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Baseline greenhouse gas emissions and removals for forest and rangelands in California

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BASELINE GREENHOUSE GAS EMISSIONS FOR FORESTS AND RANGELANDS IN CALIFORNIA

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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 Forests and Rangelands 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

This report titled *Baseline Greenhouse Gas Emissions and Removals for Forests and Rangelands in California* sought to quantify the baseline of changes in carbon stocks on forest and range 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*. The report replaces an earlier assessment that only included three out of the five California regions and in addition enhances the estimates of forest carbon sequestration. These baselines provide an estimate of the emissions and removals of GHGs attributable to changes in the use and management of forest and rangeland.

The analysis revealed that forests and rangelands were responsible for a net removal of carbon dioxide from the atmosphere of 24.95 million metric tons of carbon dioxide per year ($MMTCO_2eq/yr$). Non-CO_2 GHG emissions from forest and range lands were estimated to be 0.21 $MMTCO_2eq/yr$, or equivalent to about 0.86% of the removals by these systems. The overall net result was a removal of 23.0 $MMTCO_2eq/yr$ by forests and 1.9 $MMTCO_2eq/yr$ by rangelands.

Executive Summary

Objectives

This report's goal is to quantify the baseline of changes in carbon stocks on forest and range 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 and rangeland sectors were incomplete and did not include all the changes taking place on these lands.

In 2004 Winrock published a report on baseline emissions from forests, rangelands and agriculture from the same time period (Brown et al. 2004), however, in this earlier report data for only three out of the five regions were available for assessment. In this report all five regions are included and enhancements have been made in how the carbon sequestration of forest and rangeland areas with no measureable changes in canopy cover is accounted.

Outcomes

In this report, methods for estimating baseline carbon emissions and removals from forests and rangelands are presented with corresponding results. However, given the nature of the databases used in this analysis, the time periods encompassed by the baselines vary. Across the five regions of California the assessment periods varied with different periods for each region of 4 to 6 years between 1994 and 2002.

To develop the baselines, three types of data were used: (1) the area of the forests and rangelands at the start and end of the time interval, (2) the area and magnitude of change in canopy cover during the time interval, and (3) the carbon stocks in each land-use type for each time. Areas were derived from the California Land Cover Mapping and Monitoring Program (LCMMP). Carbon estimates for various forests and rangeland types with corresponding canopy cover were derived from Forest Inventory and Analysis (FIA) datathe literature and California Department of Forestry's Fire and Resource Assessment Program (FRAP)staff.

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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 24.95 $MMTCO_2eq/yr$ (Table S-1). Non-CO_2 GHG emissions from forest and range lands were estimated to be 0.16 $MMTCO_2eq/yr$, or equivalent to about 0.76% of the removals by these systems. The overall net result was a removal of 23.01 $MMTCO_2eq/yr$ by forests and 1.94 $MMTCO_2eq/yr$ by rangelands.

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]	**+ 23.19**	**- 0.015**[2]	**- 0.166**[3]
Rangelands[1]	**+ 1.97**	**- 0.003**[2]	**- 0.031**[3]
	+25.16	**-0.017**	**-0.197**

[1] Measurement interval between 1994-2002 (actual period and number of years varies between regions)
[2] Calculated only for fire
[3] Calculated only for fire and harvest

The baseline 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 data. In other words, the baseline includes all changes in carbon stocks, from measured and unmeasured changes in canopy coverage.

The previous version of this assessment used a single carbon sequestration rate per forest type across all three regions to estimate the sequestration in forests with no measurable change in canopy cover. In addition, this rate was calculated from a data set that itself was for net emissions. Here we calculate a sequestration rate from FIA data for each forest and rangeland type in each of the five regions.

A change in canopy cover was measured on 4,622 km^2 of forests and rangelands across California. This is approximately 1.8% of the total area of forests and rangeland in the regions. For 83% of the changed area, the cause of change was identified and verified.

For forests, a removal of 27.10 $MMTCO_2eq/yr$ and an emission of 4.09 $MMTCO_2eq/yr$ were estimated (Table S-2). The greatest emissions were found in the North Sierra region with its dry conditions and resultant fires, as well as timber harvesting. 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 removal of 2.57 $MMTCO_2eq/yr$ exceeding an emission of 0.63 $MMTCO_2eq/yr$ (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	15.16	0.07	0.54
Cascade Northeast	0.88	5.44	0.08	0.45
North Sierra	1.49	4.74	0.12	0.22
South Sierra	0.22	1.10	0.05	0.47
South Coast	0.11	0.66	0.30	0.89
TOTAL	**4.09**	**27.10**	**0.63**	**2.57**

Fire and harvest were the dominant causes of emissions on forestlands; these causes were responsible for 1.83 $MMTCO_2eq/yr$ and 1.42 $MMTCO_2eq/yr$ respectively. On rangeland, harvest was less important, accounting for just 5% of the total emissions as opposed to 54% 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 California. However, much of the unverified change could include development that tends to occur in smaller patches than those recorded under the pattern of verified changes.

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

$MMTCO_2eq/yr$	*FORESTS*	*RANGELANDS*
Fire	-1.83	-0.34
Harvest	-1.42	-0.03
Development	-0.01	-0.01
Other/Unverified	-0.83	-0.24
Regrowth	+ 27.10	+ 2.57

- 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. The largest increases in carbon stocks (detectable and undetectable canopy change) are in the high volume fast-growing conifer forests of the North Coast and Cascades Northeast. Despite a high fire incidence the lower carbon stocks of the forests in the southern regions leads to emissions levels that are not greatly elevated.

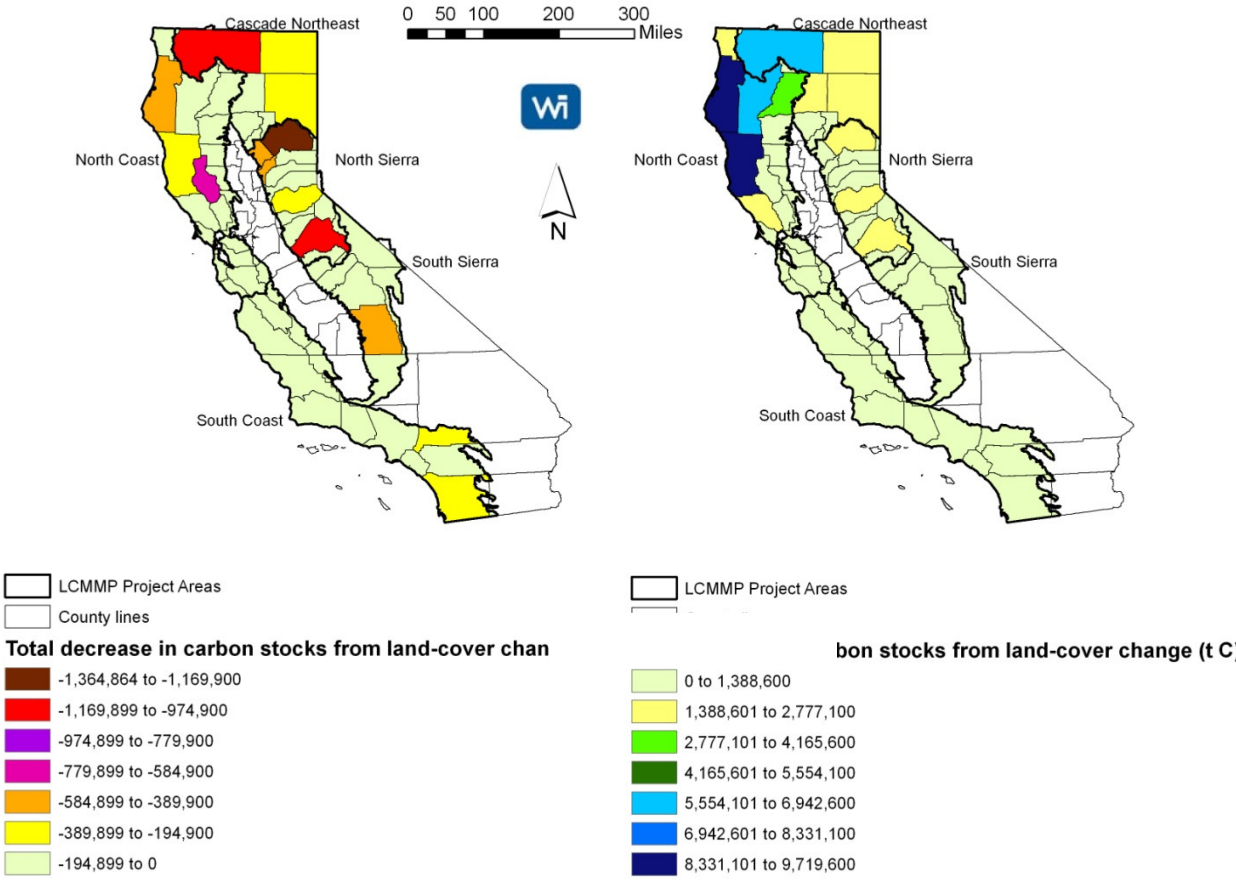

Figure S-1. County Level Summary of the Decreases (Left figure), and Increases (right figure) in Carbon Stocks on Forests and Rangelands in the North Coast (1994-1998), the Cascades Northeast (1994-1999), North Sierra (1995-2000), South Sierra (1995-2001) and South Coast (1997-2002).

The estimated total removals of 27.10 MMTCO_2eq/yr and emissions of 4.09 MMTCO_2eq/yr (net 23.01 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). 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 1994/1995-2002.

The estimated removal also differs from the previous Winrock assessment of 10.96 MMTCO_2eq/yr and emissions of 3.76 MMTCO_2eq/yr, based on only three regions of California. The difference between the previous estimate and the one produced in this report is accounted for through the inclusion of the final two regions (South Coast and South Sierra) and the use of an improved method for calculating sequestration in the forests with no canopy cover change[2].

[2] The lower emissions, even with the two added regions, are due to low emissions from forests in the South Sierra and South Coast regions and a recalculation for the North Coast region - standardized to a five year period instead of

1.0 General Approach

This report follows from and builds on an earlier assessment of baseline sequestration and emissions for Californian forests and rangelands (Brown et al. 2004). Due to data availability, the earlier assessment only examined three out of five forest and rangeland regions in California. This report includes the additional two regions – South Sierra and South Coast. In addition, improvements have been made in the methodology of calculating the annual sequestration from forests with no measurable change (could be a loss of gain) in canopy cover.

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. 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 obtained from maps developed by 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 three processes: 1) measurable decreases in canopy cover and the resulting decreases in carbon stocks (emissions of carbon), 2) measurable increases in canopy cover and resulting increases in carbon stocks, and 3) gains in carbon stocks for forests and rangelands that had no detectable measure of change in canopy closure in the remote sensing imagery. 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 assumed an increase in carbon stocks for all forests and rangelands that showed no detectable change in canopy closure. We used 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.

2.0 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

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four years used in the original calculation 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):

- 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.

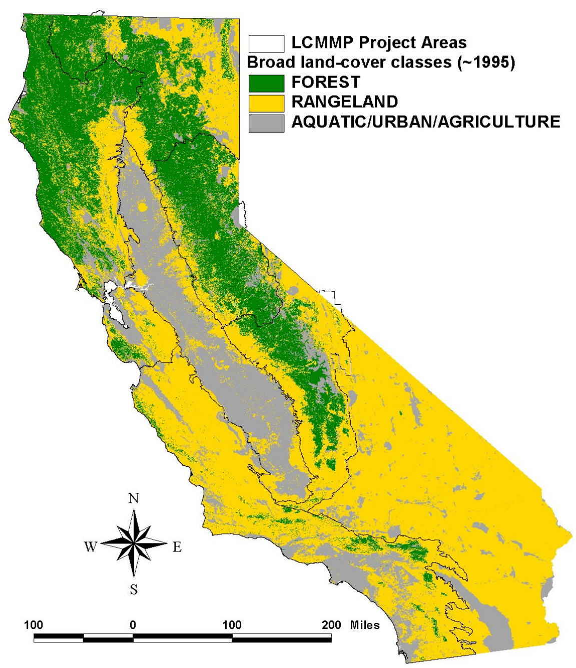

Figure 1. The CDF-FRAP Multi-source Land-cover Map Reclassified into Three Broad Classes with the LCMMP Regions Superimposed on Top in Black

3.0 Area of Forests and Rangelands

3.1. Calculating Areas from Satellite Data

3.1.1. 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.

3.1.2. 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 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%)

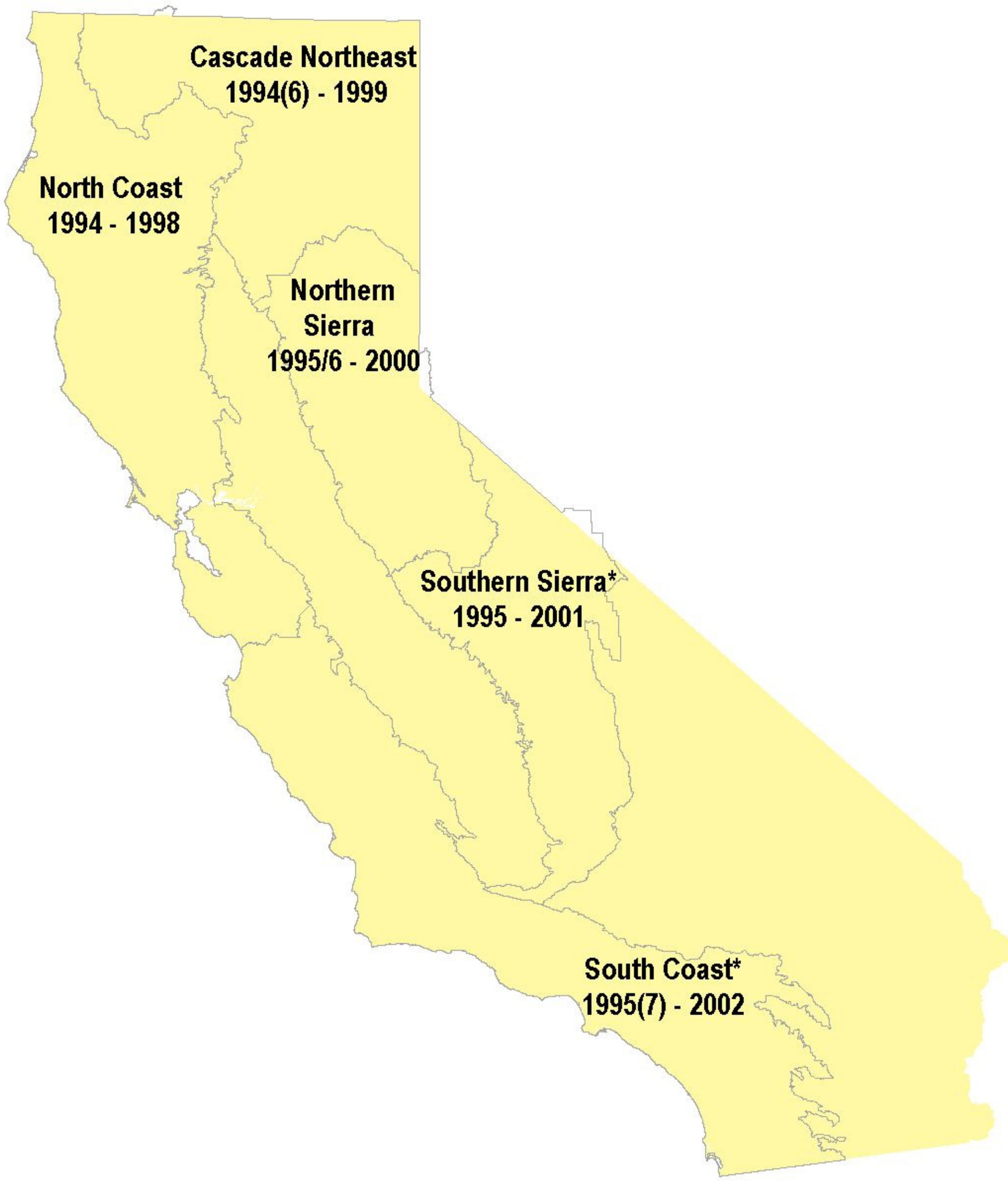

Figure 2. Satellite Image Dates for CDF-FRAP's LCMMP Change Analysis (Time 1–Time 2).

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

- Large Decrease in Vegetation
- Moderate Decrease in Vegetation
- Small Decrease in Vegetation

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

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

- 71 to 100% cover decrease
- 41 to 70% cover decrease
- 16 to 40% cover decrease
- +15 to -15% (Little or No Change)
- 16 to 40% cover increase
- 41 to 100% cover increase
- Shrub/Grass Decrease > 15%
- Shrub/Grass Increase > 15%
- Non-vegetative Change Including Urban (or "Change within Existing Urban Area" in some regions)
- Cloud/Shadow/Smoke (includes "fog" in some regions)

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

Table 1. California Regions and Dates of Baselines, Cause and Change Data

Area	Baseline years	Assumed # years
Cascade Northeast	1994– 1999	5
North Coast	1994 - 1998	4
North Sierra	1995/6 - 2000	5
South Coast	1995(7) - 2002	6
South Sierra	1995 - 2001	6

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.

3.1.3. 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).

4.0 Carbon Stocks in Forests and Rangelands

4.1. 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 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 2):

- Forests
    - Douglas fir
    - Fir-Spruce
    - Redwood
    - Other Conifer
    - Hardwood
    - Shrubs and Grasses[3]
- Rangelands
    - Woodland Vegetation
    - Shrubs and Grasses

---

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

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

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 (Figure 4).

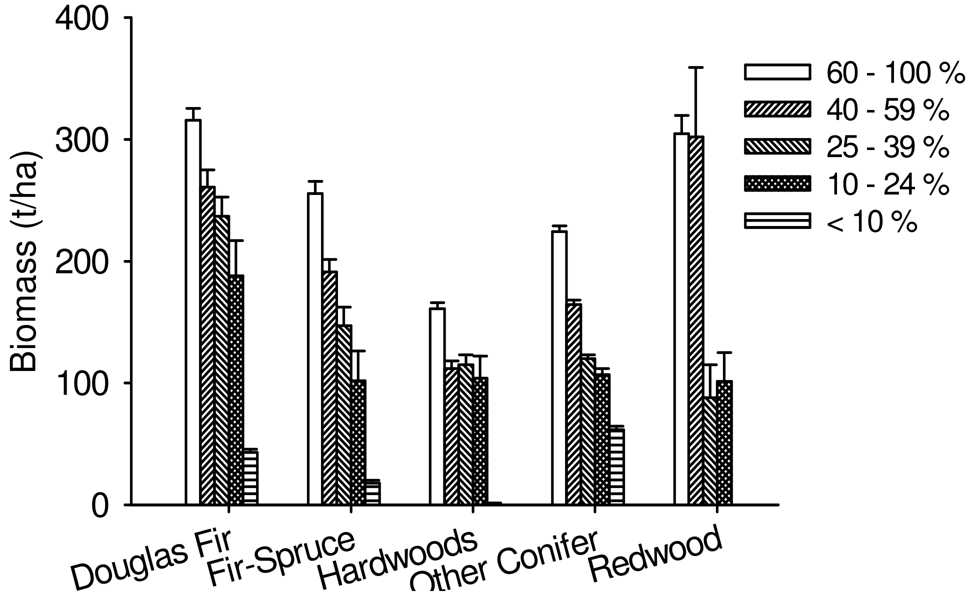

Figure 3. Mean Above- and Below-ground Biomass Estimates (± 1 SE) Calculated for Each Canopy Crown Coverage Class (in %)

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.

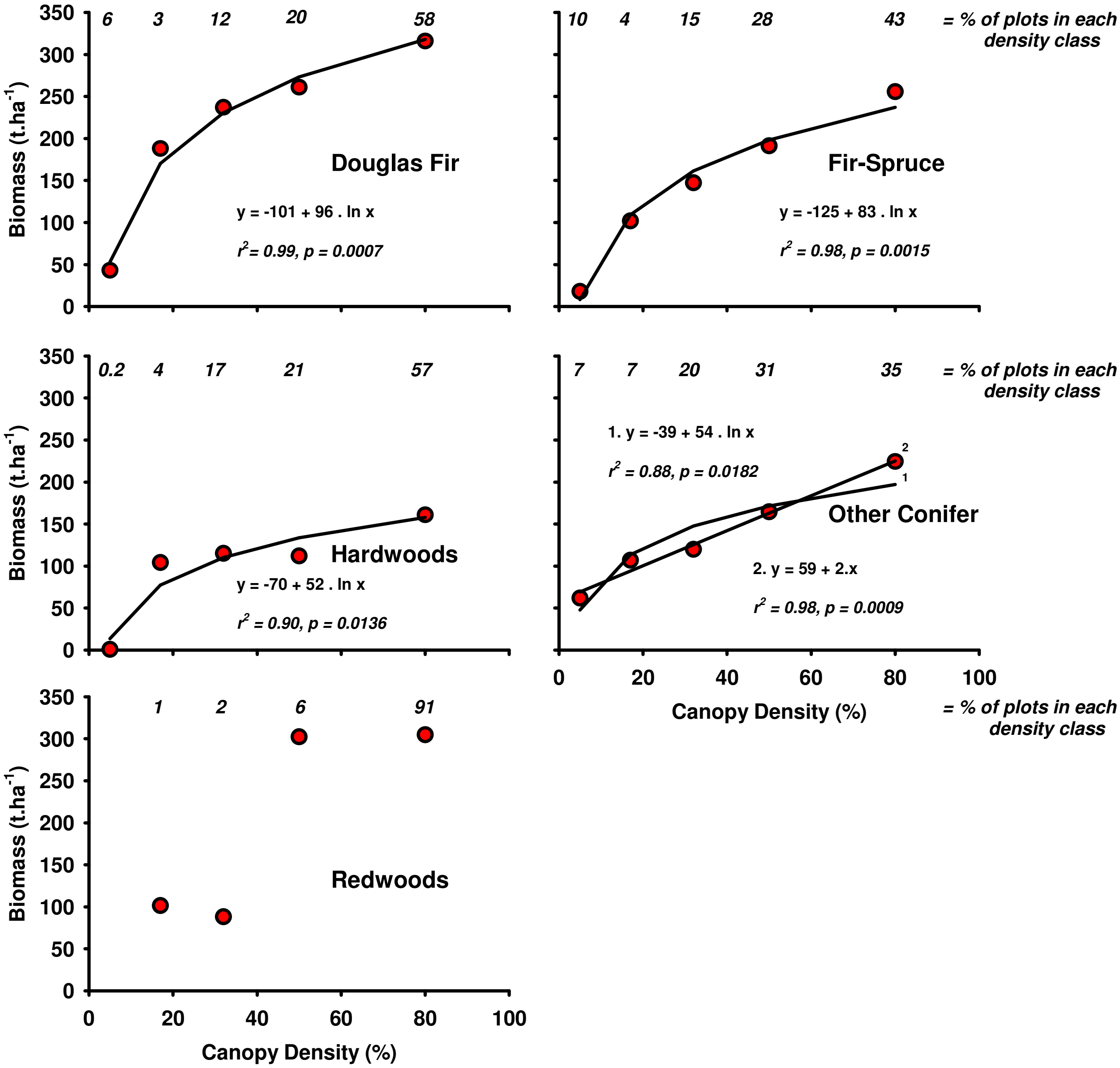

Figure 4. Relationships between Biomass (t/ha) and Canopy Coverage (%). Regression Equations, r^2 and p Values are Indicated. For Each Species the Percentage of Individual Plot Data Recorded in Each Density Class is Indicated above the Graphs

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 43t 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%).

4.2. 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).

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

We use data from the USFS FIA database to estimate 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. .

For California, FIA data are available for 1994 and then from annual inventory data between 2001 and 2007. The data from 1994 do not include plot data from the National Forests and so the later time period is used here. The West Coast is on a ten year cycle for plot remeasurement so data are used from across the 2001-2007 period. Although this only barely overlaps with the spatial analysis time period the resulting growth rates are used with the assumption that the distribution of species groups and age classes is likely to be broadly consistent through time and space. In this analysis the current distribution of biomass values is used to approximate the rate at which carbon in biomass accumulates through time.

From the FIA web site, we downloaded total aboveground oven-dried biomass stocks and total forest areas by forest type, by five-year age classes and by county. Dividing total stock by area gives a biomass stock per hectare for each forest type[4]. These biomass values were plotted against age and a curve fitted for each forest type (Figures 5 and 6).

4 For Western White Pine, Hemlock Sitka Spruce and Elm Ash Cottonwood FIA data were used from plots in all Western states (CA, OR, WA, ID, MT, CO, NV, AZ, NM, WY, UT) rather than just California alone due to the paucity of data in CA alone.

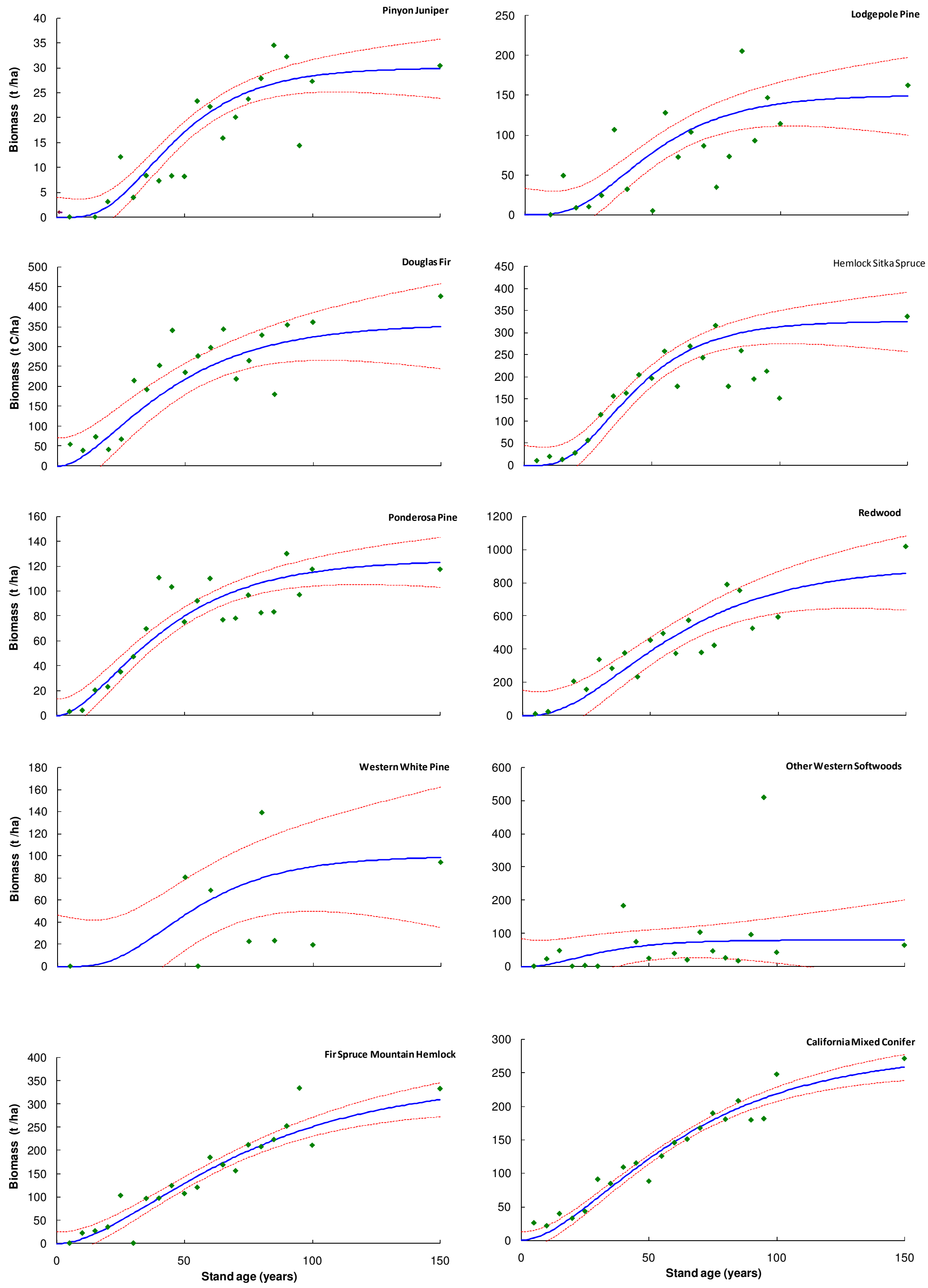

Figure 5. Relationships between aboveground biomass and age for softwood forest species groups in California derived from USFS FIA data. Shown are the FIA data for each age class and the curve giving the best fit to the data (blue line) plus and minus 95% confidence interval (red lines)

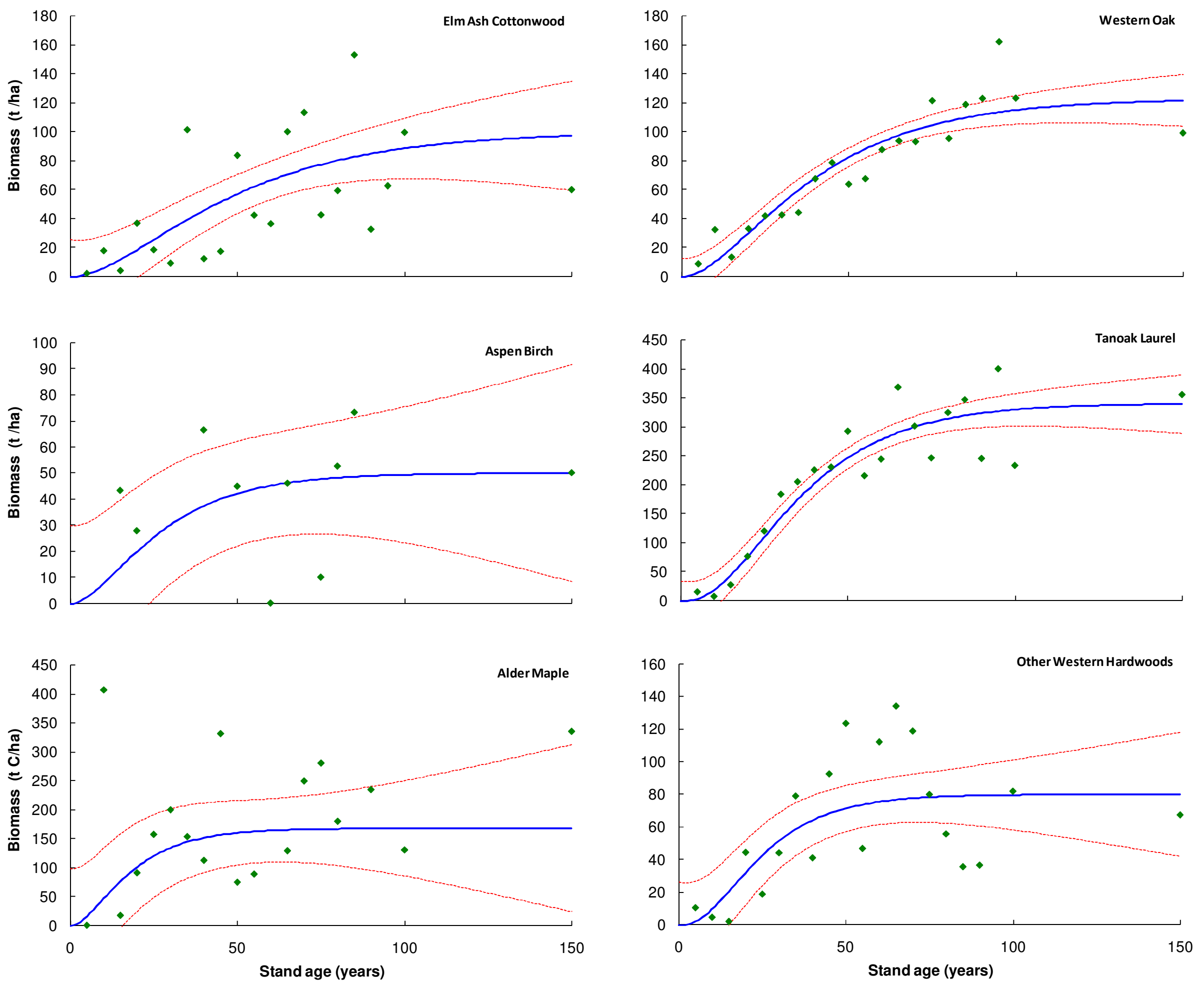

Figure 6. Relationships between aboveground biomass and age for hardwood forest species groups in California derived from USFS FIA data. Shown are the FIA data for each age class and the curve giving the best fit to the data (blue line) plus and minus 95% confidence interval (red lines

From the models in Figs 5 and 6, the mean annual sequestration rate was calculated in each 5-year age class for each forest type (see Figure 7).

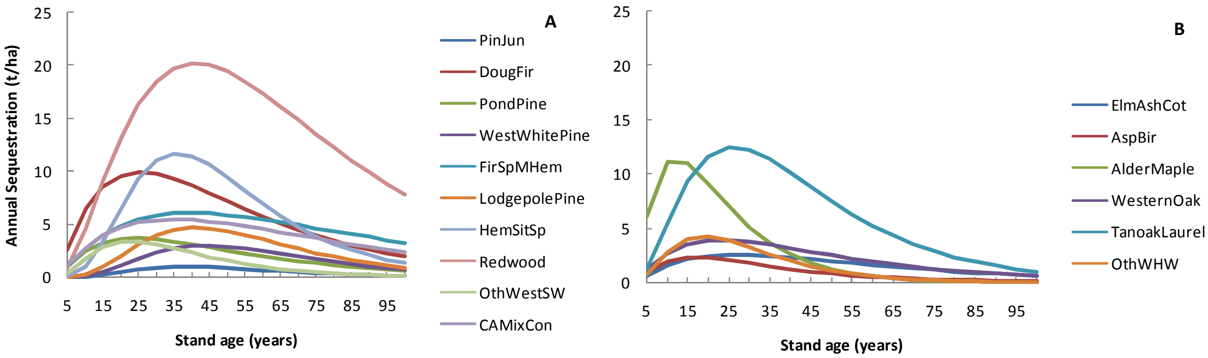

Figure 7. Aboveground biomass accumulation curves for each of the FIA species groups. A – softwoods; B - hardwoods

The FIA forest types were cross-walked to the Smith categories (Table 3). Within each forest type the distribution of forest areas across FRAP regions, FIA forest type and age classes were used to generate a weighted average rate of biomass accumulation for each of the forest and rangeland types in each FRAP region (Table 3). Where the FIA analysis did not reveal forest cover within a specific forest type for a given region, but this type is present in the same region in the analysis of the FRAP imagery a biomass accumulation rate from an adjacent region was applied.

For rangelands with no tree cover it was assumed that the shrubs and grasses are at a steady state and are not accumulating biomass unless an increase in canopy coverage is recorded.

Table 3. Aboveground carbon accumulation rates calculated for each of the FRAP regions and the division of FIA species groups in order to derive rates

Baseline Forest Type	FIA Forest Types	North Coast	Cascades NE	North Sierra	South Sierra	South Coast
			t C ha^{-1} yr^{-1}			
Redwood	Redwood	5.6			2.3	
Fir-spruce	Fir-Spruce-Mountain Hemlock / Hemlock-Sitka Spruce	2.2	1.4	1.1	0.4	
Douglas fir	Douglas fir	2.5				
Other Conifer	Western White Pine / Ponderosa Pine / Lodgepole Pine / California Mixed Conifer / Other Western Softwoods	0.9	1.0	1.0	0.4	0.3
Hardwood	Elm-Ash-Cottonwood / Aspen-Birch / Alder-Maple / Tanoak-Laurel / Other Western Hardwoods	2.7	0.7	0.6	0.4	0.9
Hardwood Range	Western Oaks / Pinyon Juniper	0.5	0.4	0.5	0.3	0.4

The values in Table 3 compare with the following rates used in the original baseline assessment (Brown et al. 2004):

Redwood: 2.59 t C ha^{-1} yr^{-1}
Fir-Spruce: 1.21 t C ha^{-1} yr^{-1}
Douglas Fir: 1.36 t C ha^{-1} yr^{-1}
Other Conifer: 1.93 t C ha^{-1} yr^{-1}
Hardwood: 1.05 t C ha^{-1} yr^{-1}
Hardwood Rangeland: 0.3 t C ha^{-1} yr^{-1}

It is apparent that the new analysis gives lower rates for the "other conifer" class. In addition, across all other types the new rates are higher in the North Coast region but lower in the two Sierran regions and in the South Coast region. These differences will lead to significant disparities in total annual sequestration from the findings of Brown et al. (2004).

5.0 Carbon Stock Changes in Forests and Woodlands

There are eight causes for changes in canopy cover (Table 4) determined by the LCCMP separately from this study. Fire, harvest (commercial timber extraction) and development (construction) each reduce canopy cover and carbon stocks. The regrowth of forests and woodlands on abandoned land or after a catastrophic event such as a fire increase canopy cover and 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 (in all other regions) "pest-related" becomes its own category and the "other" category is dominated by reductions in canopy coverage and carbon stocks. 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.

Events that cause large changes in canopy cover such as fire, harvest or development are assumed to have occurred on average at the midpoint between two censuses.

Table 4. 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.

5.1. 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 8). 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.

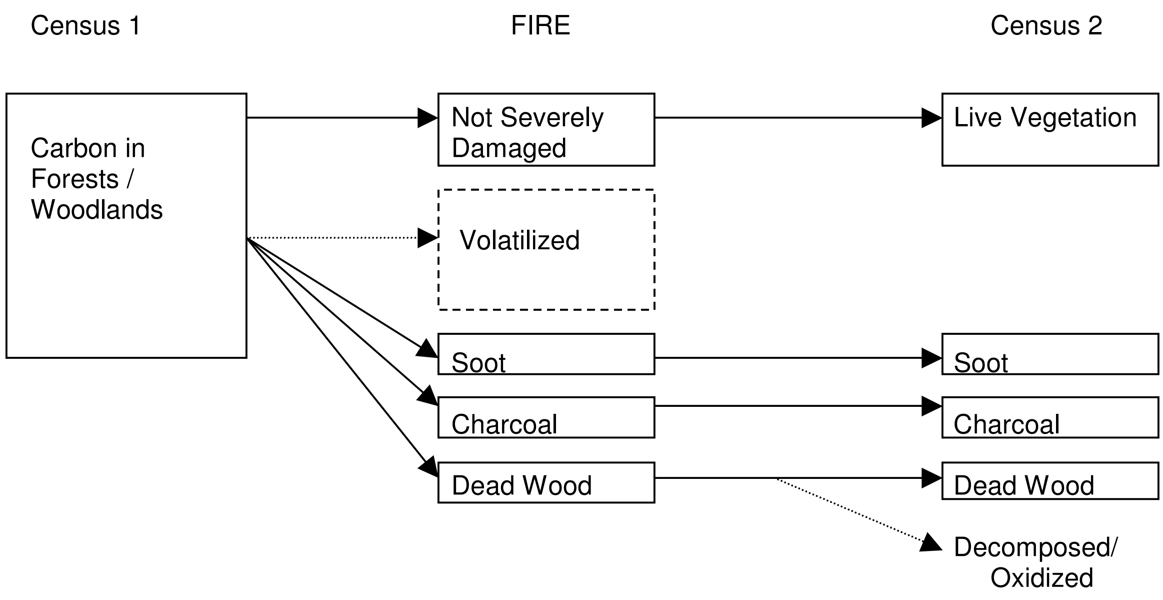

Figure 8. Flow Diagram Illustrating the Various Destinations of Pre-burn Carbon after a Fire

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 5, McNaughton et al. 1998; Carvalho et al. 2001). If the volatilized proportion is subtracted from the proportion of vegetation killed, 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 5; 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 5. 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

5.2. Harvest

The net destination of carbon after commercial harvest is illustrated in Figure 9. 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.

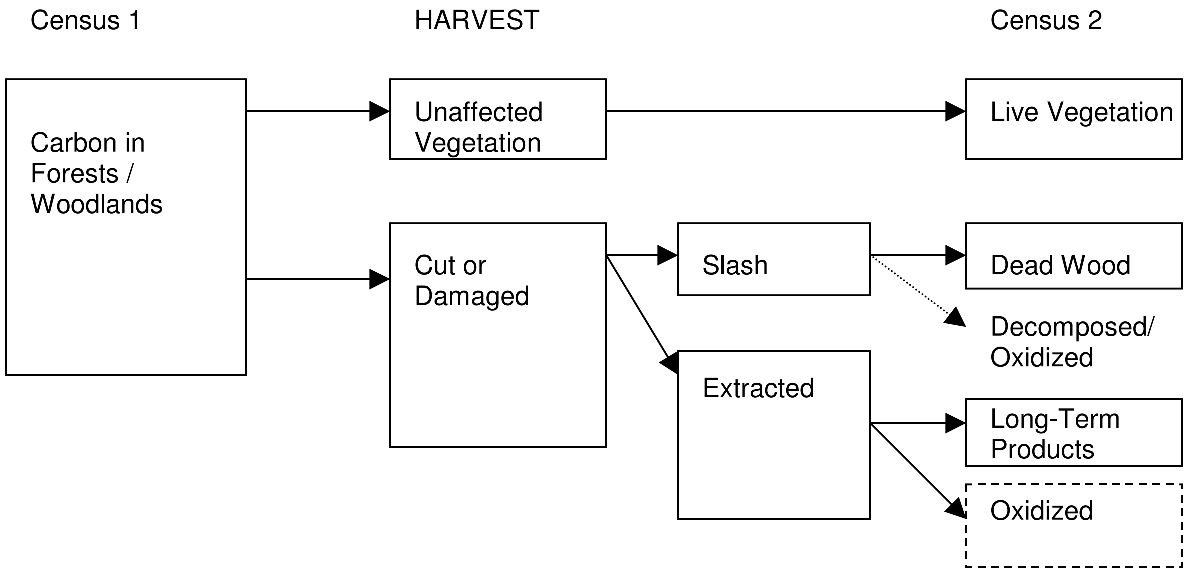

Figure 9. Flow Diagram Illustrating the Various Destinations of Pre-harvest Carbon after Commercial Harvest

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.

5.3. 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 10a.

For fir-spruce, other conifer and hardwoods it was assumed that the extracted trees are destroyed and all carbon rapidly oxidized. The fate of carbon during development for these vegetation types is illustrated in Figure 10b.

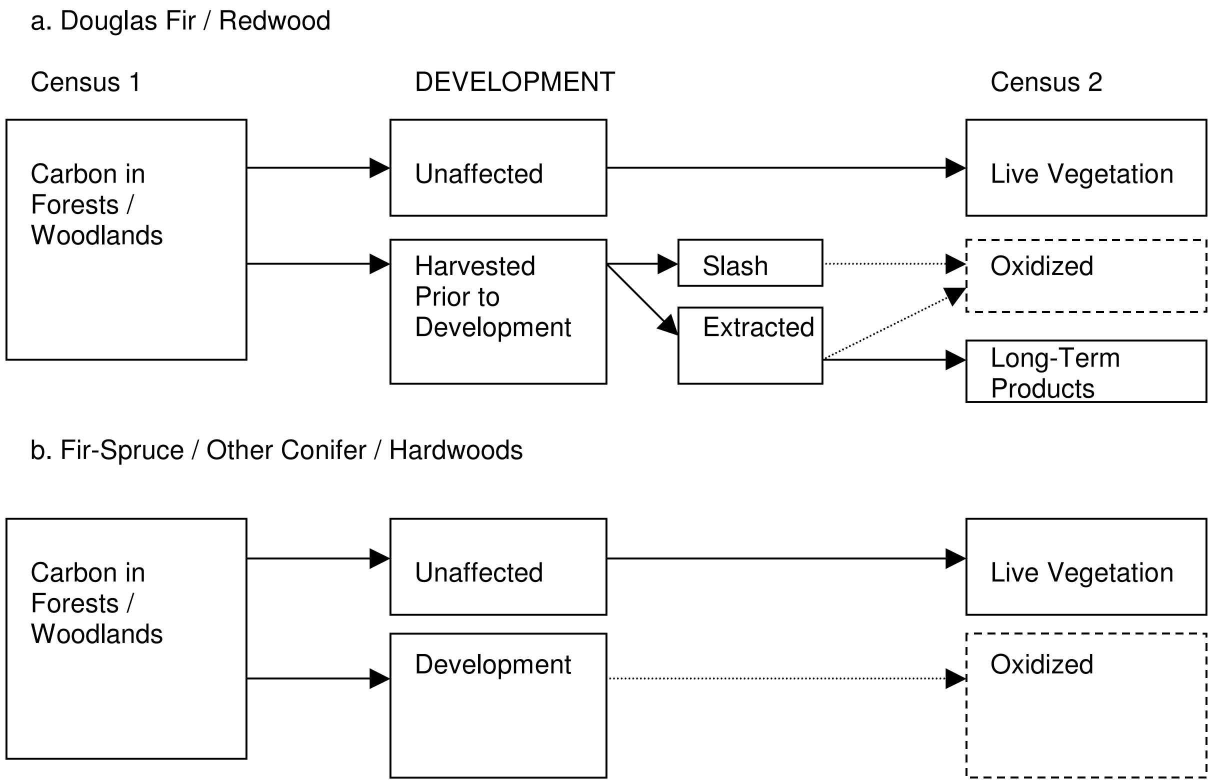

Figure 10. Flow Diagram Illustrating the Various Destinations of Pre-development Carbon after Development has Occurred

5.4. 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 in direct regrowth calculations 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 4.3. (above).

5.5. 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).

5.6. Other Changes

The pest-related category only exists in the Cascades Northeast region. In the other regions, pest effects 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 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.

5.7. 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 the cause of change for these forest types is "harvested" and is the cause for change for the other forest types is "development".

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

5.8. 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 clear cut. 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.

5.9. 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 6). 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 6. 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 would be needed to validate and refine the assumptions
	b. HARVEST		Detailed assessment of the forestry and milling industries to refine estimations of extracted proportion and proportion entering long-term products
	softwoods	10.8	
	hardwoods	8.6	
	TOTAL		
	Fire	38.5	
	Harvest-softwood	39.0	
	Harvest-hardwood	38.4	
	All other causes	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.

6.0 Results

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

6.1. North Coast

The area showing a change in canopy cover between 1994-98 (a 4 year period) 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 11). Harvest is a significant cause, albeit in small patches, through the redwood and Douglas fir forests of Humboldt and Mendocino Counties.

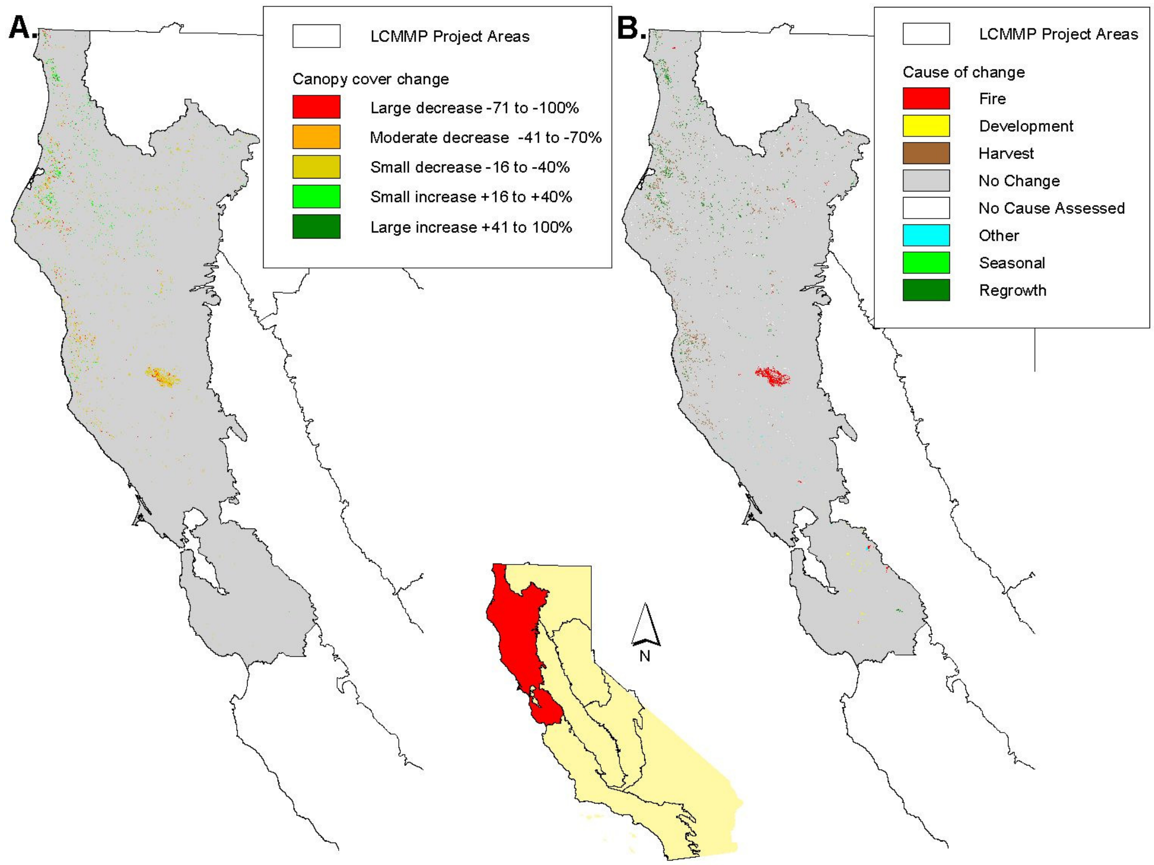

Figure 11. Forest and rangeland areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B) for the North Coast region

6.1.1. 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 7).

Table 7. 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 more than 700,000 tons of carbon (Table 8). 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 655,000 t C (Table 8), or about 164,000 t C per year.

Table 8. 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	643,843	**645,866**
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**	**643,843**	**731,014**
NET – t C								
Woodlands	-4,983	-2,698	-159	-8,258	**-16,098**	2,023	643,843	**645,866**
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**	**643,843**	**731,014**
+/- uncertainty	*13,360*	*3,825*	*471*	*11,229*	***17,872***	*32,602*	*115,892*	***118,685***

6.1.2. Forests

A total area of about 96,000 hectares of North Coast forest were affected by canopy crown change between 1994 and 1998 (Table 9). The dominant cause 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 9. 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 10). 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 20.7 million t C, 98% of which was from the estimated unmeasured increases in canopy coverage. Overall for the North Coast, removals exceeded emissions by 19.2 million t C (Table 10), or about 4.8 million t C/yr. Accounting for the uncertainties, the North Coast net removals could range between 17.0 to 24.3 million t C.

Table 10. 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	5,329,288	**5,425,181**
Fir-Spruce	-3,053	-15,417	0	-13,141	**-31,611**	9,460	616,375	**625,835**
Other Conifer	-148,453	-66,521	0	-47,433	**-262,407**	44,587	945,949	**990,536**
Hardwood	-130,274	-171,688	-1,379	-68,823	**-372,164**	60,226	7,428,077	**7,488,303**
Redwood	0	-1,252,205	-506	-91,846	**-1,344,558**	139,668	5,990,101	**6,129,769**
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**	**20,309,790**	**20,671,550**

NET – t C								
Douglas-fir	-127,146	-171,430	-460	-38,755	**-337,792**	95,893	5,329,288	**5,425,181**
Fir-Spruce	-2,211	-6,851	0	-15,552	**-24,615**	9,460	616,375	**625,835**
Other Conifer	-107,919	-29,560	0	-66,963	**-204,442**	44,587	945,949	**990,536**
Hardwood	-94,693	-101,025	-1,379	-116,180	**-313,278**	60,226	7,428,077	**7,488,303**
Redwood	0	-556,449	-339	-43,469	**-600,257**	139,668	5,990,101	**6,129,769**
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**	**20,309,790**	**20,671,550**
+/- uncertainty	*128,354*	*337,474*	*823*	*105,724*	***376,220***	*-135,298*	*3,655,762*	***3,658,265***

6.2. Cascade Northeast

The area that underwent a change in canopy cover between 1994-99 (5 years) 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 12). Fire and regrowth occur over units of a larger area, especially fire where wide areas are affected in Modoc and Siskiyou Counties.

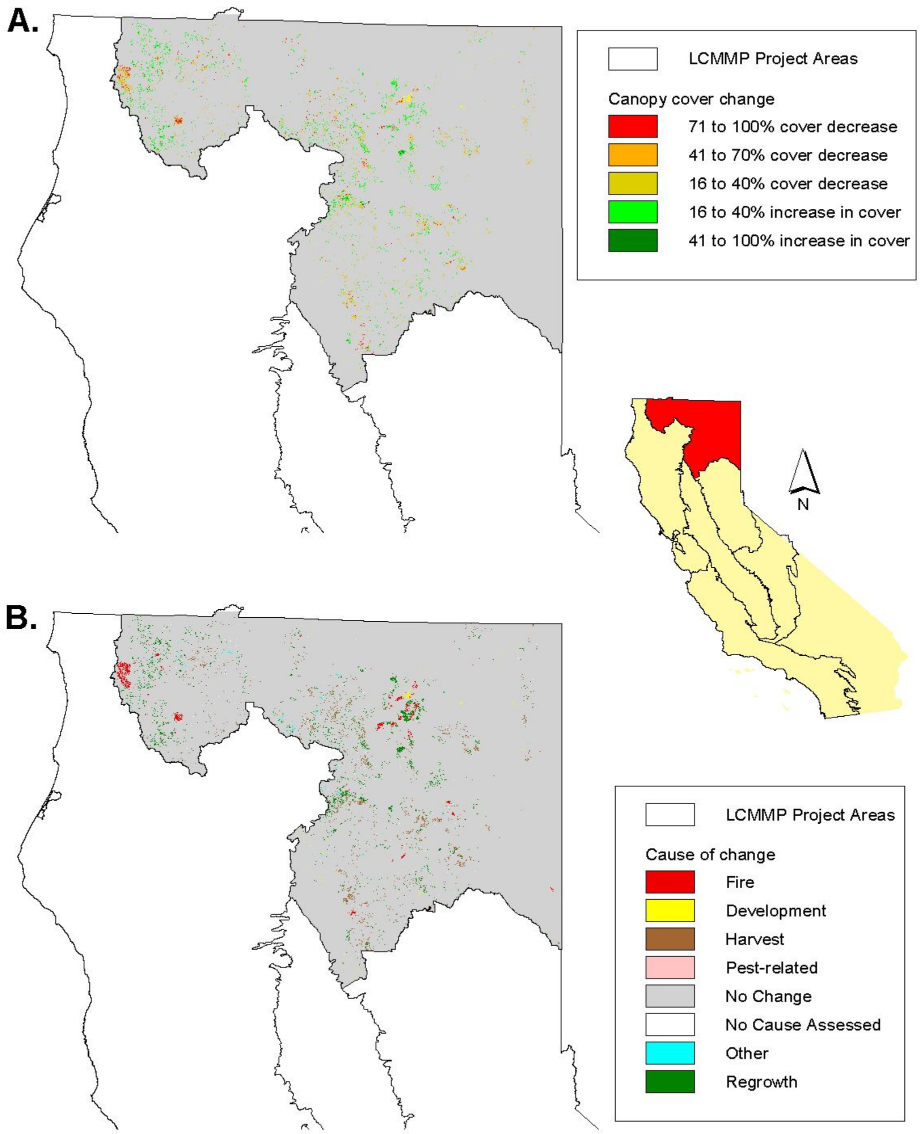

Figure 12. Illustration of Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B) in the Cascades Northeast Region

6.2.1. 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 11).

Table 11. 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 108,000 t C, 53% of which was caused by fire (Table 12). Total removals were estimated to be about 218,600 t C. Removals exceeded emissions by 110,600 t C during the period 1994-99.

Table 12. 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	529,155	**535,483**
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**	**529,155**	**615,092**
NET – t C									
Woodlands	-11,893	-2,377	0	-70	-12,612	**-26,952**	6,328	529,155	**535,483**
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**	**529,155**	**615,092**
+/- *uncertainty*	*21,950*	*9,014*	*27*	*543*	*9,498*	***25,565***	*32,140*	*95,248*	***100,524***

6.2.2. Forests

About 113,000 ha of forests were affected by a canopy change in the Cascades Northeast between 1994-99, including about 49,000 hectares of regrowth, about 41,000 hectares of harvest, and about 13,000 hectares of fire damage (Table 13). Considerably more than half of the affected area occurred in the "other conifer" forests.

Table 13. 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 14). 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 7.95 million t C, 61% of which is caused by other conifers. The net balance for the region is a removal of 6.26 million t C (or about 1.25 million t C/yr), with a range of 5.0-7.5 million t C.

Table 14. 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	1,265,036	**1,401,565**
Fir-Spruce	-14,599	-164,708	0	-11,752	-17,527	**-208,586**	38,227	955,076	**993,303**
Other Conifer	-263,104	-1,066,273	-4,630	-20,031	-81,042	**-1,435,079**	565,461	3,976,765	**4,542,216**
Hardwood	-55,199	-40,197	-58	-2,658	-17,136	**-115,248**	42,895	437,943	**480,838**
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**	**6,634,820**	**7,417,922**
NET – t C									
Douglas-fir	-146,109	-29,573	0	-5,289	-7,675	**-188,646**	136,529	1,265,036	**1,401,565**
Fir-Spruce	-10,553	-73,192	0	-11,752	-17,527	**-113,025**	38,227	955,076	**993,303**
Other Conifer	-190,128	-473,825	-4,630	-20,031	-81,042	**-769,656**	565,461	3,976,765	**4,542,216**
Hardwood	-39,789	-23,653	-58	-2,658	-17,136	**-83,294**	42,895	437,943	**480,838**
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**	**6,634,820**	**7,417,922**
+/- uncertainty	*149,217*	*235,276*	*1,755*	*14,899*	*46,305*	***282,825***	*294,157*	*1,194,268*	***1,229,961***

6.3. North Sierra

The area that underwent a measured change in canopy cover between 1995-2000 (5 years) 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 13). Large patches of fire damage can be seen in Plumas, Yuba, Tuolumne and Butte counties.

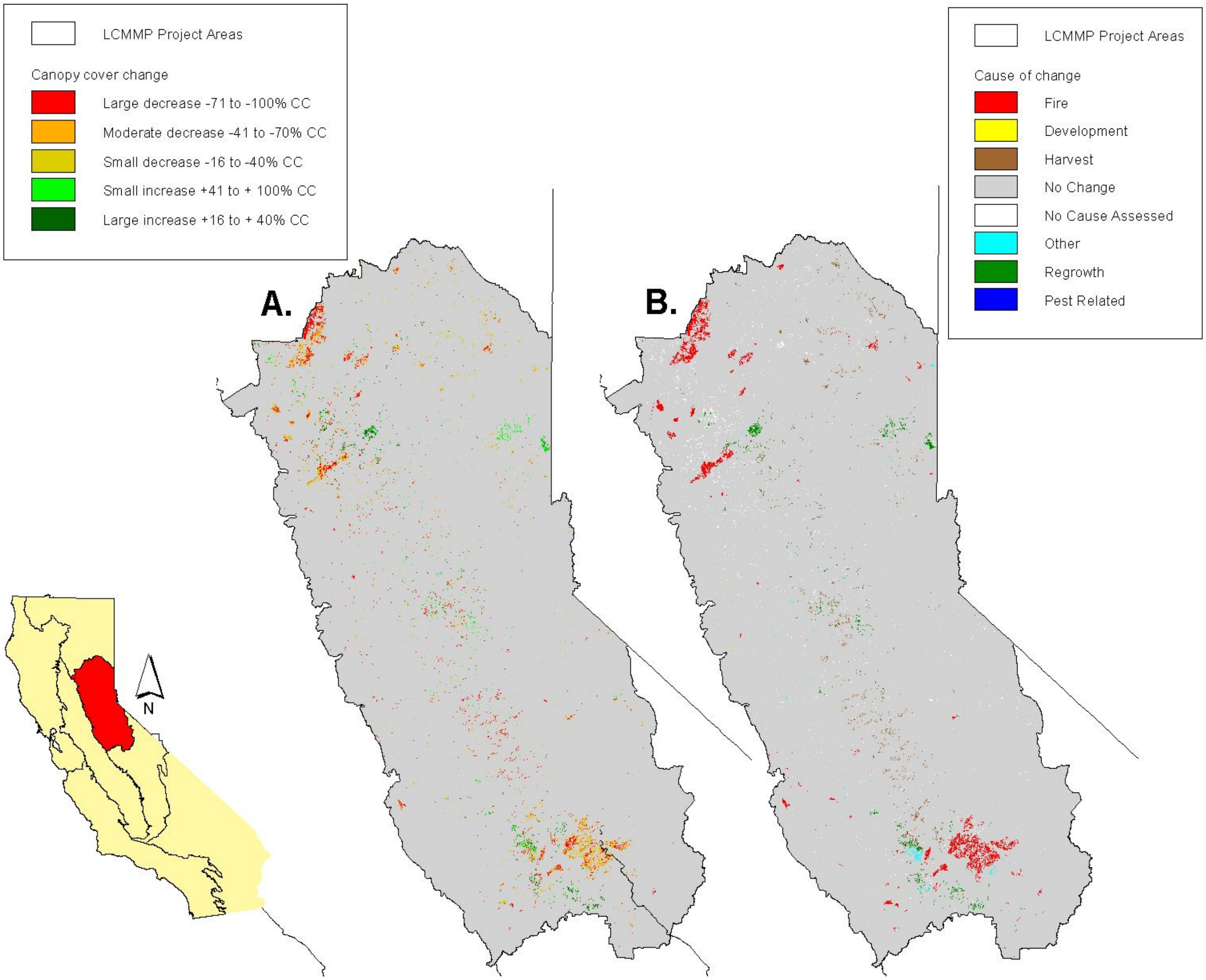

Figure 13. Illustration of Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B) in the North Sierra Region

6.3.1. Rangelands

The area of rangelands affected by canopy change between 1995-2000 (5 years) was 17.6 thousand hectares. The dominant causes were fire and regrowth each responsible for over 5 thousand hectares (Table 15). Ninety percent of the area affected was in the shrub/grass classes as opposed to woodland.

Table 15. 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 16). Total removals are estimated to be about 295,000 t C. Overall, the rangelands of this region are a net sink of carbon of about 142,000 t C (Table 16).

Table 16. 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	252,806	**253,941**
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**	**252,806**	**295,047**
NET – t C								
Woodlands	-20,701	0	-2,374	-31,363	**-54,437**	1,135	252,806	**253,941**
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**	**252,806**	**295,047**
+/- uncertainty	*25,820*	*2,093*	*1,226*	*28,919*	***38,844***	*15,798*	*45,055*	***49,988***

6.3.2. Forests

The total area of measured change in forests is about 72,600 hectares (Table 17). 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 17. 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 18). The North Sierras produce a greater source of CO_2 than either the North Coast (Table 10) or the Cascade Northeast (Table 14). Total removals by forests in the North Sierra region are 6.46 million t C. Overall, the region is a net remover (sink) of carbon of about 5.3 million t C (or 1.1 million t C/yr), with a range of 3.3 – 5.8 million t C.

Table 18. 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	1,015,486	**1,044,539**
Fir-Spruce	-288,736	-25,893	-2,249	-41,604	**-358,482**	7,086	940,676	**947,762**
Other Conifer	-706,206	-429,818	-1,117	-362,987	**-1,500,127**	166,703	3,387,965	**3,554,668**
Hardwood	-370,156	-21,032	-3,019	-122,319	**-516,526**	22,288	890,872	**913,160**

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**	**6,234,999**	**6,460,129**
NET – t C								
Douglas-fir	-121,514	-14,219	0	-35,845	**-171,578**	29,053	1,015,486	**1,044,539**
Fir-Spruce	-208,255	-11,506	-2,249	-41,604	**-263,614**	7,086	940,676	**947,762**
Other Conifer	-510,106	-191,000	-1,117	-362,987	**-1,065,209**	166,703	3,387,965	**3,554,668**
Hardwood	-266,521	-12,376	-3,019	-122,319	**-404,235**	22,288	890,872	**913,160**
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**	**6,234,999**	**6,460,129**
+/- uncertainty	*425,991*	*89,302*	*2,391*	*210,537*	***483,502***	*84,250*	*1,122,300*	***1,125,458***

6.4. South Sierra

The area that underwent a measured change in canopy cover between 1995-2001 (6 years) was approximately 28,335 ha, which is 0.7% of the total land area or 0.8% of the area of forests and rangelands. In the South Sierra region, fire with moderate to large decreases in canopy is the most obvious causes of change (Figure 14). A single large patch of fire damage can be seen in Tulare County.

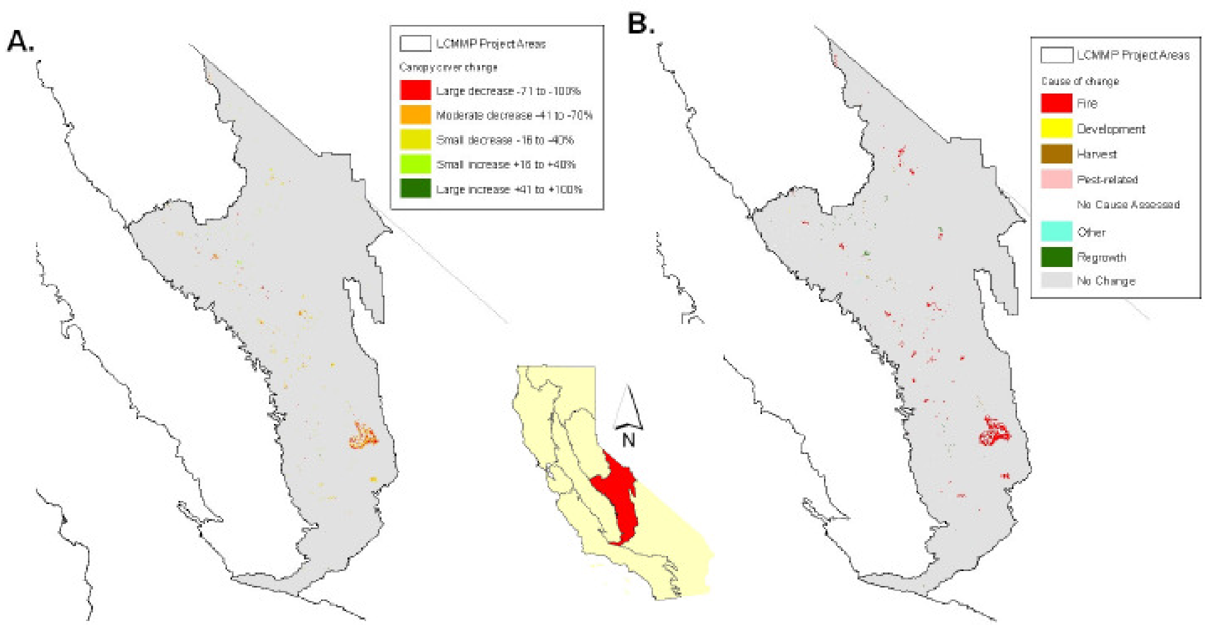

Figure 14. Illustration of Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B) in the South Sierra Region

6.4.1. Rangelands

The area of rangelands affected by canopy change between 1995-2001 was 13.1 thousand hectares. The dominant cause was fire which was responsible for 76% of the canopy change (Table 19). Eighty-five percent of the area affected was in the shrub/grass classes as opposed to woodland.

Table 19. Change in Area of South 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	1,521	35	43	48	0	27	0	264	74	**2,012**
Grasses /	8,370	103	27	1,048	24	171	8	631	703	**11,085**
SUM AREA	**9,891**	**138**	**70**	**1,096**	**24**	**198**	**8**	**895**	**777**	**13,097**

Overall, the rangelands emit a net of about 75,319 t C, most of which is due to fire (77%) (Table 20). Total removals are estimated to be about 629,995 t C. Overall, the rangelands of this region are a net sink of carbon of 566,261 t C (Table 20).

Table 20. Changes in the Carbon Stock of South 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	-31,477	-1,071	-752	-9,693	**-42,993**	970	629,995	**630,965**
Grasses /	-35,385	-1,064	-143	-4,836	**-41,428**	10,615	-	**10,615**
SUM GROSS	**-66,861**	**-2,135**	**-894**	**-14,529**	**-84,420**	**11,585**	**629,995**	**641,580**
NET – t C								
Woodlands	-22,816	-630	-752	-9,693	**-33,891**	970	629,995	**630,965**
Grasses /	-35,385	-1,064	-143	-4,836	**-41,428**	10,615	-	**10,615**
SUM NET	**-58,201**	**-1,695**	**-894**	**-14,529**	**-75,319**	**11,585**	**629,995**	**641,580**
+/- uncertainty	*22,407*	*640*	*335*	*5,434*	***23,068***	*4,333*	*113,399*	***113,443***

6.4.2. Forests

The total area of measured change in forests is 15,238 hectares (Table 21). As in the North Sierra region fire is the dominant cause of change in canopy cover in the forests of the South Sierra region, accounting for 76% of the total measured change. The higher percentage in the South Sierra region is caused by a lower area of harvest in this region. The “other conifer” class is again the dominant forest type reflecting the coverage by ponderosa pine and lodgepole pine.

Table 21. Change in Area of South 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	0	0	0	0	0	0	0	0	**2**
Fir-Spruce	182	128	0	100	4	0	0	25	20	**459**
Other Conifer	8,900	848	28	1,129	52	24	0	139	204	**11,324**
Hardwood	1,925	211	58	169	6	69	0	192	69	**2,699**
Redwood	0	0	0	0	0	0	0	0	0	**0**
Shrubs/grasses	527	14	0	73	4	63	0	54	19	**754**

SUM AREA	**11,536**	**1,201**	**86**	**1,471**	**66**	**156**	**0**	**410**	**312**	**15,238**

In terms of carbon in the South Sierra region, the net emissions from all measured changes is 323,408 t C, of which is 88% is caused by fire (Table 22). This total emission is just 17% of the total emission of the North Sierra region (Table 18). Total removals by forests in the South Sierra region are 1.50 million t C. Overall, the region is a net remover (sink) of carbon of about 1.18 million t C (0.20 million t C/yr), with a range of 0.89 – 1.47 million t C.

Table 22. Changes in the Carbon Stock of South 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	-38	0	0	0	**-38**	0	255	**255**
Fir-Spruce	-10,589	-8,501	0	-1,248	**-20,338**	1,896	296,283	**298,179**
Other Conifer	-326,692	-31,694	-919	-5,431	**-364,736**	24,157	881,063	**905,220**
Hardwood	-51,969	-6,697	-2,237	-7,105	**-68,007**	2,135	297,818	**299,952**
Redwood	0	0	0	0	**0**	0	0	**0**
Shrubs /	-2,487	-60	0	-692	**-3,239**	320	-	**320**
SUM GROSS	**-391,774**	**-46,951**	**-3,155**	**-14,476**	**-456,357**	**28,508**	**1,475,419**	**1,503,927**
NET – t C								
Douglas-fir	-27	0	0	0	**-27**	0	255	**255**
Fir-Spruce	-7,633	-3,778	0	-1,248	**-12,658**	1,896	296,283	**298,179**
Other Conifer	-236,287	-14,084	-919	-5,431	**-256,721**	24,157	881,063	**905,220**
Hardwood	-37,481	-3,940	-2,237	-7,105	**-50,763**	2,135	297,818	**299,952**
Redwood	0	0	0	0	**0**	0	0	**0**
Shrubs /	-2,487	-60	0	-692	**-3,239**	320	-	**320**
SUM NET	**-283,915**	**-21,862**	**-3,155**	**-14,476**	**-323,408**	**28,508**	**1,475,419**	**1,503,927**
+/- uncertainty	*109,307*	*8,539*	*1,180*	*5,414*	***109,780***	*10,662*	*265,575*	***265,789***

6.5. South Coast

The area that underwent a measured change in canopy cover between 1995/7-2002 (6 years) was approximately 88,536 ha, which is 1.3% of the total land area or 1.6% of the area of forests and rangelands. In the South Coast region, fire and regrowth with small to moderate decreases in canopy are the most obvious causes of change, with scattered areas of other causes and an area of large decrease due to fire in San Bernardino County (Figure 15).

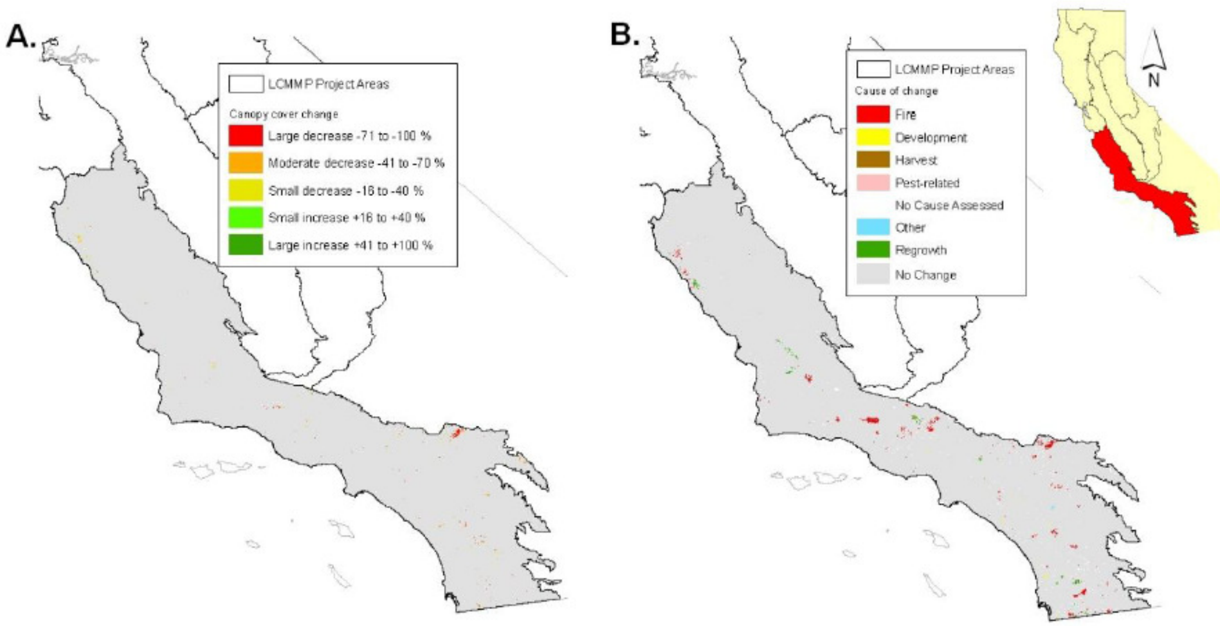

Figure 15. Illustration of Areas Experiencing a Change in Canopy by Magnitude of Change (A) and by Cause (B) in the South Coast Region

6.5.1. Rangelands

The area of rangelands affected by canopy change between 1997-2002 was 79.5 thousand hectares. The dominant cause was fire which was responsible for 47% of the canopy change and the unverified class which was responsible for 30% of the total area of canopy change (Table 23). Ninety-three percent of the area affected was in the shrub/grass classes as opposed to woodland.

Table 23. Change in Area of South Coast 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	2115	0	9	212	0	0	0	2,889	141	**5,366**
Grasses / Shrubs	35,208	0	3,551	13,449	11	1,168	13	18,541	2,201	**74,142**

SUM AREA	37,323	0	3,560	13,661	11	1,168	13	21,430	2,342	79,508

Overall, the rangelands emit a net of about 467,437 t C, most of which is due to fire (52%) and unverified causes (44%) (Table 1-24). Total removals are estimated to be about 1,127,317 t C. Overall, the rangelands of this region are a net sink of carbon of 750,856 t C (Table 24).

Table 24. Changes in the Carbon Stock of South 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	-40,004	0	-336	-80,759	**-121,099**	2,980	1,127,317	**1,130,297**
Grasses /	-215,629	0	-15,907	-125,845	**-357,381**	87,996	-	**87,996**
SUM GROSS	**-255,633**	**0**	**-16,243**	**-206,604**	**-478,481**	**90,975**	**1,127,317**	**1,218,293**
NET – t C								
Woodlands	-28,960	0	-336	-80,759	**-110,056**	2,980	1,127,317	**1,130,297**
Grasses /	-215,629	0	-15,907	-125,845	**-357,381**	87,996	-	**87,996**
SUM NET	**-244,589**	**0**	**-16,243**	**-206,604**	**-467,437**	**90,975**	**1,127,317**	**1,218,293**
+/- uncertainty	*94,167*	*0*	*6,075*	*77,270*	***121,963***	*34,025*	*202,917*	***214,684***

6.5.2. Forests

The total area of measured change in forests is just 9,038 hectares (Table 25). Fire is once again the dominant cause of change in canopy cover in the forests of the South Coast region, accounting for 69% of the total measured change. Harvest is entirely absent as a cause of canopy cover change in the region. In contrast to all the other regions, the "hardwood" class is again the dominant forest type.

Table 25. Change in Area of South Coast 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	4	0	0	0	0	0	0	0	0	**4**

Fir-Spruce	0	0	0	0	0	0	0	2	0	**2**
Other Conifer	1,718	0	0	15	55	2	0	210	4	**2,004**
Hardwood	3,747	0	5	236	49	0	0	1,422	323	**5,782**
Redwood	8	0	0	8	1	0	0	1	0	**18**
Shrubs/grasses	803	0	19	169	0	1	0	165	71	**1,228**
SUM AREA	**6,280**	**0**	**24**	**428**	**105**	**3**	**0**	**1,800**	**398**	**9,038**

In terms of carbon in the South Coast region, the net emissions from all measured changes is 165,270 t C, of which is 72% is caused by fire (Table 26). This total emission is overwhelmingly the lowest for the forests of the five California regions reflecting the fact that the region has just 4% of the forests in the state. Total removals by forests in the South Coast region are 0.89 million t C. Overall, the region is a net remover (sink) of carbon of about 0.73 million t C (0.12 million t C/year), with a range of 0.56 – 0.90 million t C.

Table 26. Changes in the Carbon Stock of South 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	-102	0	0	0	**-102**	0	3,276	**3,276**
Fir-Spruce	0	0	0	-35	**-35**	0	1,133	**1,133**
Other Conifer	-60,566	0	0	-6,741	**-67,308**	212	127,354	**127,567**
Hardwood	-98,253	0	-214	-38,959	**-137,426**	5,212	647,723	**652,934**
Redwood	-127	0	0	0	**-127**	0	109,192	**109,192**
Shrubs /	-3,793	0	-74	-732	**-4,599**	834	-	**834**
SUM GROSS	**-162,841**	**0**	**-288**	**-46,466**	**-209,596**	**6,257**	**888,678**	**894,935**
NET – t C								
Douglas-fir	-74	0	0	0	**-74**	0	3,276	**3,276**
Fir-Spruce	0	0	0	-35	**-35**	0	1,133	**1,133**
Other Conifer	-43,661	0	0	-6,741	**-50,402**	212	127,354	**127,567**
Hardwood	-70,895	0	-214	-38,959	**-110,067**	5,212	647,723	**652,934**
Redwood	-93	0	0	0	**-93**	0	109,192	**109,192**
Shrubs /	-3,793	0	-74	-732	**-4,599**	834	-	**834**
SUM NET	**-118,516**	**0**	**-288**	**-46,466**	**-165,270**	**6,257**	**888,678**	**894,935**

+/- uncertainty	45,629	0	108	17,378	**48,826**	2,340	159,962	**159,979**

7.0 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 27).

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 27).

Table 27. 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	rangelands	34,700	555	12,769	10	4	1,130	0.9
Coast	forests	333,386	5,334	122,686	10	37	10,855	0.9
Northeast	rangelands	57,014	912	20,981	10	6	1,856	0.9
Cascades	forests	387,577	6,201	142,628	10	43	12,620	0.9
North	rangelands	67,066	1,073	24,680	10	7	2,184	0.9
Sierra	forests	1,106,470	17,704	407,181	10	122	36,027	0.9
South	rangelands	58,201	931	21,418	10	6	1,895	0.9
Sierra	forests	283,915	4,543	104,481	10	31	9,244	0.9
South	rangelands	244,589	3,913	90,009	10	27	7,964	0.9
Coast	forests	118,516	1,896	43,614	10	13	3,859	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	rangelands	34,700	416	9,577	8	3	807	0.6
Coast	forests	333,386	4,001	92,015	8	26	7,754	0.6

Northeast	rangelands	57,014	684	15,736	8	4	1,326	0.6
Cascades	forests	387,577	4,651	106,971	8	30	9,014	0.6
North	rangelands	67,066	805	18,510	8	5	1,560	0.6
Sierra	forests	1,106,470	13,278	305,386	8	87	25,733	0.6
South	rangelands	58,201	698	16,063	8	5	1,354	0.6
Sierra	forests	283,915	3,407	78,361	8	22	6,603	0.6
South	rangelands	244,589	2,935	67,507	8	19	5,688	0.6
Coast	forests	118,516	1,422	32,710	8	9	2,756	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 28).

Table 28. 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	rangelands	10,154	1	33	0.09
Coast	forests	865,922	75	1,733	0.05
Northeast	rangelands	24,038	4	99	0.11
Cascades	forests	601,566	77	1,770	0.08
North	rangelands	5,595	1	16	0.08
Sierra	forests	229,128	22	512	0.06
South	rangelands	1,695	0	6	0.10
Sierra	forests	21,862	2	52	0.06
South	rangelands	0	0	0	0.00
Coast	forests	0	0	0	0.00

8.0 Forests and Rangelands of California as Sources and Sinks of Greenhouse Gases

Across the 423,970 km^2 of California, there are an estimated 95,694 km^2 of forest and 126,751 km^2 of rangelands. Of this area 4,622 km^2 of forests and rangelands had a change in canopy cover between the measurement periods (equal to 2.0% of the total area). Of this area of change 83% had a verified cause. Sixty-six percent of the changes were on forestland and 33% on rangeland.

On forestland, 31% of the area with a canopy change was caused by commercial harvest, 27% by forest regrowth and 27% 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 fire was the cause of 47% of the change area in the North Sierras, 69% in the South Coast and 76% in the South Sierra region.

On rangeland, fire was the dominant cause of change in canopy cover accounting for 40%. Next in significance was measured regrowth with 27%. However, 60% of the total rangeland area affected by fire was in the South Coast region alone.

In terms of carbon, 5.03 million t C were emitted from forestland in California (Table 29). On forestland, fires emitted as much as 2.2 million t C, however, 50% of this total came from the North Sierra alone. During the same period, approximately 36.9 million t C were removed.

On rangelands, 0.88 million t C were emitted between the regional time intervals across California, included in this total are 0.46 million t C emitted through fire (Table 29). During the same period it is estimated that 3.5 million t C were removed through rangeland regrowth and natural tree growth.

Table 29. Summary of the Carbon Emitted and Removed in Forests and Rangelands of Five Regions of California between a 4-6-year Interval during 1994-2002 (Actual Periods Vary by Region)

Forests	**Net t C**					
	North Coast	**Cascades Northeast**	**North Sierra**	**South Sierra**	**South Coast**	**TOTAL**
EMISSIONS						
Fire	-333,386	-387,577	-1,106,470	-283,915	-118,516	**-2,229,864**
Harvest	-865,922	-601,566	-229,128	-21,862	0	**-1,718,479**
Development	-2,201	-4,692	-6,392	-3,155	-288	**-16,728**
Other/Unverified	-282,686	-163,646	-562,932	-14,476	-46,466	**-1,070,206**
EMISSIONS TOTAL	**-1,484,195**	**-1,157,481**	**-1,904,923**	**-323,408**	**-165,270**	**-5,035,277**
Estimated error	*376,220*	*282,825*	*483,502*	*109,780*	*48,826*	***685,377***
REMOVALS TOTAL	**20,671,550**	**7,417,922**	**6,460,129**	**1,503,927**	**894,935**	**36,948,463**
Estimated error +/-	*3,658,265*	*1,229,961*	*1,125,458*	*265,789*	*159,979*	***4,032,195***

Rangelands	**Net t C**					
	North Coast	**Cascades Northeast**	**North Sierra**	**South Sierra**	**South Coast**	**TOTAL**
EMISSIONS						
Fire	-34,700	-57,014	-67,066	-58,201	-244,589	**-461,570**
Harvest	-10,154	-24,038	-5,595	-1,695	0	**-41,483**
Development	-1,259	-72	-3,279	-894	-16,243	**-21,747**
Other/Unverified	-30,023	-26,850	-77,323	-14,529	-206,604	**-355,329**
EMISSIONS TOTAL	**-76,137**	**-107,974**	**-153,262**	**-75,319**	**-467,437**	**-880,129**
Estimated error	*17,872*	*25,565*	*38,844*	*23,068*	*121,963*	***133,750***
REMOVALS TOTAL	**731,014**	**615,092**	**295,047**	**641,580**	**1,218,293**	**3,501,026**
Estimated error +/-	*118,685*	*100,524*	*49,988*	*113,443*	*214,684*	***292,657***

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).

8.1. 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 Sierras and South Coast and fast forest growth rates principally in the North Coast), or due to a lag in the regrowth response (Figures 16, 17, 18, 19). The areas with low emissions and low removals do coincide with the more highly developed areas along the coast and in the Sierras.

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 Humboldt and Mendocino where the fast growing, high biomass Douglas fir and redwood forests are located (Figure 16 and 17).

When emissions and removals are summed the high sequestration rates in the northwestern counties dominate, but on a per unit area basis the low rates of removals leave the highest net emissions in the southern counties of San Diego, Riverside, Orange, San Bernardino and Ventura and the far western counties of Mono and Inyo (Figures 18 and 19).

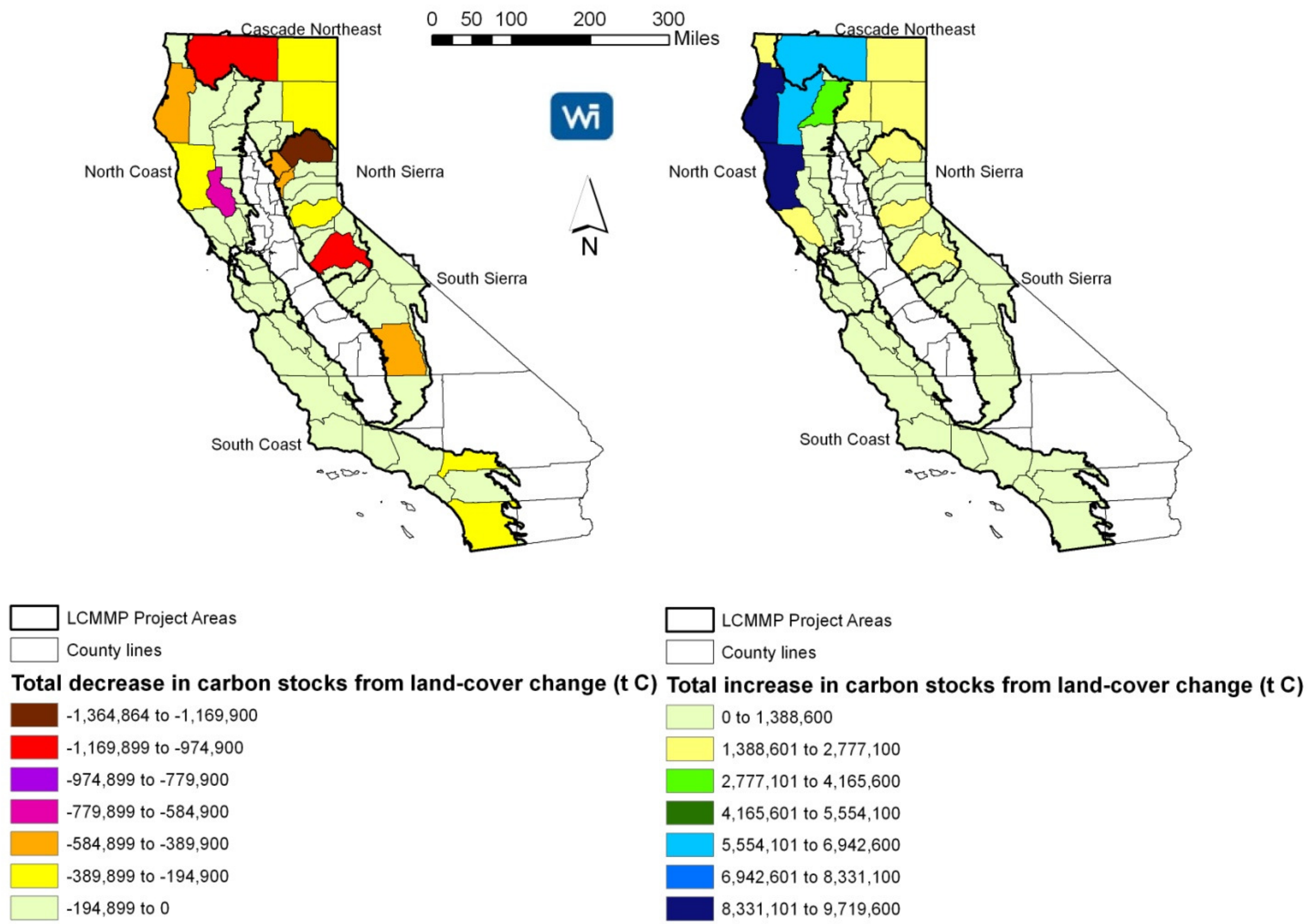

Figure 16. County Level Summary of the Decreases (left), and Increases (right) in Carbon Stocks in the North Coast (1994-1998), the Cascades Northeast (1994-1999), the North Sierra (1995-2000), the South Sierra (1995-2001) and the South Coast (1995/7-2002)

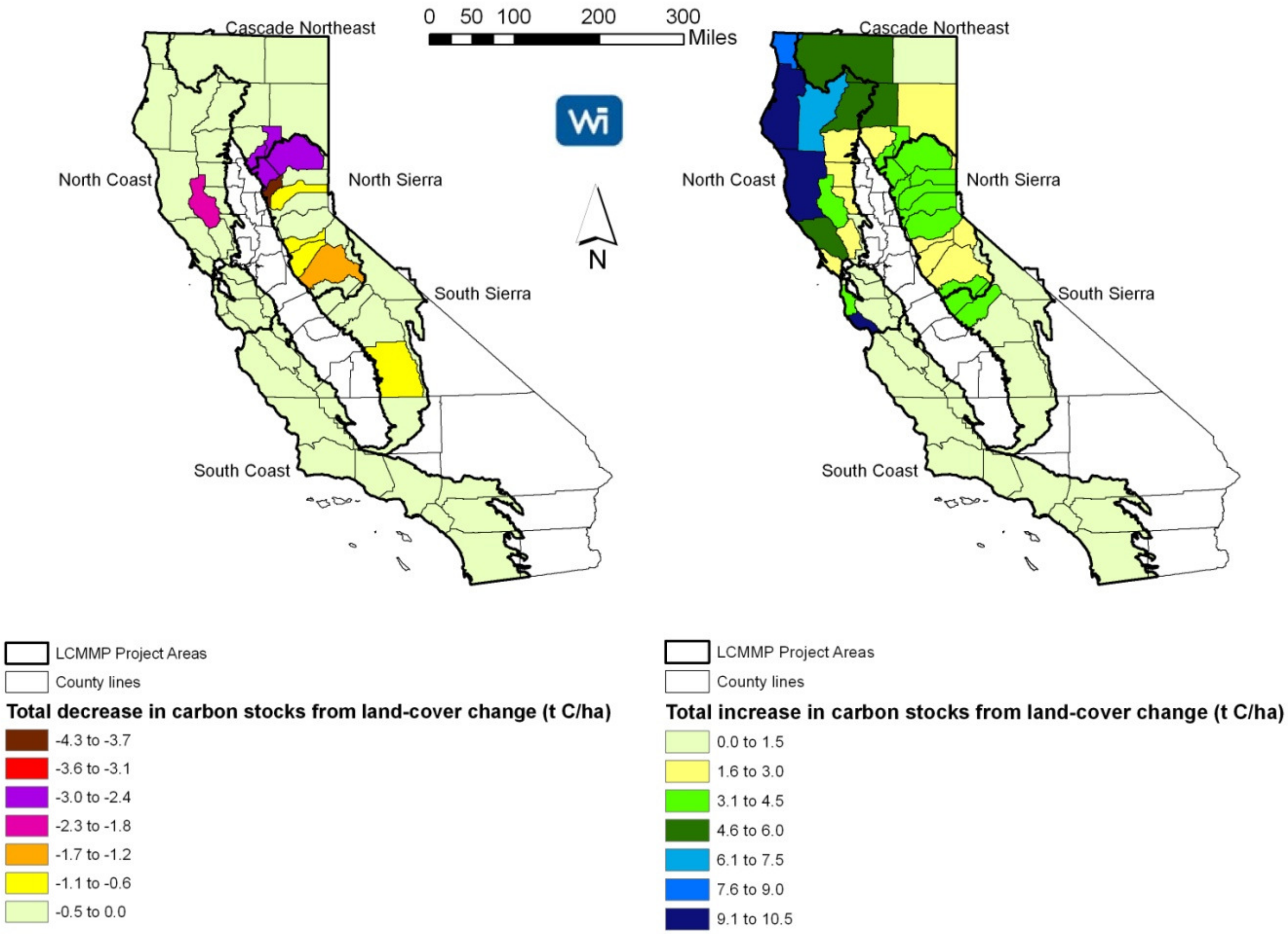

Figure 17. County Level Summary of the Decreases (left), and Increases (right) in Carbon Stocks Normalized by County Area in the North Coast (1994-1998), the Cascades Northeast (1994-1999), the North Sierra (1995-2000), the South Sierra (1995-2001) and the South Coast (1995/7-2002)

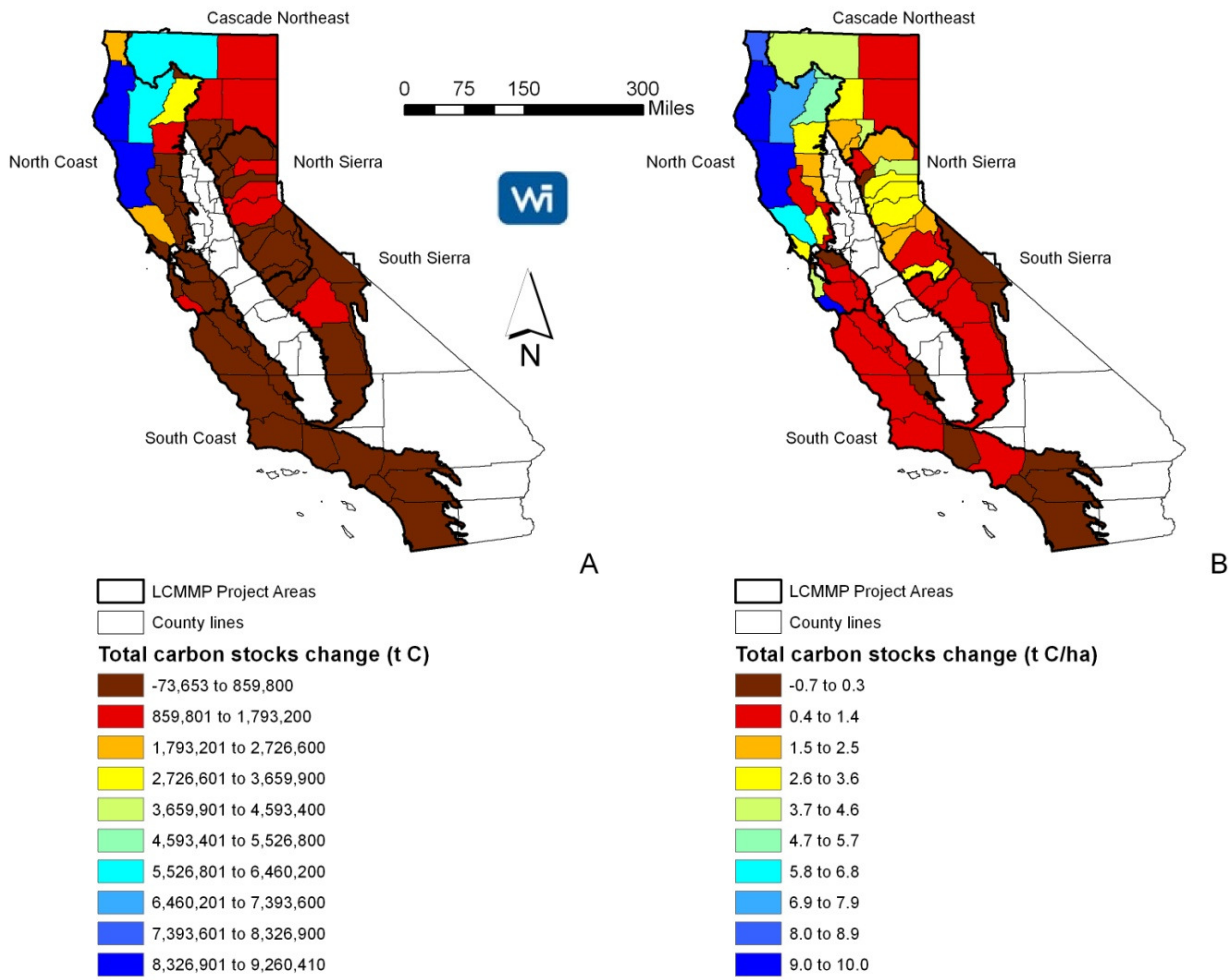

Figure 18. County Level Summary of the Summed Decreases and Increases in Carbon Stocks in the North Coast (1994-1998), the Cascades Northeast (1994-1999), the North Sierra (1995-2000), the South Sierra (1995-2001) and the South Coast (1995/7-2002) (A displays total change and B displays change normalized by County area)

8.2. Carbon Dioxide Equivalents

If the non-CO_2 gases are included and all values are converted to carbon dioxide equivalents, across California 19.36 million metric tons of carbon dioxide equivalents (MMTCO_2eq) were emitted between the census dates from forest land and 3.41 MMTCO_2eq from rangelands. This converts to an annual emission of 3.90 MMTCO_2eq from forests and 0.59 MMTCO_2eq from rangelands (Table 30).

During the same periods 135.48 MMTCO_2eq were estimated to have been removed by forestland and 12.84 MMTCO_2eq on rangeland. This is equal to an annual rate of removals of 27.10 MMTCO_2eq in forests and 2.57 MMTCO_2eq on rangelands (Table 30).

Table 30. 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	18.46	0.07	0.82	**19.36**	3.23	0.02	0.17	**3.41**
Removals	135.48	-	-	**135.48**	12.84	-	-	**12.84**
MMTCO_2eq/year								
Emissions	3.90	0.01	0.16	**4.09**	0.59	0.003	0.03	**0.63**
Removals	27.10	-	-	**27.10**	2.57	-	-	**2.57**

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

8.3. 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 for this report was completed in 1994. The data reported by Birdsey and Lewis are modeled net emissions or removals through 1997 from the 1994 inventory. The Energy Commission report then 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 undetectable changes. It must be acknowledged that the flux from undetectable changes greatly exceeded that from measured changes.

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 is reported as 27.10 MMTCO_2eq/yr and if emissions are included, the net removals are 23.01 MMTCO_2eq/yr for forestland. No measure of uncertainty is included in the Energy Commission report in contrast to our analyses.

The estimates from the Energy Commission report are different from those that we report on here. Reasons for the differences 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.

Errors are also likely in the methods employed here, especially given the predominance of the growth estimated without a change in canopy cover. However, the detail in the calculation of emissions and precision on area of background growth gives additional credence to the approach employed here.

The results presented here also differ from the results reported in Brown et al. (2004) – the earlier version of this baseline assessment. This difference goes beyond just the inclusion of two additional Californian regions – South Sierra and South Coast. Analysis differences arise from the standardization in estimating the time interval for each region (4-6 years) and a new more detailed region-specific calculation of carbon accumulation rates for forests with no detectable change in canopy cover.

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 1994/5-2002.

9.0 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, including detectable and undetectable changes in canopy coverage in the remote sensing products. .
- A change in canopy cover was measured on 4,622 km^2 of forests and rangelands across California. This is approximately 1.8% of the total area of forests and rangeland in the regions. For 83% of the changed area, the cause of change was verified.
- For forests, a net removal of 27.1 $MMTCO_2eq/yr$ and a net emission of 4.1 $MMTCO_2eq/yr$ were estimated (Table 1-30). 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 2.57 $MMTCO_2eq/yr$ exceeding a net emission of 0.63 $MMTCO_2eq/yr$ (Table 1-30).
- Fire and harvest were the dominant causes of emissions on forestlands; these causes were responsible for 1.83 $MMTCO_2eq/yr$ and 1.42 $MMTCO_2eq/yr$ respectively. On rangeland, harvest was less important, accounting for only 5% of the total emissions as opposed to 54% for fire on rangelands. Development appears to be a minor cause of carbon emissions through land-use change in both forest- and range-land in California.

However, much of the unverified change could include development that tends to occur in smaller patches and goes undetected in the remote sensing imagery.

- 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. The largest increases in carbon stocks (detectable and undetectable canopy change) are in the high volume fast-growing conifer forests of the North Coast and Cascades Northeast. Despite a high fire incidence the lower carbon stocks of the forests in the southern regions leads to emissions levels that are not greatly elevated.
- The calculated removals of 27.10 $MMTCO_2eq$/yr and emissions of 4.09 $MMTCO_2eq$/yr with a net removal of 23.0 MMTCO2eq/yr, for the forest sector differs from the reported removal of 17.3 $MMTCO_2eq$/yr in the California Energy Commission's report (CEC, 2002). 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 1994/1995–2002.

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