Arnold Schwarzenegger
Governor

CARBON SUPPLY FROM CHANGES IN MANAGEMENT OF FOREST AND RANGE LANDS IN SHASTA COUNTY, CALIFORNIA

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Prepared By:
Winrock International
Winrock International

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Prepared By:
Winrock International
Ecosystem Services Unit
Sandra Brown
Silvia Petrova
Nick Martin
Aaron Dushku
Jonathan Winsten
Timothy Pearson
John Kadyszewski
1621 N. Kent St, Suite 1200
Arlington, VA 22209
Email: sbrown@winrock.org

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Prepared For:
Public Interest Energy Research (PIER) Program
California Energy Commission

Guido Franco,
Contract Manager

Kelly Birkinshaw,
Program Area Lead
Energy-Related Environmental Research

Martha Krebs
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

B. B. Blevins
Executive Director

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Preface

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

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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

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

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) Program established the **California Climate Change Center** to document climate change research relevant to the states. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

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

Carbon Supply from Changes in Management of Forest and Range Lands in Shasta County, California is a final report for the Assessing Impacts of Forest Management on GHG Emissions project (contract number 500-02-004, MR-006) conducted by Winrock International.

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

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Abstract

This report summarizes two classes of activities to sequester carbon in terrestrial ecosystems through changes in management of lands: afforestation of rangelands and forest fuel reduction to reduce greenhouse gas emissions from wildfire. These opportunities, earlier analyzed at the state level for the California Energy Commission, are here evaluated for Shasta County using additional information and finer-resolution data. For afforestation of rangelands, methods for assessing forest suitability, carbon accumulation potential, and total costs of afforestation are presented, resulting in estimates of total carbon supply at various price points for 20, 40, and 80-year time periods, and the areas and locations within the county of the least to most expensive carbon sequestration opportunities. For forest fuel reduction, the report provides a Geographic Information Systems (GIS)-based analysis of the areas, locations, and carbon stocks of forests in Shasta County at high to very high fire risk; the ranked suitability of these forest lands for reducing fuel loads and removing fuel to biomass energy facilities; and more detailed analysis of one particular fuel reduction prescription, including areas accessible, potential biomass yield, and costs. First-order approximations are presented addressing the question of whether emissions reductions from fuel treatment, if valued at commonly used prices of CO_2 credits and compared to baseline emissions from wildfire, might be sufficient to allow the sale of carbon credits to fill the gap that often exists between high costs of treatment and low product value, leading ultimately to more acres treated. A more complete assessment of net carbon benefits from forest fuel reduction in Shasta County will be undertaken as part of the West Coast Regional Carbon Sequestration Partnership – Phase II.

Keywords: Carbon, sequestration, emission, forest, rangeland, hazardous fuel reduction, Shasta County

Executive Summary

Introduction

California is committed to reduced net greenhouse gas (GHG) emissions as demonstrated by the passage of California Assembly Bill 32. A suite of measures will be required to comply with AB32, including increasing the carbon stock in California's lands.

Past statewide studies by the California Energy Commission's Public Interest Energy Research (PIER) program on the potential to sequester carbon in terrestrial ecosystems suggest ample opportunities for such measures in California. Statewide studies, however, cannot afford the level of detail that can be used in local or regional studies. In addition, it is necessary to corroborate the statewide analysis with more in-depth regional analyses to determine the confidence that should be given to the statewide analysis.

Purpose

The project's purpose was to evaluate the potential for afforestation of lands in Shasta County, California, to determine the feasability of and benefits from implementing such measures. *Afforestation* is the establishment of new forests on lands that have not been recently forested. In addition, the researchers studied the potential of a hazard fuel reduction (HFR) program designed the reduce the likelihood of major forest fires as a tool to reduce net GHG emissions in California.

Project Objectives

The main objectives of this study were to (1) estimate the potential carbon supply from afforestation of rangelands in Shasta County, and (2) to generally identify the areas and carbon stocks of Shasta County's forests that are suitable for hazardous fuel reduction, as well as the quantity of fuel potentially available for biomass energy plants.

Project Ouctomes

Shasta County was chosen because it contains highly diverse land-cover classes representative of California. Also, based on the statewide analysis of carbon sequestration potential, it was concluded that Shasta contained opportunities for implementing a range of important types of sequestration projects. The study's approach generally follows that of previous work on the carbon supply from range and forest lands for the whole of California.

The approach for estimating the carbon supply from rangelands was to identify and locate existing rangelands where conditions could favor the establishment and growth of forests, estimate rates of carbon accumulation for the forest types projected to grow, and estimate the costs associated with the practice needed to increase the net accumulation of carbon. Carbon supply was estimated for three time durations—20, 40, and 80 years of forest growth—to reflect the impact of an activity's duration on the likely carbon supply and to assess near–term and longer-term planning horizons.

Conclusions

The total area of Shasta County is approximately 2.46 million acres (996,000 hectares), of which approximately 749,000 thousand acres (303,000 hectares) are classed as rangeland. The total area

suitable for afforestation activities is about 600,000 acres (243,000 hectares), which represents about 80 percent of the total lands classed as rangelands (**Figure S-1**). Woody rangelands suitable for afforestation activities cover about 159,160 acres (64,412 hectares), or 27 percent of the total suitable rangelands.

Estimates of the potential sequestered carbon by afforestation on the rangeland areas represent the carbon stocks in living trees, standing and lying dead wood, understory, and litter. Estimates of carbon stocks ranged from 5 t C (tons of carbon)/acre (12 t C/ha) after 20 years for rangeland hardwood forests to about 166 t C/acre (411 t C/ha) after 80 years for mixed conifers.

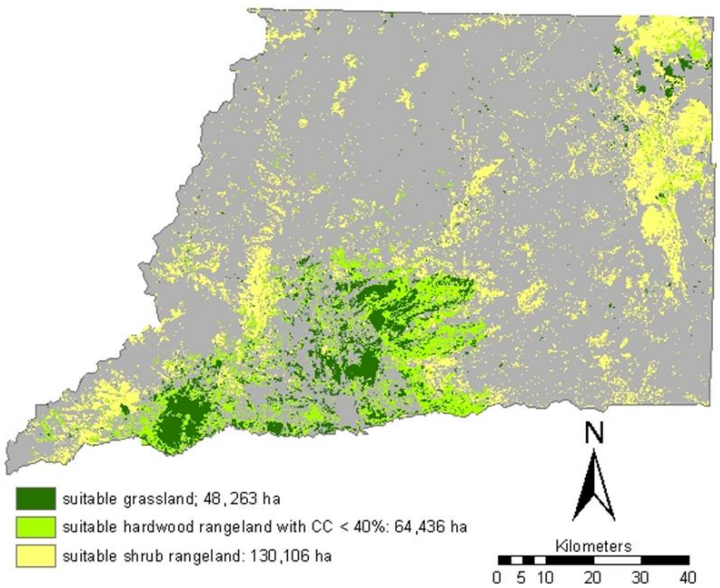

Figure S-1. Map of areas of existing rangelands suitable for afforestation activities

The report presents the entire range of costs and potential carbon available for afforesting rangelands. **Table S-1** summarizes the amount of carbon and the area available for three price points: ≤ \$10.0/t CO_2 (\$36.7/t C), ≤ \$5.5/t CO_2 (\$20/t C), and ≤\$2.7/t CO_2 (\$10/t C).

Table S-1. Summary of the quantity of carbon (million metric tons CO_2 [Mt CO_2]) and area (thousand acres) available at selected price points: ≤$2.7/t CO_2 ($10/t C), ≤ $5.5/t CO_2 ($20/t C), and ≤ $10.0/t CO_2 ($36.7/t C)—for afforestation on existing rangelands in Shasta County over 20-year, 40-year, and 80-year periods

Price points ($/t CO_2)	Quantity (Mt CO_2)	Area (Thousand acres)
20 years		
≤ 2.7	0.01	0.06
≤ 5.5	65.06	330.71
≤ 10.0	67.94	345.37
40 years		
≤ 2.7	2.77	10.95
≤ 5.5	87.44	345.83
≤ 10.0	88.47	355.23
80 years		
≤ 2.7	211.28	346.37
≤ 5.5	214.00	354.76
≤ 10.0	216.21	379.95

A second goal of this work was to determine how incorporation of more detailed data and higher resolution geographic information system (GIS) products into the analyses, accomplished by focusing on one key county, affect the estimated carbon supply potential. The first result of the comparison showed that the statewide-level study produced an estimated area of suitable rangeland in Shasta County for afforestation to be about 538,000 acres (217,729 hectares), compared to the 600,000 acres (242,820 hectares) identified in the detailed county-level analysis. It was also found that the area suitable for afforestation at different time periods was higher at the county scale than at the state-scale analysis, For example, after 20 years and < $10/t CO_2, the county scale identified 345,000 acres (139,622 hectares) as being afforested, whereas the state-scale analysis identified only 122,000 acres (49,373 hectares) as being afforested. The main cause for the difference in area suitable for afforestation was the use of higher-resolution maps for the county-scale analysis (30 meter [m]) pixels for the county scale compared to 100 m pixels for the state scale, or a more than 10-fold difference in scale.

In the previous statewide report, a preliminary analysis was performed to assess the potential for hazardous fuel reduction to reduce catastrophic forest fires that in turn reduce CO_2 and non-CO_2 greenhouse gas emissions from burning, and use the biomass to generate electricity and offset fossil fuel emissions from conventional power plants. In this study, the state-level method was extended to produce a first-order approximation of the areas and carbon stocks of forests suitable for fuel reduction to reduce their fire risk, their location relative to existing power plants in Shasta County, and the potential quantity of fuel that could be removed and at what cost.

After applying the constraints for identifying lands suitable for CSCH treatment, the total area available for fuels reduction in Shasta County was estimated to be approximately 215,000 acres (87,000 ha) or approximately 15 percent of the high to very high fire risk forest. The quantity of

biomass in the CSCH-treatable forests was estimated based on field data collected in Shasta County and the California Department of Forestry's Fire and Resource Assessment Program's (CDF-FRAP) maps. The biomass for CSCH treatable forest was estimated to be approximately 23.4 million tons, or approximately 11.7 million t C (42.9 million t CO_2 eq).

The total fuel available for removal would be much less than this quantity, as not all biomass on the land will be removed through the treatment. The average carbon stock of understory vegetation, small trees, and lying dead wood was 23 t C/ha across all forest types. Thus the potential removable fuel in a CSCH operation is 23 t C/ha.

Recommendations

This study should be further enhanced with actual field demonstration studies. In fact, the authors of this report are such performing a follow-up study involving a pilot reforestation demonstration study that will further validate the findings presented in this report. In addition, the authors are involved in development and testing of a methodology designed to improve the estimation of how much emission reductions would be attributable to hazardous fuel reduction practices.

Benefits to California

This study has shown that significant amount of carbon can be sequestered in Shasta county at relatively modest costs. It also appears from this preliminary analysis that the order of magnitude in emissions reductions attributable to hazardous fuel reduction (HFR), assuming commonly used prices for carbon offsets, is within the realm of practicality to cover subsidies needed for HFR—adding support to the argument for qualifying fuel reduction activities as carbon offset projects. In other words, a landowner could receive two revenue streams—from sale of the biomass and from sale of carbon credits gained from reducing fire severity. Furthermore, if the power plant was also receiving a monetary benefit from using biomass to substitute for fossil fuel (a large GHG benefit in its own right), it is possible that the plant operators could pay more for the biomass fuel giving the landowner more resources than just to break even. The benefits to California are obviously linked to the California Global Warming Solutions Act of 2006 (Assembly Bill 32, Nunez, Chapter 488, Statutes of 2006) which requires the state to reduce net greenhouse gas emissions by 2020 such that 2020 emissions cannot be higher than those emitted by California in 1990.

1.0 Introduction

The main goals of this report are: (1) to estimate the potential carbon supply from afforestation[1] of range lands in Shasta County, and (2) to produce a first-order approximation of the areas and carbon stocks of forests in Shasta County suitable for hazardous fuel reduction and the quantity of fuel potentially available for biomass energy plants. Shasta County was chosen for this study because it contains highly diverse land-cover classes representative of the State of California. Also, based on the statewide analysis of carbon sequestration potential, it was concluded that Shasta contained opportunities for implementing a range of important classes of sequestration projects. The approach used in this report generally follows that of previous work on the carbon supply from range and forest lands for the whole of California (Brown et al. 2004a; Petrova et al. 2006) and also uses information in the report on baseline greenhouse gas (GHG) emissions and removals for Shasta County (Pearson et al. 2005).

At the state level, it was found that at a price of < \$5.5/tons of carbon dioxide (t CO_2) (< \$20/ton of carbon, or t C), 345 million metric tons CO_2 could be sequestered on 2.7 million acres after 20 years and 3 billion metric tons CO_2 could be sequestered on 14.8 million acres after 40 years via afforestation using native species on existing rangelands suitable for forests (Brown et al. 2004a). From the same analysis and for Shasta County alone, 10.2 million metric tons CO_2 could be sequestered by afforesting 71 thousand acres after 20 years and 74 million metric tons CO_2 could be sequestered by afforesting 343 thousand acres after 40 years at a price of <\$5.5/t CO_2. The present analysis incorporates more detailed data and higher-resolution GIS products, focusing on one key county, to determine whether this affects the estimated carbon supply potential and the implications for the statewide estimates.

This report focuses on two classes of activities only: afforestation of rangelands and hazardous forest fuel management. It does not include any new analyses of extending forest rotations nor widening forest riparian zones, because the original statewide report (Brown et al. 2004a) was done at the county scale, due to the nature of the original databases (particularly the USDA Forest Inventory and Analysis database). Results of the statewide analysis for Shasta County found, for example, that extending forest rotations under permanent contracts by 5, 10, and 15 years could sequester an additional 0.67, 1.05, and 1.25 million metric tons of CO_2, respectively, over an economically optimum baseline at costs of \$54–\$85/t CO_2.

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[1] Under the U.S. Department of Energy (U.S. DOE) revised 1605(b) guidelines, *afforestation* is the establishment of new forests on lands that have not been recently forested, that is a land-use change; reforestation is the re-establishment of forest cover, naturally or artificially, on lands that have recently been harvested or otherwise cleared of trees. In contrast, the California Climate Action Registry does not use the term *afforestation* and instead defines reforestation as the establishment and subsequent maintenance of native tree cover on lands that were previously forested, but have had less than 10% tree canopy cover (essentially non-forested) for a minimum time of 10 years. This report uses the term *afforestation* as defined by U.S. DOE.

2.0 Rangelands

2.1. Introduction

The main goal of this section of the report is to generate carbon supply estimates for potential changes in the use of rangelands in Shasta County. Specifically:

- Identify the area and current use and cover of existing rangelands.
- Estimate the area and geographic location of existing rangelands that could be afforested and the rates of carbon sequestration on the identified lands.
- Estimate the total cost of afforesting existing rangelands, including opportunity cost, conversion cost, maintenance cost, and measurement and monitoring cost.
- Estimate how many carbon credits will be offered at various prices for afforesting existing rangelands.
- Determine the geographic distribution of available carbon credits at various prices.

2.2. Methods

2.2.1. General Approach

The analysis incorporates information about current land use; potential changes in land use and the incremental carbon resulting from the change; and opportunity costs, conversion costs, annual maintenance costs, and measurement and monitoring costs. The analysis was performed in a geographic information system (GIS) to include the diversity of existing land cover, rates of carbon sequestration, and costs in the analyses.

The general approach was to identify and locate existing rangelands where there is potential to change the use to a higher carbon content, estimate rates of carbon accumulation for each major potential land-use change activity, assign values to each contributing cost factor, identify datasets and methods to estimate risks, and identify datasets and methods to estimate co-benefits. The carbon supply is estimated for three time durations: 20 years, 40 years, and 80 years, to reflect the impact of activity duration on the likely supply and to provide an assessment for the near–term and longer-term planning horizons.

This study used a wide variety of spatial and non-spatial data sets. The spatial data include:

- California Spatial Information Library's 30 meter (m) DEM grids (derived from 1:24,000 Digital Elevation Models (DEMs) developed by USGS) (CASIL 2004).
- Natural Resources Conservation Service SSURGO soil survey maps and databases (USDA – NRCS).
- DAYMET Mean Annual Temperature map (Thornton et al. 1997).

- PRISM Precipitation maps (Taylor and Daly 2004).

- California Department of Forestry's Fire and Resource Assessment Program's 2003 Multi-source land-cover map and land ownership map (CDF-FRAP 2003).

Non-spatial data include, for example, regression equations based on original field data for converting canopy crown cover classes in CDF-FRAP maps to biomass carbon, U.S. Forest Service's Forest Inventory and Analysis (FIA) program (USFS FIA) data, published literature, and Winrock's experience from other activities. The details of these non-spatial data are given in the appropriate sections below.

The steps needed for estimating the carbon supply for afforestation activities on rangelands are described in detail in Brown et al. (2004a).

2.2.2. Scale of Analysis

The present study aims to estimate the approximate amount of carbon that can be sequestered on the selected areas through forestry activities. This analysis was conducted at 30-meter grid cell resolution, a finer resolution than the analysis conducted at the state level, and thus the analysis are more accurate and relevant for Shasta County. The datasets used in this analysis with relevant source, date, and scale are shown in **Table 2-1**.

Table 2-1. Scales and resolution of the datasets used by the model

Data	Data Source	Time Period	Publication Date	Resolution / Scale
Multi-source land-cover map	CDF - FRAP	1999	2002	MMU - 2.5 acres
Soil Available Water Capacity to 150 cm	SSURGO[2]		2004	1:20,000
Mean Annual Air Temperature map	DAYMET[3]	1980–1997	2004	1 km x 1 km
Annual Precipitation map	PRISM[4]	1961–1990	2004	1 km x 1 km
Slopes map	CASIL[5]		1997	30 m x 30 m

[2] SSURGO – Soil Survey Geographic Database

[3] DAYMET – Data Center for Daily Surface Weather Data and Climatological Summaries

[4] PRISM – Precipitation data set developed by collaborative effort between the Spatial Climate Analysis Services and the Oregon Climate Service (SCAS), http://www.ocs.orst.edu/prism/

[5] CASIL – California Spatial Information Library, http://gis.ca.gov/

Elevation map	CASIL	1997	30m x 30m

2.2.3. Definition and Area of Rangelands

The area of existing rangelands in Shasta County was determined using the California Department of Forestry's Fire and Resource Assessment Program's (CDF-FRAP) multi-source land-cover map (CDF-FRAP 2003) (**Figure 2-1**). This map was reclassified based on the classification scheme devised through consultation with researchers at the University of California at Davis Rangeland Studies Department (**Table 2-2**) (M. George 2003, Agronomy & Range Science Department, University of California-Davis, pers. comm.) to identify rangelands, forests, and other (**Figure 2-2**). The total area of Shasta County is approximately 996 thousand hectares, with approximately 302 thousand hectares of rangeland, representing 30% of the total area of Shasta County.

Table 2-2. The Wildlife Habitat Relationship (WHR) rangelands reclassification system applied to Shasta County

Wildlife Habitat Relationship Land-cover Type	Reclassification
Aspen	FOREST
Closed Cone Pine-Cypress	FOREST
Douglas Fir	FOREST
Eastside Pine	FOREST
Jeffrey Pine	FOREST
Klamath Mixed Conifer	FOREST
Lodgepole Pine	FOREST
Montane Hardwood Conifer	FOREST

Montane Hardwood	FOREST
Montane Riparian	FOREST
Ponderosa Pine	FOREST
Red Fir	FOREST
Subalpine Conifer	FOREST
Sierran mixed Conifer	FOREST
White Fir	FOREST
Barren	OTHER
Agriculture	OTHER
Urban	OTHER
Water	OTHER
Annual Grass	RANGE
Bitterbrush	RANGE
Blue Oak Foothill Pine	RANGE
Blue Oak Woodland	RANGE
Chamise-Redshank Chaparral	RANGE
Juniper	RANGE
Low Sagebrush	RANGE
Mixed Chaparral	RANGE
Montane Chaparral	RANGE
Sagebrush	RANGE
Valley Oak Woodland	RANGE
Wet Meadow	RANGE

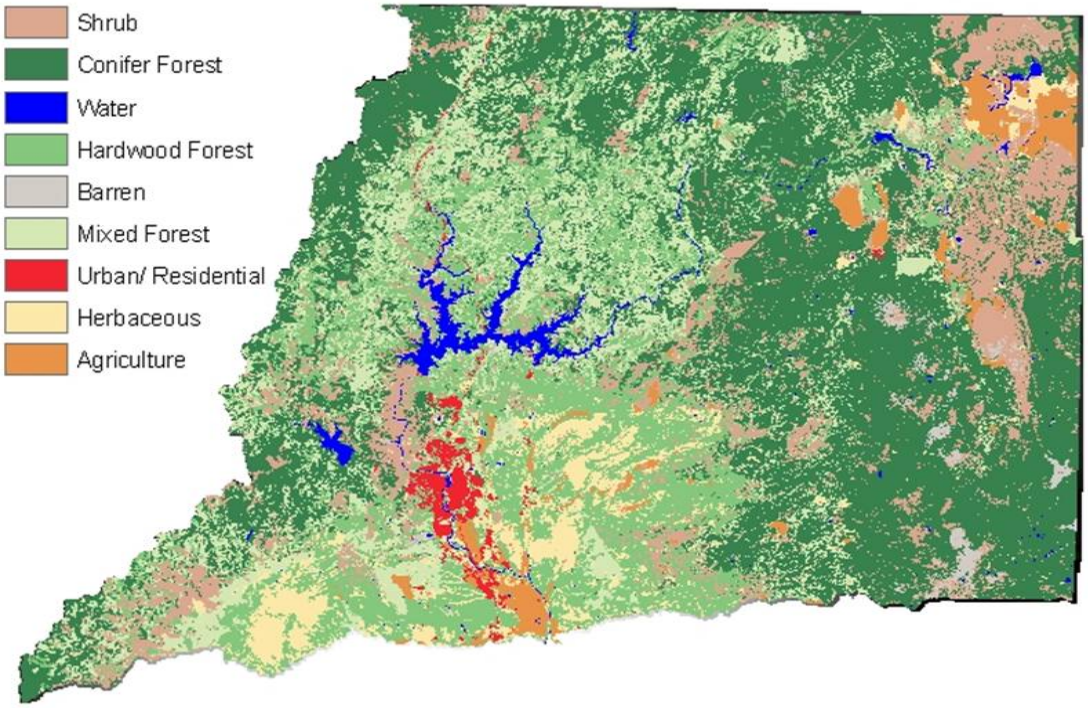


Figure 2-1. CDF-FRAP multi-source land-cover map classified into major land-cover types (31 WHR classes are actually present in the map)

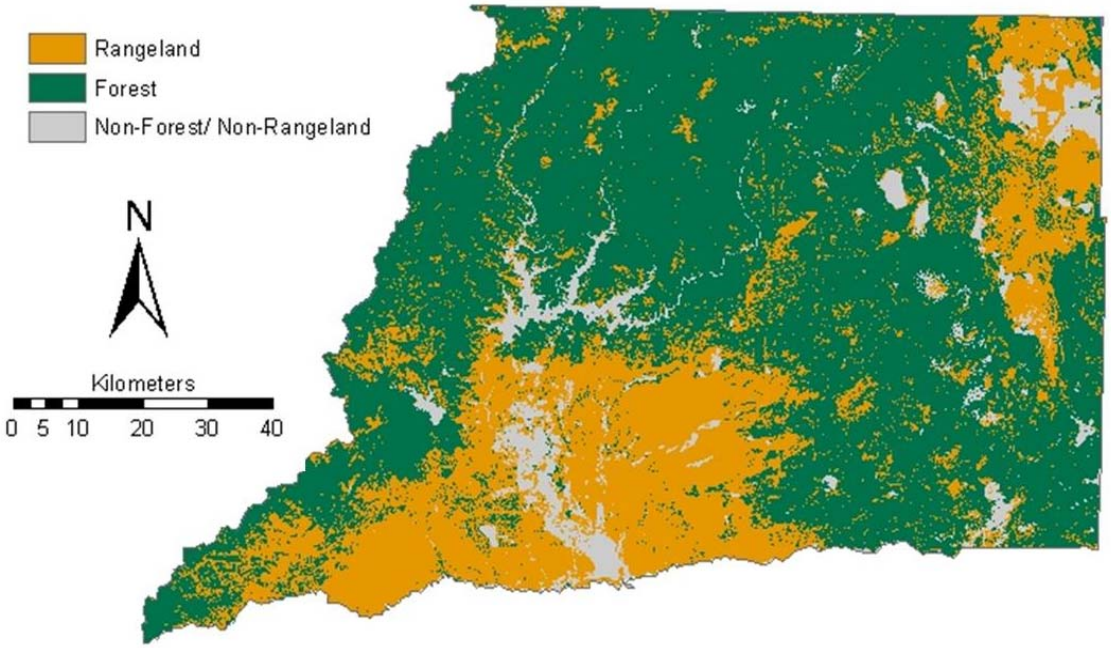


Figure 2-2. Reclassification of CDF-FRAP multi-source land-cover map into three classes: rangeland, forest, and non-forest/non-rangeland

2.2.4. Identification of Rangeland Suitable for Afforestation

2.2.4.1. Determining forest suitability

In the first step of the analysis, the goal is to identify which existing rangelands could potentially be afforested. To accomplish this task, the map of Shasta County rangelands was cross-referenced to suitability maps for forest land-cover. The same model that was developed for the work on the whole state (Brown et al. 2004a) was used in this analysis. Basically this model combined several different biophysical factor maps to produce a suitability map for forest growth, calibrated using empirical locations of actual forests, based on factors of elevation, slope, mean annual temperature for time period 1980–1997, mean annual precipitation for time period 1961–1990 and available water capacity of soil to 150 centimeters (cm). The quantitative factor maps given in Table 2-3 were used to gauge biophysical properties of the landscape which favor forest growth (**Table 2-3**).

Table 2-3. Factor maps used to developed forest suitability map with sources

Data	Source
Soil Available Capacity to 150 cm	
Soil surveys #604, #606, #607, and #708	SSURGO
Soil survey #707	SSURGO
Additional data	STATSGO
Mean annual air temperature map	Thornton et al. (1997)
Annual average precipitation map (1961–1990)	PRISM (Taylor and Daly 2004)
Slope map	CASIL (2004)
Elevation map	CASIL (2004)

These factor maps were divided into categories, where categories were grouped into classes based on equal intervals—for example, values in the elevation map were grouped into intervals of 100 m (e.g., elevation categories of 0–100, 100–200 meters above sea level, etc.). For each factor map, the model extracts empirical information on the proportion of the number of forested grid cells within each of these categories (**Figures 2-3 through 2-7**). This proportional information was used to weight each category in each factor map for forest suitability. The weights were then substituted for the old values of the categories (i.e., "proportion of forest in category" replaces "meter above sea level" range), creating probability maps based on each factor. Then all grid cells in the factor maps, with these new weights as their values, were averaged across all maps to create one map with a general suitability value in each cell. This methodology uses analysis modules featured within the IDRISI Kilimanjaro GIS and remote sensing software package (Eastman 2003a).

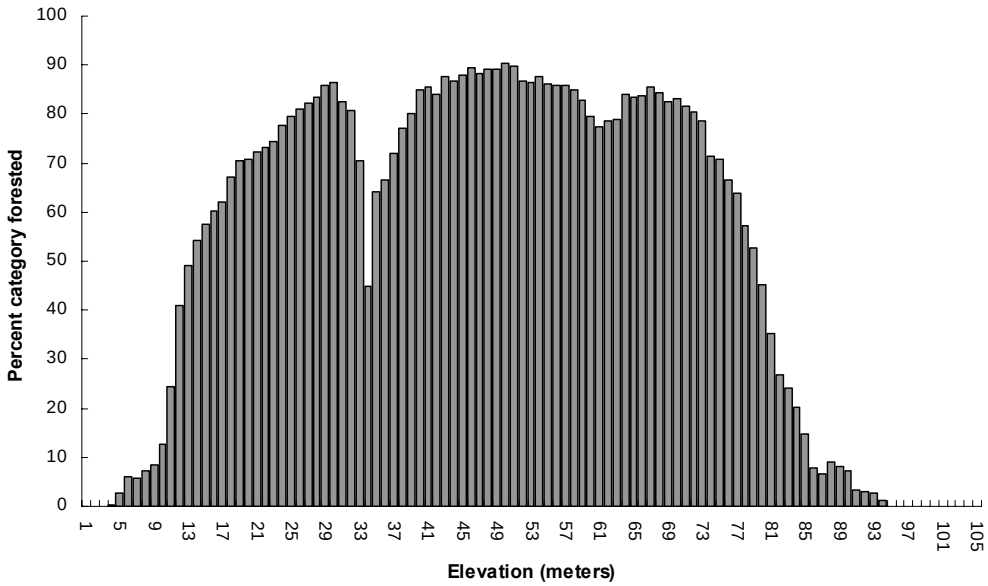


Figure 2-3. Proportion of actual forest in each of the elevation map classes

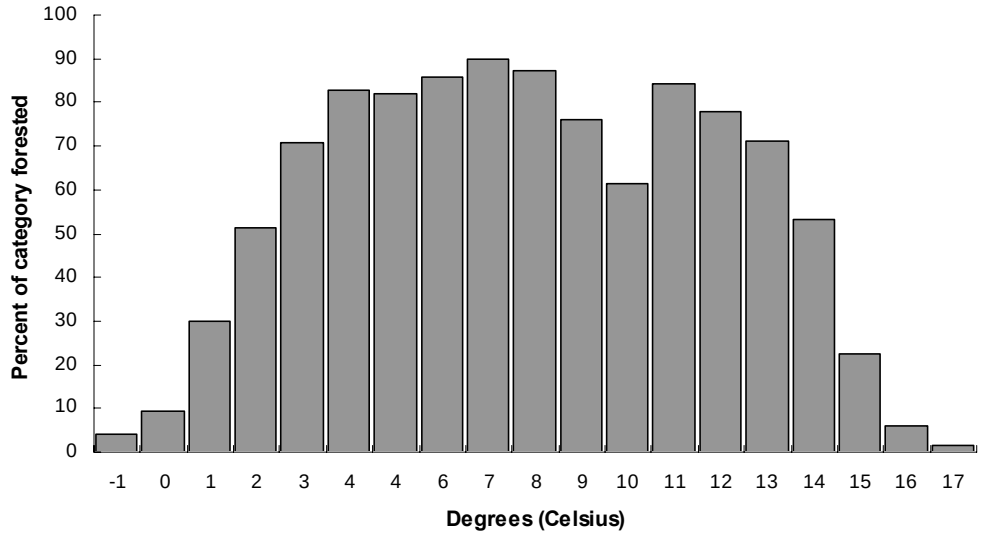


Figure 2-4. Proportion of actual forest in each of Mean Annual Temperature map classes

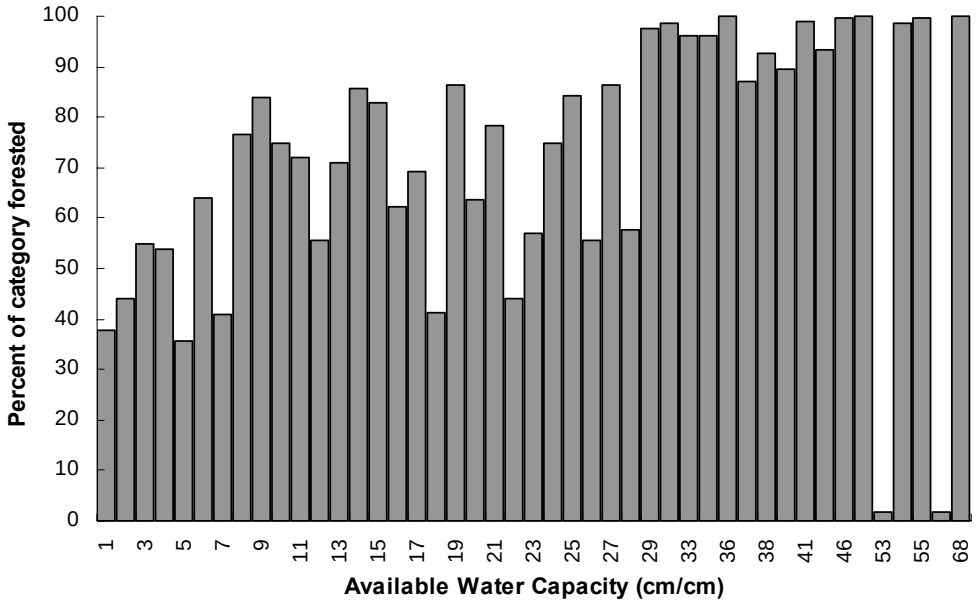


Figure 2-5. Proportion of actual forest in each of Soil Available Water Capacity map classes

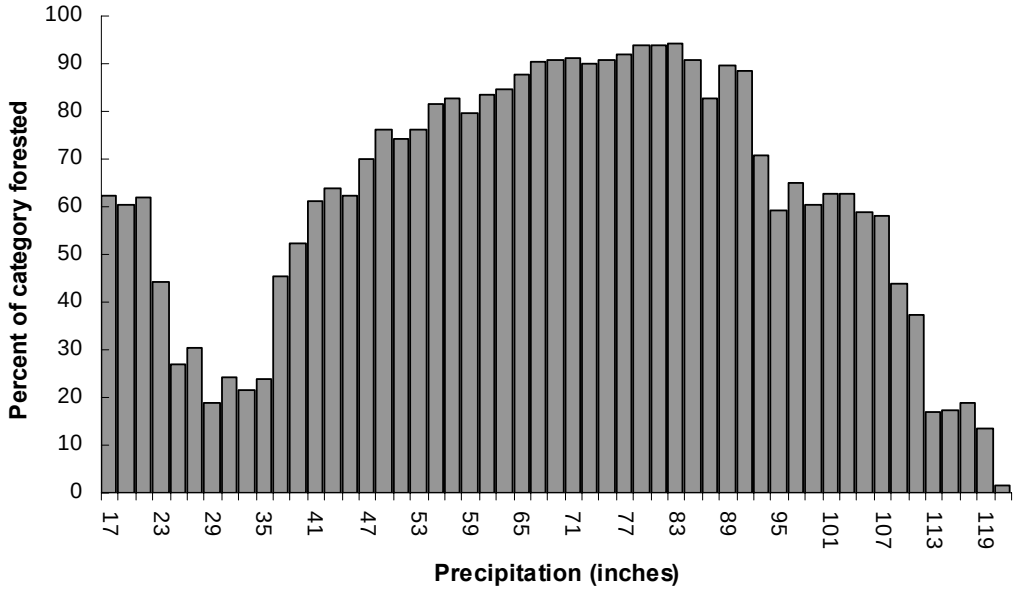


Figure 2-6. Proportion of actual forest in each of Precipitation map classes

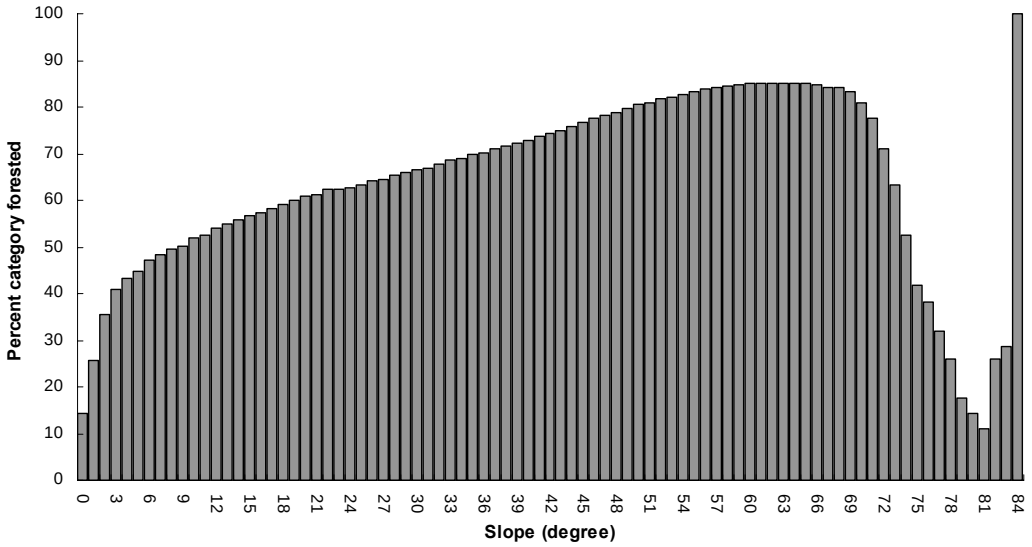


Figure 2-7. Proportion of actual forest in each of Slope map classes

The model is empirically driven, based on the distribution of forestlands within the factor map classes. Because of this, some factor maps may be cross-correlated (i.e., elevation and precipitation) but no statistical analysis was conducted to quantify this. To be classified among the most suitable sites, a location needs to have high values across **all** the factor maps. In this analysis, a constraint was introduced whereby lands that fell into a category of any one of the factor maps where there were no existing forests were eliminated as candidate lands for afforestation. In other words, the concept of limiting factors was used. For example, a constrained site might be one where the mean annual precipitation class is one in which forests commonly exist across the county, but there are no forests growing in areas with mean annual temperature values as low as the site in question. In this example, the site would be constrained from candidacy for afforestation because of the prohibiting factor of mean annual temperature despite meeting the suitability constraint for mean annual precipitation.

The suitability maps for forest growth across the total area and across the rangeland in Shasta County are shown in **Figure 2-8**.

The two-class forest/rangeland land-cover map was then compared to the suitability map to show the current range and forest distributions within their different suitability classes (**Figure 2-9**). This shows the ranges within the suitability scale where forests and rangelands currently exist and where potential transformation of rangelands to forests should be explored.

There is a substantial overlap of forest classes in areas that exhibit the same biophysical characteristics as current rangelands from an approximate suitability score of 45 to 85 (**Figure 2-9).** About 50% of the total area of rangelands overlaps with scores that currently support forests. It is also possible to see what proportions of some more specific land-cover types currently exist in the different forest suitability map classes by comparing maps of generalized WHR-classes to the suitability map (**Figures 2-10**). It can be seen that the higher forest suitability classes currently contain mostly mixed conifer forest but also some hardwood forest and shrubs.

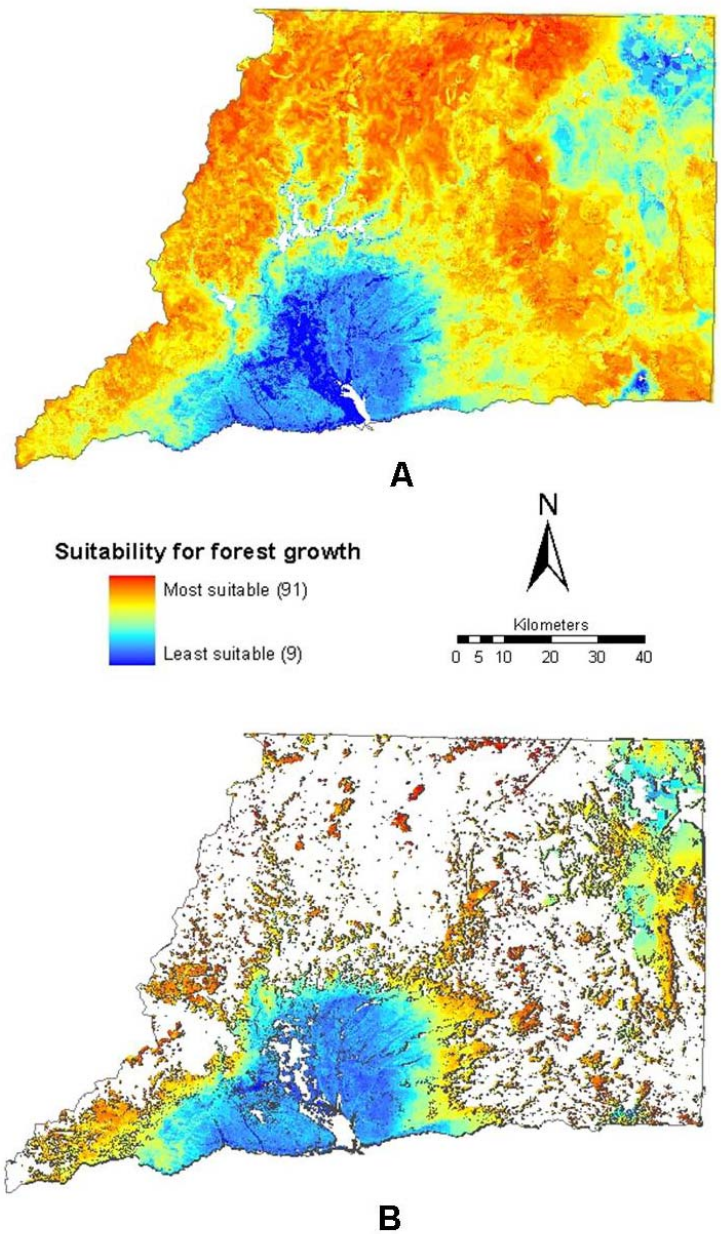


Figure 2-8. (A) All areas "suitability" for forest growth, and (B) rangeland areas "suitability" for forest growth according to the model. Low score means unsuitable for forests; the higher the score, the more suitable the area is for forest growth.

The current rangeland WHR types that exist in the different forest suitability classes show that montane and mixed chaparral classes occur at the higher suitability scores (**Figure 2-11**), suggesting that forests predated these classes. Some blue oak foothill pines and blue oak woodland also exist in those higher classes of forest suitability.

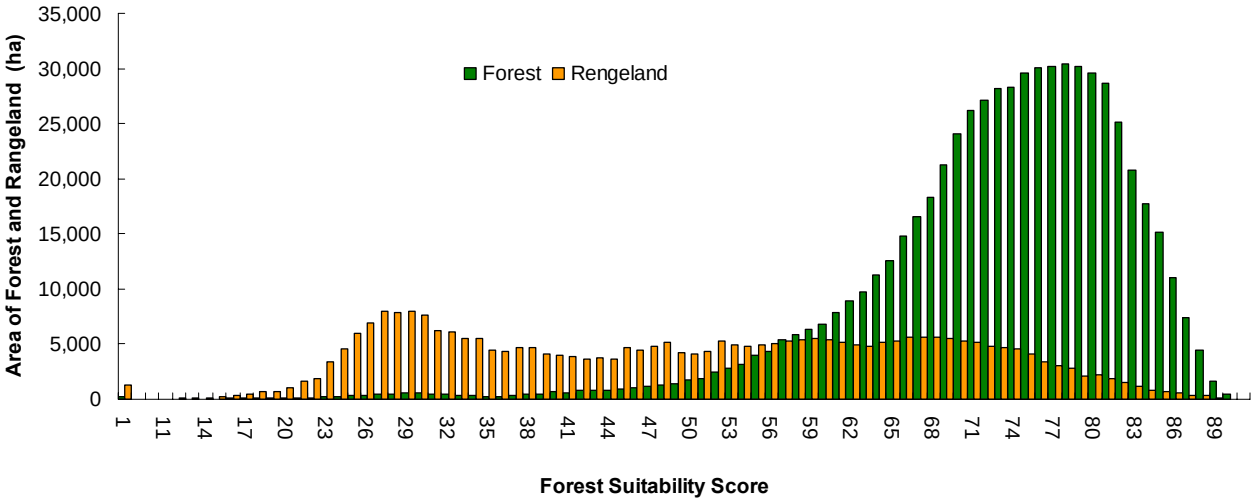


Figure 2-9. Distributions of areas of current rangeland and forest across forest suitability classes

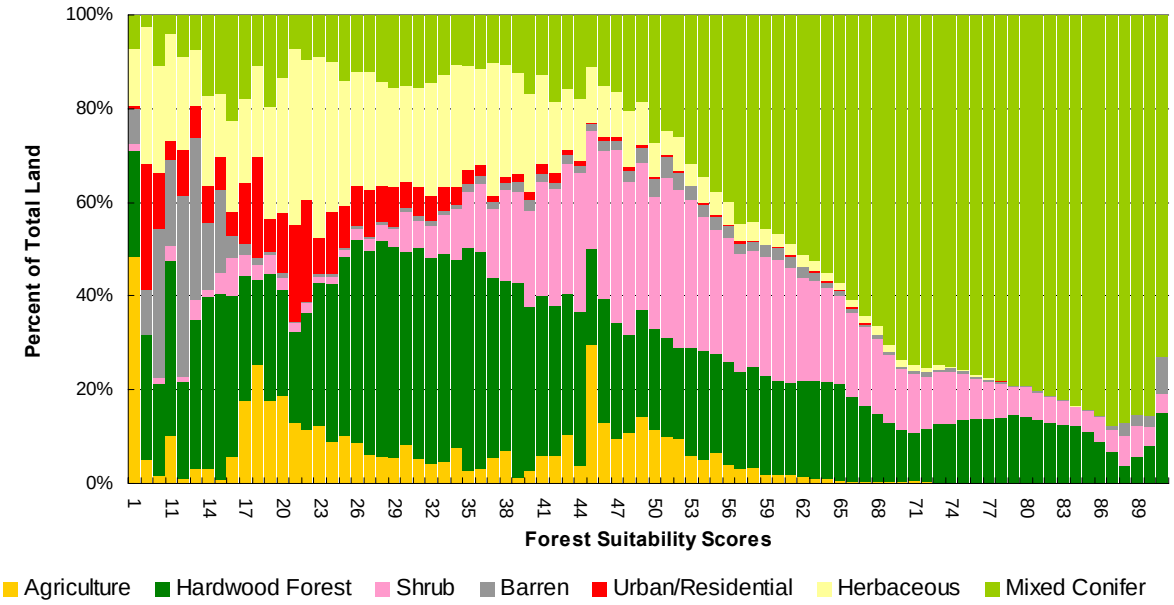


Figure 2-10. Distribution of 7 WHR generalized classes across the forest suitability classes

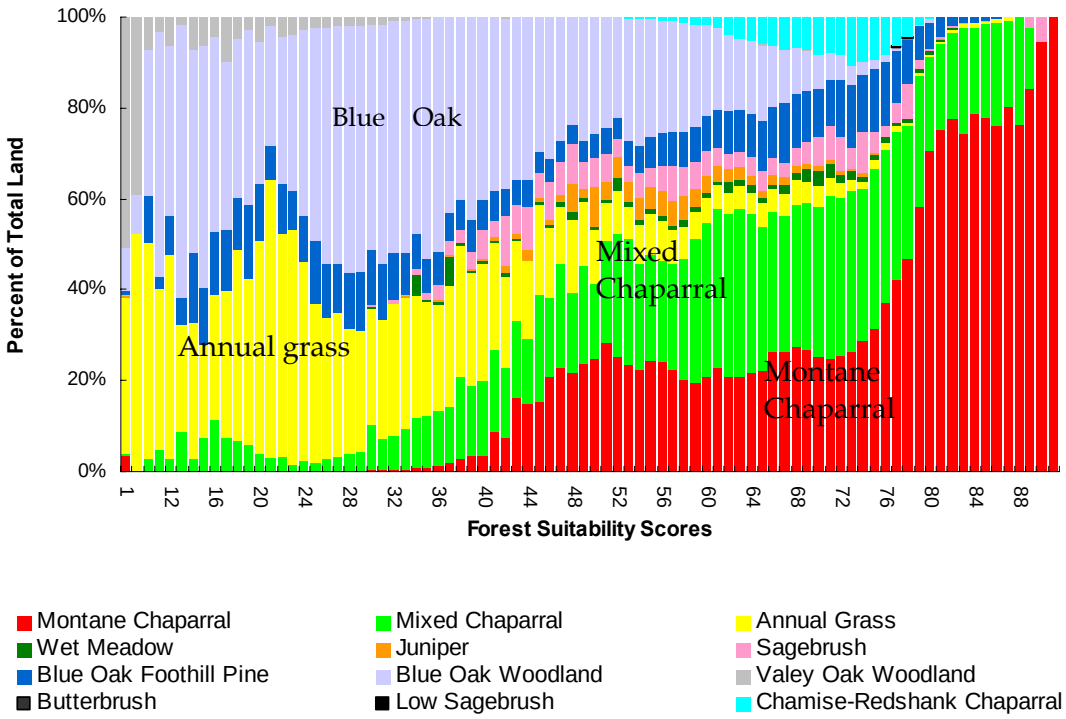


Figure 2-11. Distribution of rangeland WHR classes within the forest suitability classes

2.2.4.2. Determining rangeland suitable for afforestation activities

The above analysis identified rangelands that could potentially support forest, according to the forest suitability model. In this section the analysis is refined to identify rangelands suitable for afforestation. For example, some of the wooded rangelands have canopy cover greater that 40% and are likely not suited for further afforestation, and some of the grassy rangelands are dominated by wet meadows and may not be suited for growing trees (**Figure 2-12**).

Canopy closure of the various land-cover classes is determined by CDF-FRAP through remote sensing analyses and field reconnaissance and is provided as part of their multi-source land-cover product's geo-database (CDF-FRAP 2003). The canopy closure database was used to identify woody rangelands suitable for additional afforestation activities—it was assumed that these rangelands are mapped by density classes S and P (percent canopy closure of < 40%). Rangelands mapped with canopy closure classes M and D (percent canopy closure of > 40%) were assumed not to be suitable for additional afforestation activities. Wet meadows were eliminated based on the original WHR map. Thus, the candidate rangelands, suitable for afforestation activities, are those areas that are either non-woody rangelands, excluding wet meadows, or woody rangelands with a canopy cover of less than 40% (**Figure 2-13**).

The total area suitable for afforestation activities is about 243 thousand ha, which represents about 80% of the total lands classed as rangelands. Woody rangelands suitable for afforestation activities cover about 64,436 ha, or 27% of the total suitable rangelands.

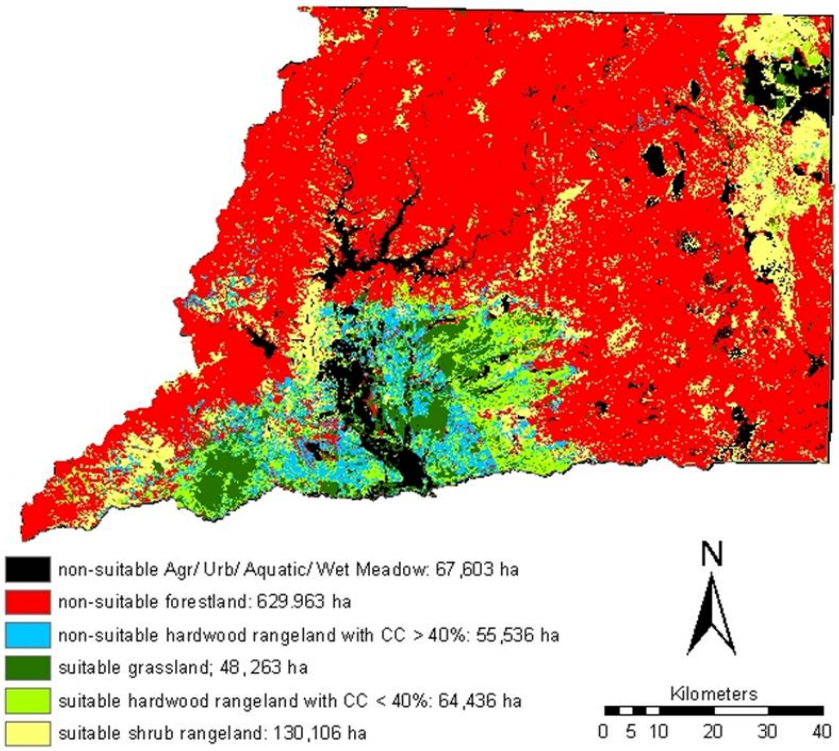


Figure 2-12. Suitable and non-suitable areas for potential afforestation activities

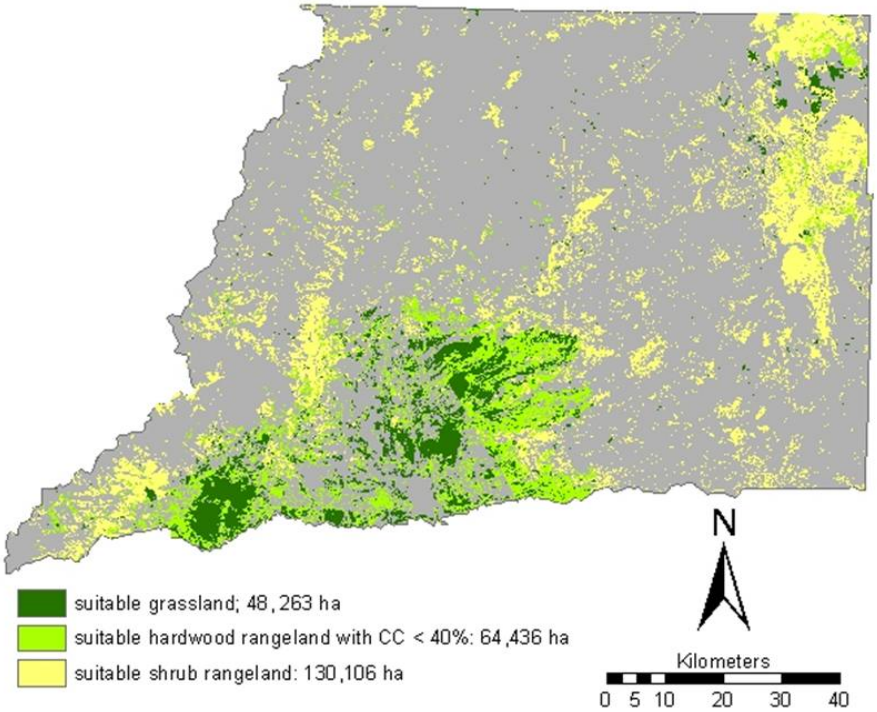


Figure 2-13. Map of suitable areas for afforestation activities

2.2.4.3. Determining potential woody species to plant on rangeland

To determine the carbon sequestration potential on rangelands, it is necessary to examine the forest species that could potentially be planted. Here the steps performed to accomplish this are described.

First, to determine which species could grow successfully in rangeland areas that were determined to be suitable for forest growth, the forest WHR classes were aggregated into three classes—hardwood, hardwood range, and mixed conifer—based on USDOE[6] (2006) classification. Then, the reclassified forest map was superimposed on the forest suitability map to determine which woody species is dominant for each forest suitability category.

Second, the rangeland map was superimposed on the forest suitability map. This allowed for rangelands that fall within a particular forest suitability class to be assigned a dominant woody species suitable for afforestation activity. The re-classed classes of hardwood range and hardwood were dominant for the low-scoring forest suitability index, thus they were assigned to the rangeland falling within the low forest suitability categories. The mixed conifer class was dominant for the high forest suitability categories and therefore it was assigned as woody species suitable for planting on rangelands that fall within high forest suitability categories (**Table 2-4).**

Table 2-4. Reclassification scheme of WHR classes according USDOE (2006) classification

WHR	Birdsey class
Montane Riparian	Hardwood
Montane Hardwood	Hardwood
Aspen	Hardwood
Blue Oak Woodland	Hardwood Range
Blue Oak Foothill Pine	Hardwood Range
Valley Oak Woodland	Hardwood Range
Juniper	Hardwood Range
Subalpine Conifer	Mixed Conifer
Closed Cone Pine-Cypress	Mixed Conifer
Lodgepole Pine	Mixed Conifer
Sierran Mixed Conifer	Mixed Conifer
Eastside Pine	Mixed Conifer
Klamath mixed Conifer	Mixed Conifer

[6] Ultimately carbon stock values need to be applied to the rangelands suitable for afforestation—these are obtained from U.S. DOE (2006) and thus the need to re-classify the WHR classes into these classes.

Jeffrey Pine	Mixed Conifer

2.2.4.4. Projecting forest carbon sequestration potential

To estimate the potential accumulated carbon by afforestation on the suitable rangeland areas, carbon data were obtained from a variety of sources. All of the estimates represent the carbon stocks in living trees (above and below ground), standing and lying dead wood, understory, and forest floor (also referred to as litter and duff) at 20, 40, and 80 years (**Table 2-5**).

Table 2-5. Estimates of the potential carbon stocks from afforestation of suitable rangeland areas (see Table 2-4 for description of forest classes)

Forest class	**Carbon stock at 20 yr** (t C/ha)	**Carbon stock at 40 yr (t C/ha)**	**Carbon stock at 80 yr (t C/ha)**
Mixed conifer	132.4	170.3	411.1
Hardwood	24.8	77.4	217.5
Hardwood range	12	37	59

The data for the hardwood class (mostly montane hardwoods) was obtained from the look–up table for the Pacific Southwest hardwood (Table B29). For the mixed conifer, the FIA data for all plots within this class for Shasta County were downloaded and sorted by age class (a total of 30 plots). Using the methods described in Brown et al. (2004b), these data were converted to estimates of aboveground biomass of trees. A model was fit to the data that related aboveground biomass to stand age (significant relationship with $r^2 = 0.60$). This model was then used to estimate the biomass, converted to carbon (carbon = 0.5 x biomass) at 20, 40, and 80 years. Estimates of belowground carbon were added by using a multiplier of 1.25 (see Brown et al. 2004b). To account for the other components (dead wood, understory, and litter and duff) the research team used the data in Table B27 (Pacific Southwest mixed conifers) of the USDOE (2006) to generate multipliers of total live tree carbon for these components by the three age classes—for 20 years the multiplier was 3.10, for 40 years it was 1.60, and for 80 years it was 1.55. The estimated multipliers for the other components were verified against the field data collected by Winrock for a similar forest type in Blodgett (Brown et al. 2004b). For example, the total live carbon in trees at age 20 years was 42.7 t C/ha, and using the multiplier of 3.10 resulted in a total carbon stock of 132.4 t C/ha.

Carbon stocks for the hardwood range class were obtained from the statewide analysis (Brown et al. 2004). The values used in that analysis only included live trees (above and below ground biomass). To account for the carbon stocks in dead wood, understory, and forest floor, the live tree estimates were increased by 30%, based on field data collected for hardwood forests in Shasta County. Applying the carbon stock estimates to the map of rangelands suitable for afforestation results in a map of carbon sequestration potential (**Figure 2-14).**

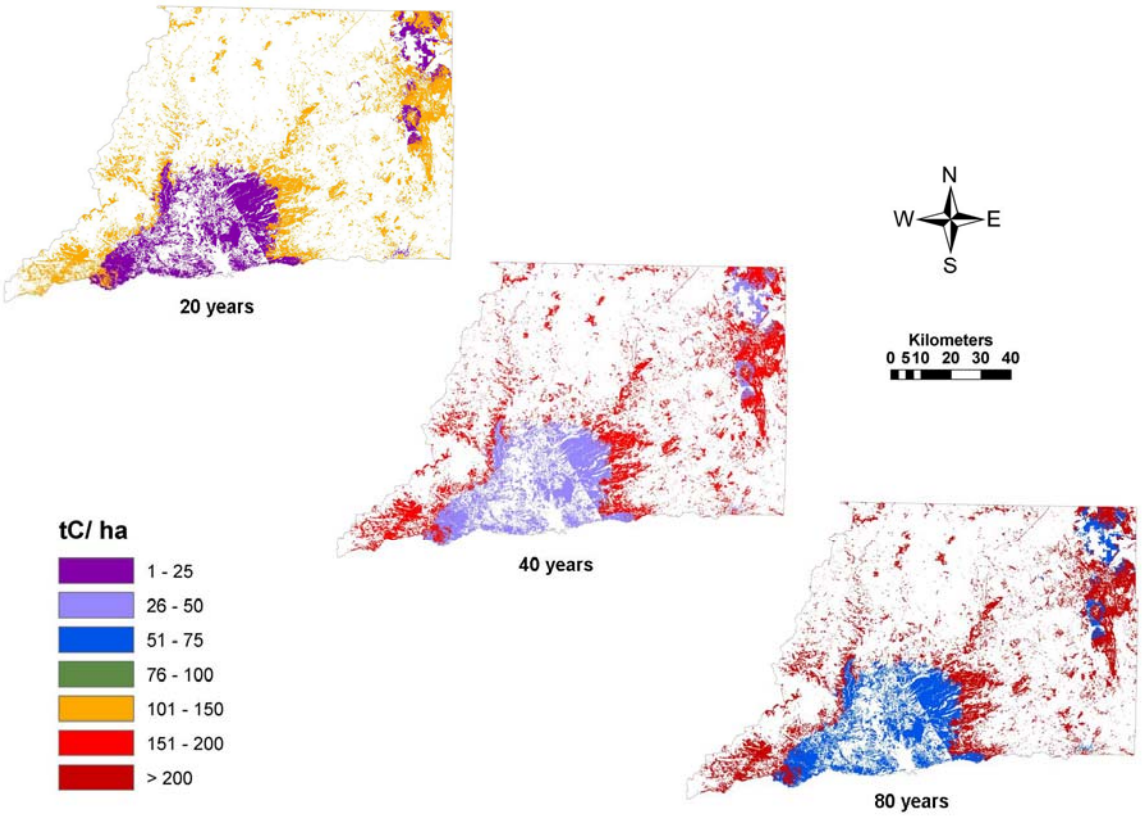


Figure 2-14. Carbon sequestration potential on rangelands suitable for afforestation activities for 20, 40, and 80 years

2.2.5. Analysis of Carbon Sequestration Costs

This section describes all of the estimated costs for producing carbon through afforestation of rangeland in Shasta County. These costs are used in the construction of carbon supply curves that depict, for this class of activities, the estimated quantity of carbon supplied over a range of possible carbon prices. The categories of costs that were estimated in this analysis include: opportunity costs, planting and other conversion costs, measuring and monitoring (M&M) costs, and maintenance costs. Each of these cost categories is described and quantified next.

2.2.5.1. Opportunity costs

Simply put, the opportunity cost is the most highly valued alternative to the activity being considered. In this case, the activity being considered is afforestation of rangelands. The most highly valued alternative to afforestation is cattle ranching.[7] Therefore, the profitability per hectare of cattle ranching in Shasta County represents the opportunity cost of producing carbon (i.e., afforestation).

[7] Except in those cases there the lands classed as rangelands are actually in some form of arrested succession (see Section 2.2.5.2).

An alternative to afforestation of rangelands could be conversion to urban development, and depending upon the price of real estate, the opportunity cost for this alternative could be high. This alternative was not considered in this analysis.

The focus on estimating opportunity cost for rangeland is for cattle ranching for beef, not for dairy. The profitability of cattle ranching varies greatly from year to year and from ranch to ranch. This is due primarily to weather conditions and cyclical fluctuations in the price of beef. Unfortunately, in California, annual enterprise budgets for cattle ranching (which indicate profitability) are not officially kept, as they are for many other agricultural activities. Because of this, input of several ranchers and rangeland extension specialists was used to calculate an average annual profitability value for cattle ranching representative of Shasta County. The revenue was estimated to be about $574/cow and costs were estimated to be $479/cow, with a profitability or average annual profit per cow of $95.

Other than the wide swings in the price received for cattle, the most critical variable in determining ranching profitability is the forage production potential of the rangeland. Forage production determines the carrying capacity of the land. Higher forage production can support more cows per area and therefore results in higher profits.

California rangeland specialists use an average of 791 pounds (lbs.) of forage dry matter (DM) to represent the monthly requirements for cattle being fed on rangeland forages (L. Metz 2003, USDA-NRCS, Davis, California, pers. comm.). This monthly requirement is termed an *animal unit month* (AUM)—if one acre of rangeland produces 791 lbs. of forage DM over the course of one month, that acre is said to produce one AUM of forage. This translates into an annual per cow forage requirement of 9,492 lbs DM (12 times the AUM). This forage requirement estimate (i.e., AUM of 791 lbs.) and the average annual per cow profitability of $95 was used to estimate the profitability potential (i.e., opportunity cost) for rangelands in Shasta County.

The forage production of any given acre of rangeland determines its carrying capacity. The carrying capacity determines the profit that can be made from that acre. For example, rangeland that only produces 100 lbs. of forage DM per acre will require almost 95 acres to support one head of cattle for a year. The annual per acre profitability of this low-producing rangeland is estimated to be only $1.00 (i.e., $95/95 acres). High producing rangeland of 2,000 lbs DM per acre per year will require only 4.75 acres to support one head. In this case, the annual per acre profitability is $20 (i.e., $95/4.75 acres). The relationship between annual average per cow profitability ($95) and annual average per cow forage DM requirements (9,492 lbs.) yields a constant relationship, indicating that each lb of forage DM is equal to $0.00998 in ranch profits. This average profitability per lb of forage DM production was used to project the profitability of rangelands in Shasta.

The California State Soil Geographic Database (Schwarz and Alexander 1995) reports forage production for rangelands in Shasta County. The forage production estimates were translated into a livestock carrying capacity for the land and combined with the average per cow profitability to estimate the average annual opportunity cost of afforestation for each pixel of rangelands on the map. The present value of the annual opportunity cost for every year over the time interval 20, 40, and 80 years was then calculated using a 4% real discount rate.

2.2.5.2. Stratifying the rangeland into suitable and not suitable for grazing

Although cattle ranching is the common activity on most rangelands identified to be suitable for afforestation, site visits to Shasta County demonstrated that this is not the case in all locations, and indeed some areas mapped as rangelands were in some form of arrested succession. Based on this, the rangeland class was further stratified into two subclasses: those rangelands suitable for grazing, and those unsuitable for grazing.

Rangeland unsuitable for grazing, and where succession was arrested, were assumed to be those classed as chaparral in the WHR map and falling within the perimeters of wildfire that occurred during 1987 to 1994. These areas tended to be covered with dense shrubs such as manzanita and were generally impenetrable for animals. Second, the rangeland WHR classes of montane chaparral and mixed chaparral with density greater than 40% (as mapped in the FRAP maps) were also considered unsuitable for grazing. All other rangelands were suitable for grazing (**Figure 2-15**).

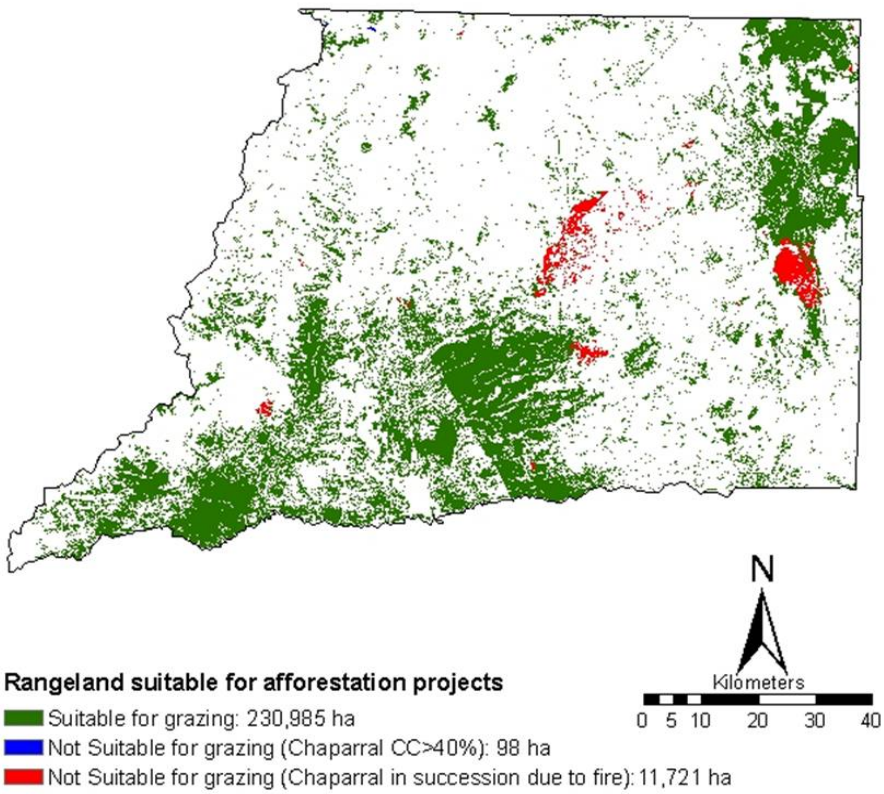


Figure 2-15. Suitable for grazing and not suitable for grazing rangeland areas, candidate for afforestation projects

2.2.5.3. Methodology for estimating forage production

The county-scale soils database, SSURGO, provides estimates of forage production (in pounds per acre per year) for each soil component within each map-unit polygon. A map was produced using forage production estimates for the dominant soils component in each map polygon (as indicated by the "comppct" field in the database). This analysis resulted in a map showing forage production ranging from 100 to 3000 lbs/acre/year for rangeland suitable for

afforestation activities (**Figure 2-16**). The soil surveys do not cover the entire area of Shasta County, thus the forage productivity for some rangelands was not calculated directly from the SSURGO datasets. To estimate the forage productivity on these rangelands, the weighted average of forage productivity on rangeland per forest suitability category with available SSURGO data was assigned to the rangelands within the same forest suitability category with no SSURGO data.

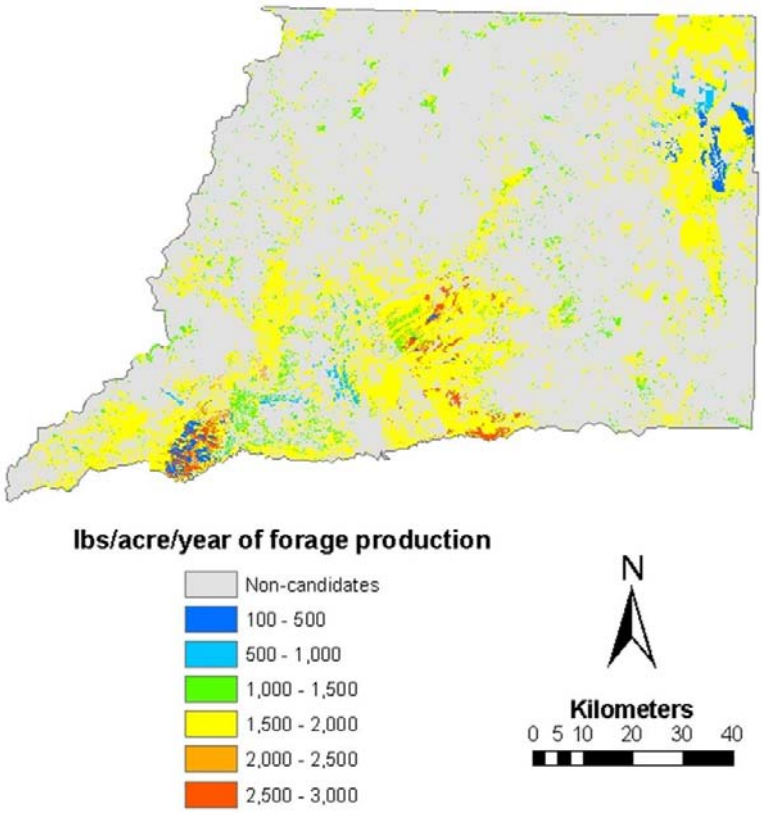


Figure 2-16. Forage productivity across rangeland classes, in pounds per acre per year [NOTE: To convert from lbs/acre/year to t/ha/year, divide by 907.]

2.2.5.4. Conversion costs

Conversion costs represent the estimated cost for establishing tree plantings on rangelands and include site preparation costs as well as the cost of seedlings and of planting itself. The costs of establishing forests can range from $300 to $1,500 per acre, depending upon a variety of factors such as slope, site preparation needs (only herbicide or mechanical site preparation), move-in/move-out cost for the equipment, area to be treated, type of equipment to be used, and other factors (Adam Wyman 2005, Field Forester, Shasta Ranger Unit, CDF, pers. comm. and E. Murphy 2003, Inventory Forester, Sierra Pacific Industries, Redding, California, pers. comm.). Slope of the land is a critical factor in the total cost of afforestation—reasonably well managed rangeland on a slope 30% and less will be lower in conversion cost than rangeland on a slope greater than 30% (A. Wyman, pers. comm.).

Given the above information, four conversion cost functions were applied to the rangelands: $450/acre for rangelands suitable for grazing with slopes < 30%, $600/acre for rangelands suitable for grazing with slopes ≥ 30%; $900/acre for rangelands unsuitable for grazing with slopes < 30%, and $1,100/acre for rangelands unsuitable for grazing with slopes ≥ 30%.

2.2.5.5. Measurement and monitoring (M&M) costs

This category represents the costs of measuring and monitoring the change in carbon stocks over the life of the activity. The annualized M&M costs associated with carbon production contracts are estimated to be $1.60/acre/year, $1.08/acre/year, and $0.80/acre/year for 20-, 40-, and 80-yr periods, respectively, based on Winrock's experience with measuring and monitoring afforestation activities throughout the United States. Several factors affect this cost, including which pools are measured and monitored (in this case only aboveground biomass in included), frequency of monitoring (once every five years over duration of project), area, and whether the lands are contiguous or dispersed (assumed here to be contiguous). The area of the activity is an important factor and economies of scale exist for M&M costs; therefore, per-acre M&M costs may be significantly higher for smaller activities.

2.2.5.6. Maintenance costs

It is expected that maintenance costs will be incurred for a period of five years from the beginning of the activities to ensure that enough tree seedlings survive to generate a well-stocked stand. Activities expected (depending upon local conditions) include replanting seedlings that died, weeding (or herbicide application), possibly fertilizing and adequate fencing to control livestock incursion until the trees get established. Annual maintenance costs are estimated to be approximately $8/ac/year during the first five years of the activities.

2.2.5.7. Total costs

To estimate the total costs of producing carbon on rangelands in Shasta County, the conversion and land management costs are combined with the present value of the M&M and opportunity costs over the life of the activities (**Table 2-6**). For rangelands unsuitable for grazing, the opportunity cost is not included in the present value analysis. Because so little is currently known regarding the future structure of carbon contracts, these costs are currently assumed to be zero.

Although no opportunity costs are included in the rangelands unsuited for grazing, the high cost of site preparation and planting result in these lands being the most expensive, particularly over the shorter time frame of 20 years and on low forage productivity lands.

For every parcel of suitable rangeland, the total cost of producing carbon through afforestation is estimated. The costs per ton of carbon sequestered are then calculated based upon the estimates of carbon stock for each specific parcel.

Table 2-6. Net present value of total costs, in $/ha over the time period, for afforesting rangelands in Shasta County for three time periods

Forage production	Total costs		
Lbs/acre.yr	20 year	40 year	80 year
Suitable for grazing with slopes <30%			
100	$1,298	$1,312	$1,317
500	$1,432	$1,507	$1,552
1000	$1,599	$1,751	$1,847
1500	$1,767	$1,995	$2,142
2000	$1,934	$2,239	$2,437
Suitable for grazing with slopes >30%			
100	$1,668	$1,682	$1,687
500	$1,802	$1,878	$1,923
1000	$1,970	$2,122	$2,218
1500	$2,137	$2,366	$2,513
2000	$2,305	$2,610	$2,807
Unsuitable for grazing with slopes <30%			
100	$2,376	$2,375	$2,369
500	$2,376	$2,375	$2,369
1000	$2,376	$2,375	$2,369
1500	$2,376	$2,375	$2,369
2000	$2,376	$2,375	$2,369
Unsuitable for grazing with slopes >30%			
100	$2,870	$2,869	$2,863
500	$2,870	$2,869	$2,863
1000	$2,870	$2,869	$2,863
1500	$2,870	$2,869	$2,863
2000	$2,870	$2,869	$2,863

2.3. Results: Potential Carbon Supply

It is assumed that landowners would be willing to produce and sell carbon credits if the price paid for these credits is greater than the present value of the stream of costs incurred in producing them. Generally, the cost per ton of carbon produced is greater for the shorter time periods (20 years) and less for the longer time periods (80 years) (**Figure 2-17**). The primary reasons for this result include the influence of the economic discount rate used in calculating the present value cost of carbon (the longer the time period, the greater effect discounting has on the costs) and the rate of carbon accumulation over time (the longer the duration, the greater the change in carbon stock).

After 80 years, about 57.6 million tons of carbon could be sequestered at a cost of less than $10/t C ($2.7/t CO_2). In contrast, about 17.7 million t of carbon could be sequestered after 20 years at a cost of < $20/t C ($5.45/t CO_2). These quantities could be sequestered on about 57% of the rangeland suitable for afforestation (**Figure 2-18**). The costs rise steeply with limited additional carbon on the remaining 44% of the rangelands suitable for afforestation, because these lands tend to be most suited for rangeland hardwoods with low rates of carbon sequestration.

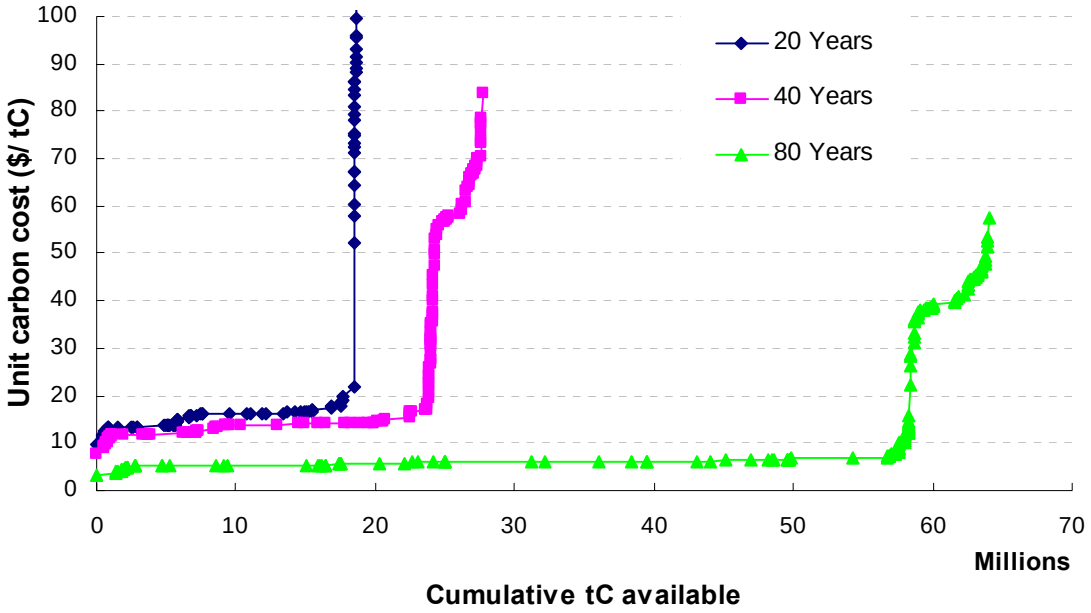


Figure 2-17. Carbon supply curves for afforestation activities on rangelands at 20, 40, and 80 years

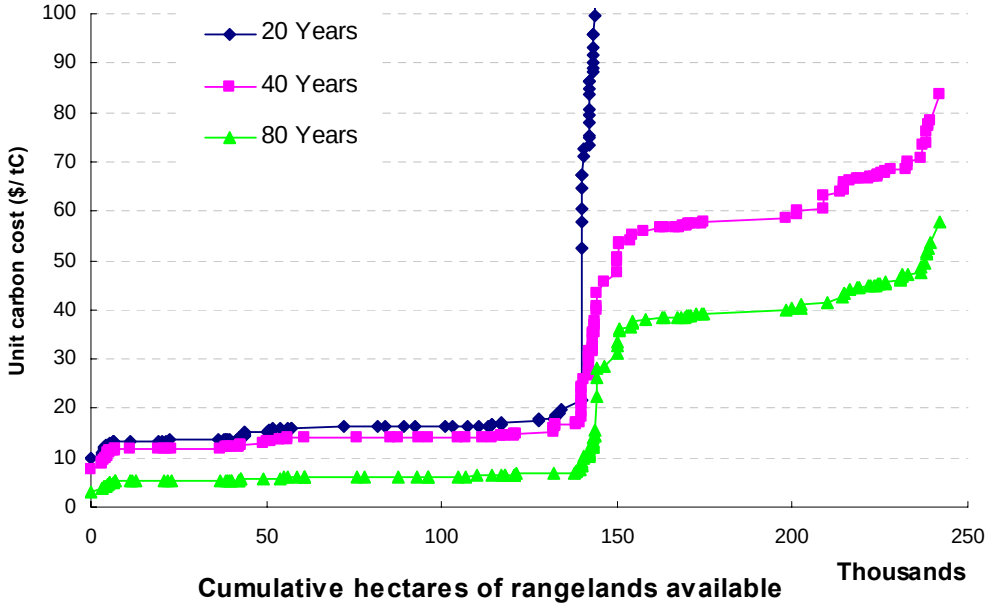
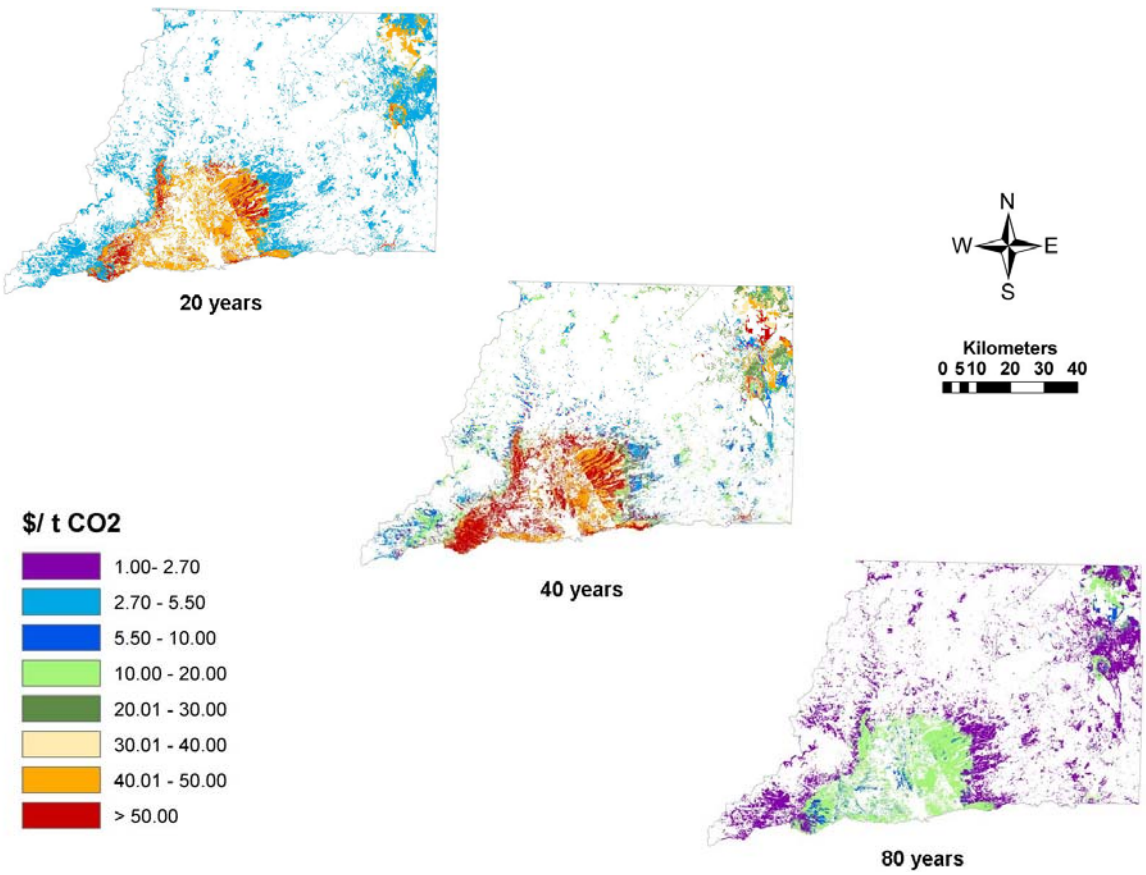
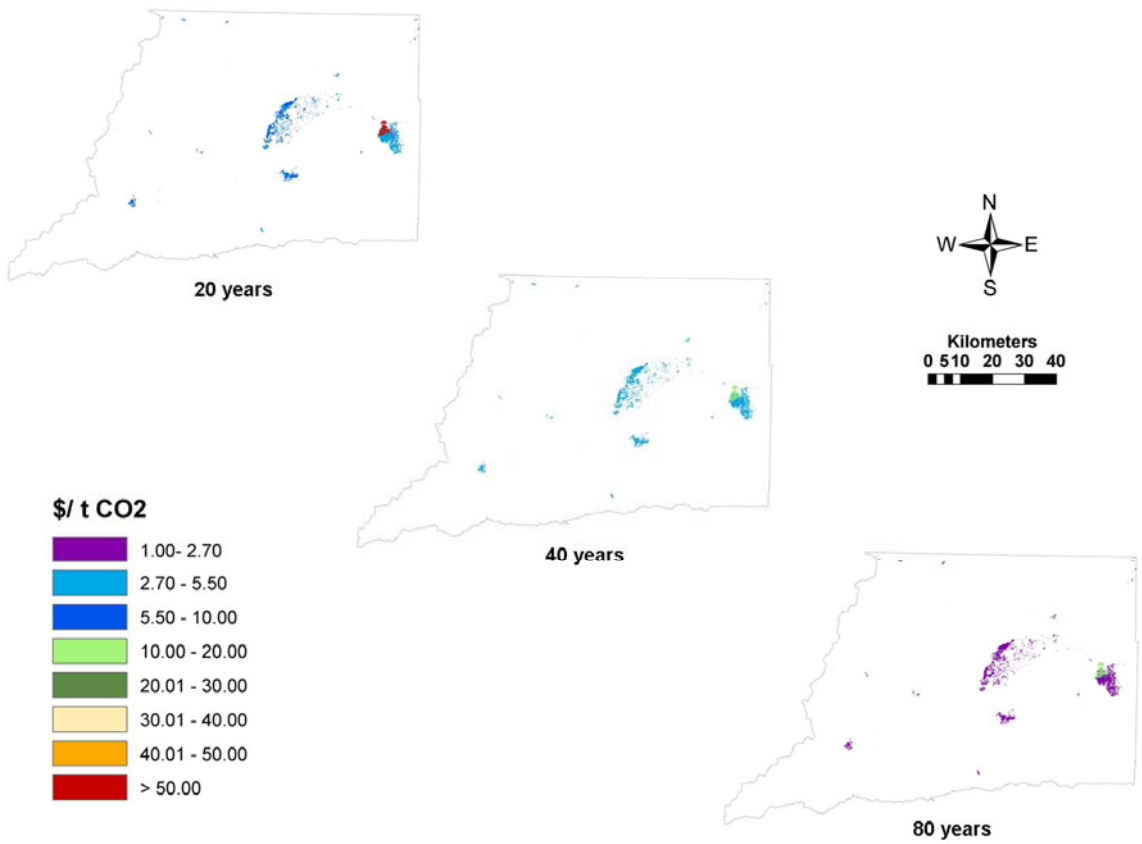


Figure 2-18. Land supply curves for afforestation activities on rangelands at 20, 40, and 80 years

The location of rangelands and associated cost of carbon sequestration though afforestation is shown in **Figure 2-19**, including those suitable (A) and unsuitable (B) for grazing**.** The most expensive carbon on lands suited for grazing (> \$40/t CO_2) is located in the south to southwest part of the county (**Figure 2-19 A**). The least expensive carbon after any of the three time intervals is located in the east to northeastern part of the county. The small amount of rangeland unsuited for grazing produces carbon at a mid-range of costs (**Figure 2-19 B**).



A



B

Figure 2-19. Distribution of cost of carbon sequestration through afforestation of rangelands (A) suitable and (B) unsuitable for grazing in Shasta County

2.3.1. Comparison with the State-level Analysis

The results obtained here for afforesting rangelands in Shasta County were compared to results obtained from the statewide analysis (Brown et al. 2004a) (**Figure 2-20**). The first result of the comparison showed that the statewide-level study produced an estimated area of suitable rangeland in Shasta County for afforestation to be about 218,000 ha, compared to the 243,000 ha identified in the detailed county-level analysis. It was also found that the area suitable for afforestation at different time periods was higher at the county scale than at the state scale analysis—e.g., after 20 years and < \$10/t CO_2, the county scale analysis identified 140,000 ha as being afforested, whereas the state scale analysis identified only 49,400 ha as being afforested. The main cause for the difference in area suitable for afforestation was the use of higher resolution maps for the county scale analysis (30 meter (m) pixels for the county scale compared to 100 m pixels for the state scale, or a more than 10-fold difference in scale). However the other factors, such as the quantities of carbon sequestered and costs, also play a role.

It is clear from Figure 2-20 that large differences exist between the two scales of analysis for the 20-year time period, whereas the differences after 40 years are slight. Even though a range of conversion costs were used in the county scale (\$450–\$1100/acre) compared to the use of one statewide conversion cost (\$450/acre), the main reason for the large difference in both cost per ton and quantity after 20 years is related to the different amounts of sequestered carbon that

were allocated to the forest classes—especially the mixed conifer forest class. In the state-scale analysis, only the carbon sequestered in living trees (above and below ground) was included, whereas in the county-scale analysis the carbon sequestered in dead trees and on the forest floor (litter and duff) was included in addition to the trees.

In general, the county-level analysis for Shasta County showed more carbon could be sequestered at a lower cost than the state-level analysis. This difference was largely attributable to the differences in carbon accumulation at the end of the three time periods:

- All the lower cost carbon (< \$10/t CO_2) in the county scale occurs on lands that the model allocated to the mixed conifer forest class that contains on average 132.4 t C/ha over all the suitable area (about 139 thousand ha);
- All the lower cost carbon (< \$10/t CO_2) in the state scale occurs on lands that the model allocated to a variety of forest classes with different amount of carbon sequestration, that contain on average 84.5 t C/ha over all the suitable area (about 49.4 thousand ha);
- The overall area-weighted carbon after 20 years was 82 t C/ha for the county scale and 35 t C/ha for the state scale, or a more than two-fold difference, due mostly to the inclusion of the other non-live-tree components.

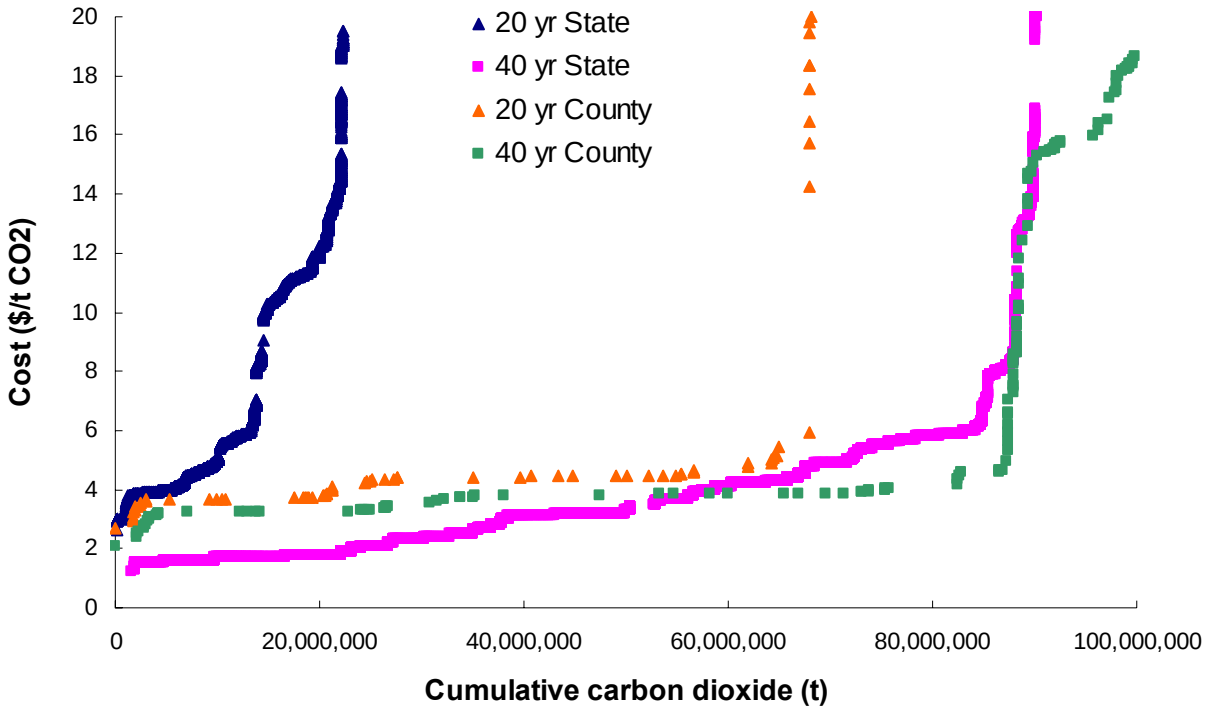


Figure 2-20. Carbon supply curves for afforestation activities on candidate rangelands in Shasta County at 20 and 40 years, based on the county level analysis and the statewide analysis

2.4. Uncertainties, Benefits, and Risks of Afforestation of Rangelands

2.4.1. Uncertainties in Data and Mapping

As a result of the relative coarseness of the data, suitability for growth of certain tree species on a given site cannot be interpreted to mean that every parcel of land in a given grid cell is suitable. Instead, it should mean that on the average, the areas within the grid cells, +/- 1 cell, are suitable. The same is true for interpretation of the data layers for rates of carbon sequestration and forage production, and thus the opportunity and total cost estimations. In addition, the variables used to model suitability for afforestation have themselves sometimes been altered as a result of historical land-use change and the estimates of forest suitability that they reflect might understate the actual potential found across the county. For example, low available water content in the soils might be a result of the systematic removal of native tree species in an area. Some studies suggest that if considerable effort is made to gradually prepare a site for introduction (or reintroduction) of forest species, once they were established, factors such as available water content or precipitation would respond (Egan 1996; S. Morse 2003, College of the Atlantic, Bar Harbor, ME, pers. comm.). Sites mapped as completely unsuitable for forest growth may actually be so degraded that conventionally acceptable levels of seedling mortality might need to be reconsidered. In other cases, simply replanting trees may not suffice to restore the ecosystem but more advanced levels of intervention may be necessary, possibly including a phased approach.

The only alternative to ranching on rangelands considered in this study is afforestation. However, another alternative is the potential for conversion to urban development, which is likely to have a much higher opportunity cost given the price of land in California. Landis and Reilly (2003) concluded that projected urban growth is only a significant to moderate threat to grazing lands in Alameda, Los Angeles, Orange, Placer, Riverside, Sacramento, San Diego, San Bernardino Santa Cruz, Santa Barbara, Solano, and Ventura counties, and a minor threat elsewhere in the state.

This analysis only considered a limited range of costs (opportunity, conversion and maintenance, and monitoring), however other costs could be incurred such as:

- Would afforesting existing rangelands have a fire risk and if so what would be the cost for insurance—either in monetary terms or potentially in "carbon terms" (such as keeping aside some of the carbon for insurance). (See also Section 2.4.3 below.)
- To maximize the carbon sequestration, what would be the cost to the landowner for managing the lands? And would they have to "hire" experts to plant and maintain until "free to grow"?
- If large scale afforestation took place, how would this affect the beef production in California and how would this affect prices to the consumer?
- How would large-scale afforestation affect the scenic vistas of expanses of rangelands?
- How would afforestation of rangelands affect water resources and at what scale is water affected? And what would be the "costs" of this to other users of water?

These additional costs are poorly known, but yet need attention and analyses if afforestation activities were to be widely adopted by land owners.

2.4.2. Co-benefits from Afforestation

Restoration of biological diversity and water resources are possible additional benefits that could accrue from afforestation of existing rangelands. In addition to carbon sequestration, these co-benefits could be achieved through incentives to land owners. The sale of carbon credits is one such incentive. Similar incentives could be offered for the creation of biodiversity, wildlife habitat, water quality, etc. on rangelands.

Freilich et al. (2003) lists several possible ecological benefits from a shift from grazing activities on rangelands to afforestation. Ideas for indicators could be derived from such a list:

1. Reintroduction of native carnivores and other "problem animals" into the food chain.
2. Turn the tide of the present truncation of the food web through the elimination of carrion for scavenger species and decomposition of biomass in ecosystem carbon cycles.
3. Habitat defragmentation by increased contiguity of forested landscapes and reduction in fencing and, possibly road networks.
4. Reduction of exotic weed presence in range ecosystems and in the chemicals used to control them.
5. Positive impacts on water supplies and riparian habitats.

Policies could be designed to reward the creation of these public goods as co-benefits related to carbon sequestration activities. Additional incentive mechanisms could be created to enhance the payment from potential future carbon offset markets. Quantification and valuation of these co-benefits are an important area of future research related to these activities.

If landowners elect to afforest their rangelands in response to new policies, a consequence of decreasing the area of grazed rangelands could be a decrease in the number of cattle. Cows are responsible for a significant proportion of non-CO_2 greenhouse gases. Consequently a decreased number of cows could lead to a net GHG benefit for Shasta County and the state of California. The reduction of each head of cattle on rangelands results in 2.3 t of carbon dioxide equivalent (CO_2eq) of emissions avoided per year. For afforestation of rangelands, not only would the carbon benefits arise from the increase in carbon stocks of the trees, but there would also be additional GHG benefits from the elimination of cattle. This would result in even cheaper carbon credits. More detailed analyses at a finer scale where information on likely head of cattle that would be eliminated by converting rangelands to forests is needed to fully factor in this effect on the carbon supply.

2.4.3. Risk of Fire

The potential occurrence of fire is probably the largest risk to any carbon sequestration activity in Shasta County. Thus, in addition to the costs of physical management of the afforested areas, attention must be paid to the threat of fire to these investments. Prior to tree planting activities, burning may be necessary to clear lands for planting and to reduce fuel loads. After this initial fuel load treatment, certain areas may need special attention over the lifetime of the activity (the carbon purchase contract's lifetime). Models can be developed to estimate the costs of such treatments.

To address the risk of fire, the Fire Rotation Interval map was used. The Fire Rotation Interval map for Shasta County (**Figure 2-21**) was clipped out of the CDF-FRAP fire rotation interval

map created from 50 years of fire history maps on land areas that have been grouped according to fire-related factors such as climate, vegetation, and land ownership. The Fire Rotation Interval is the number of years it would take for past fires to burn an area equivalent to the area of a given group. Fire Rotation Interval is calculated by dividing total area of the group by the annual number of acres burned and then dividing into four classes. It can be seen that 61% of the identified areas for afforestation fall within the 100–300 year fire rotational interval, and an additional 15% fall within the < 100 year interval (**Table 2-7**). However, from a cost perspective, the "High" to "Very High" rotation intervals contain potentially some of the most costly carbon. Further research on the potential risk to carbon from fires and the costs of fire prevention activities is warranted. Refinements in the Fire Rotation Interval map to define the "Undetermined" areas might also add greater understanding of these phenomena.

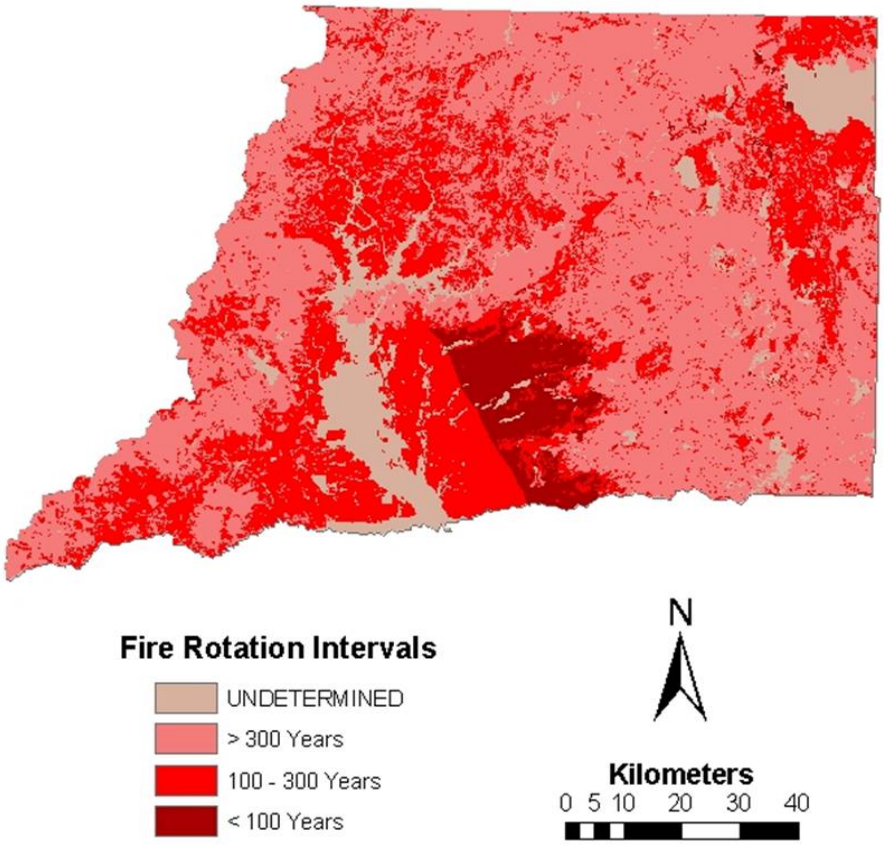


Figure 2-21. Fire rotation interval map for Shasta County, provided by the California Department of Forestry – Fire and Range Assessment Program (CDF-FRAP)

Table 2-7. Percentage of rangeland suitable for afforestation in Shasta County that falls within CDF-FRAP fire rotation interval classes

Fire rotation interval class description	Years	% of candidate Rangeland
UNDETERMINED	UNDETERMINED	8
MODERATE	> 300	17
HIGH	100–300	61
VERY HIGH	< 100	15

2.4.4. Potential Impacts of Climate Change

A recent report to the California Energy Commission's Public Interest Energy Research Program (CEC 2003) was undertaken to assess the impacts of potential climate change on California. Climate models were used to project changes in climate across the state of California through 2100. Recent analyses of climate models showed that they did not, on average, project California becoming wetter or drier and that no firm conclusion about the future change in the direction of precipitation could be drawn. A dynamic general vegetation model was used to estimate the effects on the distribution and the productivity of terrestrial ecosystems at a scale of 100 km^2. The report concluded that under all climate change scenarios, forests and other types of vegetation would migrate to higher elevations as warmer temperatures make those areas more suitable for survival. The report also estimated that if it gets wetter, forests would expand in northern California. On the other hand, if it got drier areas of grasslands would increase across the state. What these changes would mean for afforested areas in today's rangelands is unknown but worthy of further investigation; the effect would most like be relevant to those lands where afforestation was planned to extend up to 80 years or more, the period over which the cheapest carbon is produced.

3.0 Forest Fuel Reduction

3.1. Introduction

Fire occurrence has a significant effect on the amount of carbon in forests. Fire management techniques that reduce carbon emissions by reducing the risk of wildfires through removal of biomass fuels potentially offer an opportunity to supply carbon credits. Not only would reductions in catastrophic forest fires reduce carbon and non-CO_2 GHG emissions from burning, but the use of the biomass to generate electricity would offset emissions from fossil fuel use. The overall objective of this section is to produce a first-order approximation of the areas and carbon stocks of forests suitable for fuel reduction to reduce their fire risk, the location of these forests relative to existing power plants in Shasta County, and potential biomass yield. This analysis uses the same methods described in the previously submitted report for the whole state of California (Petrova 2006).

3.1.1. Hazardous Fuel Reduction Treatments Available, and Scope of this Analysis

A range of potential hazardous fuel reduction (HFR) treatments and technologies is available to address the fire risk problem. Prescribed fire is a relatively low-cost way to reduce fuel loading and ultimately perhaps the preferred treatment if the goal is to reintroduce fire into forest ecosystems. Prescribed fire is fairly constrained in its use today because of the potential for fire escape (especially at the wildland-urban interface), relatively short windows of appropriate conditions, and air quality and sediment yield concerns.

One could envision a range of available HFR treatments, each with different constraints, costs, yield of merchantable and submerchantable material and thus revenues, air quality impacts, ground impacts, and GHG emission impacts (**Figure 3-1, Table 3-1**).

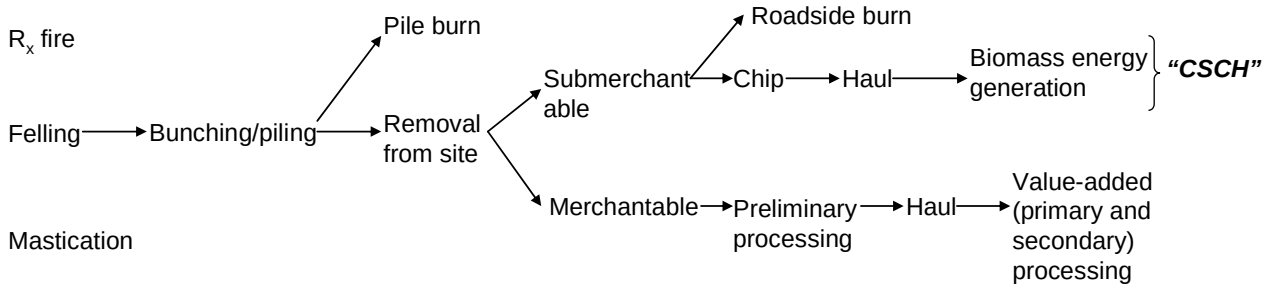


Figure 3-1. Schematic of potential hazardous fuel reduction treatments (adapted from USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003)

Table 3-1. Benefits, constraints and representative costs for HFR treatments

Hazardous fuels reduction treatment	Product yield	Benefits	Constraints	Representative costs
R_x fire	No	Less expensive, re-introduces fire	Air quality, ground impacts, fire escape (Wildland Urban Interface), seasonal restrictions, immediate CO_2 emissions to atmosphere	$35–$300/acre, average $92/acre[8] $23–$223/acre[9]
Masticate – leave on site	No	Efficient, useful for less accessible sites where fuel removal not a goal	Leaves fuel on site, gradual CO_2 emissions to atmosphere	$100–$1,000/acre[2]
Cut-pile-burn	No	Less expensive, can be used on inaccessible or steep sites	Leaves fuel on site, air quality, immediate CO_2 emissions to atmosphere	$100–$750/acre[2]
Cut-lop-scatter	No	Less expensive, can be used on inaccessible or steep sites	Leaves fuel on site, gradual CO_2 emissions to atmosphere	$105–$280/acre[10]
Cable yarding for biomass removal	Yes	Makes less accessible or steeper sites treatable	Expensive, ground impacts	$80–$130/ hundred cubic feet (CCF) [4]
Cut-skid-chip-haul (for submerchantable biomass) "CSCH"	Yes	Removes fuel from site; some product value to offset costs; allows renewable energy generation greatest CO_2 benefit	More expensive; limited to gentler slopes, areas closer to roads for removal, limited haul distance to biomass plant	$34–$48/BDT + haul cost $0.35/BDT/mile[1] $560–$1,634/acre[11]

[8] USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003.

[9] Chalmers and Hartsough, no date.

[10] Fight et al. 2004; Barbour et al. 2004.

[11] Fried et al. 2003.

Table 3-1. (continued)

Hazardous fuels reduction treatment	Product yield	Benefits	Constraints	Representative costs
Cut-skid-process-load-haul (for merchantable biomass)	Yes	Greatest product value to offset costs; removal of merchantable material may be necessary to reduce fire risk (Crowning Index) and meet spacing or forest health goals	More expensive; limited to gentler slopes, areas closer to roads for removal, limited haul distance to processing facility; environmental controversy/frequent litigation	Variable

The present analysis is confined to a single HFR treatment—cut-skid-chip-haul, or "CSCH"—because this appears to be the practical way to reduce fuel loading in the forest while producing fuel for biomass energy facilities. The analysis attempts to estimate the total area of Shasta forest lands at high and very high fire risk, how much of this area meets a series of constraints making it feasible to treat using CSCH, how much biomass could be removed from this area using CSCH and be available to existing biomass power plants, and what might be the economics of using CSCH on those forested acres. Thus the focus is primarily on submerchantable biomass, and the use of forest fuels for generating heat and power in biomass energy facilities.

The approach chosen here is necessarily a simplification of the reality of HFR as practiced today, in which a variety of treatments can be applied for different locations, terrain, slope or other conditions. Perhaps most importantly, most HFR prescriptions call for a mix of submerchantable and merchantable material removal, both for economic reasons and to target a desired future forest condition that is defined in terms of residual spacing or basal area, residual fuel loading, reduced ladder fuels to prevent ground fires from moving into the crown, and reduced crown density or crown-touching to prevent crown fires from being sustained or spreading over long distances (Fried et al. 2003). While diameter limits are sometimes applied, it is rarely appropriate to exclude all merchantable material to meet these desired future conditions. Accordingly, different treatment types, technologies, and product yield mean different economics of HFR and different types of sites that become treatable either in technical terms (e.g., treatments available for steep slopes) or in economic terms (e.g., treatments that yield more merchantable material, offsetting costs and allowing the contractor to remove more submerchantable biomass to reduce ladder fuels or treat lands on the margin of the maximum haul distance from a biomass energy facility). There is a large literature focused on the economics of different treatments, models to estimate costs of treatment (STHARVEST and others), and models to estimate quantities of biomass available from a given area or the best locations to site biomass energy facilities (FIA Biosum, Coordinated Resource Offering Protocol, and others) (Fight et al. 2003, 2004; Fried, Barbour and Fight 2003; Fried et al. 2002, 2003;

Barbour et al. 2001, 2004; Christensen et al. 2002; Chalmers and Hartsough, no date; Mater 2005).

Confining the analysis to CSCH, the area treated and biomass yield associated with this approach results in conservative estimates. Additional area would become economically treatable if merchantable material were included in the analysis; additional area would become technically treatable if other treatment types, not attempting to remove biomass but still reducing fuel loads (e.g., cut-pile-burn for steep slopes) were considered. In addition, the GHG emission impacts of different treatment choices have not been analyzed. These refinements will be addressed in later analyses.

3.2. Approach and Analysis

The three primary objectives of this study were:

- Identify areas of forestland within Shasta County with high to very high fire risk.
- Conduct a multi-criteria evaluation to identify forestlands suitable for fuel removal. This analysis assigned a Suitability for Potential Fuel Reduction (SPFR) score to all forested areas, based on criteria affecting the feasibility of treating these lands, removing and transporting fuels for biomass energy generation.
- Conduct more detailed analysis of one potential HFR treatment, "Cut-Skid-Chip-Haul," and assess the area of high to very high fire risk forestlands in the county to which this treatment could be applied and how much biomass this fuel might generate for use in power plants, and at what cost.

3.2.1. Forested Land at High to Very High Fire Risk

The first step in this analysis was to identify forested areas at high to very high risk of fire. Forested areas were extracted from the California Land Cover Mapping & Monitoring Program (LCMMP) GIS layer of vegetation (USGS, Gap Analysis Program 2005) and re-classed into four classes (Smith and Heath 2002) as in an accompanying report on baselines for Shasta county (Pearson et al. 2006) (**Table 3-2**).

Table 3-2. Distribution of forest area (ha) by forest type in Shasta County

Forest type Smith categories	Area (ha) County-wide
Douglas Fir Forest	68,828
Fir-Spruce Forest	32,636
Hardwood Forest	173,771
Other Conifer Forest	354,977
Total	630,212

A map of all forest types across the county, called "Forest," was created and combined with a CDF-Fire and Resource Assessment Program (FRAP) fuel rank map to separate forests at high and very high wildfire risk (**Figure 3-2**). The FRAP fuel rank map was derived by using detailed surface fuel layers and information based on quantities of ladder and crown fuels (CDF-FRAP 2004). For additional information on the land-cover/fire data and methods, refer to the

metadata downloadable from the FRAP website. Forest lands with low and moderate classes in the fuel rank map were left out of the analysis, while the forest lands with high and very high fuel rank were combined into new layer called "Shasta High Risk Forest" (**Figure 3-2**). The total area of these forested lands is approximately 572 thousand hectares, which comprises approximately 90% of the total forest lands in Shasta County.

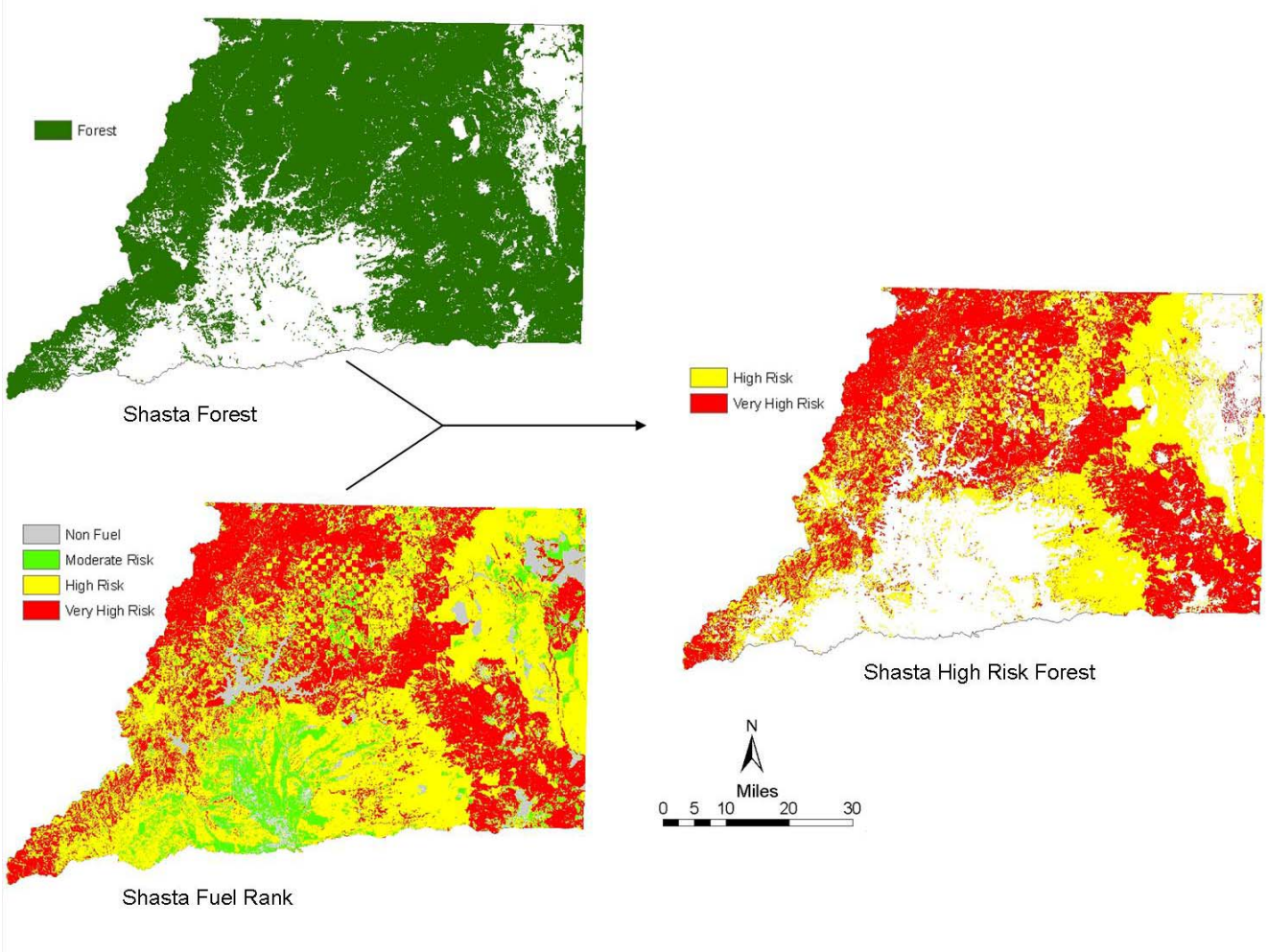


Figure 3-2. Distribution of forest lands in Shasta County at high and very high risk for wildfires

3.2.2. Suitability for Potential Fuel Reduction

The second component of this analysis consisted of a multi-criteria evaluation to identify forest lands suitable for fuel removal. Three factor maps were used in the decision support tool for a Multi-Criteria Evaluation module (MCE): distance from roads, distance from power plants, and slope. These factor maps were combined to create a single raster map showing Suitability for Potential Fuel Removal (SPFR) scores.

The first factor analyzed was distance from roads. Six transportation layers (local roads, other thoroughfares, railroads, state highways, U.S. highways, and vehicular trails) were downloaded for Shasta County from the California Spatial information Library (CASIL 2004). All

transportation layers were combined to create a layer representing all roads. The Euclidean distance module was used to create a distance map from all roads. This map was standardized into a range from 0 to 255 using the "FUZZY" module in GIS software IDRISI Kilimanjaro (Eastman 2003b), so that the starting point for most suitable areas was 100 meters away from the roads to avoid a risk of fire close to roads. The greatest travel distance to reach a road was assigned the lowest road factor suitability score (0), and the least travel distance the highest road factor suitability score (255), indicating that as yarding distance increases, cost of removal increases and suitability for fuel removal thus decreases (**Figure 3-3**).

The second factor analyzed was slope. A slope map was created from the Digital Elevation Model (DEM) acquired from the CASIL web site at 30 meters resolution. The slope map was standardized with a fuzzy classifier to range of 0 to 255, with 255 representing the gentlest slope (easiest access and least ground impact from fuel removal, thus most suitable) and 0 the steepest slope (least suitable) (**Figure 3-3**).

The third factor analyzed was distance from existing power plants. Locations of operational biomass power plants in California producing 0.1 megawatts (MW) and above were provided by the California Energy Commission (Energy Commission), and were used to create a distance map. The distance map was created and standardized to a scale of 0 to 255, with the greatest travel distance to reach a power plant assigned the lowest suitability score (0) and the least travel distance the highest suitability score (255), indicating that as the distance to the nearest power plant increases, cost of hauling fuel increases and suitability for fuel removal thus decreases (**Figure 3-3**).

All three factor maps were used as inputs for the MCE module—a GIS decision making tool in IDRISI Kilimanjaro software. The output of this module was a SPFR score map on a standard scale from 0 to 255, where 0 represents the least suitable areas and 255 the most suitable areas for potential fuel reduction accounting for distance to roads, slope, and distance to power plants **(Figure 3-3**).

The range of the SPFR scores for the "Shasta High Risk Forest" and locations of the existing six power plants in Shasta County are shown in **Figure 3-4**. The SPFR scores for the forest lands in Shasta County at high and very high wildfire risk indicated the suitability for treating these forestlands, removing and transporting the fuels to biomass energy generation facility, based on three factors: distance from roads, slope, and distance from power plants. The highest suitability is assigned to forest close to roads and power plants, and on gentle slopes.

The "Shasta High Risk Forest" map was overlaid with the SPFR scores to determine distribution of forest lands at high and very high risk of wildfire across the range of SPFR scores. A histogram of the area of forests shows few areas of forest in the lowest SPFR classes (less than 125), with the area of forest gradually increasing until reaching its first peak at SPFR = 175, slowly declining and then increasing again until reaching the second peak at SPFR = 225, and after that point decreasing through the rest of the SPFR classes (**Figure 3-5**).

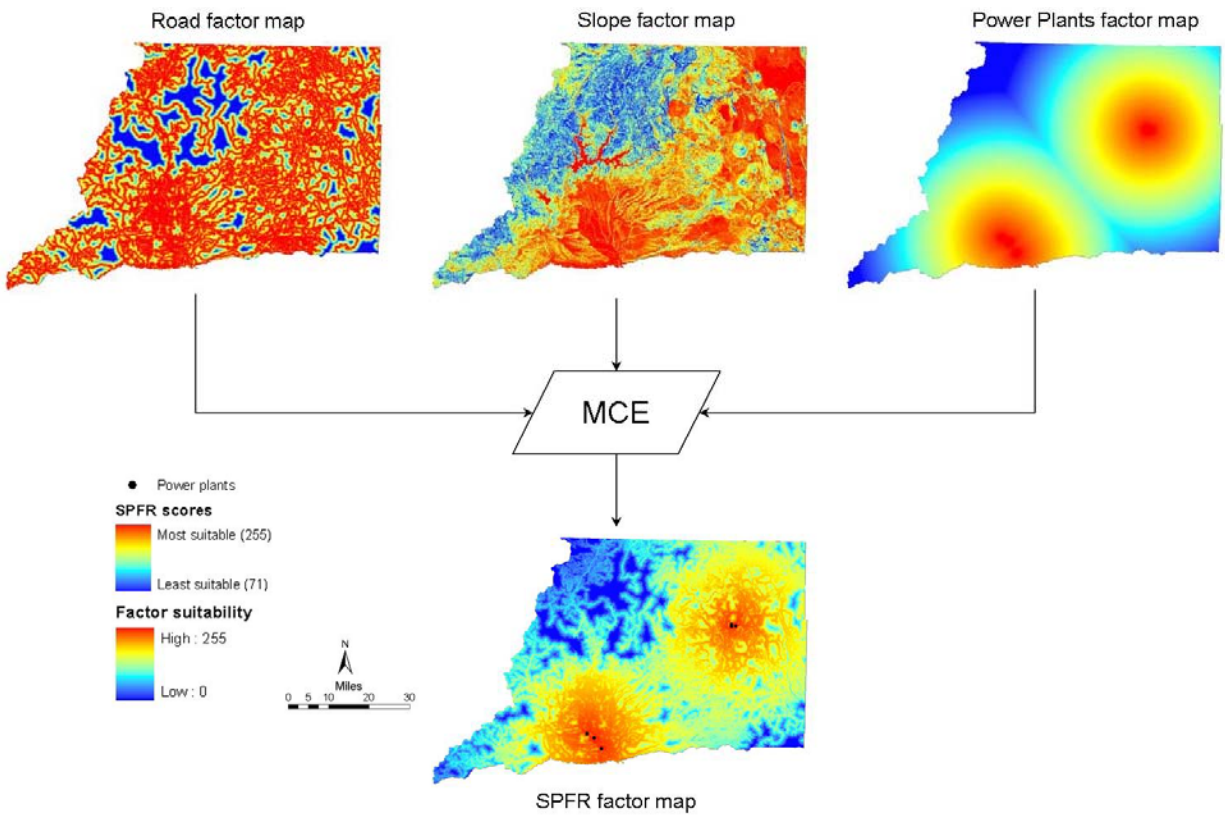


Figure 3-3. Suitability for Potential Fuel Removal (SPFR) scores for Shasta County, with highest suitability assigned to areas close to roads, on gentle slopes, and close to existing power plants

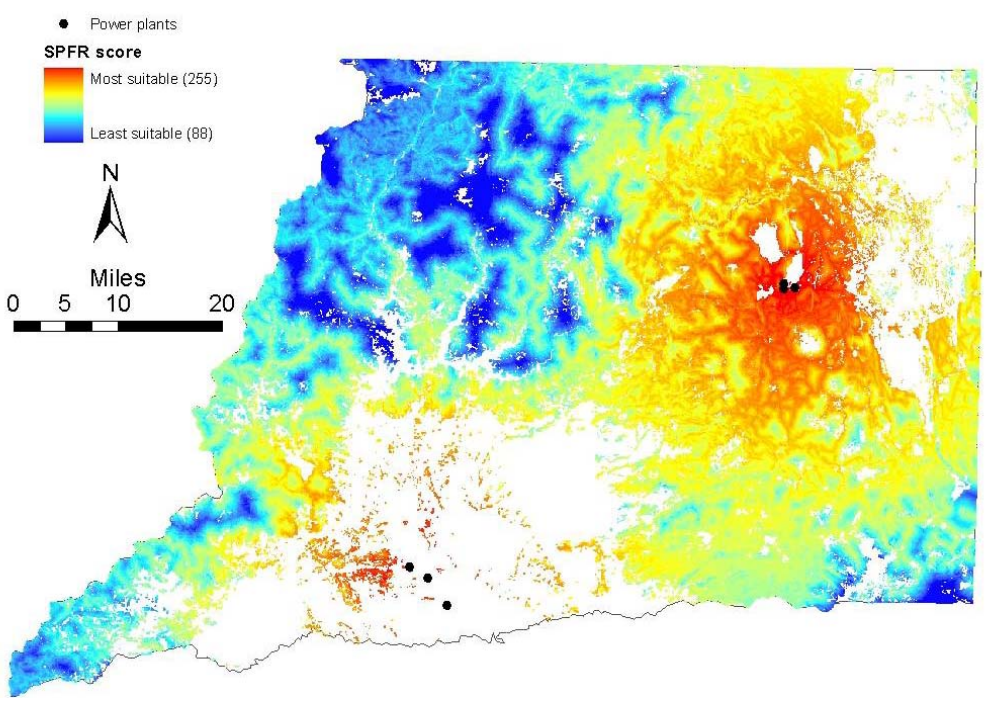


Figure 3-4. Suitability for Potential Fuel Reduction (SPFR) scores for forest lands in Shasta County at high and very high risk of wildfire

SPFR scores for the forests at risk of wildfire range from 88 to 255. The Other Conifer Forest type was a predominant category across all SPFR scores with a considerable increase above 200. This forest type historically had more frequent fires, and thus fuel loads were maintained relatively low and fires were less intense than they are today (Agee and Skinner 2005). There is broad consensus among forest managers that active management to reduce fuel loads is needed to reduce the risk of uncharacteristically severe fires.

The second most represented forest type was the Hardwood Forest category with larger representation between SPFR scores of 110 and 195. The Douglas Fir Forest type was present between the SPFR scores of 130 and 190 and not present in the lower and the higher range of the SPFR scores. There was a relatively small representation of Fir-Spruce Forest type through the SPFR score of 238 (**Figure 3-6**). Both the moister Douglas fir and high elevation fir-spruce forest types historically experience fires but they burn infrequently, are typically stand replacement fires, and are driven more by meteorological conditions (Agee and Skinner 2005). For these forest types, there tends to be less need for active fire management.

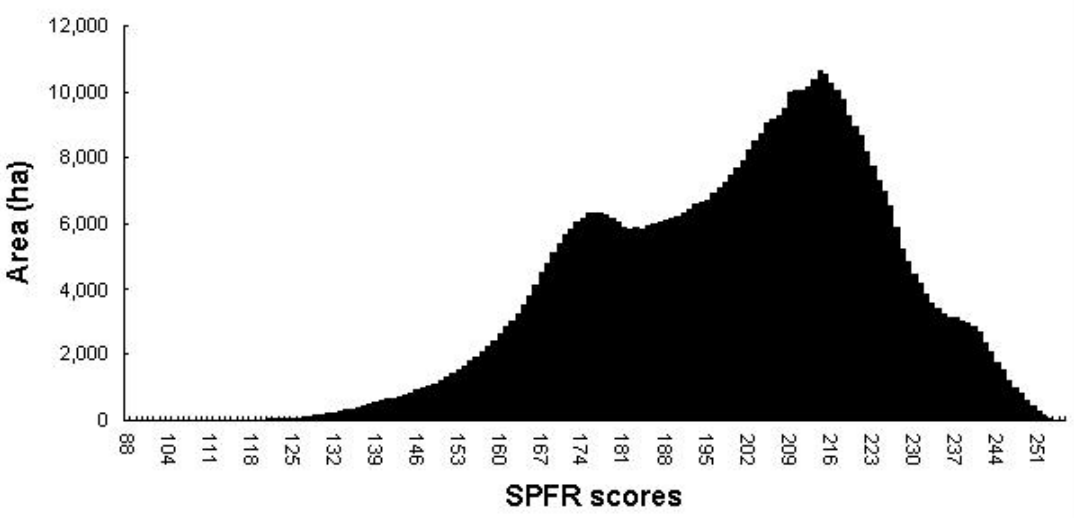


Figure 3-5. Area of forest lands at high and very high risk for wildfires per SPFR classes

3.2.3. Analysis of High to Very High Risk Forests Treatable with CSCH

The third component of this analysis looked in more detail at one potential hazardous fuels treatment—Cut-Skid-Chip-Haul (CSCH)—a treatment in which hazardous fuel is harvested in the woods, bunched and skidded to a landing, chipped into a chip van, and hauled to a biomass energy facility for electricity and/or heat generation. The objective was to assess the area of high to very high fire risk forestlands in Shasta County to which this treatment could be applied, how much biomass fuel this might generate for use in power plants, and at what cost.

In this analysis, the following constraints for CSCH treatment were applied sequentially to identify the area of high to very high fire risk forest available for CSCH:

- *Maximum slope constraint.* Only lands of < 40% slope may be treated with CSCH (Fight et al 2003; Fried et al 2002; Fried et al 2003; Fried, Barbour and Fight 2003). Steeper slopes may be treated in other ways (e.g., cut-pile-burn), but do not allow CSCH due to machinery and equipment access, ease of removal, and ground impacts from harvest and skidding.
- *Maximum yarding distance constraint*. Only lands within 0.25 miles (400 meters) of existing roads may be treated with CSCH. This is used as a general rule of thumb for the maximum distance low-value material would be skidded to a landing where a chipper and chip van is parked (Bob Rynearson, WM Beaty & Associates, pers comm. 9/15/05).
- *Minimum block size to justify move-in costs of equipment and personnel.* A general rule of thumb is that a treatment block must be at least 80–100 acres to justify move-in costs, although this number may be slightly less if equipment is already sited nearby for another project (Bob Rynearson, WM Beaty & Associates, pers comm. 9/15/05).

Depending on the scale of this treatment, another critical constraint should be also considered - *Maximum haul distance constraint.* Only lands within 50 miles of existing power plants may be treated with CSCH due to transport cost. This maximum haul distance may be considerably affected by the volume/value of merchantable material in the prescription. This constraint was irrelevant to the scale of the analysis, because the entire forest lands in Shasta County fall within 50 miles of one or more of the existing biomass facilities.

Constraints were applied sequentially so that only lands meeting all three constraints were available for CSCH treatment. Forest lands at high to very high wildfire risk (**Figure 3-7 A**) were superimposed on a slope map and all forestlands of > 40 % slope were excluded (**Figure 3-7 B**). To meet the requirement of maximum 0.25 miles yarding distance, a buffer layer was created and overlain with the high to very high fire risk forest on gentle slopes to exclude any lands further than 0.25 miles from roads (**Figure 3-7 C**). Finally, to meet the minimum block size to justify the cost of move-in equipment and personnel, forest blocks of area less than 80 acres were excluded (**Figure 3-7 D**).

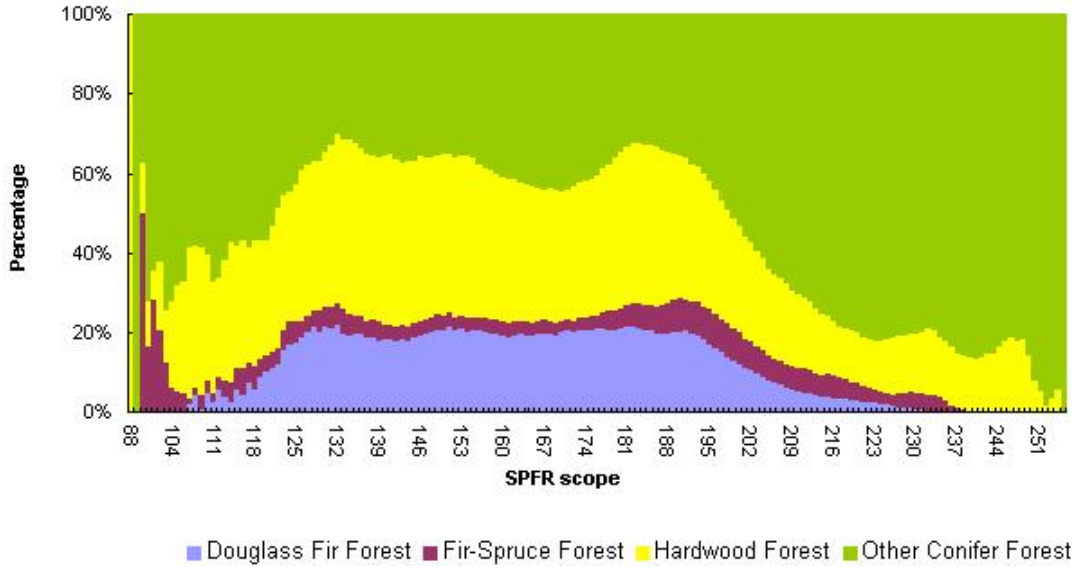


Figure 3-6. Forest types at high to very high risk for wildfires per SPFR classes

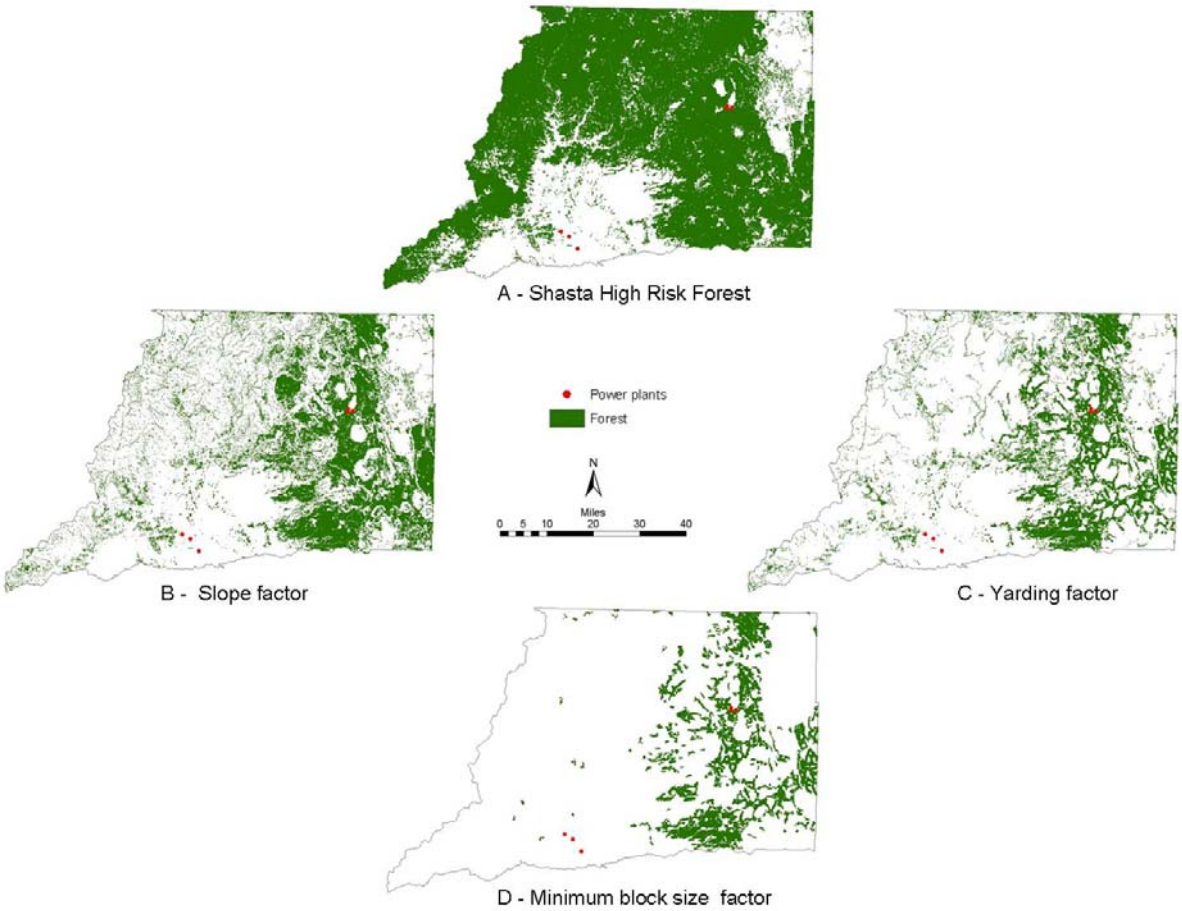


Figure 3-7. Critical factors to determine forest lands suitable for CSCH fuel treatment: A – Shasta County High Risk Forest; B – Slope less than 40%; C – Yarding distance less than 0.25 mi; D – Minimum block size of 80 acres

The total area of forest lands at high to very high risk of wildfire was estimated at approximately 572 thousand ha. After applying the constraints of slope, yarding distance, and minimum block size, the total area available for CSCH treatment in Shasta County was estimated to be approximately 87 thousand ha (approximately 15% of the high to very high fire risk forest). The forest type included on these lands are the drier mixed conifer type that, as mentioned above, are well suited for active management to reduce their fuel load and prevent uncharacteristically severe fires.

The quantity of biomass in the CSCH-treatable forests was then estimated based on field data collected in Shasta County. The CDF-FRAP map reports a canopy cover attribute for all vegetation types; these were used with the regression equations of biomass versus canopy cover reported in the Shasta County baseline report.[6] In addition to the data collected to develop the regression equations, field data were also collected in the same forest plots (45 total plots) on the quantity of understory fuel (small trees, shrubs, dead wood and litter/duff). From these field data, estimates of the aboveground carbon stocks in live trees and understory were estimated and applied to the forest areas suitable for the CSCH treatment. The total biomass of CSCH-treatable forest was estimated to be approximately 23.4 million tons, or approximately 11.7 million t C. Distribution of the available carbon for the forest areas suitable for CSCH treatment is shown in **Figure 3-8**.

The total fuel available for removal would be much less than this quantity, as not all biomass on the land will be removed through the treatment. The average carbon stock of understory vegetation, small trees (with diameter at breast height (dbh) < 10 cm), lying dead wood, and litter/duff was 50 t C/ha (n = 45, 95% confidence interval = 27% of the mean) across all forest types; without the litter/duff, the average carbon stock was 23 t C/ha. Thus the potential removable fuel in a CSCH operation is 23 t C/ha.

Actual percent removal will be highly variable by stand, pre-treatment condition and desired future condition (D. Goehring and D. McCall, PG&E Natural Resources, pers. comm. 9/16/05), making it difficult to assign a percent removal across a broad scale such as a county. Over the landscape as a whole, more than 50% removal of the pre-treatment fuel loading may be needed to significantly reduce fire risk (Torching Index and/or Crowning Index; Fried et al. 2002, 2003). To help understand the relationship between the potential fuel removal quantity and the subsequent carbon benefits associated with that removal it was assumed that the CSCH will remove (a) all of the potentially removable biomass, or 46 t biomass/ha (23 t C/ha), and (b) 50% of the removable biomass, or 23 t/ha (11.5 t C/ha).

In the first scenario, biomass of approximately 4 million tons would be available to biomass energy facilities in Shasta County from CSCH treatments to reduce fire risk on approximately 86.7 thousand ha forest lands. Removing approximately 4 million tons means that the forests will initially lose approximately 2 million t C.[12] However, balancing this initial reduction would be avoided losses to wildfire of the carbon stocks in the pools left on site (e.g., large trees, litter/duff); increased growth rates (carbon sequestration) in the post-treatment stand; avoided losses of carbon stocks in other stands, upwind and up-slope, that would have burned in a larger fire in the absence of treatment; and displacement of fossil fuels in the energy plant. Following the same analogy, the second scenario will result in approximately 2 million t of available biomass associated with an initial loss of approximately 1 million t C from the CSCH treatable forests.

The next component of this analysis concerns costs. Costs for CSCH range widely depending on the treatment prescription, presence or absence of merchantable material in the prescription, region of the country, and the factors identified above (slope, yarding distance, haul distance and minimum size block). Here the values quoted in a recent broad-scale strategic assessment covering 15 states and a wide range of experience with HFR were used: the treatment analogous to CSCH had a cost range of $34–$48/BDT (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003). Assuming from above that biomass of approximately 4 million t[13] would be removed from the forest lands in question, the first scenario would have a total cost of approximately $136 million (low) to approximately $192 million (high). Treating these forest lands in the second scenario and removing biomass of approximately 2 million t, would have a cost of approximately $64 million (low) to approximately $96 million (high).

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[12] Carbon stocks are calculated as 50% of the biomass.

[13] Biomass removals are measured in units of bone dry tons (BDT) which contain more moisture than oven dry reported here.

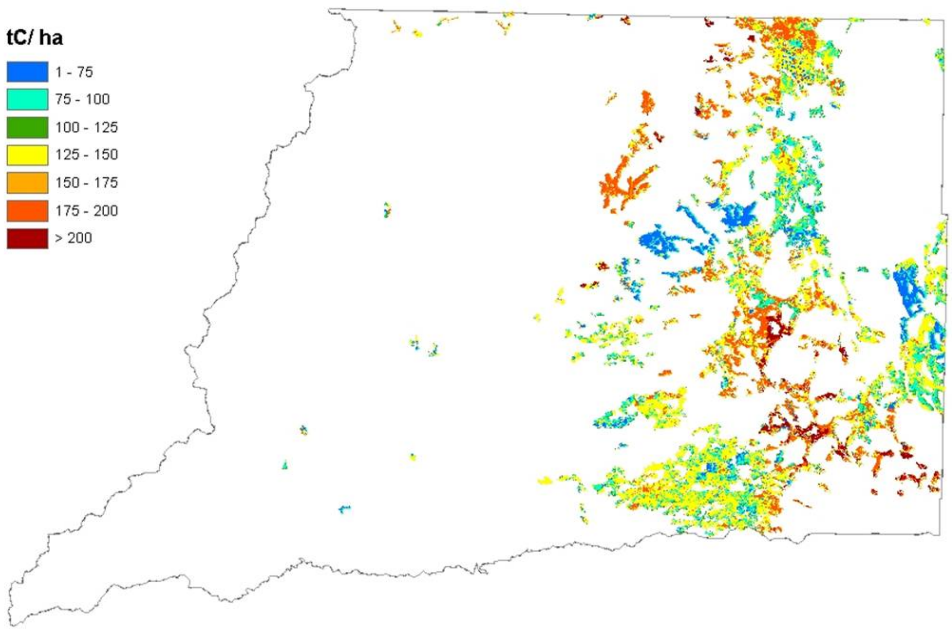

Figure 3-8. Available tons of carbon in the CSCH treatable forests of Shasta County

The value of this biomass for purchase by biomass facilities is estimated at $36/BDT (Fried et al 2003), although market prices for fuel will vary somewhat by region depending on the number of biomass plants in operation and thus competition for fuel. For both scenarios of quantity removed, the amount of revenue that the biomass facilities would generate and subsidy that they would need to remove the available biomass from the forest lands was estimated. The first scenario would have a value of approximately $144 million, and thus range from generating a net revenue of approximately $8 million (if value = $36/BDT and cost = $34/BDT), to requiring a total subsidy of approximately $48 million to treat all these lands (if value = $36/BDT and cost = $48/BDT). The second scenario would generate a net revenue of $4 million to a subsidy of $24 million. The subsidy may be met by some combination of merchantable material; green power incentives and utilities' Renewable Portfolio Standard obligations, increasing demand for biomass energy and thus increasing above $36/BDT the price biomass plants can pay for fuel; and new sources of revenue such as the sale of emissions reductions credits from HFR on current and future markets (e.g., voluntary purchases for GHG mitigation, future cap-and-trade systems).

To attempt to investigate whether removal of hazardous fuel that results in reduced fire intensity and reduced carbon emissions (i.e., conservation of forest carbon stocks) makes economic sense, the following first-order calculations are presented. Assuming the higher costs for biomass removal as described above, to treat the 86.7 thousand ha estimated to be treatable using CSCH would require a per-hectare subsidy of $554 ($48 million total subsidy divided by 86.7 thousand ha) for removal of 46 t/ha, or $277 ($24 million divided by 86.7 thousand ha) for removal of 23 t/ha. Assuming commonly used prices of CO_2, would emissions reductions attributable to HFR activities be sufficient so that the sale of carbon credits from these projects could cover the per-hectare subsidy required?

Depending upon the price of carbon assumed (two commonly used values are \$2.4/t CO_2 and \$10/t CO_2), the quantity of carbon emissions that would need to be reduced through HFR in order to cover the per-hectare subsidies needed—essentially, to make high-cost CSCH a break-even activity—varies from as little as about 8 t C/ha to as much as 63 t C/ha (**Table 3-3**). Whether HFR could produce this order of magnitude of emissions reductions depends on baseline emissions from fires of varying intensities, and whether HFR prior to fire reduces the intensity of fires. In the baseline report for this county (Pearson et al. 2006), the average emissions from fires for all forest types was about 43 t C/ha, with a range of 38–79 t C/ha. In other words, if HFR resulted in fire prevention, there would be a reduction in carbon emissions attributable to HFR of 38–79 t C/ha. The reduction in emissions that would need to be achieved by HFR to cover the per-hectare subsidies required, 7.6–63 t C/ha, is generally within this range or lower (**Table 3-3**). Thus it appears, in a preliminary analysis, that the order of magnitude in emissions reductions attributable to HFR, assuming commonly used prices for carbon offsets, is within the realm of practicality to cover subsidies needed for HFR—adding support to the argument for qualifying fuel reduction activities as carbon offset projects. It should be emphasized that this preliminary analysis needs further research, including collection of additional data on emissions from wildfires of varying severity, and policy discussion of what reductions in fire intensity and/or emissions should qualify as attributable to pre-fire HFR treatment.

Table 3-3. Quantity of CO_2 emissions reductions (t CO_2/ha and t C/ha) that would need to be produced by HFR activities in order to cover estimated per-hectare subsidies needed for CSCH

Subsidy	\$2.4/t CO2		\$10/t CO2	
	t CO2/ha	t C/ha	t CO2/ha	t C/ha
\$554/ha	231	63.0	55.4	15.1
\$277/ha	115	31.5	27.7	7.6

The present analysis defers to the future a set of questions around the GHG emissions impacts of wildfire, and the potential of GHG emissions credits or offset markets to provide another stream of revenues that will alter the economics of HFR and fire management in the United States. Such an analysis would quantify the CO_2 and other GHG emissions avoidance attributable to HFR treatments that reduce the occurrence, extent, or severity of wildfire. These emissions reduction credits could in the future be transacted, providing another stream of revenues—in addition to the value of merchantable material, biomass fuel value, green power incentives, and even other marketed ecosystem services enhanced by these treatments—that would improve the challenging economics of HFR, make more area treatable, and help federal, state, and private landowners to mount a more effective response to the wildfire problem. This analysis could also compare different HFR treatments and technologies in terms of their GHG emission impacts: for example, "CSCH" would be assigned a triple emission reduction benefit of reduced emissions from wildfire, reduced emissions from offset fossil fuel-generated electricity, and enhanced carbon sequestration in the residual forest stand. Prescribed fire or cut-pile-burn could be assigned a quantifiable benefit for reducing the incidence or severity of wildfires, but would still put a greater portion of the forest carbon removed in the treatment

into the atmosphere. The primary constraints on such an analysis are a present lack of data about the baseline effects of fire on forest carbon stocks, and yet-to-be-developed scientific consensus, necessary to support market transactions, around what emission reduction benefit could be attributable and creditable to an HFR activity. Both of these constraints will be addressed through additional fieldwork, data collection, and refinements to this analysis in the second phase of WESTCARB.

Appendix A contains a technical summary of this project.

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5.0 Glossary

AUM	animal unit month
BDT	bone dry tons
CASIL	California Spatial Information Library
CCF	hundred cubic feet
CDF	California Department of Forestry and Fire Protection
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
CSCH	Cut-Skid-Chip-Haul
DAYMET	Data Center for Daily Surface Weather Data and Climatologically Summaries
dbh	diameter at breast height
DEM	Digital Elevation Model
DM	dry matter
FIA	U.S. Forest Service's Forest Inventory and Analysis program
FRAP	Fire and Resource Assessment Program
GHG	greenhouse gas
GIS	Geographic Information Systems
HFR	Hazardous Fuel Reduction
LCMMP	California Land Cover Mapping & Monitoring Program
MCE	Multi-Criteria Evaluation module
Mt CO_2	million metric tons of CO_2
NRCS	Natural Resources Conservation Service
PIER	Public Interest Energy Research
PRISM	Precipitation dataset developed by collaborative effort between the Spatial Climate Analysis Services and the Oregon Climate Service
RD&D	Research, Development, and Demonstration
SPFR	Suitability for Potential Fuel Reduction
SSURGO	Soil Survey Geographic Database
STHARVEST	Software for estimating the cost of harvesting small timber
t C/acre	tons of carbon per acre
t C/ha	tons of carbon per hectare
t CO_2	tons of carbon dioxide
t/ha	tons per hectare
U.S. DOE	U.S. Department of Energy
USDA	U.S. Department of Agriculture
USGS	U. S. Geological Survey
WHR	Wildlife Habitat Relationship

Appendix A

Technical Summary

Appendix A

Technical Summary

Introduction

California is committed to reduced net greenhouse gas (GHG) emissions as demonstrated by the passage of California Assembly Bill 32. A suite of measures will be required to comply with AB32 including increasing the carbon stock in California's lands.

Past statewide studies by the California Energy Commission's Public Interest Energy Research (PIER) program on the potential to sequester carbon in terrestrial ecosystems suggest ample opportunities for such measures in California. Statewide studies, however, cannot afford the level of detail that can be used in local or regional studies. In addition, it is necessary to corroborate the statewide analysis with more in-depth regional analyses to determine the confidence that should be given to the statewide analysis.

Purpose

The purpose of this project was to evaluate the potential for afforestation of lands in Shasta County, California, to determine the feasibility of and benefits from implementing such measures. *Afforestation* is the establishment of new forests on lands that have not been recently forested. In addition, the researchers studied the potential of a hazard fuel reduction (HFR) program designed the reduce the likelihood of major forest fires as a tool to reduce net greenhouse gas emissions in California.

Project Objectives

The main objectives of this study were to (1) estimate the potential carbon supply from afforestation of rangelands in Shasta County, and (2) to generally identify the areas and carbon stocks of Shasta County's forests that are suitable for hazardous fuel reduction, as well as the quantity of fuel potentially available for biomass energy plants.

Project Outcomes

Shasta County was chosen because it contains highly diverse land-cover classes representative of California. Also, based on the statewide analysis of carbon sequestration potential, it was concluded that Shasta contained opportunities for implementing a range of important types of sequestration projects. The study's approach generally follows that of previous work on the carbon supply from range and forest lands for the whole of California.

The approach for estimating the carbon supply from rangelands was to identify and locate existing rangelands where conditions could favor the establishment and growth of forests, estimate rates of carbon accumulation for the forest types projected to grow, and estimate the costs associated with the practice needed to increase the net accumulation of carbon. Carbon supply was estimated for three time durations—20, 40, and 80 years of forest growth—to reflect the impact of an activity's duration on the likely carbon supply and to assess near–term and longer-term planning horizons.

Conclusions

The total area of Shasta County is approximately 2.46 million acres (996,000 hectares), of which approximately 749,000 thousand acres (303,000 hectares) are classed as rangeland. The total area suitable for afforestation activities is about 600,000 acres (243,000 hectares), which represents about 80 percent of the total lands classed as rangelands (**Figure 1**). Woody rangelands suitable for afforestation activities cover about 159,160 acres (64,412 hectares), or 27 percent of the total suitable rangelands.

Shasta County was chosen for this study because it contains highly diverse land-cover classes representative of the State of California. Also, based on the statewide analysis of carbon sequestration potential, it was concluded that Shasta contained opportunities for implementing a range of important classes of sequestration projects. The approach used in this report generally follows that of previous work on the carbon supply from range and forest lands for the whole of California.

Basically, the approach for estimating the carbon supply from rangelands was to identify and locate existing rangelands where conditions could favor the establishment and growth of forests, estimate rates of carbon accumulation for the forest types projected to grow, and assign values to each contributing cost factor. Carbon supply is estimated for three time durations: 20 years, 40 years, and 80 years of forest growth, to reflect the impact of activity duration on the likely supply and to provide an assessment for the near–term and longer-term planning horizons.

The total area of Shasta County is approximately 2.46 million acres (996,000 hectares) of which approximately 749,000 thousand acres (303,000 hectares) are classed as rangeland. The total area suitable for afforestation activities is about 600,000 acres (243,000 hectares), which represents about 80 percent of the total lands classed as rangelands (**Figure 1**). Woody rangelands suitable for afforestation activities cover about 159,160 acres (64,412 hectares), or 27 percent of the total suitable rangelands.

Site visits to Shasta County demonstrated that some areas mapped as rangelands were in fact covered with dense shrubs and not really suitable for grazing. Thus, the rangeland class was stratified into two subclasses: (1) suitable for grazing, and (2) unsuitable for grazing. Rangelands unsuitable for grazing were assumed to be those classed as chaparral in the Wildlife Habitat Relationship (WHR) map and that fell within the perimeters of wildfire that occurred during 1987 to 1994, plus those WHR classes of montane chaparral and mixed chaparral with density greater than 40 percent, as mapped in the Fire and Resource Assessment Program (FRAP) maps. The total area of rangelands unsuited for grazing was estimated to be 29,200 acres (11,817 hectares) or about 5 percent of the total rangeland area suitable for afforestation. This division of the rangelands into two subclasses classes affected the range of total costs rather than the carbon sequestration potential. Even though unsuitable lands had no opportunity costs, their dense vegetation cover led to considerably higher estimates for their conversion costs.

Estimates of the potential sequestered carbon by afforestation on the rangeland areas represent the carbon stocks in living trees, standing and lying dead wood, understory, and litter.

Estimates of carbon stocks ranged from 5 t C (tons of carbon)/acre (12 t C/ha) after 20 years for rangeland hardwood forests to about 166 t C/acre (411 t C/ha) after 80 years for mixed conifers.

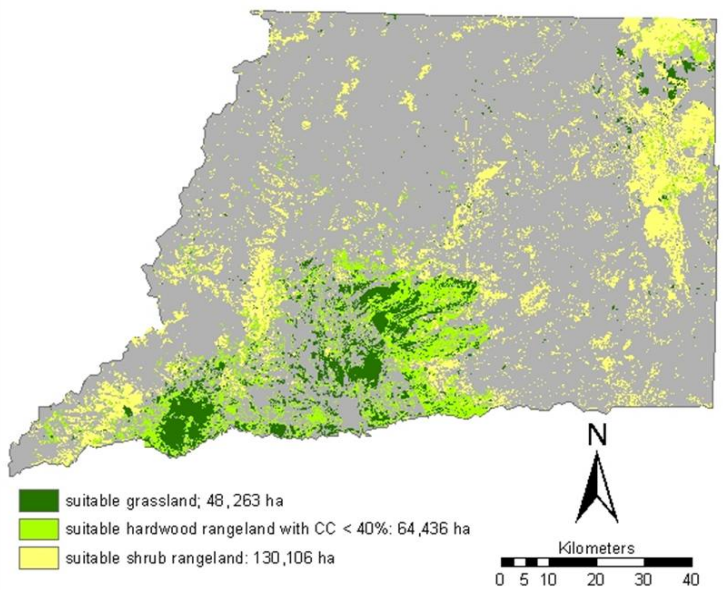

Figure 1. Map of areas of existing rangelands suitable for afforestation activities

The report presents the entire range of costs and potential carbon available for afforesting rangelands. **Table 1** summarizes the amount of carbon and the area available for three price points: ≤ \$10.0/t CO_2 (\$36.7/t C), ≤ \$5.5/t CO_2 (\$20/t C), and ≤\$2.7/t CO_2 (\$10/t C).

For afforestation of rangelands, longer durations or growth produce lower-cost carbon, but landowners may be more hesitant to commit land to projects of such duration (**Figure 2**). Afforestation of rangelands at a cost of ≤ \$10.0/t CO_2 provides about 68 Mt CO_2 at 20 years, to 88 Mt CO_2 at 40 years, and to 216 Mt CO_2 at 80 years (**Table 1**).

A second goal of this work was to determine how incorporation of more detailed data and higher resolution geographic information system (GIS) products into the analyses, accomplished by focusing on one key county, affect the estimated carbon supply potential. **Figure 3** summarizes the main differences.

A second goal of this work was to determine how incorporation of more detailed data and higher resolution geographic information system (GIS) products into the analyses, accomplished by focusing on one key county, affect the estimated carbon supply potential.

Table 1. Summary of the quantity of carbon (million metric tons CO_2 [Mt CO_2]) and area (thousand acres) available at selected price points: ≤$2.7/t CO_2 ($10/t C), ≤ $5.5/t CO_2 ($20/t C), and ≤ $10.0/t CO_2 ($36.7/t C)—for afforestation on existing rangelands in Shasta County over 20-year, 40-year, and 80-year periods

Price points ($/t CO_2)	Quantity (Mt CO_2)	Area (Thousand acres)
20 years		
≤ 2.7	0.01	0.06
≤ 5.5	65.06	330.71
≤ 10.0	67.94	345.37
40 years		
≤ 2.7	2.77	10.95
≤ 5.5	87.44	345.83
≤ 10.0	88.47	355.23
80 years		
≤ 2.7	211.28	346.37
≤ 5.5	214.00	354.76
≤ 10.0	216.21	379.95

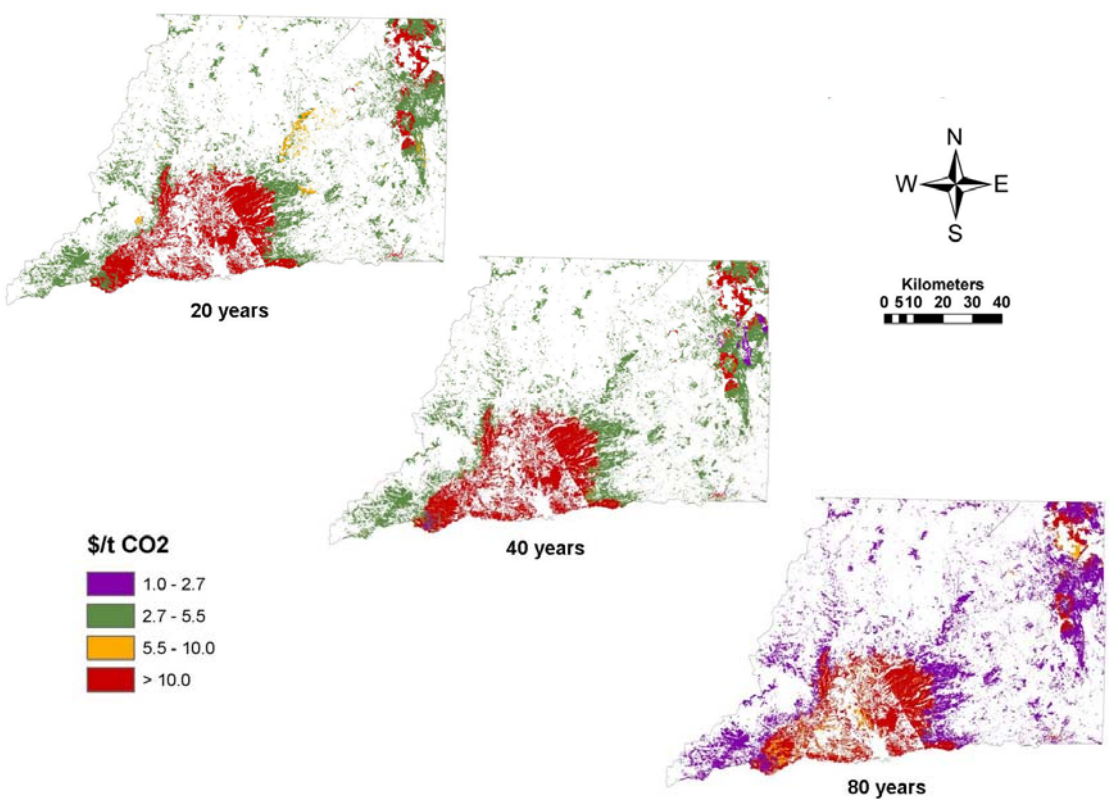

Figure 2. Distribution of cost of t CO_2 sequestration through afforestation of rangelands in Shasta County

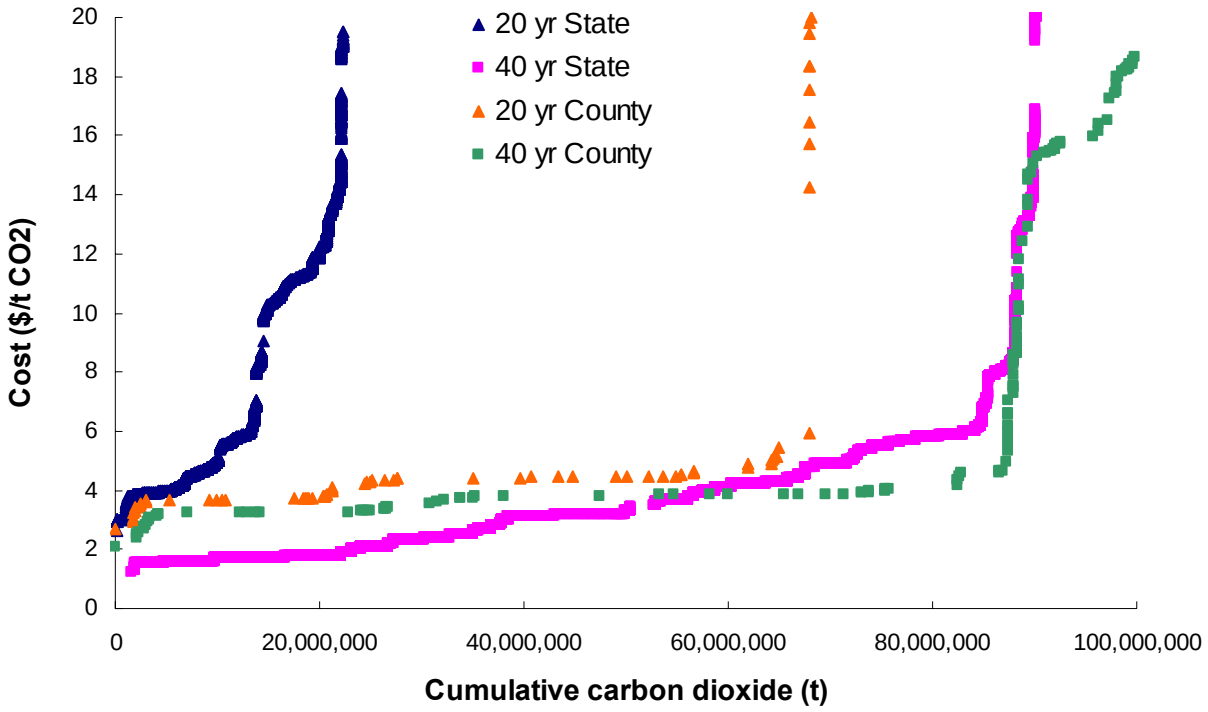

Figure 3. Comparison of the main differences in potential carbon supply between the country scale and the statewide scale analyses for Shasta County after 20- and 40-year time periods

The first result of the comparison showed that the statewide-level study produced an estimated area of suitable rangeland in Shasta County for afforestation to be about 538,000 acres (217,729 hectares), compared to the 600,000 acres (242,820 hectares) identified in the detailed county-level analysis. It was also found that the area suitable for afforestation at different time periods was higher at the county scale than at the state-scale analysis, For example, after 20 years and < \$10/t CO_2, the county scale identified 345,000 acres (139,622 hectares) as being afforested, whereas the state-scale analysis identified only 122,000 acres (49,373 hectares) as being afforested. The main cause for the difference in area suitable for afforestation was the use of higher-resolution maps for the county-scale analysis (30 meter [m]) pixels for the county scale compared to 100 m pixels for the state scale, or a more than 10-fold difference in scale.

It is clear from **Figure 3** that large differences exist between the two scales of analysis for the 20-year time period, whereas the differences after 40 years are only slightly different. Even though a range of conversion costs were used in the county scale (\$450–\$1100/acre, or \$1100–\$2700/hectare) compared to the use of one statewide conversion cost (\$450/acre, or \$1100/hectare), the main reason for the large difference in both cost per ton and quantity after 20 years is related to the different amounts of sequestered carbon that were allocated to the

forest classes, especially the mixed conifer forest class. In the state-scale analysis, only the carbon sequestered in living trees (above and below ground) was included, whereas in the county-scale analysis the carbon sequestered in dead trees and on the forest floor (litter and duff) was included in addition to the trees. At 20 years, the other components contained twice as much carbon as was in the trees, whereas at 40 and 80 years, the other components contained only 60 percent of that in trees.

In the previous statewide report, a preliminary analysis was performed to assess the potential for hazardous fuel reduction to reduce catastrophic forest fires that in turn reduce CO_2 and non-CO_2 greenhouse gas emissions from burning, and use the biomass to generate electricity and offset fossil fuel emissions from conventional power plants. In this study, the state-level method was extended to produce a first-order approximation of the areas and carbon stocks of forests suitable for fuel reduction to reduce their fire risk, their location relative to existing power plants in Shasta County, and the potential quantity of fuel that could be removed and at what cost.

Three main steps were used to accomplish these goals:

1. Identify areas of forestland within Shasta County at high to very high fire risk.
2. Conduct a multi-criteria evaluation to identify forestlands suitable for fuel removal. This analysis assigned a Suitability for Potential Fuel Reduction (SPFR) score to all forested areas, based on criteria affecting the feasibility of treating these lands, and removing and transporting fuels for biomass energy generation.
3. Conduct more detailed analysis of one potential HFR treatment, "Cut-Skid-Chip-Haul" (CSCH), and assess the area of high to very high fire risk forestlands in the county to which this treatment could be applied and how much biomass this fuel might generate for use in power plants, and at what cost.

Results from the first step showed that the total area of forest lands in Shasta County at high risk for fire is approximately 1.41 million acres (572,000 ha), which comprises approximately 90 percent of the total forest lands.

For step 2, three factor maps were used in the decision support tool for a Multi-Criteria Evaluation module (MCE): distance from roads, distance from power plants, and slope. These factor maps were combined to create a single map showing SPFR scores (**Figure 4**). The highest suitability is assigned to forests close to roads and power plants, and on gentle slopes. In the case of Shasta county, practically all lands are within 50 mile (80 kilometer, km) radius of power plants capable of burning biomass.

"Cut-Skid-Chip-Haul" is a treatment in which hazardous fuel is harvested in the forest, bunched and skidded to a landing, chipped into a chip van, and hauled to a biomass energy facility for electricity and/or heat generation. In step 3, the research team estimated area of high to very high fire risk forestlands in Shasta County to which this treatment could be applied, together with how much biomass fuel this treatment might generate for use in power plants, and at what cost.

After applying the constraints for identifying lands suitable for CSCH treatment, the total area available for fuels reduction in Shasta County was estimated to be approximately 215,000 acres (87,000 ha) or approximately 15 percent of the high to very high fire risk forest. The quantity of biomass in the CSCH-treatable forests was estimated based on field data collected in Shasta County and the California Department of Forestry's Fire and Resource Assessment Program's (CDF-FRAP) maps. The biomass for CSCH treatable forest was estimated to be approximately 23.4 million tons, or approximately 11.7 million t C (42.9 million t CO_2 eq) (**Figure 5**).

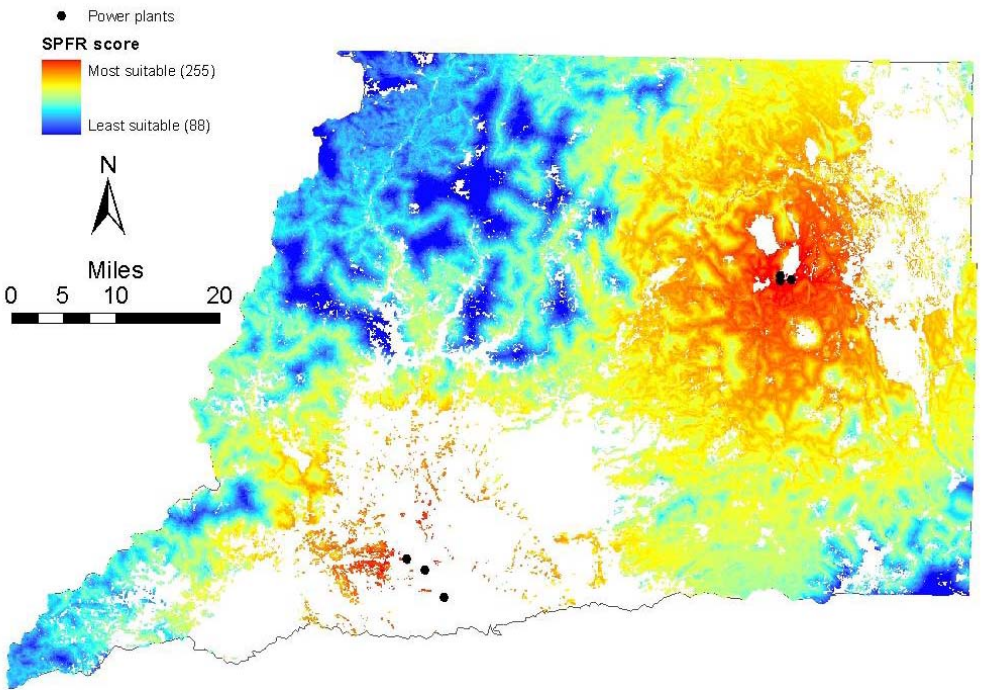

Figure 4. Suitability for Potential Fuel Reduction (SPFR) scores for forest lands in Shasta County at high and very high risk of wildfire

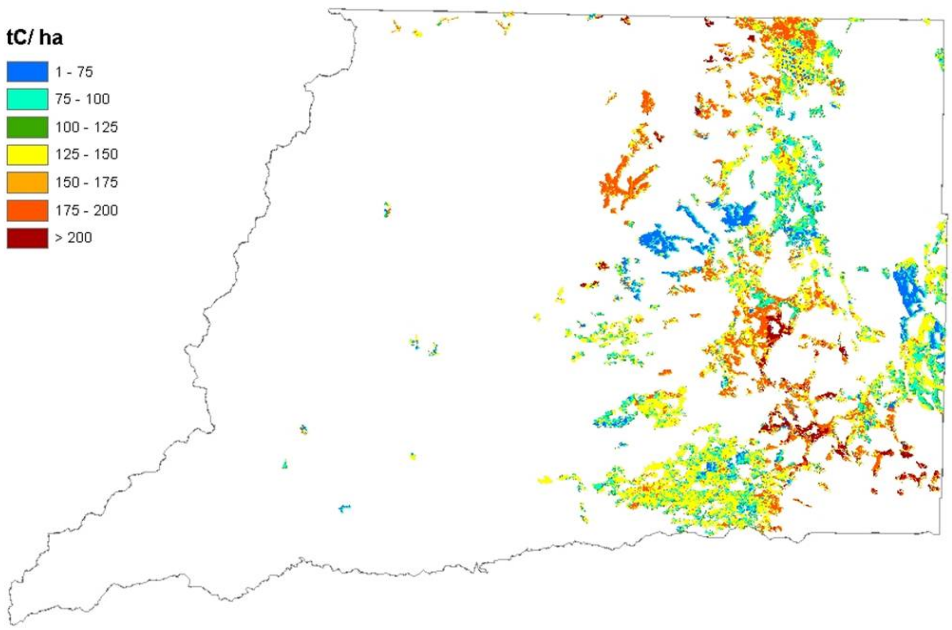

Figure 5. Available tons of carbon in the CSCH-treatable forests of Shasta County

The total fuel available for removal would be much less than this quantity, as not all biomass on the land will be removed through the treatment. The average carbon stock of understory vegetation, small trees, and lying dead wood was 23 t C/ha across all forest types. Thus the potential removable fuel in a CSCH operation is 23 t C/ha.

Recommendations

This study should be further enhanced with actual field demonstration studies. In fact, this report's authors are performing such follow-up research involving a pilot reforestation demonstration study that will further validate this report's findings. In addition, the authors are involved in development and testing of a methodology designed to improve the estimation of how much emission reductions would be attributable to hazardous fuel reduction practices.

Benefits to California

This study has shown that significant amount of carbon can be sequestered in Shasta county at relatively modest costs. To help understand the relationship between the potential fuel removal quantity and the subsequent carbon benefits associated with that removal, it was assumed that the CSCH will remove (a) all of the potentially removable biomass or 46 t biomass/ha (23 t C/ha); and (b) 50 percent of the removable biomass, or 23 tons per hectare (t/ha) (11.5 t C/ha).

According to the first scenario, biomass of approximately 4 million tons would be available to biomass energy facilities in Shasta County from CSCH treatments, to reduce fire risk on approximately 215,000 acres of forest lands. Removing approximately 4 million tons of biomass means that the forests will initially lose approximately 2 million t C. However, this reduction would be balanced by: avoided losses to wildfire of the carbon stocks in the pools left on site; increased growth rates (carbon sequestration) in the post-treatment stand; avoided losses of carbon stocks in other stands, upwind and upslope, that would have burned in a larger fire in the absence of treatment; and displacement of GHG emissions from conventional power plants. Following the same analogy, the second scenario will result in approximately 2 million tons of available biomass associated with an initial loss of approximately 1 million t C from the CSCH-treatable forests.

The purchase value of the biomass by biomass facilities is estimated at $36/bone dry tons (BDT) and the costs for CSCH treatments to a potential landowner are estimated to range from $34–$48/BDT (from literature sources). For both scenarios of quantity removed, the amount of revenue or subsidy that the landowner would receive or need for the biomass was estimated. The first scenario would have a value of approximately $144 million, and thus range from generating a net revenue of approximately $8 million (if cost = $34/BDT), to requiring a total subsidy of approximately $48 million to treat all these lands (if cost = $48/BDT). The second scenario would generate a net revenue of $4 million to a subsidy of $24 million.

To attempt to investigate whether removal of hazardous fuel to reduce fire risk makes economic sense to a landowner, the following calculations are presented. Assuming the $48/BDT costs for biomass removal, to treat the 215,000 acres (87,011 hectares) would require a per-acre subsidy of $223 ($48 million total subsidy divided by 215,000 acres) for removal of 19 t/ac (46 t/ha), or $112 for removal of 9 t/ac (23 t/ha). Depending upon the price of carbon assumed (two

commonly used values are \$2.4/t CO_2 and \$10/t CO_2), the quantity of carbon emissions that would need to be reduced through HFR in order to cover the per-acre subsidies needed—essentially, to make high-cost CSCH a break-even activity—varies from as little as about 3.2 t C/ac (8 t/ha) to as much as 25.5 t C/ac (63 t/ha). Whether HFR could produce this order of magnitude of emissions reductions depends on baseline emissions from fires of varying intensities, and whether HFR prior to fire reduces the intensity of fires. In the baseline report for this county, the average emissions from fires for all forest types is about 17.4 t C/ac (43 t/ha), with a range of 15–32 t C/ac (37–79 t/ha). In other words, if HFR resulted in fire prevention, there would be a reduction in carbon emissions attributable to HFR of 15–32 t C/ac. The reduction in emissions that would need to be achieved by HFR to cover the per-acre subsidies required, 3.2–25.5 t C/ac (8–63 t/ha), is generally within this range or lower.

It also appears from this preliminary analysis, that the order of magnitude in emissions reductions attributable to hazardous fuel reduction (HFR), assuming commonly used prices for carbon offsets, is within the realm of practicality to cover subsidies needed for HFR—adding support to the argument for qualifying fuel reduction activities as carbon offset projects. In other words, a landowner could receive two revenue streams—from sale of the biomass and from sale of carbon credits gained from reducing fire severity. Furthermore, if the power plant was also receiving a monetary benefit from using biomass to substitute for fossil fuel (a large GHG benefit in its own right), it is possible that the plant operators could pay more for the biomass fuel giving the landowner more resources than just to break even. The benefits to California are obviously linked to Assembly Bill 32, which requires the state to reduce net greenhouse gas emissions by 2020 such that 2020 GHG emissions cannot be higher than those emitted by California in 1990.