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PILOT PROJECT OPPORTUNITIES FOR CARBON SEQUESTRATION IN SHASTA COUNTY, CALIFORNIA

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Preface

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

The PIER Program, managed by the California Energy Commission (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.

Pilot Project Opportunities for Carbon Sequestration in Shasta County, California is the final report for the Pilot Project Opportunities for Carbon Sequestration in Shasta County, California project, contract number 500-02-004, work authorization 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 builds on previous work by Winrock that assesses potential carbon sequestration in California. It describes two classes of terrestrial carbon sequestration opportunities that could be implemented in Shasta County and potentially replicated elsewhere in California: afforestation of rangelands to sequester carbon, and improved fuels management to reduce greenhouse gas emissions from wildfire. For each opportunity, suitable lands within the county, net carbon sequestration potential, and representative costs are summarized. These opportunities will be tested and validated through pilot projects in Shasta County under the U.S. Department of Energy-funded West Coast Regional Carbon Sequestration Partnership (WESTCARB) – Phase II, led by the California Energy Commission.

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

Executive Summary

Introduction

With the passage of California Assembly Bill 32, California demonstrated its committment to reducing net greenhouse gas (GHG) emissions. One measure that can be used to help comply with AB32 is to increase carbon stocks in California's lands.

Purpose

The project's purpose was to conduct a series of analyses to identify and quantify terrestrial carbon sequestration opportunities that could be achieved by changing California's land use and land management practices.

Project Objectives

Researchers examined two opportunities that might be implemented in northern California's Shasta County: afforestation of rangelands to sequester carbon, and improved fuels management to reduce GHG emissions from wildfire. *Afforestation* is the establishment of new forests on lands that have not been recently forested. Shasta County was selected for detailed analysis because of the diversity of land use types and carbon sequestration opportunities in the county and the potential for replicating the opportunities tested and validated there elsewhere in the state.

Project Outcomes

The report summarizes, for each opportunity, suitable lands within the county, net carbon sequestration potential, and representative costs. The intended audience is landowners, land managers, and other Shasta County stakeholders, as well as other California stakeholders interested in the validation and replication of these carbon sequestration opportunities.

Rangeland Afforestation. Shasta County has substantial areas of rangelands that were once forested and meet a set of forest suitability criteria suggesting potential for afforestation. About 302 thousand hectares (ha) (746 thousand acres, or 30%) of Shasta County can be classified as various rangeland types. Rangeland areas suitable for afforestation account for about 243 thousand ha (600 thousand acres).

Net carbon sequestration potential in these rangelands ranges from about 12 tons of carbon per hectare (t C/ha) (5 t C/acre) after 20 years for rangeland hardwood forests to about 411 t C/ha (166 t C/acre) after 80 years for mixed conifers.

Researchers conducted an afforestation cost analysis and diveded rangelands suitable for afforestation into two main classes: (1) suitable for grazing, and (2) unsuitable for grazing, with each subdivided into slope classes greater than and less than 30%. Grazed lands have a higher opportunity cost, whereas lands classified as rangeland but unsuitable for grazing have no opportunity cost in this analysis but have a higher conversion cost. Conversion costs for shrub rangelands not suited for grazing were estimated at $900–$1,100/acre ($2,223–$2,717/ha), due

primarily to site preparation costs of removing dense brush prior to planting, compared to $450–$600/acre ($1,112–$1,482/ha) for grassland and woody rangelands.

The net present value of the total costs of afforestation on rangelands suited for grazing, including opportunity, conversion, maintenance, and monitoring, after 20 years was about $1,300–$1,900/ha ($526-$769/acre) on slopes less than 30%, and $1,700–$2,300/ha ($688-$931/acre) on slopes greater than 30%. On rangelands not suited for grazing, with no opportunity cost assigned, the net present value of total costs after 20 years was about $2,400/ha ($972/acre) for lands less than 30% slope and $2,900/ha ($1,174/acre) for lands greater than 30% slope.

The most suitable lands for an afforestation pilot project are those that are presently dominated by shrub rangeland types, such as a variety of the chaparral classes. For a project duration of 40 years, more than 23 million t C (87 million t CO_2) would be available at a cost of less than $20/t C ($5.50/t CO_2) on about 140 thousand ha (346 thousand acres).

Improved Forest Fuels Management. A potentially attractive carbon sequestration option for Shasta County and California is improved management of forest fuel loads to reduce the risk, intensity, and extent of catastrophic wildfires. Net carbon benefits versus the business-as-usual scenario would result from the following:

- Reduced losses of forest carbon stocks.
- Avoided emissions of CO_2, nitrous oxide (N_2O), and methane (CH_4) from wildfires.
- Increased carbon sequestration through enhanced growth rates in the post-treatment stand.
- Displacement of emissions from fossil-fuel generated electricity, when biomass fuel removed to reduce wildfire risk is transported and burned in a biomass power plant.

Developing the necessary methodologies and measuring, monitoring, and verification (MMV) protocols to support sale of carbon credits from improved fuels management would provide a new stream of revenues to improve the economics of hazardous fuel reduction, in which treatment costs often exceed product revenues.

Of Shasta County's total 630 thousand hectares (1.56 million acres) of forest lands, approximately 572 thousand hectares (1.41 million acres, or over 90%) are at high or very high fire risk. The Shasta County lands that are in the most urgent need of treatment and most feasible to treat can be identified.

A GIS-based analysis estimated the area available for fuel reduction using a typical prescription—"Cut-Skid-Chip-Haul" (CSCH)—in which fuel is harvested in the forest, bunched and skidded to a roadside landing, chipped into a chip van, and hauled to a biomass plant. The area of Shasta County high to very high fire risk forest lands meeting CSCH criteria is approximately 87 thousand hectares (215 thousand acres), or 15% of the total area of high to very high fire risk forest.

Two scenarios were examined: (a) removal via CSCH of all the potentially removable biomass or 57 tons/ha (28 t C/ha), and (b) removal of 50% of this biomass, or 28 tons/ha (14 t C/ha).

Treating the 87 thousand hectares would yield 4.9 million tons (oven dry) of biomass for biomass energy facilities in the first scenario, and 2.5 million tons in the second. These values should be taken as conservative.

With an assumed fuel value of $36/ bone-dry ton (BDT) and treatment costs ranging from $34–$48/BDT, treating all 87 thousand hectares of CSCH-accessible, high and very high fire risk forest lands in the county and removing 57 t C/ha would range from generating a net revenue of approximately $11 million to requiring a total subsidy of approximately $59 million. Assuming the higher costs of biomass removal, this implies a per-hectare "subsidy" required of $679 ($275/acre).

To address the potential role of carbon credits from improved fuels management, the key question to address is whether emissions reductions from fuels treatments would be sufficient to make the sale of carbon credits from these projects, assuming commonly used prices of CO_2 credits, cover the per-hectare subsidies required for treatment. Depending upon the price of carbon assumed (two commonly used values are $2.40/t CO_2 and $10/t CO_2), the quantity of emissions that would need to be reduced through hazardous fuel treatment in order to cover a per-hectare subsidy of $679 ranges from 18.5 t C/ha to as much as 77 t C/ha.

Estimated baseline emissions from fires for all forest types in Shasta County ranged from 38 to 79 t C/ha. If fuel reduction could be shown to prevent these fires, there would be a reduction in carbon emissions versus the business-as-usual scenario of 38 to 79 t C/ha—in the same range as the 18.5 to 77 t C/ha reductions needed to cover the subsidies—even without accounting for additional carbon benefits from increased growth rates and displaced fossil fuel emissions. Even just preventing emissions to the atmosphere from burning of the litter and duff layer—21.7 t C/ha on average across forest types in Shasta County according to field measurements—would be sufficient to cover the per-hectare subsidies required for CSCH at a price of $10/t CO_2, and because litter and duff are not assumed to be removed in a fuels reduction prescription, this would be a reduction in emissions creditable to fuels treatment without any initial reduction in carbon stocks in these pools.

Benefits to California

Afforestation. Planting forests on rangelands would provide a net carbon benefit equivalent to the average carbon stocks of mature forests of a given age and species mix, less the baseline carbon stocks of rangelands, multiplied by the total area afforested. Selling carbon credits from these projects would provide a new source of revenue for landowners that may exceed the net present value of opportunity costs, conversion costs, maintenance costs, and measurement/monitoring/registration costs.

Improved Forest Fuels Management. If supported by validation through more detailed analysis and methodology development under U.S. Department of Energy-funded West Coast Regional Carbon Sequestration Partnership (WESTCARB) – Phase II project, fuel treatments whose cost now often exceed product value could, at least on some lands, become cost-effective if landowners could secure market recognition for the net carbon benefits of the treatments. Carbon credits would not pay the full cost of treatment, but might "fill the gap" for many lands that would otherwise go untreated.

1. Introduction

Winrock International has been working with the State of California over the past several years to identify and quantify opportunities for sequestration of carbon in terrestrial ecosystems that could be achieved by changing land use and land management practices.[1] This report builds on earlier state-level analyses, including: (1) development of a baseline of carbon emissions and sequestration in the land use and forestry sector of California for the period 1990–2000 (Brown et al. 2004a); (2) estimation of potential carbon supply for the major classes of potential land-use and forest-based activities in California (Brown et al. 2004b); and (3) methodology and analyses for measuring and estimating the carbon benefits from two changes in forest management (Brown et al. 2004c, 2004d, 2004e).

A second phase of this work has focused attention at the county level for finer-scale analyses of carbon baselines, carbon supply potential, and pilot project opportunities. Shasta County in northern California was selected for detailed analysis because of the diversity of land use types and carbon sequestration opportunities existing in the county, and the potential for replication elsewhere in the state of opportunities tested and validated here.

This report outlines two potential pilot projects that have been identified as attractive opportunities for Shasta County:

- Afforestation of rangelands to sequester carbon[2]
- Improved management of hazardous fuels to reduce greenhouse gas (GHG) emissions from catastrophic wildfires

These opportunities are "attractive" in the sense that they: appear to deliver substantial net carbon benefits in terms of increased carbon stocks and/or reduced emissions of carbon dioxide (CO_2) and other GHGs, may be implemented at relatively low cost compared to other carbon sequestration and GHG mitigation options, offer environmental and economic "co-benefits," and are amenable to testing, validation, and replication in other parts of the state.

The pilot-project opportunities identified in this report have been incorporated into the California Energy Commission's proposal to the U.S. Department of Energy (USDOE) for the West Coast Regional Carbon Sequestration Partnership (WESTCARB) – Phase II. Phase II, which runs from 2006 through 2009, focuses on pilot projects to validate and demonstrate promising geologic and terrestrial carbon sequestration opportunities for the region.

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[1] With support from the California Energy Commission.

[2] Under the USDOE 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 reestablishment 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. In this report, the term *afforestation* is used as defined by USDOE.

2. Afforestation of Rangelands

2.1 Overview of Opportunities

Both Shasta County and the State of California as a whole have substantial areas of rangelands that were once forested and appear, according to a set of forest suitability criteria, to be capable of supporting forest. In Shasta County, these include lands classified as rangeland and currently in rangeland use—including fairly open grass rangeland, irrigated and non-irrigated areas, riparian zones, and rangelands with substantial forest cover in oaks, foothill pines, and other species but still grazed with cattle for at least portions of the year (Figure 2-1). They also include lands classified as rangeland but covered in dense brush and apparently unsuitable for grazing, many of which are entirely surrounded by forest, coincide closely with past fire perimeters, and appear to represent a sort of arrested succession to forest.

Figure 2-1. Diversity of rangelands in Shasta County: clockwise from top, rangelands with sparse conifers in the northeastern corner of the county, hardwood rangelands near Shingletown, hardwood rangelands near Igo and Ono in the southwest, and open rangelands along State Route 44

All these rangeland types could theoretically be converted back to forest through site preparation and planting with appropriate species. Afforestation of rangelands would provide a net carbon sequestration benefit equivalent to the per-unit area net change in carbon stocks of the planted forest at X age (with X representing the duration of the activity or of afforestation contracts), multiplied by the total area afforested.

Such project types are relatively straightforward to measure and monitor and are well accepted in existing carbon registries, reporting protocols, and voluntary carbon offset markets. Selling carbon credits from these projects would provide a new source of revenue for landowners; it is assumed that landowners would be willing to produce and sell carbon from afforestation if the price paid for these credits is greater than the present value of the stream of costs incurred in producing them, including opportunity costs, conversion costs, maintenance costs, and measurement/monitoring/registration costs. This may be the case, particularly for marginally profitable grazing lands and/or grazing lands where afforestation does not require permanent removal of cattle. From the perspective of carbon offset buyers, meanwhile, such projects could provide highly credible credits at a reasonable cost.

2.2 Key Findings of the State-level Analysis

Earlier analyses for the State of California suggested that the largest overall terrestrial carbon sequestration opportunity would be afforestation of grazing land. Of the state's total area of approximately 40.5 million hectares, some 56% is classified as rangeland. Historical evidence suggests that a large proportion of this area was once forested, and forest suitability analyses based on factors of elevation, slope, precipitation, temperature, and available water content suggest that forests could successfully be established and maintained on many rangelands.

The state-level carbon supply analysis suggested that at a price of <$2.70 per metric ton CO_2 ($10/t C), afforesting existing rangelands with native species could sequester approximately 1,610 million metric tons of CO_2 ($MMTCO_2$) on about 5.68 million acres of grazing lands after 40 years. Allowing the price to increase to $5.50/t CO_2 ($20/t C) would make 14.8 million acres available and generate a net benefit of over 3 billion metric tons CO_2 after 40 years (Brown et al. 2004b).

2.3 Afforestation of Shasta County Rangelands

Building on the state-level analysis, additional information and finer-resolution data sets were incorporated to evaluate potential carbon supply from afforestation of rangelands in Shasta County (Brown et al. 2006).

2.3.1 County-level Land-use Classification

The total area of Shasta County is approximately 996 thousand hectares, of which 302 thousand (30%) are categorized as rangeland, 63% as forested land and 6% in the non-forest/non-rangeland category comprised of barren, agriculture, urban, and water (Figure 2-2).

"Rangeland" includes not only open herbaceous and shrub lands (Wildlife Habitat Relationship (WHR) classes such as Annual Grass, Sagebrush, etc.), but also a variety of woodland classes (Blue Oak Foothill Pine, Blue Oak Woodland, Chamise-Redshank Chaparral, Juniper, Mixed Chaparral, Montane Chaparral, Valley Oak Woodland, Wet Meadows).

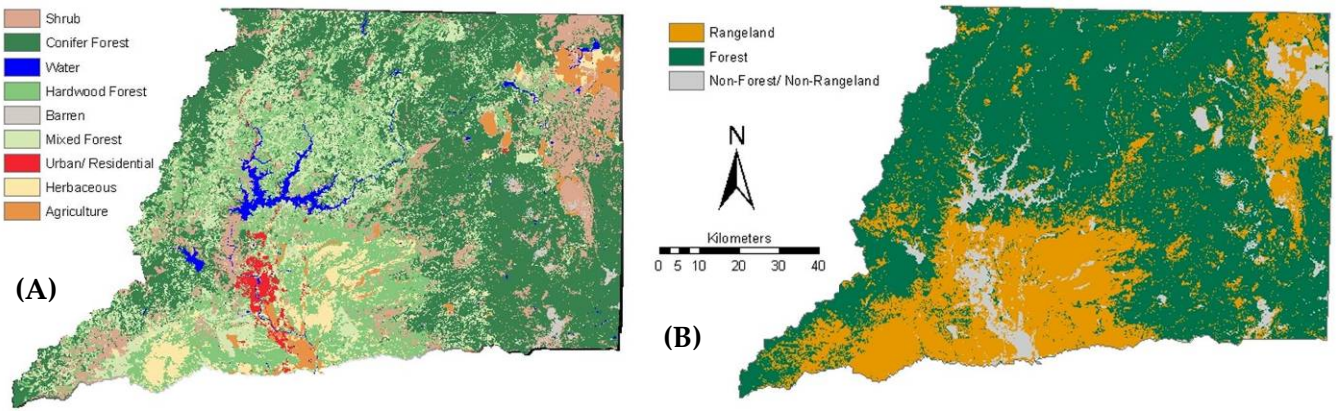

Figure 2-2. (A) CDF-FRAP multi-source land-cover map (CDF-FRAP 2003); (B) Reclassification of map into three classes—rangeland, forest, and non-forest/non-rangeland

2.3.2 Rangelands Suitable for Afforestation

In order to identify existing rangelands potentially suitable for afforestation, a forest suitability model was developed combining several biophysical factor maps (elevation, slope, mean annual temperature, mean annual precipitation, and available water capacity of the soil) and calibrated using the empirical locations of actual forests. In this approach, to be classified among the most suitable sites a location needed to have high values across all the factor maps; 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 (for details see Brown et al. 2006). Figure 2-3 shows the range in forest suitability, according to this multi-factor modeling approach, across Shasta County rangelands.

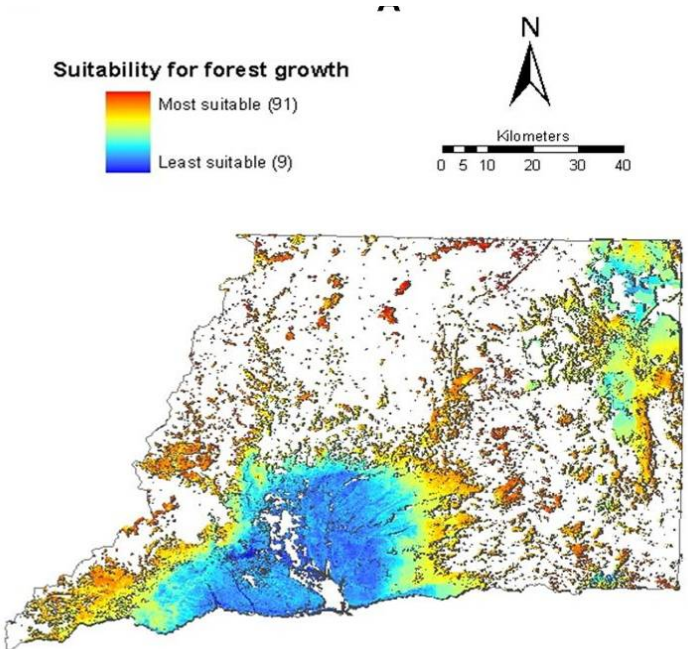

Figure 2-3. Suitability for forest growth on existing rangelands of Shasta County

When the reclassified land-cover map in Figure 2-1(B) is compared to the forest suitability map, it is notable that a significant proportion of rangeland overlaps into relatively high forest suitability scores > 50 (Figure 2-4). This area of overlap represents about 50% of the total area of lands classed as rangelands in Shasta County. This suggests that, according to their biophysical characteristics, these rangelands might successfully be converted to forest, with a net carbon benefit due to significantly higher carbon stocks of forests versus rangelands.

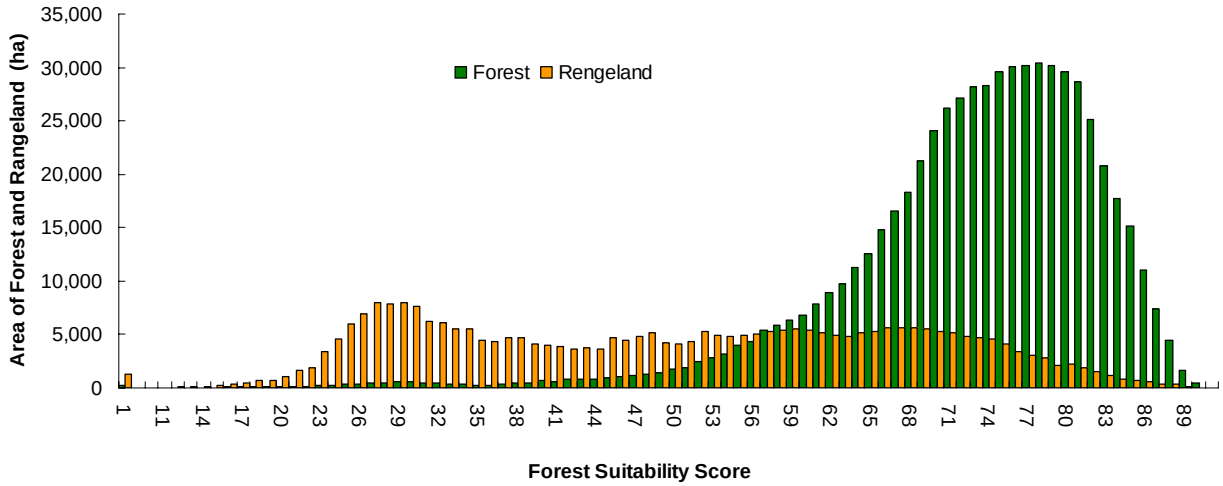

Figure 2-4. Distributions of areas of current rangeland and forest across forest suitability classes.

Among the WHR rangeland types, montane chaparral dominates the higher forest suitability scores, along with mixed chaparral, blue oak foothill pines, and blue oak woodlands (Figure 2-5). The figure indicates the specific rangeland types that might most successfully be converted to forest.

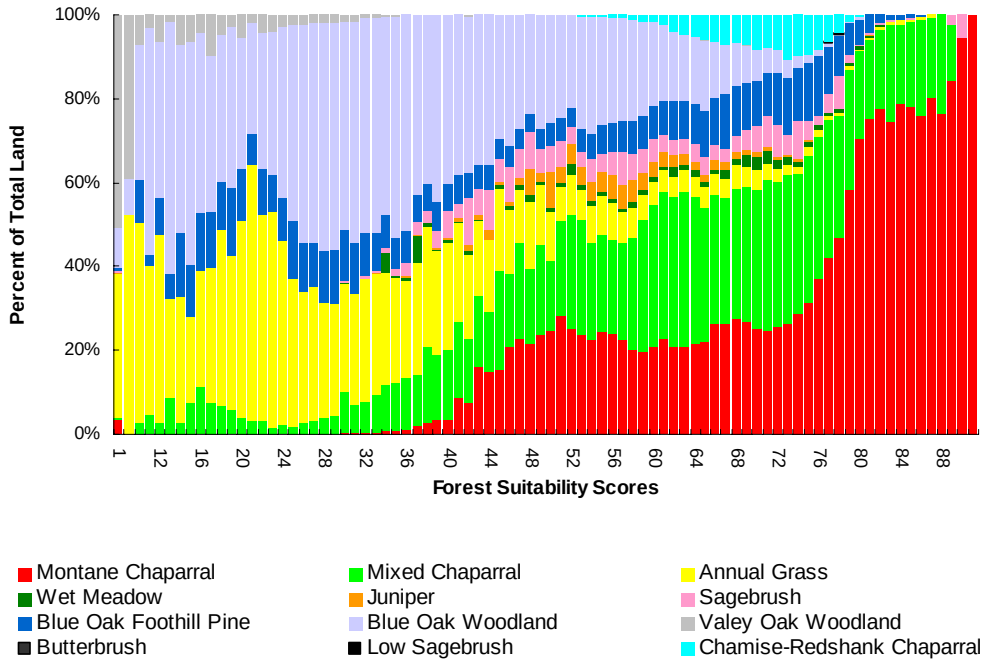

Figure 2-5. Distribution of rangeland WHR classes across the forest suitability classes

In order to identify candidate lands for afforestation among those that look attractive from a modeling perspective, it is necessary to set criteria for what constitute candidate lands. From the rangelands shown in Figure 2-2(B), wooded rangelands with canopy cover > 40%, as well as grassy rangelands dominated by wet meadows, were assumed not to be suitable candidates for afforestation and were excluded from further analysis. Thus candidate rangelands included non-woody rangelands excluding wet meadows, or woody rangelands with a canopy cover of less than 40%. The total area of these rangelands is about 243 thousand hectares (ha), which represents about 80% of the total rangelands in Shasta County, including 64,436 ha of woody rangelands suitable for afforestation (Figure 2-6).

A further stratification of candidate lands was made after observation of certain areas mapped as rangeland but apparently unsuitable for grazing. These lands, classified as chaparral in the WHR map and falling within the perimeters of past wildfires, tend to be covered with dense shrubs such as manzanita and are generally impenetrable for livestock. They appear to represent a sort of arrested succession to forest (Figure 2-7). Intuitively it would be possible to convert these lands to forest for a net carbon gain. Because they are not suitable for grazing, opportunity costs might be small to nonexistent, making them attractive candidates for afforestation; on the other hand, site preparation needed to allow forest to establish may be costly.

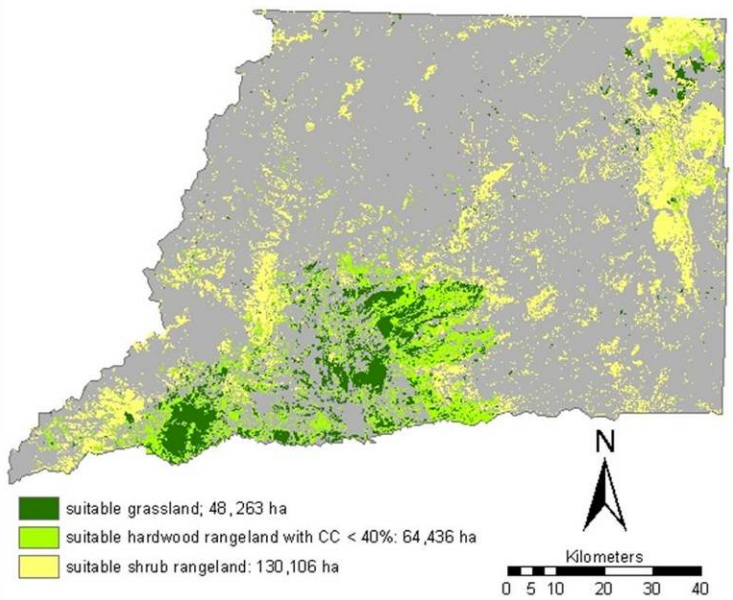

Figure 2-6. Distribution of non-woody rangelands and woody rangelands with canopy cover < 40% considered suitable for afforestation

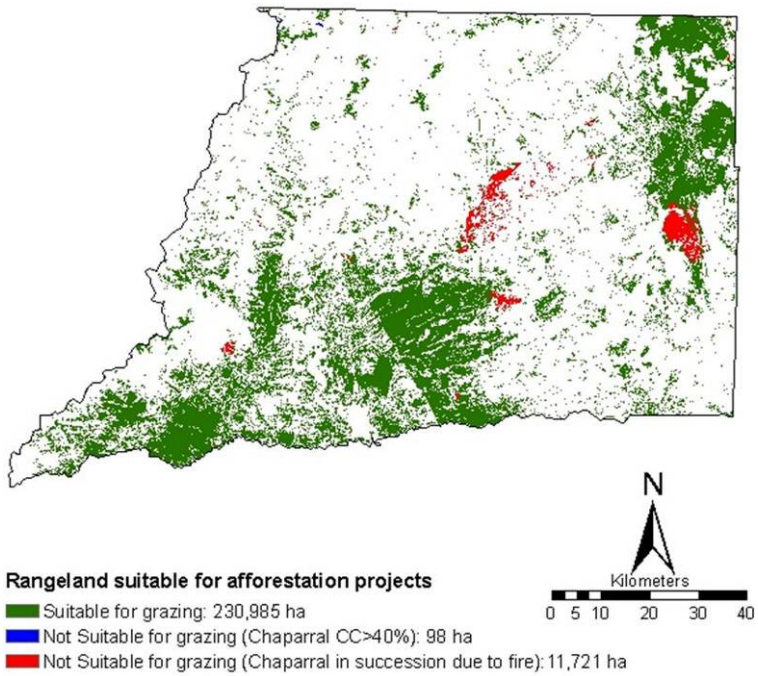

Figure 2-7. Rangelands suitable and not suitable for grazing, including chaparral areas in arrested succession due to past fires.

2.3.3 Carbon Sequestration Potential of Candidate Rangelands

To estimate net carbon sequestration benefit of converting rangelands to forest, it is necessary to consider not only the change in area from one land use to another, but also the estimated difference in average carbon stocks between the two land uses. The net carbon benefit per unit area will be the difference in carbon stocks between the forest that is to be planted, at a given age such as 20, 40, or 80 years, and the baseline carbon stocks in the current land use. The *total* net carbon benefit will be the difference in carbon stocks multiplied by the area converted from rangeland to forest.

Estimates of carbon sequestration potential for forest planted on rangelands relied on Wildlife Habitat Relationship (WHR) forest classes aggregated into three larger classes hardwood, hardwood range, and mixed conifer that correspond to species groupings in the USDOE revised 1605(b) guidelines (USDOE 2006). This classification is shown in Table 2-1. By applying carbon values in t C/ha to each simplified species group, based on USDOE 1605(b), US Forest Service Forest Inventory and Analysis (FIA) data, Winrock data from measurements in Shasta County forests, and other Winrock experience, it was possible to estimate potential carbon stocks from afforestation of suitable rangelands for each species class as shown in Table 2-2.[3]

[3] For further detail on the approach to estimating carbon accumulation potential for different species groups, see Brown et al. 2006.

Table 2-1. Reclassification scheme of WHR classes according to USDOE (2006) classification

WHR	Birdsey (USDOE 2006) 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
Jeffrey Pine	Mixed Conifer

Table 2-2. Estimates of the potential carbon stocks from afforestation of suitable rangeland areas

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

Applying these carbon stock estimates to the map of rangelands suitable for afforestation results in a map of potential carbon sequestration potential throughout the county for 20-, 40-, and 80-year project durations (Figure 2-8).

2.3.4 Costs of Afforesting Rangelands

An important consideration for landowners considering afforestation of rangelands will be the total costs compared to potential revenues from carbon credits. The ideal sites for afforestation will be those, among the candidate lands identified above, that represent some intersection of the highest forest suitability, highest net carbon sequestration potential, and lowest total costs. Among these lands, sites for afforestation pilot activities can be chosen based on the willingness of landowners to participate in an afforestation program, plant trees and at least temporarily forgo grazing, and monitor and possibly register these projects on one of the currently existing registries or reporting protocols, such as the California Climate Action Registry (CCAR) or the United States Department of Energy (U.S. DOE) 1605(b) voluntary GHG reporting program.

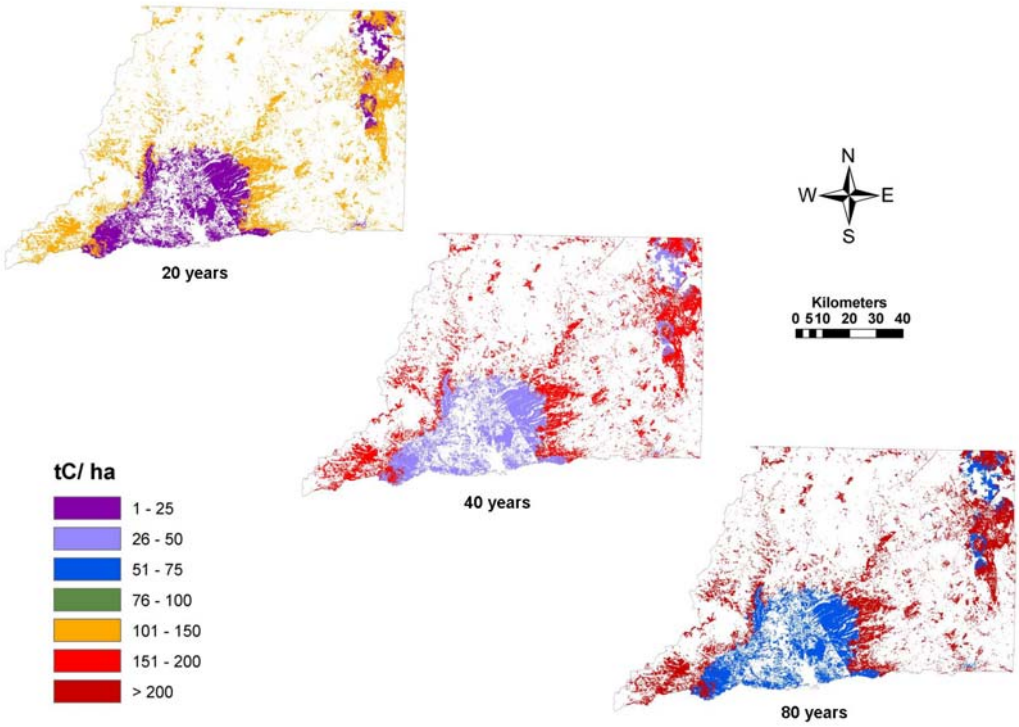

Figure 2-8. Carbon sequestration potential on rangelands suitable for afforestation activities for 20, 40, and 80 years.

Costs in this analysis included opportunity costs, conversion costs such as site preparation and planting, measuring and monitoring (M&M) costs, and maintenance costs (Brown et al. 2006). Total costs suggest a price at which landowners might be willing to change management of their lands, usually under a contract of some duration agreed between the landowner and a buyer of carbon credits. Not included in the analysis are transaction costs—for example, the costs to a potential buyer of seeking out willing landowners, the costs to both buyer and landowner of concluding contracts, and potentially the costs to one or both parties of registering and reporting projects.

Rangelands suitable for afforestation were divided into two main classes: (1) those that are likely grazed, and (2) those not grazed, with both subdivided into two slope classes (greater than and less than 30% slope). Those with grazing would have an associated opportunity cost, whereas those not grazed would not. However, the shrub rangelands not suited for grazing have a high conversion cost of about $900–$1,100/acre ($2,223–$2,717/ha) compared to $450–$600/acre ($1,112–$1,482/ha) for grassland and woody rangelands.

Depending upon the forage productivity of the rangeland suited for grazing, the net present value of the total costs of afforestation (opportunity, conversion, maintenance, and monitoring) after 20 years was about $1,300–$1,900/ha on slopes less than 30% and $1,700–$2,300/ha on slopes greater than 30%. On rangelands not suited for grazing, with no opportunity cost assigned, the net present value of total costs after 20 years was about $2,400/ha and $2,900/ha for less than 30% slope and greater than 30% slope, respectively—considerably higher than for lands suited for grazing, suggesting that high site preparation costs more than offset zero opportunity costs (Table 2-3).

Table 2-3. 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

While all costs appear relatively high, several points are important to note. First, Table 2-3 shows costs in $/ha; to convert to $/acre, divide by 2.47. Second, there is considerable variation, not only depending on forage production but by land type. In general, afforestation on rangelands suitable for grazing is less expensive, even though opportunity costs are higher, than on rangelands unsuitable for grazing because of very high site preparation and planting costs on the latter type of lands. For either type, it is cheaper to afforest land on slopes less than 30%. Finally, it should be emphasized that the important consideration for landowners is not so much the total cost per hectare, but rather how the net present value of a stream of costs compares to the net present value of the revenues available from sale of carbon credits. Landowners are assumed to be willing to produce and sell carbon credits from afforestation if the price paid for these credits is greater than the present value of the stream of costs incurred in producing them. The total revenues to landowners to pay for afforestation will depend on the price ($/t CO_2) of carbon assumed, and the quantity sequestered (t C or t CO_2), which varies throughout the county.

2.3.5 Location of Rangelands Most Attractive for Afforestation

By dividing the present value of the total cost of afforestation ($/ha) by the net potential carbon gain (t C/ha) at a given pixel on a map of candidate rangelands, it is possible to estimate the cost of carbon in each cell in dollars per ton. This gives a picture of the least to most expensive areas within the county for carbon sequestration through afforestation, shown in Figure 2-9 for rangelands suitable for grazing and in Figure 2-10 for rangelands unsuitable for grazing.

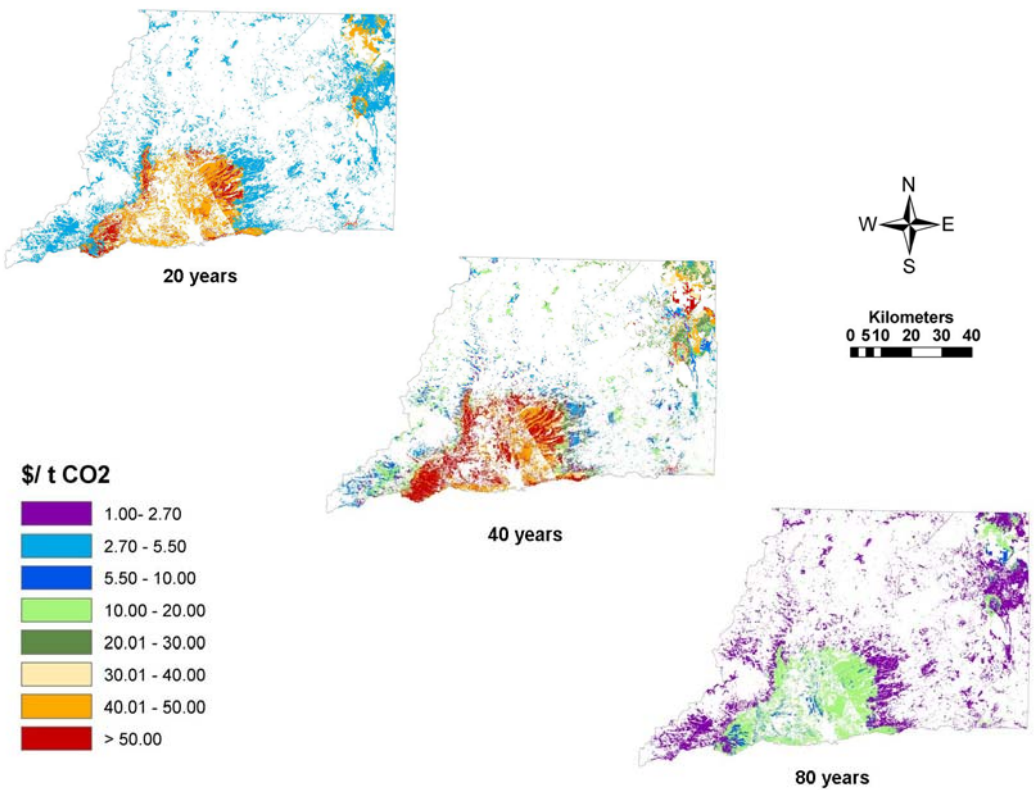

Figure 2-9. Cost of carbon sequestration through afforestation of rangelands suitable for grazing in Shasta County

The most expensive carbon on lands suited for grazing (> $40/t CO_2) is located in the south to southwest part of the county. The least expensive carbon over any of the three time intervals is located in the east and northeastern part of the county (Figure 2-9). These are the areas, not necessarily where the magnitude of carbon sequestration is greatest, but where carbon may be sequestered most cost-effectively through afforestation. The small amount of rangeland unsuited for grazing produces carbon at a mid-range of costs (Figure 2-10).

For an 80-year afforestation project, about 57.6 million tons of carbon could be sequestered at a cost of less than $10/t C ($2.70/t CO_2). In contrast, a 20-year project would sequester only about 17.7 million tons of carbon at a cost of < $20/t C ($5.45/t CO_2).

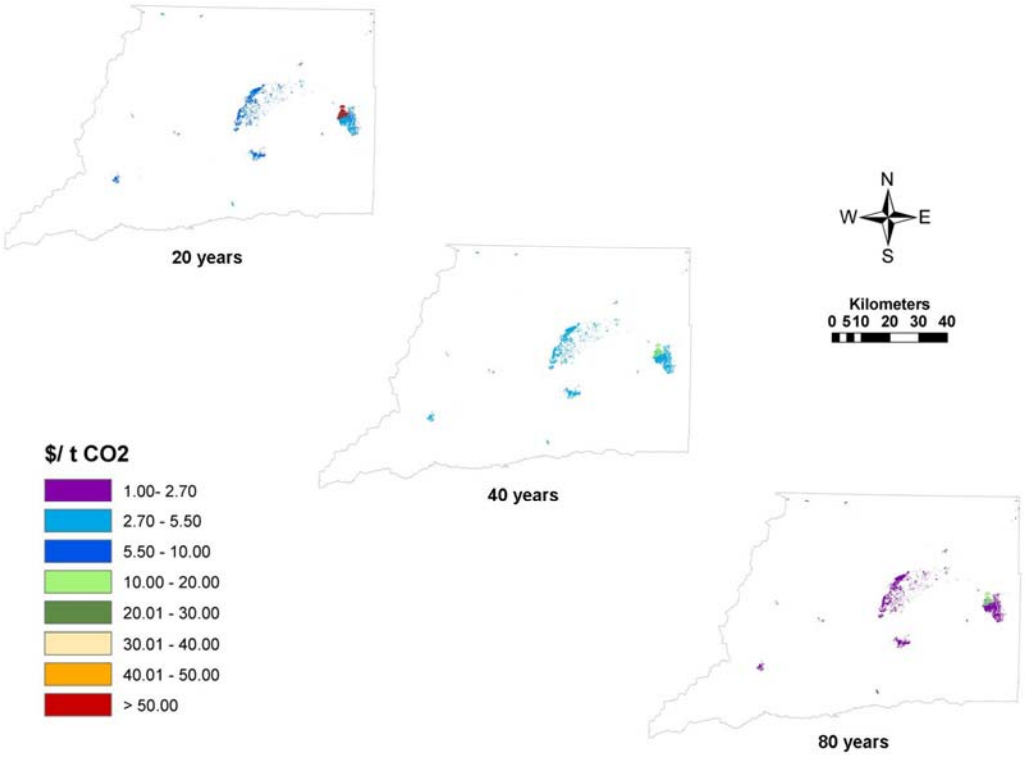

Figure 2-10. Cost of carbon sequestration through afforestation of rangelands unsuitable for grazing in Shasta County

2.4 Pilot Activities in Shasta County under WESTCARB Phase II

2.4.1 Activities

The carbon sequestration potential of afforesting rangelands in Shasta County will be further tested and validated through pilot project activities in WESTCARB Phase II. The pilot project in Shasta County will establish native forests on grazing land representative of lands available for afforestation in the region, working with public and private partners in Shasta County. The goal is to verify the carbon sequestration potential of these projects and validate the forest suitability, carbon accumulation, and cost analyses presented above. Specific activities will include:

- Review and classify rangelands that appear suited for forest from the analyses presented here, and select specific sites based on consultation with Shasta County partners and the willingness of landowners and land managers to collaborate and contribute resources to the effort.
- Prepare plan for planting and maintenance, including all necessary details of site preparation, species selection, planting density and technique, seedling sources, and subsequent maintenance, in consultation with local partners and experts. Convene a technical panel to preview the site and species selection and the planting and maintenance plan.
- Review site history and take field measurements prior to site preparation to establish baseline. Winrock will apply existing protocols for baseline determination and

measurement, monitoring, and verification (MMV) of afforestation projects, drawing on guidance from the CCAR Forest Project Protocols, Chicago Climate Exchange, and U.S. DOE 1605(b) guidelines for voluntary reporting of greenhouse gases.

- Conduct afforestation with native species and, in later years, conduct tests on afforestation using fast-growing species adapted for drier sites.
- Collect data on establishment and maintenance costs.
- Conduct end-of-project measurements to monitor success and survival of pilot activities.

2.4.2 Research Benefits

Afforestation activities in Shasta County will help answer key questions about net benefits and potential for replication elsewhere in the WESTCARB region, including:

- Developing methods for afforestation of previously forested lands
- Estimating the impacts of different afforestation activities on non-CO_2 GHGs (e.g., N_2O)
- Validating estimates of carbon sequestration from afforestation across different site classes
- Determining the minimum soil moisture and precipitation required for successful establishment of trees at pilot sites
- Evaluating the ecological impacts of afforestation activities in collaboration with other research funded by the California Energy Commission
- Determining the minimum time required to successfully establish new forests for different species
- Determining conversion and maintenance costs for different forest types
- Evaluating and testing dry-site species for harsh-site regeneration, and quantifying carbon accumulation rates
- Developing a methodology to quantify value of carbon stocks retained in forest products produced from fast-growing plantations
- Assessing the effect of planting-site preparation on baseline carbon stocks
- Collecting additional data on opportunity costs and what factors affect the cost, including effect on opportunity cost of allowing the reintroduction of cattle once planted trees reach a certain age
- Collecting additional data on conversion, maintenance, monitoring, reporting, and verification costs
- Testing measurement and monitoring protocols
- Evaluating the effects on carbon benefits and the overall costs of tree harvesting on afforested areas at economic rotation age

2.4.3 Implementing Partners

Landowners, land managers, and other implementing/technical advising partners for afforestation pilot activities in Shasta County under WESTCARB Phase II include: WM Beaty & Associates, Inc., Western Shasta Resource Conservation District, individual private ranchers, California Department of Forestry and Fire Protection, Pacific Gas & Electric Company, Sierra Pacific Industries, USDA Forest Service – Pacific Southwest Research Station, USDA Forest Service – Shasta Trinity National Forest, National Park Service – Whiskeytown NRA, National Park Service – Lassen Volcanic National Park, and USDI – Bureau of Land Management.

3. Improved Management of Hazardous Fuels

3.1 Overview of Opportunities

A potentially attractive carbon sequestration option for Shasta County and the State of California is improved management of forest fuel loads to reduce the risk, intensity, and extent of catastrophic wildfires. Fire is responsible for significant losses of forest carbon stocks, emissions of CO_2 and other GHGs, both at the state and county levels (Brown et al. 2004a, Pearson et al. 2006). Improved management of forest fuel loads could reduce wildfires and thus reduce these losses and emissions, offering a new opportunity to supply carbon credits. Such projects could potentially garner multiple carbon benefits:

- Reduced losses of forest carbon stocks in wildfires, i.e., higher long-term average forest carbon stocks than in the business-as-usual scenario. Fuel treatment would protect forest carbon stocks not only in the stand actually treated, but in stands upwind and upslope where a wildfire would tend to move, thus reducing not only the probability and intensity of the fire in the stand itself, but also the extent of wildfires that do occur.
- Avoided emissions of CO_2 from burning of trees and other vegetation, N_2O from burning of foliage, and CH_4 from the smoldering phase of some fires. N_2O has approximately 296 times, and CH_4 approximately 23 times, the global warming potential of CO_2.
- Increased carbon sequestration through enhanced growth in the residual stand, as thinning for fuel removal generally produces a healthier stand and promotes faster growth rates.
- Displacement of emissions from fossil fuel-generated electricity, when biomass fuel removed to reduce wildfire risk is transported and burned in a biomass power plant.
- A small proportion of these benefits would be offset by increased direct emissions from the treatment itself (e.g., emissions from harvesting equipment, trucks, chainsaws). These emissions can easily be quantified and subtracted from the gross carbon benefits.

The economics of hazardous fuel treatment are often challenging, with low-value products such as biomass fuel and small-diameter trees generally offsetting only a portion of the total costs of treatment, removal, and transport. Thus a key question of interest in proposing hazardous fuel reduction as a carbon sequestration opportunity is the ability not only to quantify net carbon benefits but also to value and transact those benefits, making carbon credits a new revenue stream to help public and private landowners treat more acres of forest for wildfire.

3.2 Background

The last century has seen the transformation of many western forest ecosystems from relatively open, healthy forests in which periodic low-intensity ground fire played an important role, to densely stocked forests prone to catastrophic crown fires and related insect and disease problems. The problem of overstocked forest lands with extremely high fuel loads is the result of multiple factors, but in particular of heavy logging followed by a policy of universal fire

suppression eliminating frequent low-intensity fire from these ecosystems. Forests with a natural fire return interval of 10 or 20 years (depending on forest type) have in many places been replaced by a fundamentally different forest landscape in which accumulated woody fuels create conditions for infrequent but intense and large-scale fires that can permanently alter ecosystems (Pyne et al. 1996).

The current condition of accumulated fuels, combined with the continual expansion of the "wildland-urban interface," make it generally impossible simply to forego fire suppression or introduce prescribed fire without first reducing fuel loads. Fuel reduction tends to be labor-intensive and costly, with a huge quantity of submerchantable material requiring treatment and/or removal, but constituting relatively little value to pay the high cost of handling such a large number of stems. Meanwhile public agency budgets to pay for fuels reduction have been cut repeatedly. Creative utilization strategies for understory biomass and small-diameter timber are needed, together with a broad portfolio of approaches and sources of revenue to offset the costs of treatment.

3.3 Key Findings of the State-level Analysis

Winrock's state-level analysis found fire to be the predominant cause of emissions from forest lands in the three primary forested regions of California, responsible for an estimated 1.55 $MMTCO_2eq/yr$ in emissions, exceeding even harvest (1.40 $MMTCO_2eq/yr$) as a cause of canopy cover change and associated carbon emissions (Brown et al. 2004a). This finding drew attention to the possibility of reducing emissions and preserving forest carbon stocks through actions to reduce hazardous fuel loads. Some 6.6 million hectares of California forests are at high or very high risk of wildfire according to Winrock's analyses (Brown et al. 2004b; Petrova et al. 2006).

The type of fuel reduction treatment that might be ideal from a carbon perspective—i.e., capture all the carbon benefits listed above—is one in which fuel is harvested in the forest, removed to the roadside, and transported to a biomass power plant for electricity and/or heat generation. This treatment, nicknamed "cut-skid-chip-haul" (CSCH), would not be feasible for all forest lands, however, due to economic and technical constraints. The preliminary state-level analysis assumed that only lands meeting each of three constraints would be treatable using CSCH: (1) maximum 40% slope, (2) maximum 0.25-mile yarding distance to the nearest road, and (3) maximum 50-mile haul distance from the nearest biomass energy facility. The total area of California high and very high fire risk forest meeting these constraints is approximately 907 thousand hectares, or 14% of the total area of high and very high fire risk forest. The total carbon stocks of California forests at high and very high fire risk and feasible for CSCH treatment are approximately 81 million t C (Petrova et al. 2006).

3.4 Improved Fuels Management in Shasta County

3.4.1 Forest Land and Forest Types

There are over 630 thousand hectares of forested land in Shasta County, composed of four predominant classes (Smith and Heath 2002): Other Conifer (56% of the total forested area), Hardwood (28%), Douglas Fir (11%), and Fir-Spruce (5%) (Figure 3-1).

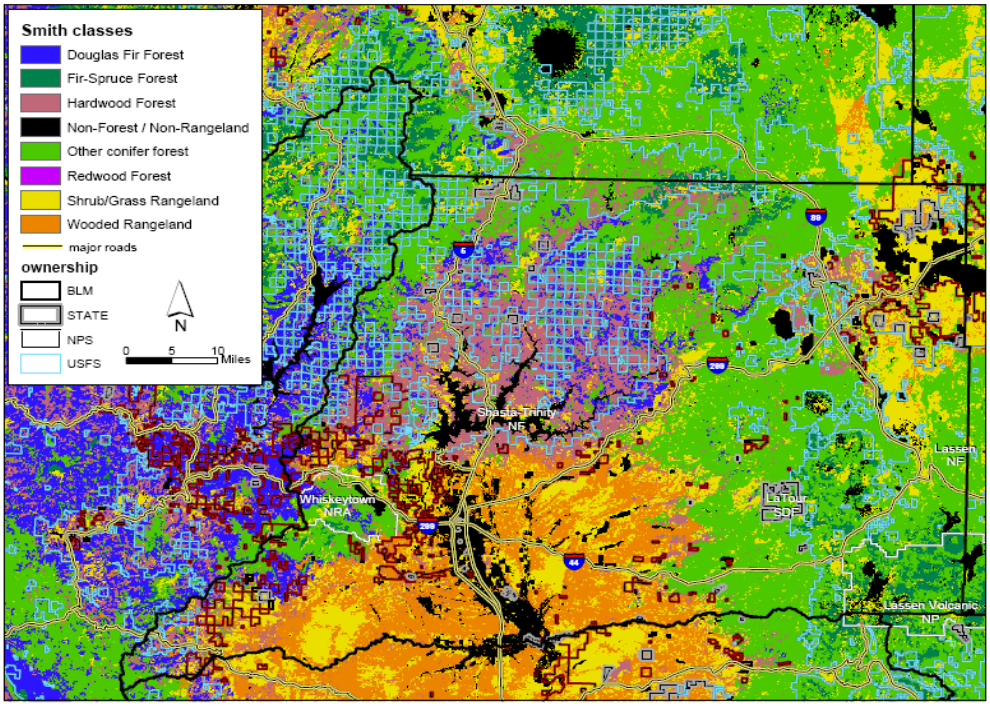

Figure 3-1. Forest types in Shasta County, California (Smith and Heath 2002)

3.4.2 Suitability for Fuel Reduction and Removal

Across forest lands in Shasta County, fire risk varies by forest type, fuel loading, and other factors. Approximately 572 thousand hectares of Shasta County forest lands—over 90% of the total forested area—are at high or very high fire risk, based on California Department of Forestry's Fire and Resource Assessment Program fuel ranking (CDF-FRAP 2004) (Figure 3-2).

The suitability for potential fuel removal (SPFR) of these forest lands can be assessed based on the degree of fire risk and a variety of technical, environmental, and economic factors affecting feasibility of treating and removing hazardous fuels. A GIS-based analysis was conducted using the three factors of distance from roads, reflecting feasibility and cost of removal of fuel to the nearest road where it could be loaded into a chip van; slope, reflecting ease of removal as well as ground impacts; and distance to the nearest biomass power plant, reflecting haul cost and access to biomass fuel markets to provide revenues to offset a portion of the costs of fuel treatment (Brown et al. 2006). Each of the three factors was converted to a standard scale, with the lowest suitability scores assigned to lands furthest from a road, on steepest slopes, and furthest from biomass power plants.

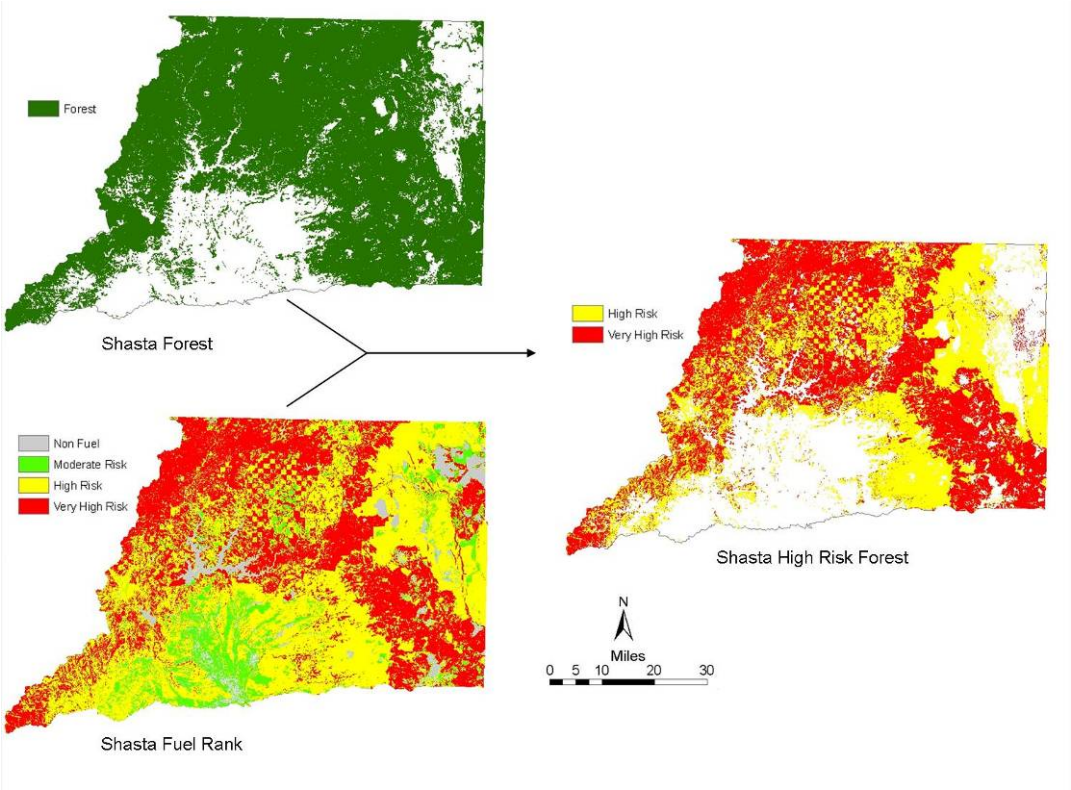

Figure 3-2. Distribution of forest lands in Shasta County at high and very high risk for wildfires

Combining the Shasta County high and very high fire risk forestlands and the SPFR scores of those same forest lands yields a map illustrating the locations of the forests most likely to burn and most feasible to treat (Figure 3-3). "Suitability" in the model represents only suitability for a treatment that removes fuel from the forest and transports it to biomass energy facilities. Other treatments are available, some of which (e.g., cut-pile-burn) address fire risk by reducing fuel loading but do not attempt to remove fuel. Feasibility of these treatments would not be affected by distance from biomass energy facilities, and only slightly affected by distance from roads (less accessible sites would still have higher move-in costs and be more expensive to treat, but access to roads suitable for a chip van would not be a consideration). Likewise, lands on steeper slopes may be treatable using methods that do not attempt to remove fuel. On the other hand, treatments that reduce fuel loading without fuel removal have no revenue from sale of biomass fuel to offset treatment costs, or to pay for the expensive approaches and equipment necessary to treat remote sites or high slopes. They may also have smaller net carbon emissions reduction benefits.

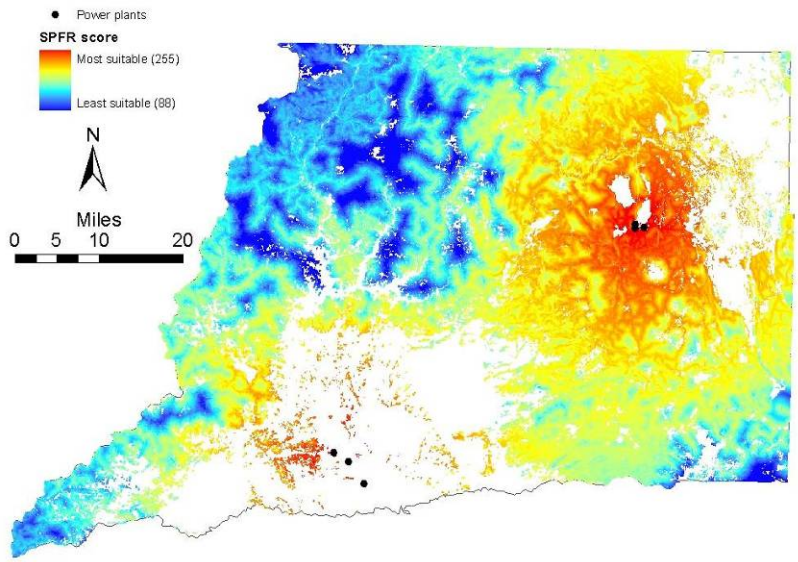

Figure 3-3. Suitability for Potential Fuel Reduction (SPFR) scores for forest lands in Shasta County at high and very high risk of wildfire

The Other Conifer forest type dominates across all SPFR scores but especially in the higher scores above 200 (Figure 3-4). This is followed by the Hardwood type, with greatest representation between scores of about 110 and 195; Douglas Fir, present in the mid-range but missing from the lowest and highest SPFR scores; and a small representation of Fir-Spruce forest type up to around SPFR score 238.

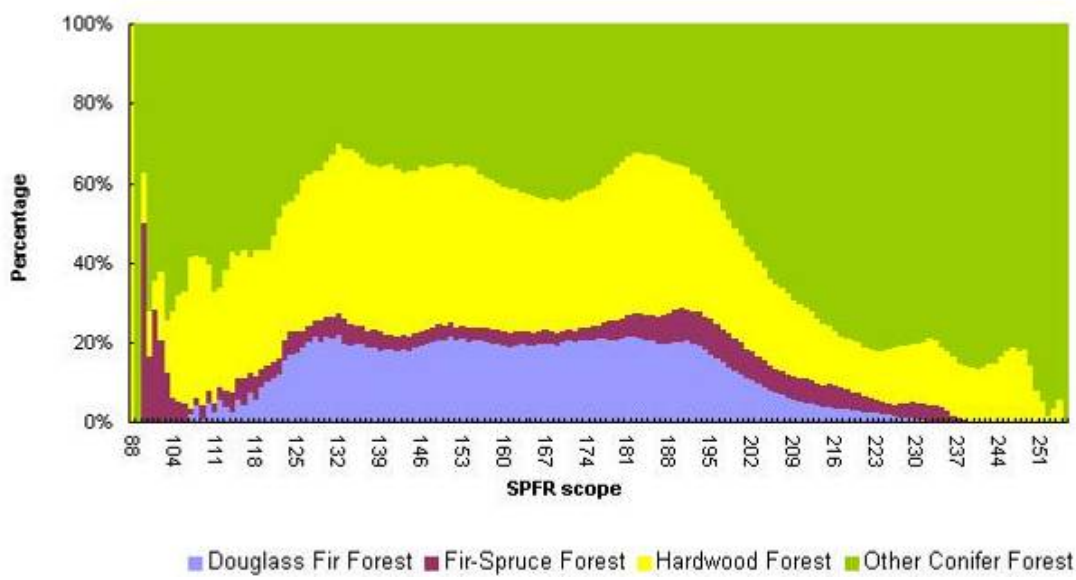

Figure 3-4. Forest types at moderate and high risk for wildfires across the range of SPFR scores

The distribution by forest type in Figure 3-4 reflects the overall areas by forest type in the county, fire risk and treatment feasibility. The fire-prone Other Conifer forests predominate as expected, due to a large total area, high fire risk, and much of this type being on gentle slopes, accessible to roads and relatively close to existing biomass plants. Fir-Spruce forest exists in mainly in two relatively remote areas of the county: the north-central and southeast corners

(Figure 3-1), which are high-risk and accessible in terms of the roads and slope factors, but relatively far from power plants. The Douglas Fir forest type is scattered through much of Shasta-Trinity National Forest, as well as some areas in the far west of the county. This type is relatively less fire-prone (having longer natural fire return intervals), and also grows generally on steeper slopes, in less roaded areas, and on the margin of feasible hauling distance from power plants. Hardwood is scattered throughout the county, but it is especially concentrated in the northwestern quarter of the county that includes Shasta-Trinity National Forest; this forest type may be intermediate in fire risk, but like Douglas Fir, large areas are on higher slopes, relatively less suitable in terms of road access, and somewhat further from biomass plants.

3.4.3 Area of Forests Accessible for CSCH Treatment

To estimate quantitatively the area available for fuel reduction, a constraints-based analysis was made of a typical fuels-management prescription, "Cut-Skid-Chip-Haul" (CSCH). In this prescription, fuel is harvested using a combination of mechanical and manual treatments, bunched and skidded to a roadside landing, chipped into a chip van, and hauled to a biomass plant for electricity and/or heat generation. CSCH is only one of several potential hazardous fuel reduction treatments, some of which reduce fuel loading without removing it, combine sub-merchantable and merchantable material in a fuel treatment prescription, burn fuel on site, or are used for locations, terrain, slope or other conditions that may not be feasible for CSCH.

Based on a review of the fuel reduction literature and consultation with partners in Shasta County, the following constraints were used to identify the area available for CSCH:

- *Maximum slope of 40%* (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 of 0.25 miles (400 meters)* from existing roads, used as a general rule of thumb for the 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.).
- *Maximum haul distance to biomass plants of 50 miles.* This maximum haul distance may be considerably affected by the volume/value of merchantable material in the prescription. This constraint was irrelevant to the county-level analysis, however, because all forest lands in Shasta County fall within 50 miles of a biomass plant.
- *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 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.).

The area of high to very high fire risk forest lands in the county meeting all four constraints for CSCH is approximately 87 thousand hectares, or 15% of the total area of high to very high fire risk forest (Figure 3-5).

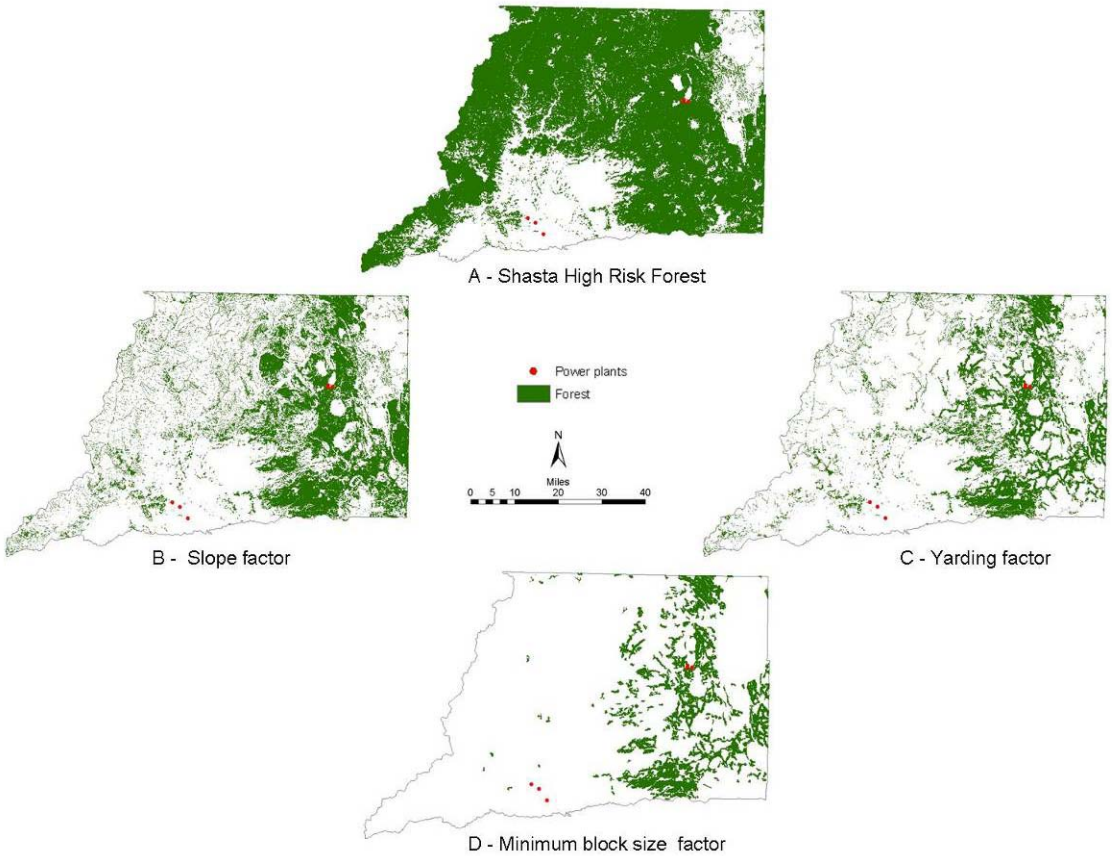

Figure 3-5. Critical factors to determine forest lands suitable for CSCH fuel treatment: A – Shasta County High Risk Forest; B – Slope less than 40%; C – Yarding distance less than 0.25 mi; D – Minimum block size of 80 acres

The total quantity of biomass in these forest lands was then estimated based on field data collected in Shasta County in September 2005. The CDF-FRAP map reports a canopy cover attribute for all vegetation types; these were used with regression equations of biomass versus canopy cover based on field measurements (Pearson et al. 2006) to estimate a total biomass of approximately 23.4 million tons (11.7 million tons carbon) on these high to very high fire risk forests accessible for CSCH.[4] This value represents *total* forest biomass, not the quantity of biomass fuel that might be removed and transported to a biomass plant, which is addressed in the following section.

3.4.4 Quantity of Biomass Fuel Based on Field Work in Shasta County

The total biomass fuel available from Shasta County high and very high fire risk forest lands determined to be treatable would depend on the proportion of total biomass targeted for removal to reduce fire risk. Fuel reduction prescriptions vary considerably depending on the stand, current condition, and desired future condition. Prescriptions may target a post-treatment spacing, stand-level residual basal area such as 80–125 square feet per acre (ft^2/acre),

[4] Carbon is calculated as 50% of biomass.

reduction in fuel loads, or reduction in Torching Index and/or Crowning Index (D. Goehring and D. McCall, PG&E Natural Resources, pers comm.; Fried et al. 2002, 2003; USDA Forest Service Research & Development/ Western Forestry Leadership Coalition 2003).

To estimate biomass in understory fuel loads, and attempt to partition forest biomass between "pools" such as large trees, small-diameter trees, understory vegetation, dead wood, and litter/duff, field measurements were made in Shasta County in September 2005. Understory vegetation, lying dead wood, trees < 10 cm, and litter/duff were sampled in 45 plots, within CDF-FRAP dominant forest types, throughout the county. Understory vegetation types sampled in the 45 fuel plots included manzanita, brush, and suppressed small-diameter conifers (Figure 3-6). Trees > 10 cm were sampled separately using nested biomass plots co-located with the fuel plots. Data from both types of plots were extrapolated to estimate biomass in tons per hectare for the various forest types, fuel classes, and canopy cover classes.

Dividing the measurements from all 45 fuel plots, regardless of forest type, into three equal groups yielded three fuel "classes" as shown in Table 3-1.

Table 3-1. Mean biomass of potential fuel by moderate, high, and very high classes based on field measurements in Shasta County

Fuel class	Mean biomass (t/ha)	95% CI	95% CI as % of mean
Moderate	38.9	5.5	14%
High	68.1	7.5	11%
Very high	192.8	57.4	30%

Biomass in understory vegetation, trees < 10 cm and litter/duff varied by forest type, from 78 tons/hectare for Hardwood up to 100 tons/hectare for Fir-Spruce and 109 tons/hectare for Other Conifer. The overall mean biomass in understory vegetation, trees < 10 cm and litter/duff throughout the county—regardless of forest type, fuel class or fuel type—was approximately 100 t/ha (n = 45, 95% confidence interval = 27% of the mean). Of this total, 43.2 tons of biomass per hectare was in understory vegetation, 13.4 tons/ha in trees < 10 cm, and 43.3 tons/ha in litter and duff.

Figure 3-6. Understory fuel types sampled in Shasta County: clockwise, small-diameter conifer "ladder fuels," manzanita beneath ponderosa pines, and an overstocked stand with both manzanita and suppressed conifers

A typical fuels-reduction prescription such as CSCH was assumed to remove some or all of the understory vegetation and trees < 10 cm, but not litter/duff for technical and economic reasons. The mean biomass in these two pools, potentially removable through CSCH, is thus about 57 tons/ha. Many fuels reduction prescriptions would also remove some trees > 10 cm (about 4") diameter, up to at least 7"–8" diameter and often including some sawtimber (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003; 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). However, due to the variation in commercial material removal, this preliminary analysis examined only the sub-merchantable category and estimated two scenarios: (1) removal via CSCH of all the potentially removable biomass or 57 tons/ha (28 t C/ha), and (2) removal of 50% of this biomass, or 28 tons/ha (14 t C/ha).

In the first scenario, approximately 4.9 million tons of biomass would be available to biomass energy facilities in Shasta County from CSCH treatments on the approximately 87 thousand hectares of high and very high fire risk forest lands meeting all constraints for CSCH. Removing 4.96 million tons of biomass implies an initial reduction in forest carbon stocks of 2.5 million t C. However, balancing this initial reduction would be avoided losses to wildfire of the carbon

stocks in the pools left on site (large trees, litter/duff, etc.); increased growth rates (carbon sequestration) in the post-treatment stand; and avoided losses of carbon stocks in other stands, upwind and upslope, that would have burned in a larger fire in the absence of treatment.

In the second scenario, if only 50% of the understory vegetation and small trees are removed, biomass of approximately 2.5 million tons would be available to biomass energy facilities, with an associated initial reduction of 1.2 million t C.

It should be emphasized that both area estimates and biomass fuel removal estimates are conservative. The area of Shasta County forest lands at high and very high fire risk—over 90% of the total forested area—is much greater than the area estimated here to be treatable using CSCH (15%). If any of the constraints were loosened (e.g., allowing a slightly longer yarding distance or smaller minimum treatment block size), more hectares of high-risk forest would be available, yielding more total biomass for power plants. Likewise, the assumed fuel reduction prescriptions have focused only on understory vegetation and trees < 10 cm (4″). If some larger and/or merchantable material were included in the prescription—as is often the case—then biomass yield would be higher; longer haul distances would become economic, opening up additional lands for treatment; and more expensive technologies (e.g., for treating steeper slopes) might also become available.

3.4.5 Costs, Revenues and Potential Role of Carbon Credits

Costs for CSCH range widely, depending on the treatment prescription, region of the country, slope, yarding distance, haul distance, size of the treatment block, and other site-specific factors. A preliminary estimate of a cost range of $34–$48/BDT[5] was used, based on a broad-scale assessment of fuels reduction across 15 Western states (USDA Forest Service Research & Development/Western Forestry Leadership Coalition 2003). The value of biomass fuel was conservatively assumed to be $36/BDT (Fried et al. 2003), though market prices for fuel vary depending on the number of biomass plants in operation and competition for fuel, and may be somewhat higher in Shasta County due to the existence of several plants.

At these cost and price levels, treating all 87 thousand hectares of high and very high fire risk forest lands in the county and removing 57 t/ha would have a total cost of approximately $166 million (low) to $236 million (high). The treatment would thus range from generating a net revenue of approximately $11 million (if value = $36/t and cost = $34/t), to requiring a total subsidy of approximately $59 million (if value = $36/t and cost = $48/t). In the second scenario, assuming removal of only 28 t/ha, the total cost would range from approximately $83 million (low) to $118 million (high). The treatment would thus range from generating a net revenue of approximately $5 million (if value = $36/t and cost = $34/t), to requiring a total subsidy of approximately $29 million (if value = $36/t and cost = $48/t).

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[5] Biomass fuel is typical referred to as *bone dry*, whereas the values based on the field work are for *oven dry*; for the calculations in this section, it is assumed that the two different moisture contents are equivalent.

These economic estimates are based on current conditions—no effects of green power incentives, natural gas price increases or other factors increasing demand and price for electricity generated from biomass, and no revenues from carbon credits. Under these conditions, many areas of the county where total treatment cost exceeds the $36/t assumed value of biomass fuel would require a subsidy to treat. Thus many areas will remain untreated, while others will be treated with the "subsidy" being met by some merchantable material removal. With biomass energy price increases, green power incentives, or increases in utilities' Renewable Portfolio Standard obligations, the price biomass plants are able to pay for fuel may rise above $36/t. Finally, the sale of emissions reductions credits for improved fuels management on current and future markets may provide new sources of revenue.

Detailed examination of the net carbon benefits of improved fuels management, and the potential additional revenues that carbon credits could provide if these benefits became transactable, is a key activity of WESTCARB – Phase II. WESTCARB partners will work to develop a methodology for quantifying baseline emissions from wildfire and estimate net carbon benefits of improved fuels management, taking into account the preservation of forest carbon stocks, reduced emissions of CO_2 and non-CO_2 greenhouse gases, enhanced growth in the residual stand, displaced fossil-fuel emissions, and direct emissions from treatments themselves.

Here, first-order calculations are presented, to be refined through of WESTCARB – Phase II, of whether fuel management that results in reduced emissions might make economic sense in relation to the costs, revenues and subsidies of the foregoing section. Assuming commonly used prices of CO_2 credits, would emissions reductions from fuels treatments be sufficient that the sale of carbon credits from these projects could cover the subsidies required?

Assuming the higher costs for biomass removal of $48/t and biomass fuel value of $36/t, to treat the 87 thousand CSCH-treatable hectares in Shasta County would require a per-hectare subsidy of $679 ($59 million total subsidy divided by 86.7 thousand ha) for removal of 57 tons biomass/ha, or $340 ($29 million total subsidy divided by 86.7 thousand ha) for removal of 28 t/ha.

Depending upon the price of carbon assumed (two commonly used values are $2.40/t CO_2 and $10/t CO_2), the quantity of emissions that would need to be reduced through hazardous fuel treatment in order to cover these per-hectare subsidies – essentially, to make CSCH a break-even activity – varies from as little as about 9 t C/ha to as much as 77 t C/ha (Table 3-2).

Table 3-2. Quantity of CO_2 emissions reductions (t CO_2/ha and t C/ha) that would need to be produced by hazardous fuel treatments to cover estimated per-hectare subsidies needed for CSCH

Subsidy required	$2.40/t CO_2		$10/t CO_2	
	t CO_2/ha	t C/ha	t CO_2/ha	t C/ha
$679/ha	283	77.2	67.9	18.5
$340/ha	142	38.6	34	9.3

Whether fuel reduction could produce this order of magnitude of avoided emissions depends on baseline emissions from fires of varying intensities, and whether fuel reduction reduces the intensity of fires. In the baseline report for Shasta 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. If fuel reduction could be shown to prevent these fires, there would be a reduction in carbon emissions versus the business-as-usual scenario of 38–79 t C/ha. The reduction in emissions needed to cover the per-hectare subsidies, 9–77 t C/ha, is generally within this range or lower.

Even just preventing emissions to the atmosphere from burning of the litter and duff layer—21.7 t C/ha on average across forest types in Shasta County according to field measurements—would be sufficient to cover the per-hectare subsidies required for CSCH at a price of \$10/t CO_2 (Table 3-2). Litter and duff are not assumed to be removed in a fuels reduction prescription, so this would be a reduction in emissions creditable to fuels treatment without any initial reduction in carbon stocks in these pools.

Thus it appears, in a preliminary analysis, that the order of magnitude in emissions reductions attributable to fuel reduction, assuming commonly used prices for carbon credits, is within the realm of practicality to cover subsidies needed for fuel reduction – adding support to the argument for qualifying these activities as carbon offset projects.

3.5 Pilot Activities in Shasta County under WESTCARB Phase II

3.5.1 Activities

The opportunity to reduce GHG emissions and sequester carbon through improved fuels management will be tested through pilot activities in Shasta County in WESTCARB - Phase II. The key objective will be to develop and test fuel management activities across ownership types and forest types so that available models and results can be evaluated for each management class and be used to build consensus behind methods for setting baselines and carrying out measurement and monitoring activities to verify results.

Carbon benefits in the fuels management pilot activity will result from:

1. Decreasing the intensity and extent of forest fires, and consequently reducing emissions and preserving higher long-term average forest carbon stocks versus the business-as-usual scenario;
2. Reducing emissions of non-CO_2 greenhouse gases N_2O and CH_4;
3. Enhancing growth rates (carbon sequestration) in a healthier and more productive post-treatment stand;
4. Burning extracted fuels to generate electricity in biomass power plants, and so
    a) Displacing emissions from an equal quantity of electricity (megawatt hours) generated from fossil fuels;
    b) Reducing other emissions (particulates, etc.), that would be released in a wildfire, due to complete combustion and pollution control equipment on the biomass plant.

The project will quantify net benefits compared to the business-as-usual scenario, and will take steps toward being able actually to report and transact carbon credits from such projects by developing baseline, measurement, and monitoring protocols and working with the California Climate Action Registry and the Climate Trust to establish the eligibility of fuels reduction/biomass energy projects for reporting and marketing.

The specific activities to be undertaken include:

- Conducting and quantifying fuel treatments on public and private lands, potentially including USDA Forest Service – Shasta Trinity National Forest, USDI Bureau of Land Management, National Park Service – Whiskeytown NRA and Lassen Volcanic National Park, Pacific Gas & Electric company lands, LaTour State Demonstration Forest or other lands managed by the California Department of Forestry and Fire Protection, timberlands managed by WM Beaty & Associates, and other industrial or non-industrial private forest lands.
- Designing a methodology to determine carbon benefits from improved fuels management, and developing measuring and monitoring protocols and carry out pre- and post-treatment field measurements of fuel loads and carbon stocks.
- Transporting removed fuels to biomass energy facilities, including the Wheelabrator Shasta biomass plant, and analyzing emissions reduction benefits of fossil fuel displacement.
- Collecting data on treatment and transport costs to evaluate the viability of fuel management activities, with and without revenues from carbon offset market credits.
- Working with the California Climate Action Registry, Climate Trust, Chicago Climate Exchange, and other reporting and market mechanisms to develop methodologies and protocols for reporting, crediting, and transacting carbon benefits from improved fuels management and biomass energy.

3.5.2 Research Benefits

Improved fuels management pilot activities in Shasta County will have the following research benefits in terms of answering key questions about net benefits, and potential for replication elsewhere in the WESTCARB region, of this class of activities:

- Develop fire management treatment practices that optimize carbon sequestration while reducing fire risk.
- Provide information on the level of fuels reduction (removal volumes) that is sufficient to reduce fire intensity.
- Estimate N_2O and methane impacts of different fire management activities.
- Use stratified sampling of chronosequence sites to validate impacts of past fires for various forest types.
- Evaluate predicted changes in carbon stocks for various forest types using fire models currently used by different land managers in the region.

- Evaluate ecological impacts of fire management activities in collaboration with other research funded by the California Energy Commission.
- Develop peer-reviewed methodology for determining appropriate baselines for carbon losses due to fire.
- Determine costs for collecting and transporting fuel from forests to biomass plants as functions of site conditions and location.
- Evaluate and where possible quantify co-benefits of fuels management treatments in terms of forest health and productivity, watershed management, wildlife habitat, job creation, and other factors.
- Estimate, at various prices for fuel and for carbon credits, how much additional income could be generated for landowners and how many acres would be offered for fuels reduction.

3.5.4 Implementing Partners

Landowners, land managers, and other implementing/technical advising partners for improved fuels management pilot activities in Shasta County under WESTCARB - Phase II include WM Beaty & Associates, Inc., the Western Shasta Resource Conservation District, Wheelabrator Shasta Energy Company, the California Department of Forestry and Fire Protection, Pacific Gas & Electric Company, Sierra Pacific Industries, USDA Forest Service – Pacific Southwest Research Station, USDA Forest Service – Shasta Trinity National Forest, the National Park Service – Whiskeytown NRA, National Park Service – Lassen Volcanic National Park, and USDI – Bureau of Land Management.

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Appendix A

Technical Summary

Appendix A
Technical Summary

Winrock International has conducted a series of analyses to identify and quantify terrestrial carbon sequestration opportunities that could be achieved by changing land use and land management practices in the State of California. This report examines in greater detail two opportunities that might be implemented in Shasta County in northern California: afforestation of rangelands to sequester carbon, and improved fuels management to reduce greenhouse gas emissions from wildfire. Shasta County was selected for detailed analysis because of the diversity of land use types and carbon sequestration opportunities in the county, and the potential for replicating the opportunities tested and validated here elsewhere in the state.

This report summarizes, for each opportunity, suitable lands within the county, net carbon sequestration potential, and representative costs. The intended audience is landowners, land managers, and other Shasta County stakeholders, as well as other California stakeholders interested in the validation and replication of these carbon sequestration opportunities.

Afforestation of Rangelands

Shasta County has substantial areas of rangelands that were once forested and meet a set of forest suitability criteria suggesting potential for afforestation. Planting forests on rangelands would provide a net carbon benefit equivalent to the average carbon stocks of mature forests of a given age and species mix, less the baseline carbon stocks of rangelands, multiplied by the total area afforested. Selling carbon credits from these projects would provide a new source of revenue for landowners that may exceed the net present value of opportunity costs, conversion costs, maintenance costs, and measurement/monitoring/registration costs.

The total area of Shasta County is approximately 996 thousand hectares (ha) (2.46 million acres), of which 302 thousand ha (746 thousand acres, or 30%) are in various rangeland types. Classifying the "forest suitability" of current rangelands based on factors of elevation, slope, mean annual temperature, mean annual precipitation, and available water capacity of the soil shows that a high proportion of current rangelands overlap into relatively high forest suitability scores. This is particularly true of the montane chaparral, mixed chaparral, blue oak foothill pine, and blue oak woodlands rangeland types.

Rangeland areas suitable for afforestation include non-woody rangelands and woody rangelands with canopy cover less than 40%, together accounting for about 243 thousand ha (600 thousand acres). A small portion of these lands (11,700 ha or 29 thousand acres) are classified as rangeland but apparently unsuitable for grazing, representing chaparral in a state of arrested succession to forest due to past fires.

Net carbon sequestration potential ranges from about 12 tons of carbon per hectare (t C/ha) (5 t C/acre) after 20 years for rangeland hardwood forests, to about 411 t C/ha (166 t C/acre) after 80 years for mixed conifers.

An afforestation cost analysis was performed including opportunity costs based on forage production and ranching profitability, conversion costs such as site preparation and planting,

measuring and monitoring (M&M) costs, and maintenance costs. Rangelands suitable for afforestation were divided into two main classes: (1) suitable for grazing, and (2) unsuitable for grazing, with each subdivided into slope classes greater than and less than 30%. Grazed lands have a higher opportunity cost, whereas lands classified as rangeland but unsuitable for grazing have no opportunity cost in this analysis but have a higher conversion cost. Conversion costs for shrub rangelands not suited for grazing were estimated at $900–$1,100/acre ($2,223–$2,717/ha), due primarily to site preparation costs of removing dense brush prior to planting, compared to $450–$600/acre ($1,112–$1,482/ha) for grassland and woody rangelands.

The net present value of the total costs of afforestation on rangelands suited for grazing, including opportunity, conversion, maintenance, and monitoring, after 20 years was about $1,300–$1,900/ha ($526-$769/acre) on slopes less than 30%, and $1,700–$2,300/ha ($688-$931/acre) on slopes greater than 30%. On rangelands not suited for grazing, with no opportunity cost assigned, the net present value of total costs after 20 years was about $2,400/ha ($972/acre) for lands less than 30% slope and $2,900/ha ($1,174/acre) for lands greater than 30% slope. These lands, despite being more attractive from a net carbon sequestration perspective, are available at a cost considerably higher than the rangelands suited for grazing, suggesting that high conversion costs more than offset zero opportunity costs.

The most suitable lands for an afforestation pilot project are those that are presently dominated by shrub rangeland types, such as a variety of the chaparral classes. For a project duration of 40 years, more than 23 million t C (87 million t CO_2) would be available at a cost of less than $20/t C ($5.50/t CO_2) on about 140 thousand ha (346 thousand acres).

Table A-1 summarizes the total magnitude of potential carbon sequestration through afforestation, for different price points and project durations. This is shown graphically in Figure A-1, which illustrates the variation in cost of carbon sequestration through afforestation across the county.

Table A-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-, 40-, 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

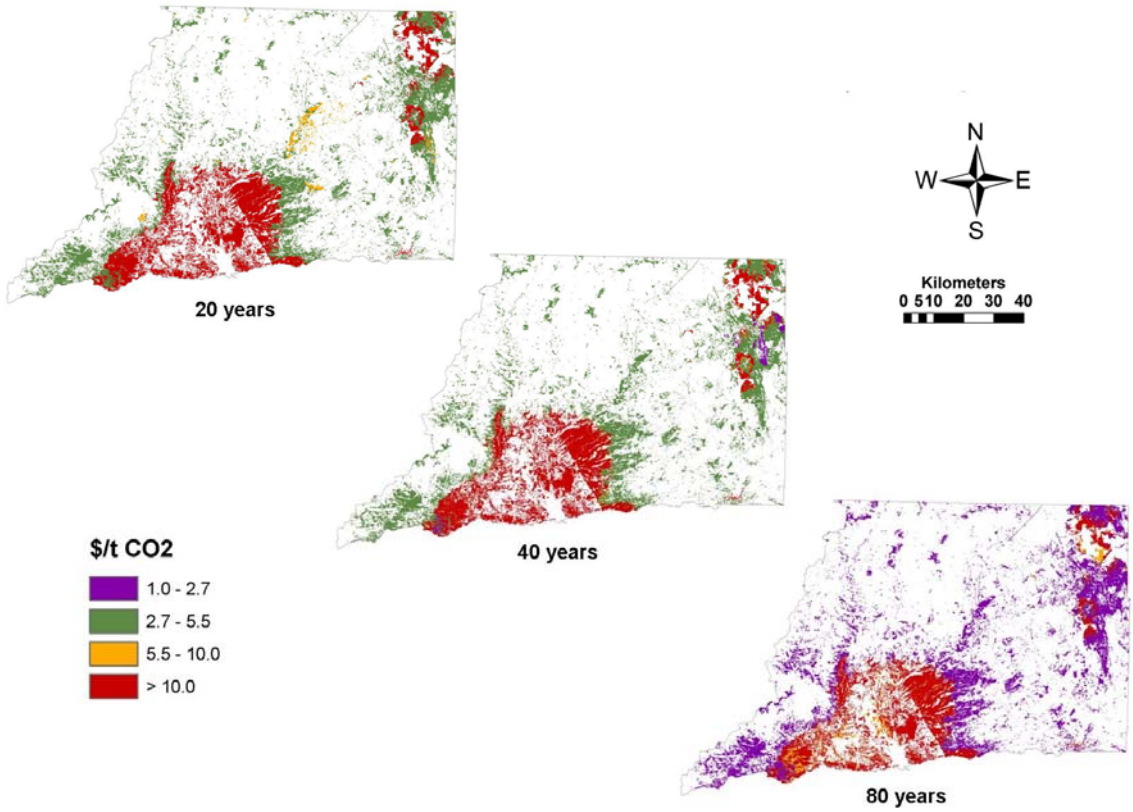

Figure A-1. Distribution of cost of carbon sequestration through afforestation of rangelands in Shasta County

Improved Management of Forest Fuels

A potentially attractive carbon sequestration option for Shasta County and the State of California is improved management of forest fuel loads to reduce the risk, intensity, and extent of catastrophic wildfires. Net carbon benefits versus the business-as-usual scenario would result from: reduced losses of forest carbon stocks (both in the stand actually treated and by slowing the expansion of wildfires into stands upwind and upslope); avoided emissions of CO_2, nitrous oxide (N_2O), and methane (CH_4) from wildfires; increased carbon sequestration through enhanced growth rates in the post-treatment stand; and displacement of emissions from fossil-fuel generated electricity, when biomass fuel removed to reduce wildfire risk is transported and burned in a biomass power plant. Developing the necessary methodologies and measuring, monitoring and verification (MMV) protocols to support sale of carbon credits from improved fuels management would provide a new stream of revenues to improve the economics of hazardous fuel reduction, in which treatment costs often exceed product revenues.

Of Shasta County's total 630 thousand hectares (1.56 million acres) of forest lands, approximately 572 thousand hectares (1.41 million acres, or over 90%) are at high or very high fire risk. The Shasta County lands that are in the most urgent need of treatment and most feasible to treat can be identified by evaluating their Suitability for Potential Fuel Reduction (SPFR)—based on criteria of proximity to roads, slope, and proximity to biomass power plants—and by comparing the resulting SPFR maps to maps of Shasta County high and very high fire risk forest lands. These lands are dominated by the Other Conifer forest type, due to a

large total area, high fire risk, and much of this type being on gentle slopes, accessible to roads and relatively close to existing biomass plants. Hardwood, Douglas Fir, and Fir-Spruce forest types have lower SPFR scores due to lower fire risk, higher slopes, and more remote locations in relation to roads and biomass power plants.

A GIS-based analysis estimated the area available for fuel reduction using a typical prescription—"Cut-Skid-Chip-Haul" (CSCH)—in which fuel is harvested in the forest, bunched and skidded to a roadside landing, chipped into a chip van, and hauled to a biomass plant. In this analysis, to be available for CSCH, lands had to have a maximum slope of 40%, maximum yarding distance to the nearest road of 0.25 miles (400 meters), maximum haul distance to the nearest biomass plant of 50 miles (80 kilometers), and minimum block size to justify move-in costs of 80 acres (32 hectares). The area of Shasta County high to very high fire risk forest lands meeting all four constraints is approximately 87 thousand hectares (215 thousand acres), or 15% of the total area of high to very high fire risk forest (Figure A-2). The estimated total biomass on these forest lands is approximately 23.4 million tons (11.7 million tons carbon).

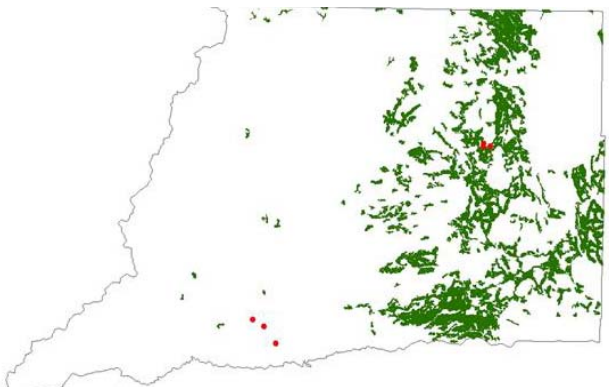

Figure A-2. Shasta County forest lands at high to very high fire risk and meeting all four hypothesized constraints for CSCH treatment (maximum 40% slope, maximum 0.25 miles yarding distance, maximum 50 miles haul distance to nearest biomass facility, and minimum block size of 80 acres)

Based on field measurements in Shasta County, mean biomass in understory vegetation, trees < 10 centimeters (cm) (< 4 inches), and litter/duff vary from 78 tons/hectare for Hardwood up to 100 tons/hectare for Fir-Spruce and 109 tons/hectare for Other Conifer, with a overall average of 100 tons/ha (50 t C/ha). Of this total, some 57 tons biomass per hectare are in the understory vegetation and small trees that would be the target of a CSCH operation. Two scenarios were examined: (a) removal via CSCH of all the potentially removable biomass or 57 tons/ha (28 t C/ha), and (b) removal of 50% of this biomass, or 28 tons/ha (14 t C/ha). Treating the 87 thousand hectares would yield 4.9 million tons (oven dry) of biomass for biomass energy facilities in the first scenario, and 2.5 million tons in the second. These values should be taken as conservative: the area treatable would increase if any of the constraints above were loosened, and the total biomass fuel available would increase if larger material (sub-merchantable material > 10 cm diameter, and merchantable material) were included in the prescription, as is often the case.

With an assumed fuel value of $36/ bone-dry ton (BDT) and treatment costs ranging from $34–$48/BDT, treating all 87 thousand hectares of CSCH-accessible, high and very high fire risk forest lands in the county and removing 57 t/ha would range from generating a net revenue of approximately $11 million to requiring a total subsidy of approximately $59 million. Assuming the higher costs of biomass removal, this implies a per-hectare "subsidy" required of $679 ($275/acre).

In order to address the potential role of carbon credits from improved fuels management, the key question to address is whether emissions reductions from fuels treatments would be sufficient to make the sale of carbon credits from these projects, assuming commonly used prices of CO_2 credits, cover the per-hectare subsidies required for treatment. Depending upon the price of carbon assumed (two commonly used values are $2.40/t CO_2 and $10/t CO_2), the quantity of emissions that would need to be reduced through hazardous fuel treatment in order to cover a per-hectare subsidy of $679 ranges from 18.5 t C/ha to as much as 77 t C/ha. Estimated baseline emissions from fires for all forest types in Shasta County ranged from 38 to 79 t C/ha. If fuel reduction could be shown to prevent these fires, there would be a reduction in carbon emissions versus the business-as-usual scenario of 38 to 79 t C/ha—in the same range as the 18.5 to 77 t C/ha reductions needed to cover the subsidies—even without accounting for additional carbon benefits from increased growth rates and displaced fossil fuel emissions. Even just preventing emissions to the atmosphere from burning of the litter and duff layer—21.7 t C/ha on average across forest types in Shasta County according to field measurements—would be sufficient to cover the per-hectare subsidies required for CSCH at a price of $10/t CO_2, and because litter and duff are not assumed to be removed in a fuels reduction prescription, this would be a reduction in emissions creditable to fuels treatment without any initial reduction in carbon stocks in these pools.

This conclusion, while it requires validation through more detailed analysis and methodology development under U.S. Department of Energy-funded West Coast Regional Carbon Sequestration Partnership (WESTCARB) – Phase II, suggests an innovative new element in the economic calculus of fuels management: fuel treatments whose cost often exceeds product value could, at least on some lands, become cost-effective if landowners could secure market recognition for the net carbon benefits of the treatments. Carbon credits would not pay the full cost of treatment, but might "fill the gap" for many lands that would otherwise go untreated.

Activities in Shasta County under WESTCARB – Phase II

The carbon sequestration opportunities outlined in this report will be tested and validated through pilot projects in Shasta County under the U.S. Department of Energy-funded West Coast Regional Carbon Sequestration Partnership (WESTCARB) – Phase II, led by the California Energy Commission. For each opportunity, planned activities, research benefits, and implementing partners are summarized at the end of the section.

Landowners, land managers, and implementing/technical advising partners for WESTCARB – Phase II include WM Beaty & Associates, Western Shasta Resource Conservation District, individual private ranchers, Wheelabrator Shasta Energy Company, California Department of Forestry and Fire Protection, Pacific Gas & Electric Company, Sierra Pacific Industries, USDA Forest Service – Pacific Southwest Research Station, USDA Forest Service – Shasta Trinity

National Forest, National Park Service – Whiskeytown National Recreation Area (NRA), National Park Service – Lassen Volcanic National Park, and U.S. Department of the Interior (USDI) – Bureau of Land Management.