18.0	2.5	20.5	17.6	2.5	20.1	18.5	2.9	21.4
Orange	5.9	0.6	6.5	2.5	1.1	3.7	2.1	0.6	2.7

Table 2-4. (continued)

COUNTY	1987 Woody	1987 Non-woody	1987 Agricultural Land	1992 Woody	1992 Non-woody	1992 Agricultural Land	1997 Woody	1997 Non-woody	1997 Agricultural Land
Placer	2.2	15.7	17.9	1.9	9.6	11.5	0.2	9.8	10.0
Plumas	0	0.3	0.3	0	0.3	0.3	0	0.3	0.3
Riverside	49.7	93.2	142.9	46.5	83.5	130.1	33.1	83.3	116.4
Sacramento	4.1	75.2	79.3	3.4	75.0	78.4	4.0	73.0	77.0
San Benito	5.3	35.8	41.1	3.5	33.4	36.9	4.0	26.8	30.8
San Bernardino	0	11.3	11.3	0	23.1	23.1	0	14.9	14.9
San Diego	42.5	19.9	62.4	33.4	16.4	49.8	33.1	11.5	44.6
San Francisco	0.6	0	0.6	0.6	0	0.6	0	0	0
San Joaquin	71.0	147.2	218.2	66.6	154.1	220.7	72.3	142.9	215.2
San Luis Obispo	3.8	131.6	135.4	3.2	127.4	130.7	6.4	79.6	86.1
San Mateo	1.2	3.5	4.7	1.2	3.5	4.7	0.8	2.8	3.6
Santa Barbara	9.7	21.7	31.4	9.6	22.3	31.9	11.0	23.1	34.2
Santa Clara	4.9	12.7	17.5	4.2	14.2	18.4	2.6	12.9	15.5
Santa Cruz	3.6	7.2	10.8	3.5	7.5	11.0	2.9	8.0	10.8
Shasta	3.4	18.4	21.8	3.8	24.0	27.7	3.8	23.9	27.7
Sierra	0	2.0	2.0	0	2.0	2.0	0	2.1	2.1
Siskiyou	0.2	45.4	45.6	0	45.6	45.6	0	45.8	45.8
Solano	7.8	56.9	64.7	8.5	56.5	65.0	7.0	56.7	63.7
Sonoma	27.1	35.2	62.3	26.2	34.0	60.1	25.3	33.4	58.7
Stanislaus	65.2	48.2	113.3	54.1	56.9	111.0	57.3	53.2	110.5
Sutter	29.5	93.2	122.7	28.1	95.3	123.4	28.1	87.9	116.1
Tehama	17.8	28.2	46.1	16.6	27.3	43.9	12.3	24.4	36.8
Trinity	0	0	0	0	0	0	0	0	0
Tulare	108.6	178.8	287.4	129.3	170.1	299.4	121.0	178.2	299.2
Tuolumne	0.8	0	0.8	0.8	0	0.8	0.8	0	0.8
Yolo	8.3	140.0	148.2	7.6	137.4	145.1	7.6	137.0	144.6
Yuba	14.2	17.5	31.7	13.5	20.1	33.5	14.9	16.1	30.9
Sum of Counties	1040.1	3074.7	4114.8	1007.8	3055.2	4062.9	1013.0	2870.2	3883.1

The pattern of increase in agricultural land is more complicated. For all agricultural land, there are four counties that had gained more than 3,000 ha. These counties include Tulare (11,817 ha), Merced (9,794 ha), Shasta (5,909 ha) and San Bernardino (3,642 ha). For non-woody cropland, there are six such counties where increase in area exceeded 3,000 ha. Beside Merced (8,337 ha), Shasta (5,544 ha) and San Bernardino (3,642), also included are Colusa (4,654 ha), Stanislaus (5,059 ha) and Shasta (5,544 ha).

Table 2-5. Top 20 Counties where Losses of Cropland and all Agricultural Land are Large (More than 3,000 Hectares) between 1987 to 1997 (All Value in Hectares)

Non-woody cropland		All agricultural land	
County name	**Loss in area**	**County name**	**Loss in area**
BUTTE	-5,423	BUTTE	-5,463
CONTRA COSTA	-4,978	CONTRA COSTA	-5,868
FRESNO	-25,051	FRESNO	-17,200
GLENN	-6,718		
IMPERIAL	-13,517	IMPERIAL	-13,274
KERN	-18,212	KERN	-19,061
KINGS	-4,937		
LOS ANGELES	-13,719	LOS ANGELES	-14,974
MODOC	-13,598	MODOC	-13,598
MONTEREY	-14,812	MONTEREY	-13,477
		ORANGE	-3,845
PLACER	-5,909	PLACER	-7,851
RIVERSIDE	-9,875	RIVERSIDE	-26,508
SAN BENITO	-8,944	SAN BENITO	-10,279
SAN DIEGO	-8,377	SAN DIEGO	-17,847
SAN JOAQUIN	-4,290	SAN JOAQUIN	-3,035
SAN LUIS OBISPO	-51,923	SAN LUIS OBISPO	-49,292
		SONOMA	-3,602
SUTTER	-5,261	SUTTER	-6,678
TEHAMA	-3,804	TEHAMA	-9,308
VENTURA	-15,338	VENTURA	-16,674
YOLO	-2,995	YOLO	-3,642

2.3. Carbon Density of Agricultural Land

For the woody agricultural crops, carbon estimates were determined from planting densities and maximal tree heights from the literature and discussions with experts; some assumptions were made about maximal stem diameters. An allometric regression equation (Winrock unpublished) was applied that determines biomass per plant from height and diameter, and then multiplied by a factor to account for roots. Then biomass per plant was multiplied by planting density resulting an estimate in metric t C per hectare (Table 2-6).

For the non-woody crops, data were obtained on biomass densities from the Food and Agriculture Organization (FAO 1978) for a range of crops typical of the mix found in California. The FAO values indicated the maximum biomass but this cannot be applied directly as the maximum biomass for any crop will only be attained for a very short period of time each year. To incorporate the temporal component, some assumptions were made about growth and harvest cycles. As a final step a weighting was made based on the proportion of each of the crop types in California to develop an estimation for non-woody crop biomass (Table 2-6). It might be of surprise that the non-woody crops have carbon density values that are as high or higher than some woody crop systems. The cause is planting density. Non-woody crops are planted very close so that density approximates 100% of the planted area, in contrast the woody crops have widely spaced rows, usually wide enough for the passage of vehicles. Consequently there may be tens of thousands of wheat or cotton plants per hectare but just 300 walnut trees.

Table 2-6.Carbon Content of Land Cover/use Types (t C/ha)

Specific land use	t C/ha	Range	Broad land use
Horticulture/Fruit	11	7.7 – 14.3	Woody croplands
Horticulture/Nut	21	14.7 – 27.3	Woody croplands
Horticulture/Vineyard	3	2.1 – 3.9	Woody croplands
Horticulture/Berry/other	2	1.4 – 2.6	Woody croplands
Cultivated crops and hay	3	2.1 – 3.9	Non-woody croplands

The estimates projected here are only what have been deduced as a first order approximation. The reality is a highly diverse system with great variability in soil quality, resource availability and farming practice. For example almond trees have been commercially planted at densities between 125 and 500 trees per hectare; trees planted at higher densities are potentially constrained to smaller sizes but it is unclear where biomass as opposed to yield is maximized or what the average value is across California. To give some estimation of uncertainty, a margin of error of plus or minus 30% in the carbon densities of the crop types was applied.

To project the uncertainty of carbon stocks for agricultural land in California, the uncertainty based on the area estimates and the uncertainty for the carbon contents of the various crop types were combined. The statistical method is to take the square root of the sum of the squares of the errors (expressed as ± 95%confidence interval around the mean value). This gives a total margin of error of 31.3%.

2.4. Change in Carbon Stock of Agricultural Land During 1987–1997

In Sections 2.4.1. and 2.4.2., the best estimations of carbon stocks and their change will be discussed. These will be based on the midpoints of the anticipated ranges of stocks. In Section 2.4.3. the uncertainty will be presented along with the implications of this uncertainty.

2.4.1. Carbon Stocks

The total carbon stock of agricultural land in California in 1997 is estimated as 20.3 million tons, with a 4% decrease in stocks between 1987 and 1997. Carbon stocks decreased in non-woody cropland by 0.6 million tons during the period 1987 to 1997; and fluctuated in woody cropland following the trend of change in area (Table 2-7). The overall decrease in carbon stocks on agricultural lands was 0.9 million t C mostly due to the loss in carbon on non-woody cropland.

Despite a three times greater area coverage, the total carbon stock of non-woody crops is lower than that of woody croplands across the whole time period (Figure 2-6, Table 2-7). The decrease in carbon stocks for non-woody croplands is small in the first five-year period (1987-1992) and considerably higher in the second five-year period (1992-1997). In contrast, the change in carbon stock of the woody cropland is a small decrease in the first period followed by a small increase in the second period.

Table 2-7. Carbon Stocks on Agricultural Land and their Change (Million Tons of Carbon)

	Agricultural Land	Woody	Non-woody
1987	21.3	12.0	9.2
1992	20.6	11.5	9.2
1997	20.3	11.7	8.6
1987-1992	-0.6	-0.5	-0.0
1992-1997	-0.3	0.2	-0.6
1987-1997	-0.9	-0.3	-0.6

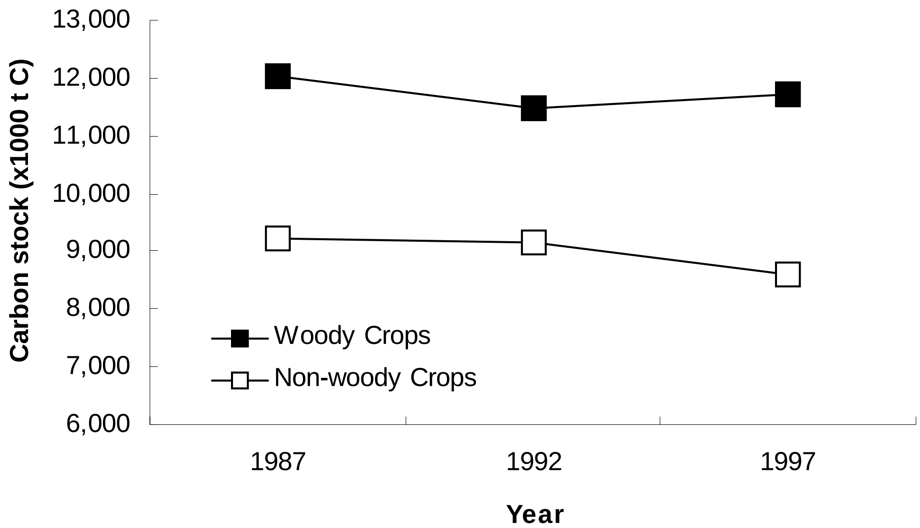

Figure 2-6. Carbon Sock of Woody and Non-woody Croplands between 1987 and 1997

Carbon stocks of specific land cover/use types are detailed in Table 2-8. Small decreases can be seen in the stocks of both fruit and nut orchards (100,000 t C and 300,000 t C respectively). The greatest decrease in this time period is in the non-woody croplands (600,000 t C).

Table 2-8. Carbon Stocks on Agricultural Land and their Change for Specific Land Cover/use Types (Million Tons of C)

	1987	1992	1997
Horticulture/Fruit	3.9	3.8	3.8
Horticulture/Nut	6.8	6.3	6.5
Horticulture/Vineyard	1.3	1.3	1.3
Horticulture/Berry/other	0.07	0.08	0.05
Woody croplands	12.0	11.5	11.7
Non-woody croplands	9.2	9.2	8.6
Total on agricultural land	**21.3**	**20.6**	**20.3**

When converted to carbon dioxide equivalents the total stocks in 1997 on agricultural land in California are estimated as 74.5 $MMTCO_2eq$ (Table 2-9). There was a net loss of 3.5 $MMTCO_2eq$ between 1987 and 1997. This is equal to an average annual source of 0.35 $MMTCO_2eq$. More than 60% of this loss was the loss in biomass of non-woody vegetation, despite the lower overall stocks of carbon in non-woody crops in California.

Table 2-9. Carbon Stocks on Agricultural Land and their Change (Million Tons of Carbon Dioxide Equivalents, $MMTCO_2eq$). Margin of Error is ± 31.4%

	Agricultural Land	Woody	Non-woody
1987	78.0	44.2	33.8
1992	75.6	42.0	33.6
1997	74.5	42.9	31.6
1987-1992	-2.3	-2.1	-0.2
1992-1997	-1.2	0.9	-2.0
1987-1997	-3.5	-1.2	-2.2

2.4.2. Carbon Stocks of Agricultural Land by County

Similar to the spatial pattern of land use and land-use changes, the geographic distribution of carbon stocks in the counties of California is heterogeneous (Figure 2-7 and 2-8; Table 2-10—Nevada and Mariposa counties (no cropland) are omitted from the table). The central valley has the highest carbon; Sierra Nevada and the north coast region have low carbon stocks on agricultural land because they have less area of agricultural land.

The pattern of change in carbon stocks follows closely the pattern of change in cropland area. For woody cropland, most of the counties had little change in carbon stock (Figure 2-9, 2-10 and 2-11). Regionally no clear pattern emerges of increases or decreases in agricultural land.

The absolute changes and the relative (%) changes are listed in Table 2-11. It is apparent that relatively few counties are responsible for a large proportion of the changes. Examples include the losses in woody crop biomass in Stanislaus (- 117,000 t C), Riverside (- 191,000 t C) and Kings (- 397,500 t C) and the gains in Humboldt (+246,000 t C), Glenn (+ 100,000 t C), San Joaquin (+ 125,000 t C) and Tulare (+ 240,000 t C) or the losses in non-woody crop biomass in San Luis Obispo (- 156,000 t C). This mirrors the changes in area.

From this analysis it is apparent that, contrary to the broad results where little change was detected, at the county level there were significant losses of carbon stocks of woody croplands in some counties but that this was balanced by significant gains in others. For example the loss in Kern county (-397,500 t C) exceeds the summed loss for the whole of California (-300,000 t C). The gains and losses in non-woody croplands were less, for example the average gain in carbon stocks between 1987 and 1997 for counties was 58,244 t C for woody croplands but just 5,649 t C for non-woody croplands.

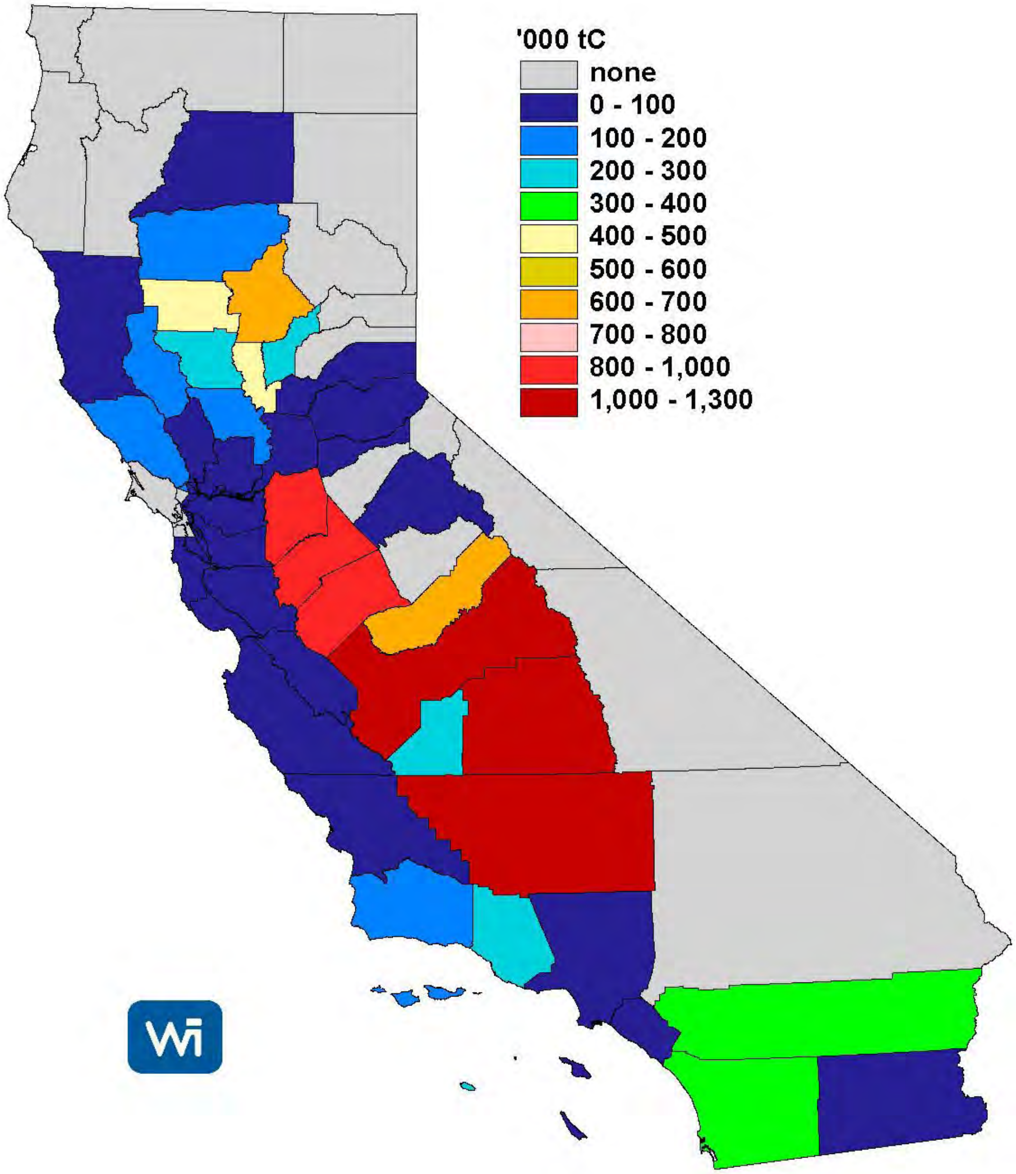

Figure 2-7. Distribution of Carbon Stock (Thousand Tons of Carbon) of Woody Cropland by County, in 1997

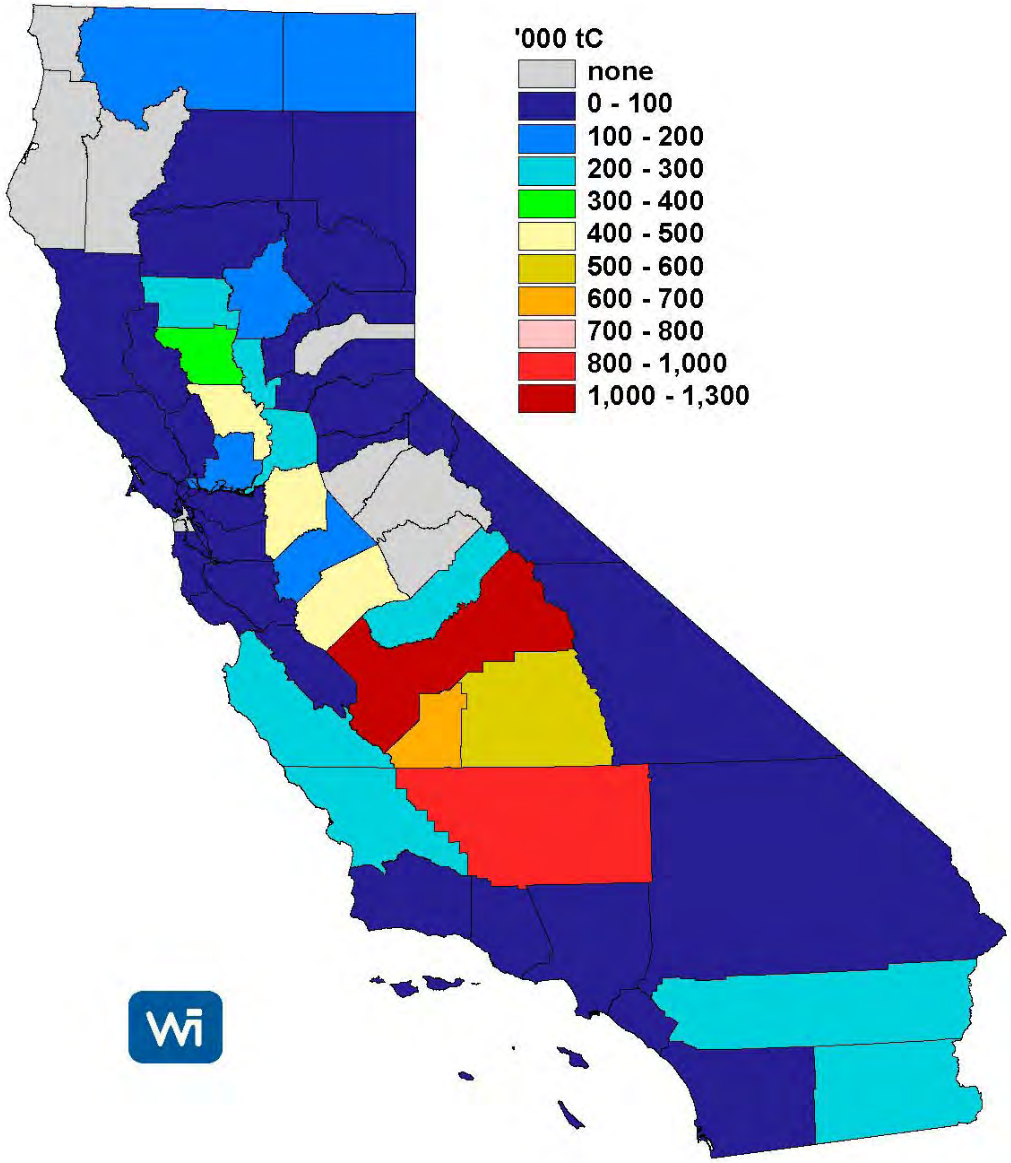

Figure 2-8. Distribution of Carbon Stock (Thousand Tons of Carbon) of Non-woody Cropland by County, in 1997

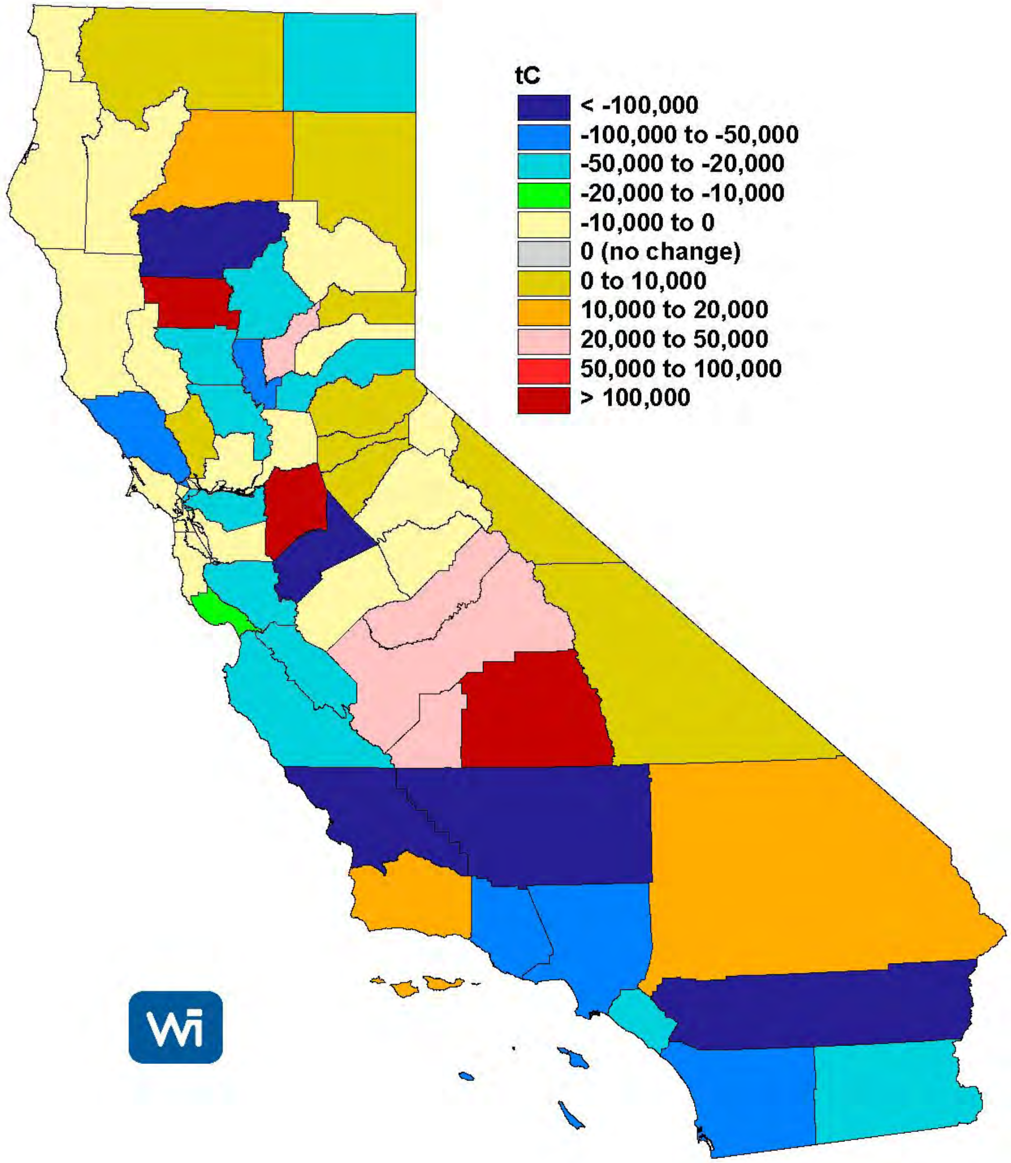

Figure 2-9. Distribution of Changes in Carbon Stocks in All Cropland by County. Values Indicate Change in Thousand Tons of Carbon, a Minus Sign Indicates a Loss and a Plus Sign Indicates a Gain from 1987 to 1997

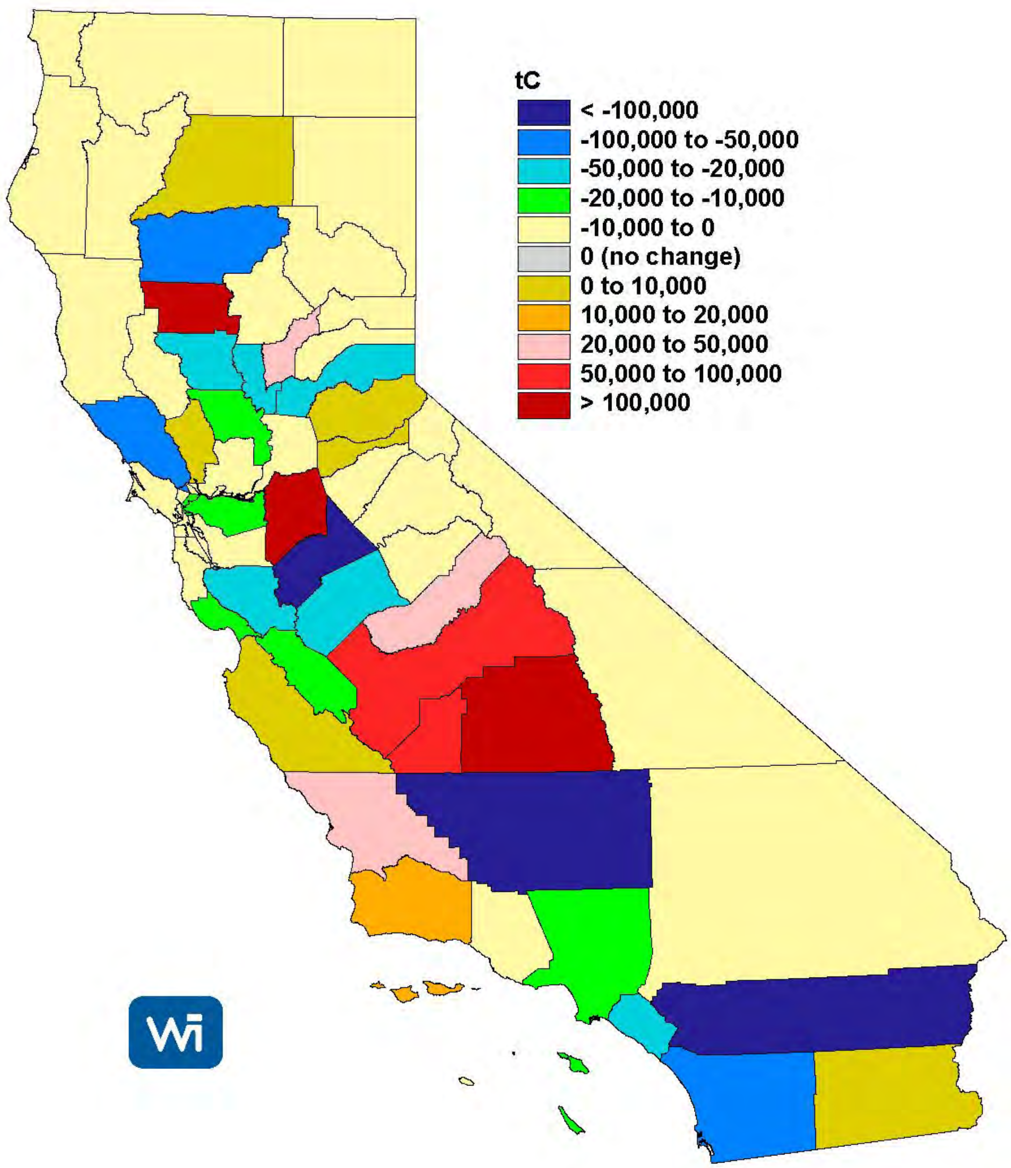

Figure 2-10. Distribution of Changes in Carbon Stocks in Woody Cropland by County. Values Indicate Change in Tons of Carbon, a Minus Sign Indicates a Loss and a Plus Sign Indicates a Gain from 1987 to 1997

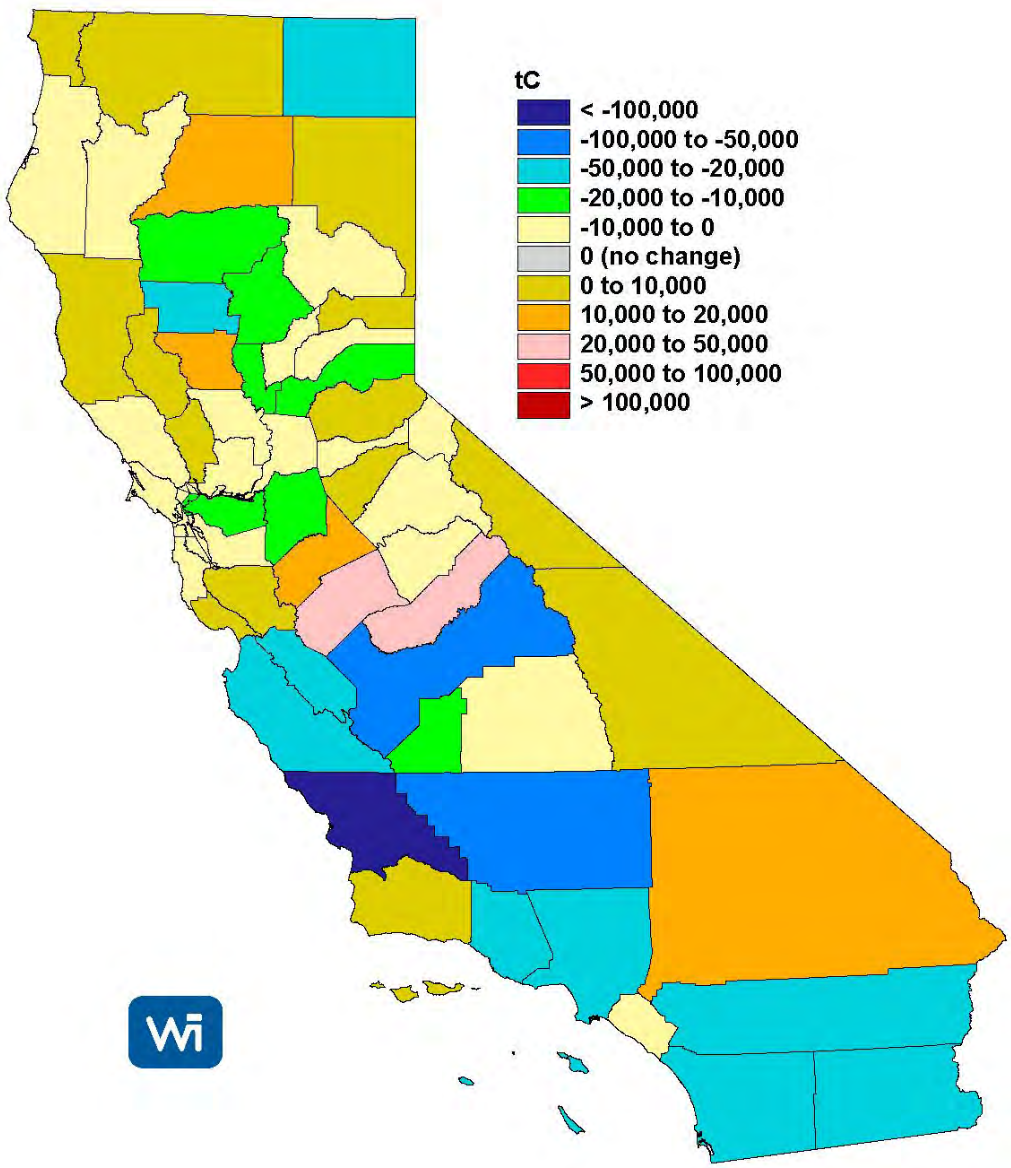

Figure 2-11. Distribution of Changes in Carbon Stocks in Non-woody Cropland by County. Values Indicate Change in Tons of Carbon, a Minus Sign Indicates a Loss and a Plus Sign Indicates a Gain from 1987 to 1997

Table 2-10. Carbon Stock in Agricultural Land by County in 1987, 1992, and 1997 (t C)

COUNTY	1987 Woody	1987 Non-woody	1987 Agricultural Land	1992 Woody	1992 Non-woody	1992 Agricultural Land	1997 Woody	1997 Non-woody	1997 Agricultural Land
Alameda	1.862	29.017	30.879	1.862	24.646	26.508	1.781	28.289	30.069
Alpine	0	728	728	0	728	728	0	728	728
Amador	5,423	3,399	8,822	6,232	2,428	8,661	7,730	2,428	10,158
Butte	655,735	210,646	866,382	613,121	207,854	820,974	650,839	194,377	845,216
Calaveras	0	121	121	0	121	121	0	243	243
Colusa	237,842	334,120	571,963	205,790	349,054	554,844	202,795	348,082	550,878
Contra Costa	75,477	78,795	154,272	63,578	70,418	133,996	57,994	63,862	121,855
Del Norte	8,337	0	8,337	8,337	0	8,337	324	121	445
El Dorado	10,603	0	10,603	10,603	850	11,453	17,726	850	18,576
Fresno	1,183,748	1,186,419	2,370,166	1,166,669	1,189,575	2,356,244	1,283,627	1,111,266	2,394,893
Glenn	227,644	279,000	506,644	211,294	295,633	506,927	473,378	258,846	732,224
Humboldt	0	850	850	0	850	850	0	364	364
Imperial	0	325,257	325,257	2,671	308,867	311,538	2,671	284,706	287,377
Inyo	0	8,377	8,377	0	8,377	8,377	0	12,141	12,141
Kern	1,670,197	985,728	2,655,925	1,731,873	912,396	2,644,269	1,272,620	931,093	2,203,713
Kings	242,577	628,540	871,117	93,405	648,329	741,734	293,286	613,728	907,014
Lake	142,535	6,435	148,970	138,529	6,435	144,964	134,037	7,042	141,078
Lassen	0	77,945	77,945	0	76,003	76,003	0	79,159	79,159
Los Angeles	78,795	75,031	153,826	86,808	42,372	129,180	64,995	33,873	98,868
Madera	667,229	224,730	891,959	737,849	249,255	987,104	693,980	244,884	938,864
Marin	0	4,735	4,735	0	4,735	4,735	0	4,735	4,735
Mendocino	67,787	6,920	74,708	67,787	6,799	74,586	62,688	8,256	70,944
Merced	953,878	458,444	1,412,322	849,870	497,295	1,347,165	928,179	483,455	1,411,634
Modoc	0	161,597	161,597	0	150,427	150,427	0	120,803	120,803
Mono	0	11,413	11,413	0	11,413	11,413	0	14,205	14,205
Monterey	38,608	303,404	342,012	28,248	300,733	328,981	39,661	258,968	298,628
Napa	77,298	7,649	84,947	75,679	7,649	83,328	79,402	8,742	88,144
Orange	47,309	1,943	49,252	22,582	3,399	25,982	19,142	1,700	20,842
Placer	24,363	47,107	71,470	21,287	28,653	49,940	971	29,381	30,353

Table 2-10 (continued)

COUNTY	1987 Woody	1987 Non-woody	1987 Agricultural Land	1992 Woody	1992 Non-woody	1992 Agricultural Land	1997 Woody	1997 Non-woody	1997 Agricultural Land
Plumas	0	971	971	0	971	971	0	971	971
Riverside	515,143	279,607	794,750	480,419	250,590	731,010	324,043	249,983	574,026
Sacramento	23,999	225,580	249,578	19,830	224,973	244,803	22,380	219,024	241,404
San Benito	68,232	107,326	175,559	55,282	100,163	155,445	53,259	80,495	133,753
San Bernardino	0	33,752	33,752	0	69,325	69,325	0	44,679	44,679
San Diego	381,187	59,612	440,799	339,220	49,171	388,391	315,626	34,480	350,106
San Francisco	2,428	0	2,428	2,266	0	2,266	0	0	0
San Joaquin	812,111	441,568	1,253,680	726,356	462,329	1,188,685	937,285	428,699	1,365,984
San Luis Obispo	50,021	394,704	444,725	47,755	382,320	430,075	79,807	238,935	318,742
San Mateo	3,885	10,441	14,326	3,885	10,441	14,326	1,700	8,256	9,956
Santa Barbara	91,826	65,197	157,024	89,762	67,018	156,781	102,065	69,447	171,512
Santa Clara	57,467	38,001	95,469	47,471	42,736	90,208	27,317	38,730	66,047
Santa Cruz	28,046	21,611	49,657	23,796	22,461	46,257	15,581	23,918	39,499
Shasta	16,107	55,120	71,227	16,755	71,875	88,629	17,604	71,753	89,358
Sierra	0	5,949	5,949	0	5,949	5,949	0	6,313	6,313
Siskiyou	405	136,222	136,627	0	136,829	136,829	0	137,315	137,315
Solano	90,329	170,581	260,910	95,307	169,488	264,795	87,739	170,095	257,834
Sonoma	174,304	105,748	280,052	161,394	101,863	263,257	121,572	100,285	221,857
Stanislaus	996,898	144,478	1,141,375	841,614	170,824	1,012,438	879,858	159,654	1,039,512
Sutter	464,191	279,607	743,798	416,234	285,921	702,155	425,947	263,824	689,771
Tehama	258,077	84,744	342,821	243,913	81,830	325,743	166,372	73,332	239,704
Trinity	0	0	0	0	0	0	0	0	0
Tulare	994,550	536,389	1,530,940	1,138,947	510,286	1,649,233	1,234,861	534,690	1,769,551
Tuolumne	9,349	0	9,349	9,349	0	9,349	9,349	0	9,349
Ventura	246,705	96,157	342,862	242,011	70,296	312,307	237,114	50,142	287,256
Yolo	149,091	419,957	569,049	136,343	412,308	548,652	135,494	410,973	546,466
Yuba	191,706	52,449	244,156	180,011	60,219	240,230	220,035	48,200	268,235
Sum of Counties	12,043,305	9,224,125	21,267,430	11,461,994	9,165,484	20,627,478	11,702,831	8,610,519	20,313,350

Table 2-11. Absolute and Relative Changes in Carbon Stocks on Agricultural Land for Woody and Non-woody Cropland

County Name	Absolute change (t C)			Relative change (%)		
	Woody cropland	Non-woody cropland	Agricultural land	Woody cropland	Non-woody cropland	Agricultural land
ALPINE	-81	-728	-809	-4	-3	-3
AMADOR	0	0	0	0	0	0
BUTTE	2,307	-971	1,336	43	-29	15
CALAVERAS	-4,897	-16,269	-21,166	-1	-8	-2
COLUSA	0	121	121	0	100	100
CONTRA COSTA	-35,047	13,962	-21,085	-15	4	-4
DEL NORTE	-17,483	-14,933	-32,416	-23	-19	-21
EL DORADO	-8,013	121	-7,892	-96	0	-95
FRESNO	7,123	850	7,973	67	0	75
GLENN	99,880	-75,153	24,727	8	-6	1
HUMBOLDT	245,734	-20,154	225,580	108	-7	45
IMPERIAL	0	-486	-486	0	-57	-57
INYO	2,671	-40,551	-37,880	0	-12	-12
KERN	0	3,764	3,764	0	45	45
KINGS	-397,577	-54,635	-452,212	-24	-6	-17
LAKE	50,709	-14,812	35,897	21	-2	4
LASSEN	-8,499	607	-7,892	-6	9	-5
LOS ANGELES	0	1,214	1,214	0	2	2
MADERA	-13,800	-41,158	-54,958	-18	-55	-36
MARIN	26,751	20,154	46,905	4	9	5
MARIPOSA	0	0	0	0	0	0
MENDOCINO	0	0	0	0	0	0
MERCED	-5,099	1,336	-3,764	-8	19	-5
MODOC	-25,698	25,010	-688	-3	5	0
MONO	0	-40,794	-40,794	0	-25	-25
MONTEREY	0	2,792	2,792	0	24	24
ALPINE	1,052	-44,436	-43,384	3	-15	-13
NAPA	2,104	1,093	3,197	3	14	4
NEVADA	0	0	0	0	0	0
ORANGE	-28,167	-243	-28,410	-60	-13	-58
PLACER	-23,392	-17,726	-41,118	-96	-38	-58
PLUMAS	0	0	0	0	0	0
RIVERSIDE	-191,099	-29,624	-220,723	-37	-11	-28

Table 2-11. (continued)

County Name	Absolute change (t C)			Relative change (%)		
	Woody cropland	Non-woody cropland	Agricultural land	Woody cropland	Non-woody cropland	Agricultural land
SACRAMENTO	-1,619	-6,556	-8,175	-7	-3	-3
SAN BENITO	-14,974	-26,832	-41,806	-22	-25	-24
SAN BERNARDINO	0	10,927	10,927	0	32	32
SAN DIEGO	-65,561	-25,132	-90,693	-17	-42	-21
SAN FRANCISCO	-2,428	0	-2,428	-100	0	-100
SAN JOAQUIN	125,174	-12,869	112,304	15	-3	9
SAN LUIS OBISPO	29,786	-155,769	-125,983	60	-39	-28
SAN MATEO	-2,185	-2,185	-4,371	-56	-21	-31
SANTA BARBARA	10,239	4,249	14,488	11	7	9
SANTA CLARA	-30,150	728	-29,422	-52	2	-31
SANTA CRUZ	-12,465	2,307	-10,158	-44	11	-20
SHASTA	1,497	16,633	18,131	9	30	25
SIERRA	0	364	364	0	6	6
SISKIYOU	-405	1,093	688	-100	1	1
SOLANO	-2,590	-486	-3,076	-3	0	-1
SONOMA	-52,732	-5,463	-58,196	-30	-5	-21
STANISLAUS	-117,039	15,176	-101,863	-12	11	-9
SUTTER	-38,244	-15,783	-54,027	-8	-6	-7
TEHAMA	-91,705	-11,413	-103,118	-36	-13	-30
TRINITY	0	0	0	0	0	0
TULARE	240,311	-1,700	238,611	24	0	16
TUOLUMNE	0	0	0	0	0	0
VENTURA	-9,591	-46,014	-55,606	-4	-48	-16
YOLO	-13,598	-8,984	-22,582	-9	-2	-4
YUBA	28,329	-4,249	24,080	15	-8	10

2.4.3. The Uncertainty in Carbon Stock Estimations

The uncertainty in the estimations reported here is high. Confidence lies within a range of plus or minus 31.3% of the values reported in the previous sections. The uncertainty is generated from two areas:

1. NRI data: the NRI reports a margin of error of 9% for cropland in California.
2. Carbon densities of crop types. High uncertainty (30%) exists around the estimation of crop carbon densities.

2.4.3.1. Effect of uncertainties

The theoretical consequence of the uncertainty is to provide a wide range within which the true carbon stock and changes in carbon stock are located (Figure 2-12). For the all croplands, the carbon stocks would be between 14.6 and 28.0 million tons of carbon (M t C) in 1987 and 13.9 to 26.7 M t C in 1997. From these ranges it is possible that any combination of outcomes could have occurred from a steady increase in stocks of 12.1 M t C over the ten years to a steady decrease in stocks of 14.1 M t C to no change at all. However, the midpoint values used and the stock change explained in the previous sections are a reasonable estimation. Confirmation is offered by the fact that the pattern of change in stocks mirrors the change in area, which has a much higher certainty. Therefore it is a fair assumption that the form and magnitude of the results are a fair representation.

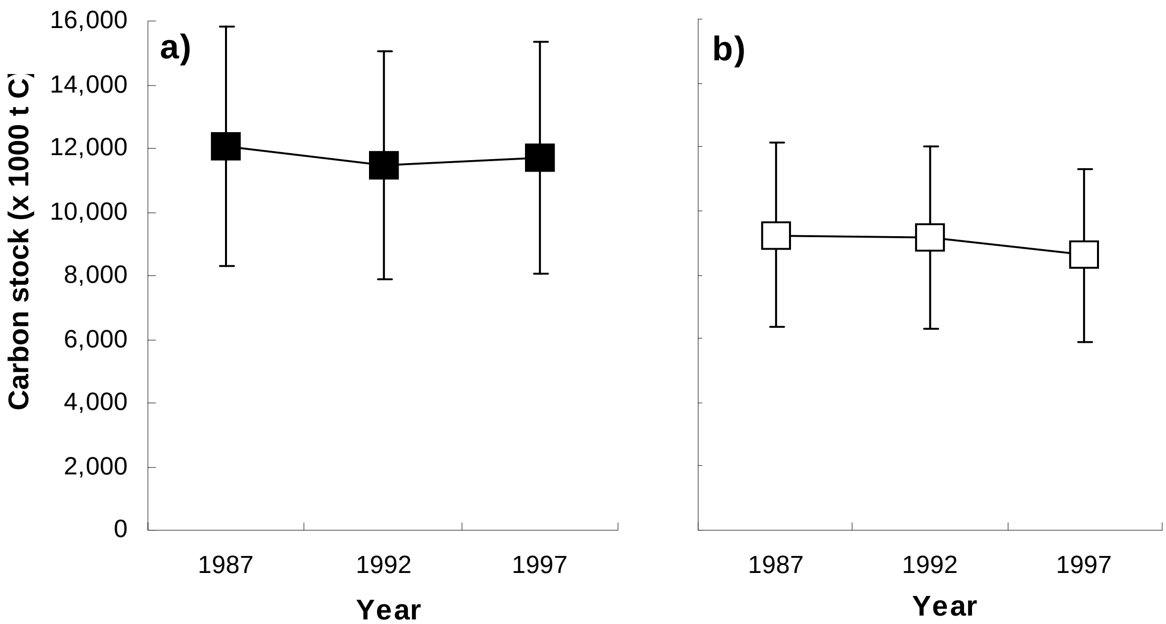

Figure 2-12. Carbon Stock of (a) Woody and (b) Non-woody Croplands Between 1987 and 1997 (mean ± 95% CI)

2.4.3.2. Potential for decreasing uncertainty

The overwhelming cause of uncertainty is the carbon densities employed here, which due to a lack of data could only be a first order approximation. It would, however, be relatively simple to greatly enhance the certainty of the numbers. It would not be difficult to refine the estimates of carbon densities in crop types; it would require the destructive harvesting of examples of the various crop types in regions around California, and for woody crops estimates of their planting density.

2.4.4. Non-CO_2 Greenhouse Gases

The primary non-CO_2 gas of importance to this section is nitrous oxide. Nitrous oxide is emitted from agricultural soils especially after fertilizer additions. Between 1990 and 1999 the California Energy Commission report a mean annual source of nitrous oxide from Californian agriculture equal to 14.54 ± 0.56 $MMTCO_2eq$ (mean ± 95% confidence interval) with no trend of increase or decrease (CEC, 2002). This is more than an order of magnitude greater than the annual source of CO_2 directly from changes in carbon stocks (0.35 $MMTCO_2eq$ per year). The CO_2 equivalents from nitrous oxide make up 98% of the total summed annual source calculated in this section for California agriculture.

On a magnitude more comparable with carbon dioxide, emissions of methane also result from agriculture. Excluding livestock processes, on average between 1990 and 1999 0.47 $MMTCO_2eq$/yr in emissions resulted from flooded rice fields in California and 0.04 $MMTCO_2eq$/yr from the burning of agricultural residues (CEC, 2002).

2.5. Conclusions

- In 1997 about 4 million hectares (9.9 million acres) were extant in agriculture in California (excluding livestock grazing lands dealt with in the rangelands report). Of this area 74% was in non-woody crops versus 26% in woody crops.
- The total carbon stock was estimated to be 74.5 $MMTCO_2eq$, of which 42% was in non-woody crops versus 58% in woody crops.
- Between 1987 and 1997, 232,000 ha of agricultural land were converted to other uses. Eighty-eight percent of this change was in non-woody crops.
- The change in cropland area was estimated to equal a net loss of 3.5 $MMTCO_2eq$ over the 10-year period, of which 63% was due to the decrease in non-woody croplands.
- At a county scale, the changes were more significant with, for example, losses in woody crop biomass of 1.5 $MMTCO_2eq$ in Kings or a gain of 0.92 $MMTCO_2eq$ in Humboldt between the same dates (1987 and 1997).
- The overwhelmingly dominant non-CO_2 gas emitted from non-livestock agriculture in California is nitrous oxide (N_2O). The California Energy Commission reported that between 1990 and 1999 the mean annual emissions was 14.54 $MMTCO_2eq$. In comparison the annual source in the form of carbon is here calculated as 0.35 $MMTCO_2eq$.
- Therefore the total annual source of greenhouse gases in California was 14.89 $MMTCO_2eq$ of which only 2% was from carbon losses.
- Using the NRI data, it will be possible to update this baseline when new inventory data are released (e.g., the 2002 NRI due for release in 2004).
- The greatest problem with the NRI data is that it is unclear where an increase or decrease has occurred and what the starting or ending condition was. Because of this, it is not possible to individually track detailed changes through time nor is it possible to know the consequence of the change. For example has the land been lost to development, to grazing or to another crop?
- Sources of error are potentially more abundant in the estimation of carbon densities. This is less likely to be significant for the non-woody crops but more information is needed for the woody crops. These data would be simple to collect and would enhance the accuracy and precision of projections.

2.6. References

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