

**Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT**



**POTENTIAL POSITIVE AND
NEGATIVE ENVIRONMENTAL
IMPACTS OF INCREASED WOODY
BIOMASS USE FOR CALIFORNIA**

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PREFACE

The California Energy Commission 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 conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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Potential Positive and Negative Environmental Impacts of Increased Woody Biomass Use for California is the final report for the Impacts of Increased Utilization of Woody Biomass for Energy Production project 500-99-013, Work Authorization Number BOA-99-247-R conducted by the University of California. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

The implementation of California's Renewable Portfolio Standard may increase the use of woody biomass for renewable energy generation. This will likely have both positive and negative environmental impacts. This report reviews the published literature relevant to the potential environmental impacts of increased woody biomass use for energy generation in California and identifies information gaps that exist in understanding those impacts.

The major environmental benefit will be the use of woody biomass residues for energy from biomass that would have otherwise decomposed or burned. Other potential environmental benefits include a reduced loss of forest carbon storage to wildfires, insect disease infestations, and severe weather events. The major environmental concerns associated with additional biomass harvesting addressed in the literature and in recent guidelines are 1) protecting long term soil productivity, 2) minimizing harvest related erosion and water quality impairment, and 3) maintaining important wildlife habitat and biodiversity elements across the larger landscape.

Much of the published literature and guidelines regarding limiting the negative environmental impacts of woody biomass for energy harvests are based on experiences in the Eastern United States and Europe. While long-term experiments in California's mixed conifer forests show no loss of long-term (~20 year) productivity from biomass harvesting, there are few results for other forest types, woodlands, or shrublands. Alternative residue management, site preparation, and transportation design and maintenance techniques could mitigate or negate forest floor and forest soil carbon losses associated with harvesting. The potential loss of certain classes of live trees, snags, and downed wood from wildfires, other disturbances, or biomass harvests could have negative effects on wildlife habitats and biodiversity. Fires are also a major source of potentially avoidable carbon dioxide and methane emissions but field based results are limited. Current predictive tools have limited capability in measuring the impacts of operations other than commercial harvests. Key information gaps could be reduced by implementing and evaluating long-term experimental wildlife habitat and forest productivity projects across a greater range of forest types - especially where treatments and wildfires interact.

Keywords: Biomass harvesting, wildlife habitat modeling, fire risk, environmental impacts

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EXECUTIVE SUMMARY

Project Goal

This report includes a review of existing literature on potential impacts to ecosystem health, biological diversity, watersheds, and climate impacts from a potential increase in forest biomass (tree and shrub residue that can be used for renewable energy) useage for energy generation in California. After low value sawmill residues, the next largest source of forest based woody biomass that could be used for renewable energy is project-based residues from timber harvests, thinnings, and fuels reduction projects. The major impact at the site level is that a substantial fraction of the harvested biomass that would have burned or decomposed in place is collected and used to generate heat and electricity. The report's focus on identifying information gaps, as well as summarizing existing information, is especially relevant considering the expected stresses on California's forests, woodlands, and shrublands related to predicted climate change scenarios. When sustainably produced biomass-based energy replaces fossil fuel based energy, there is a net reduction in the net flux of greenhouse gases into the atmosphere. Another significant potential environmental benefit in California's Mediterranean climate, where fire risks are high, is the reduction in carbon emissions and associated air pollutants related to wildfires that would have burned more forest biomass if it had not been harvested in a manner that reduced probable fire spread.

As with any vegetation altering activity, there could be negative environmental impacts associated with increased levels of woody biomass harvesting. Two recent literature reviews (Evans and Perchel, 2009, European Environment Agency, 2006) highlighted five areas of concern and strategies to prevent environmental damage.

1. Maintenance of soil and site productivity
2. Protection of water quality and riparian zones
3. Maintenance of long-term productivity through appropriate silviculture (manging forests)
4. Maintenance of dead wood and snags (standing dead trees)
5. Maintenance of wildlife habitats and biodiversity

To put the international literature review and knowledge gap analyses in perspective for California policy choices, the report starts with two overview chapters. The first chapter summarizes a survey of interested stakeholders regarding their opinions on the importance of the issues. The second is an overview of the scale and location of different additional sources of woody biomass that could be used to meet California's growing demand for renewable energy.

Producer and Consumer Stakeholder Survey

In a survey of forest landowners, regulators and environmental groups in California, all groups expressed strong interest across a wide range of issues that could be affected by new policies to support or inhibit additional production of renewable energy from biomass. They considered site, atmospheric, economic, and social sustainability outcomes to be important with regard to

the potential increased use of woody biomass for renewable energy. Compared to other groups, forest landowners were more interested in economic and social sustainability, regulators were more interested in atmospheric sustainability, and environmental groups were more interested in site level sustainability.

Overview of Potential Forest, Woodland, and Shrubland Resources and Energy Facilities

California was one of the first states to promote the use of woody biomass to supplement fossil fuel based electricity for the statewide electricity grid. A significant number of California's biomass power plants are located in forested regions and depend on sawmill and forest residues for the bulk of their fuel supply. Additional biomass is projected to come from the more efficient collection of harvest residues and from thinnings conducted as an integral part of sawtimber and pulp chip oriented forest management. Since California has become increasingly dependent on wood products from out of state, it is probable that future increases in woody biomass based energy will come from these same states and Canadian provinces. In California, an additional significant source of woody biomass could come from fire risk reduction activities. Long-term data suggests that wildfires are leading to significant losses of both forest cover and forest carbon storage in California. Some of the harvested biomass from fire risk reduction projects may be high enough quality to use for sawlogs, but much of it will be suitable only for use as an energy feedstock. Additional woody biomass may come from ecological restoration projects, orchard clearings before replanting, wildland-urban interface fuels reduction projects, and urban forests. In the near term, the prospects for woody biomass energy plantations appears limited due in large part to lack of easily accessible land with sufficient irrigation water to achieve high yields. If plantation-based biomass energy sources are developed, the environmental impacts will be similar to agricultural projects rather than managed forests.

The assessment of forest lands suggests that an increase in woody biomass harvests will come 1) as a complement to the existing flow of lumber used in California that is currently sourced in roughly equal proportions from California itself, Oregon and other western states, and western Canada, or 2) as a by-product from fuels reduction projects in accessible fire prone areas in California. Forestland cover and forest inventory data suggest that forest fires are significantly reducing the carbon content of California's forests. Although there is increasing evidence that well designed and implemented fuels reduction projects can reduce future fire risk and that the sale of the harvested products can reduce project costs, there are also numerous cases in which thinning projects that produced biomass were not that effective in reducing the fire, insect, or disease risks. In addition, the goals and constraints of forestland owners or managers may limit the potential areas in which projects could be implemented. In particular, many family forest landowners implement few land management measures of any kind, and investor or corporate ownerships often avoid projects that do not have a shortterm positive cash flow. The limited number of energy plants that use woody biomass are located more than 30 miles from many forest parcels, a distance for which transportation costs alone can be greater than the market price for delivered biomass. An expansion in the number and distribution of energy plants would be needed to increase biomass energy generation significantly.

Nutrient Cycling

Research on the effects of retaining woody residue after timber harvest has been conducted on a wide variety of temperate forest types. With good seed stock, the post-harvest forest growth rates for above ground biomass will be equal to or greater than the current conditions in most managed temperate forests. A meta-analysis (combines the results of many studies that address the research topic) of 432 papers that measured forest floor and forest soil carbon levels in harvested temperate forests concluded that historical harvest practices led to an 8 percent (+/- 3 percent) decline overall in forest floor and forest soil carbon. Alternative residue management and site preparation techniques, and the passage of time, can mitigate or negate these losses (Nave et al., 2010). Compared to other forests across the United States, California's forest soils generally have higher nutrient levels and lower evidence of "nutrient mining" from the more intensive harvesting and removal of forest biomass. Forest soil nutrient status has been widely sampled for all forest types with site to site variation within forest-type, often overwhelming variation among forest-types. Short rotation, intensively managed biomass plantations will present a very different situation than natural forests and will require more monitoring of soil nutrient status to maintain productivity. For all forest types in California, the relationship of soil nutrient losses to wildfires and potential harvest treatments to reduce wildfire impacts remains an area where only limited research results exist.

Impacts on Water Quality and Soil Productivity

The potential impacts of additional biomass harvesting on soil productivity, soil erosion, and stream water quality can be assumed to be similar to the impacts of more intensive forest harvesting regimes used for short (15 to 30 year) rotations for pulp production or to the use of precommercial and commercial thinnings in sawtimber production. Decades of research across North America have led to the development and use of many best management practices (BMPs) to protect soil productivity and water quality. The continued use of appropriate BMPs would appear warranted for biomass harvesting operations. Alternatives to biomass harvesting and removal such as mastication (grinding trees to a pulp) or prescribed burning will also have impacts related to equipment use and fire intensity.

Applying Soil-Related Findings to California Conditions

California is fortunate that many long-term replicated field experiments already are in place that can provide answers to many questions concerning biomass removal. This network of manipulative silvicultural experiments overseen by the Forest Service Pacific Southwest Research Station is perhaps the most extensive in the West. Work has been underway for about two decades to assess the long-term effects of biomass removal on soil chemical and physical properties and fundamental forest productivity. Ten-year findings from four mixed-conifer sites in the Sierra Nevada show little change in potential soil nitrogen availability following whole-tree removal, but significant declines in nitrogen availability following the removal of the forest floor. Removing the forest floor of soil and embedded biomass is not a standard biomass harvest practice but was done to identify where the critical nutrients are in the forest system and how they could be affected by different harvesting treatments. In general, no productivity differences were found between bole-only (harvesting tree trunks only) and whole-tree

harvesting through the first decade of the long-term soil productivity study in California. Less is known about how different treatments interact with wildfire intensity as few research sites have been burned by accident or design. In addition, the research network is relatively sparse in the less productive forest sites across the state.

Biodiversity and Wildlife Habitat Consequences

The measured and modeled effects of additional woody biomass harvests on biodiversity are highly variable with the reported results being strongly influenced by the wildlife species of interest and the spatial and temporal scale being evaluated. Compared to “no biomass harvest” alternatives, biomass harvests are similar to 1) the thinning and removal of less commercially valuable trees or 2) the removal of harvest residues that historically were burned or left in the forest to decay. A recent meta analysis of 33 studies of thinning impacts on biodiversity across North America found “generally positive or neutral effects on diversity and abundance across all taxa” (Verschuyl et al., 2011). The maintenance of dead and down wood is widely considered to be the area with the greatest potential negative impact of biomass harvesting. The effectiveness of indicators or principles should be independently assessed after a number of years. The maintenance and recruitment of structural elements such as large green trees and snags, logs, and coarse woody debris, which would otherwise not be replaced under an intensive biomass harvesting scenario, are issues of critical concern for biodiversity and food webs related to these elements. However, few studies have attempted the difficult task of measuring the amount of dead and downed wood/biological legacies necessary to maintain wildlife populations. More work is needed to identify critical threshold levels and response relationships. Maintaining biodiversity will require a broad approach that seeks to provide structural diversity within stands (basic forest unit) and heterogeneity across landscapes. The effectiveness of transferring specific guidelines from other forested regions to California will be limited due to the very different processes that initially create snags and downed wood and then determine their longevity on the landscape. For example, the carbon storage trajectory of snags and down wood appears to be primarily controlled by fires in high fire ecosystems and by microbial decomposition in wetter ecosystems.

Wildlife habitat-relationship models are often used to estimate changes in habitat suitability resulting from alterations to habitat structure and connectivity (Airola 1988, Beck and Suring 2009). The California Wildlife Habitat Relationship (CWHHR) system is a widely used deterministic model in California that contains habitat-relationship models for 694 regularly occurring species of amphibians, reptiles, birds, and mammals. Essential habitat elements often manipulated during biomass harvesting resulting in unsuitable post-harvest habitat include subcanopy layers: trees, shrubs, and herbs; shrubs, trees with cavities and loose bark, and trees larger than 11” in diameter. The wildlife impacts of removing logs, large and small slash, and snags, elements often manipulated during biomass harvesting, are not captured by CWHHR or are at a scale where no measurable negative effects occur. However, the limitations of deterministic models such as CWHHR in predicting changes in wildlife populations known to use habitats in woody biomass that could potentially be harvested suggests that more work on probabilistic approaches based on larger data sets could provide insights that would be more useful in risk analysis and management framework decisions.

Potential of Forest Biomass Harvesting to Alter Future Forest Losses

California's forests have high risks of loss to wildfires, insects, and disease. In many cases, fuels treatment projects and other projects have been proposed and implemented to reduce future risks. These projects could produce considerable quantities of biomass, as well as higher value wood products (Barbour, 2008), and will vary in the potential risks to other values such as current and future wildlife habitats. The projects will be expensive if they produce only low value biomass and are located at long distances from energy plants. The cost of doing nothing may involve future fires that are expensive to manage and also create environmental damage. The importance of logging slash removal after harvests illustrates the effectiveness of biomass removal — when it is not done, the risk of serious fire damage is far greater. Limited numbers of thinned intersections and fuels treatments have demonstrated the effectiveness of treatments that significantly reduce surface and ladder fuels in reducing wildfire intensity and severity. Lighter or no treatments of surface and ladder fuels often had little positive value in terms of reduced fire damage. Measurements of the effectiveness of site and landscape level treatments specifically designed to reduce severe fire susceptibility are limited and need to be significantly increased if fuels treatments are to be deployed at the levels considered necessary to alter the current increasing rate of losses. The positive effect of treatments to reduce losses from insects and disease is not as clear as the case for fuels treatments.

A summary of information gaps was created via a review of California relevant literature. The literature contains few papers on projects where a range of risk reduction treatments were compared to control sites with no interventions. In many cases, only one thinning prescription was measured and compared to a no-treatment alternative. In many cases, the single treatment proved to be less effective than predicted in terms of reducing risk of loss or measured loss from threats such as wildfire, insect attacks, or disease. Without a broader range of treatments, it was not possible to draw strong conclusions on better approaches. Implementing and monitoring designed experiments of silvicultural treatments in forest types with differing levels of fire, insect, and disease risks are needed to bridge the gap between the modeled-based evidence, opportunistic analyses after specific events, and anecdotal evidence of projects that have been affected by a fire other disturbances. Without well-designed experiments undertaken across a range of conditions, the levels of uncertainty with regard to outcomes will remain high.

Best Management Practices, Regulations, and Certification Systems

There is considerable interest in the potential benefits of transferring best management practices, regulations, and third party certification from other states or nations to California to address woody biomass use for energy. There are two main international umbrella forest certification organizations: Forest Stewardship Council-International (FSC-IC) and Programme for the Endorsement of Forest Certification (PEFC). Both organizations review and endorse national certification standards that meet their sustainability standards. FSC-IC develops its sustainability standards in-house, while PEFC uses a sustainability benchmark consisting of greater than 300 globally accepted criteria developed by an international multi-stakeholder process. The major sustainable forest management certification systems in North America are the Forest Stewardship Council-US (FSC-US), Sustainable Forestry Initiative (SFI), American

Tree Farm System/American Forest Foundation (ATFS/AFF), and Canadian Standards Association-National Sustainable Forest Management System (CAN/CSA-Z809). As of 2007, only 13 percent of the forestland in the United States was certified as having a sustainable forest management system (Pampush 2008). The majority of certified forestland is in private, industrial ownership while non-industrial family forests and public lands remain largely uncertified. Since sustainable forest management (SFM) certification systems were developed to certify a wide range of forest cover types, ownerships, and harvest treatments and objectives, their standards do not contain guidelines specific to the harvest of woody biomass for energy. Instead, it is expected that this new forest management activity will be conducted in line with the existing standards. All SFM certification systems have standards pertaining to the maintenance of ecosystem functions. Often these standards explicitly require the retention of understory vegetation, den and cavity trees and snags, and dead and downed wood for wildlife habitat, biodiversity, and soil nutrient cycling goals. The retention level that is appropriate and necessary is not explicitly addressed in SFM certification standards as appropriate levels vary considerably between sites and forest types. A variety of management approaches can be used while still meeting the certification standards. The production of woody biomass is not limited to residues removed from natural forests, woodlands, and shrublands. The International Energy Agency Bioenergy Working Group provides the organization and structure for a collective effort of 23 member countries working on bioenergy research, development, and demonstration.

Biomass production from managed forests is addressed separately from dedicated biomass energy crops. The increasing interest in using marginal lands (for example: abandoned or marginal agricultural fields, former Conservation Reserve Program lands) for producing biomass from short rotation woody crop plantations means that forest tree species could be used. These biomass-for-energy plantations are initially not likely to seek sustainable forest management certification, even if forest tree species are being grown. Instead, these projects would be addressed along with other biomass energy crop certification systems developed to concentrate on sustainability concerns with plantations and purpose grown bioenergy crops. There are many international organizations and initiatives that are working to advance sustainable bioenergy as part of the solution to growing global energy demands and climate change. The Food and Agriculture Organization (FAO) of the United Nations has several programs in place that seek to strengthen international capacity to produce sustainable bioenergy while addressing climate change, and protecting food security (BEFSCI 2010, IBEP-FAO 2006, FAO-SWES 2009).

Key Information Gaps

California has a long history of using forest biomass for energy that can be compared with “no use” areas to analyze site-level impacts. California stakeholders have a wide range of sustainability concerns regarding the increased use of biomass to meet increasing renewable energy targets. These require attention to tradeoffs and complementary outcomes of different strategies. California forest management is quite different from other forests in the United States, such as the hardwood dominated Eastern forests, which have humid summers, and the Southeastern pine plantations where forest management for pulp or chip-n-saw is very similar

to what a strong biomass for energy use would look like. While California has generated electricity from woody biomass for decades, a far smaller fraction of the state's total forest harvest is used for fuelwood or pulpwood than in Eastern forests. California's comparatively high harvesting and transport costs have led to a focus on harvesting primarily sawtimber rather than lower value products. California has a historically low annual area of forest management, increasing area of forest wildfires, and increasing imports of both building products and energy from other western states and Canadian provinces. A purely precautionary approach, with regard to increased biomass harvesting in California forests, will simply shift the state's wood and energy demands around the globe where less may be known about the environmental impacts. Decades of research in the California mixed conifer forests provide a solid basis for understanding the potential impacts of increased biomass harvesting as part of sawtimber oriented forest management. The area with the highest probability that increased biomass harvests are forests where biomass harvests would complement existing forest management practices and fuels reduction efforts. This approach could be expanded to different forest types, older stands, and uneven aged management systems where there is little current knowledge about how increased woody biomass harvests would affect forest growth, wildlife habitats, and fire risks.

Predicting the effect of new "best practices," regulations, or certification system requirements on California's forests requires a better understanding of the owner/manager intentions in different forest types, whether proposed strategies such as fire risk reduction treatments will be operationally feasible, and how operational costs and product prices will affect strategies. Whereas experimental forests and large forest owners have decades of experience in using biomass from harvest residues and fuels treatment projects, there is considerably less understanding on how woody biomass harvesting would fit into management actions designed for habitat restoration, fire risk reduction, and residential area protection projects where revenue generation is not a major determinant of forest management.

Snags, downed woody debris, and shrub cover for wildlife are the lowest quality and most expensive source of forest biomass. They also have high biodiversity and wildlife habitat values when retained within forest areas. However, simply transferring retention guidelines from forests in the eastern United States, where summers are more moist and fire prevalence is much lower, has limited promise for a number of reasons. California's deterministic wildlife habitat suitability model, California Wildlife Habitat Relationships, does not suitably assess potential harvest project impacts of non-live tree biomass. Empirical decision support tools such as the DecAID developed in the Pacific Northwest, coordinated management experiments, and other tools are most likely needed.¹ There are numerous information gaps on the potential impacts of

¹ DecAID is an advisory tool to help managers evaluate effects, of forest conditions and existing or proposed management activities on organisms that use snags and down wood. DecAID was developed under the United States Department of Agriculture Forest Service, Pacific Northwest Region, and Pacific Northwest Research Station, Portland, Oregon, with contributions of expertise from United States Department of the Interior Fish and Wildlife Service, and other agencies and institutions.

added biomass harvesting projects in forests that have different risk levels of loss to natural disturbances.

The interaction of forest growth, mortality, and fire risk is an important but poorly understood backdrop to new approaches to using more forest biomass for energy in California. How forest biomass harvesting should be integrated into fire risk reduction efforts is not well understood. Implementing a network of experimental sites across different forest types would provide the information that is necessary to guide significant expansion of biomass harvesting that is justified by fire risk reduction outcomes.

Note: All tables, figures, and photos in this report were produced by the authors, unless otherwise noted.

CHAPTER 1: Biomass Harvesting to meet California's growing demand for Renewable Portfolio Standard (RPS) energy

1.1 Background

The goal of this report is to review the literature and identify critical information gaps regarding the potential environmental impacts of increased utilization of woody biomass for energy generation for California. Assessing both the negative and positive environmental impacts of the increased utilization of woody biomass (initially forest residues with a long term potential for energy crops) has been a concern for decades (U. S. Congress Office Technology Assessment, 1993) and continues to be an area of policy discussions from North American researchers (Richter Jr. et al., 2009; Titus et al., 2009). Much of the empirical evidence from a rapid increase in woody biomass utilization comes from Europe. Sweden and Finland built upon their large existing forest industries (Börjesson et al., 1997; Finnish Forest Research Institute, 2009) and the increased role of woody biomass for renewable energy is now in continent-wide plans (Commission of the European Communities, 2007; European Parliament and the Council of the European Union, 2009; Nabuurs et al., 2008). Policies and regulations to address the potential environmental impacts of increased utilization have been the focus of extensive efforts (European Environment Agency (EEA), 2006; Framstad, 2009).

Although California already produces considerable amounts of electricity and industrial heat from the controlled combustion of woody biomass (California Energy Commission, 2009), a significant expansion of utilization in line with estimates of potentially usable supplies (California Biomass Collaborative, 2006) could have numerous positive and negative environmental impacts. Extrapolating site-specific results of biomass harvesting practices and regulations from other regions to California needs to take into account two additional factors. The first factor is the background impact of the wildfire regime on most California forests and other vegetation types. Compared to regions with moister summers, much of the biomass that could potentially be collected for use as energy feedstock will often be consumed in wildfires. Wildfire intensities and impacts vary considerably and are an integral component of an assessment of biomass harvesting, forest management, and environmental impacts. Not removing biomass for energy production does not guarantee that it will remain on the site in areas with recurring fires. The second factor is California's significant importation of both forest-based timber and energy products as well as substitute products such as cement and steel for construction and non-biomass based energy. The environmental impacts of California's consumption that occur in other Western states and Canadian provinces also need to be taken into account.

1.2 Project objectives

The project consisted of three main tasks. The first product was the development and analysis of a survey distributed to a sample of involved stakeholders to assess the relative importance they attached to a range of environmental, economic and social sustainability metrics that would be involved in an increased use of forest biomass for energy production. The second product was a set of thematic chapters and a comprehensive literature review of the published literature on the environmental impacts of the utilization of woody biomass for energy. The final product is a conclusion and a summary of the information gaps.

CHAPTER 2: Sustainability perspectives of stakeholders on the potential positive and negative environmental impacts of the increased utilization of woody biomass for energy production

Principal author: William Stewart

As part of this project to assess the potential positive and negative impacts of increased woody biomass harvesting from forests for energy, the authors conducted surveys of involved stakeholders regarding a number of sustainability aspects that they consider to be important. The sample population was contacted by personally describing the survey at public meetings and field trips where increased utilization of woody biomass was the central theme. The survey was a simple one-page questionnaire to increase the probability that survey recipients would be willing to fill out and return the survey at the meeting or soon after. The results of all 21 questions summarized by the three major stakeholder groups are shown below.

The results need to be considered in light of a number of differences between the perspectives of the different groups. Foresters and landowners are already aware that the harvesting of woody biomass in environmentally sustainable ways is required by the California Forest Practices Rules under the Cumulative Impacts Assessment Addendum #2 requirements, 916.9, 936.9, 956.9 Protection and Restoration of the Beneficial Functions of the Riparian Zone in Watersheds with Listed Anadromous Salmonids. [All Districts], 917, 937, 957 Hazard Reduction [Coast, Northern] , and other sections that refer the treatment of 'slash'. In areas of the state with wood fueled energy plants (e.g. the Northern Sierra Nevada/Cascade region and the Humboldt Bay region), foresters and landowners for decades have been addressing slash treatment requirements (for fire and insect control) by selling the woody biomass to energy plants rather than open burning it. The potential for an increase in biomass utilization has brought many new government regulators and environmental organization representatives into the policy discussions. In many cases, they had a much greater concern on issues that are typically addressed at the overall state policy rather than the individual project permit level. Although a number of representatives from environmental organizations attended the public hearings and field trips, only a small percentage of them returned the surveys.

2.1 Overall stakeholder survey results

The following results are based on answers where a '5' is very important and '1' is least important. The score of the group with the highest concern for each sub-theme is shown in bold.

Table 1 Sustainability Scores (5 = high, 3 = average, 1 = low)

Sustainability Themes	Foresters/ Landowners (n = 18)	Regulators/ Agency (n = 18)	Environ. Org (n = 2)
Forest Site Environmental Sustainability			
1. Maintenance of dead wood and snags	3.23	3.74	4.00
2. Wildlife and biodiversity	3.79	4.57	5.00
3. Water quality and riparian zones	4.07	4.68	4.50
4. Soil and site productivity	4.00	3.95	4.00
5. Biological productivity of harvested forest sites	3.93	4.16	3.50
6. Indirect land use impacts on other lands	2.94	3.47	4.50
7. Environmental sustainability of all alternative energy sources	3.83	3.70	4.00
8. Environmental impacts of energy producers	3.50	3.56	4.00
9. Environmental impacts of energy consumers	3.67	4.11	3.50
Regional Atmospheric Environmental Sustainability			
1. Particulates and pollutants from new biomass energy plants	3.29	3.74	3.50
2. Carbon dioxide produced by all energy plants	3.13	4.05	4.00
3. Avoided carbon dioxide emissions from fossil fuel energy plants	3.42	4.30	3.50
4. Avoided wildfire smoke from biomass operations	4.31	3.84	4.00
Economic Sustainability			
1. High cost to producers for permit fees	4.33	3.95	3.00
2. Higher cost to consumers of ~20% low carbon electricity	3.00	3.45	2.00
3. Higher cost to consumers of ~33% low carbon electricity	3.14	2.60	2.00

Social Sustainability			
1. Perspectives of statewide groups	3.07	3.40	2.50
2. Local livelihoods – jobs, local businesses, contracts	4.36	4.47	3.00
3. Local wildfire risk reduction benefits	4.58	4.27	4.00
4. Local quality of life perspectives – natural landscapes	3.80	3.48	3.50
5. Local quality of life perspectives – additional plant and truck activity	3.27	3.04	2.00

The following table groups the sub-themes into the four major themes and provides a simpler summary of the differences in the perspectives of the three groups.

Table 2 Major theme scores (5 = high, 3 = average, 1 = low)

Sustainability Themes	Foresters/ Landowners (n = 18)	Regulators/ Agency (n = 18)	Environmental Group (n=2)
Site Environmental Sustainability	3.7	4.0	4.2
Atmospheric Sustainability	3.5	4.0	3.8
Economic Sustainability	3.5	3.3	2.3
Social Sustainability	3.8	3.7	3.0

2.1.1 Site Environmental Sustainability

The high importance given to site level metrics by the three groups masked differences within elements. Foresters and landowners expressed high concerns for protecting the sustainability of site environmental issues that are currently covered by the California Forest Practice (FPR) rules – wildlife, biodiversity, water quality, riparian zones – but showed relatively less additional concern for dead wood, snags, and the indirect environmental impacts not already covered in the regulations. Regulators for agencies who historically have not had a role in forestry regulations generally had even higher concerns for biological factors such as wildlife, biodiversity, and water quality but showed considerably lower concern for environmental impacts if biomass was harvested on sites outside of California forests. The environmental representatives showed the greatest interest in issues that can be best assessed at the large regional (US and Canada) or the global level.

2.1.2 Atmospheric Sustainability

The regulators had a greater awareness and concern about the potential atmospheric loading of particulates and CO₂ from the energy plants that could be increasing their output if there was an increase in the utilization of woody biomass. The foresters and landowners, many of whom already are involved in selling woody biomass to energy plants, were more interested in the potential for reducing the level of wildfire smoke emissions by more cost effectively dealing with more of the harvest slash as well as fuels in untreated stands.

2.1.3 Economic Sustainability

Because California consumers have not seen any actual increase in energy prices due to the RPS requirements, it appears that most respondents perceive that low-carbon energy will not be any more expensive than our current fossil fuel dependent energy portfolio. In countries in Europe or Oceania that have significantly increased the proportion of green or low-carbon energy, the overall energy costs per unit of energy paid by consumers has increased. While this can benefit the energy producers and could increase the efficiency of energy use, it can be a noticeable new cost to energy consumers. Foresters and landowners focused primarily on the potential for higher permit fees as they nearly always accompanied greater attention to forest resources. California regulators were generally less concerned with potential price increases for consumers although this is proving to be a major concern regarding proposed national legislation.

2.1.4 Social Sustainability

All groups showed considerable concern for the social sustainability aspects. Both the forester/landowner and agency groups focused on the local impacts in areas where forest fuels could be harvested (and potentially reduce the risk of wildfire losses) and where it would be utilized for energy (and potentially creating new jobs and local income). The less measurable local and statewide 'quality of life' issues were considered relatively less important than measurable outcomes such as jobs and reduced local wildfire risk. The small sample of environmental groups was considerably less interested in local issues than the other respondents who often live in rural areas or have to respond to the concerns of local residents as part of their regulatory duties.

2.2 Overall summary of stakeholder responses

The first key point is that the different stakeholders are all interested in environmental impacts across a wide range of spatial scales. Focusing only on the project, or regional, or global scale will not address the full range of stakeholder concerns and will not address the policy themes being advanced to address emerging State of California issues. At the project scale, individual wildlife habitat elements can be positively (e.g. reduced probability of loss to future wildfire) or negatively (e.g. post-treatment biomass/LWD retention standards may be very low) impacted by treatment approaches. Who absorbs the additional costs to ensure high levels of positive benefits and low levels of negative impacts was not addressed in the survey. Across millions of acres of forests (California has over 20 million acres of conifer forests), the environmental impacts of increased woody biomass harvests will depend on larger patterns of forest habitat change resulting from forest management, wildfires, and other disturbances across both public and private lands. Local economic and quality of life concerns also become more important at

the county level. At the global scale, increased woody biomass utilization is already a GHG emission mitigation strategy increasingly used in Canada and Europe to reduce the overall emission intensity of their energy sector. A transparent and unbiased assessment of the environmental and sustainability impacts of woody biomass to energy options requires a clear presentation of the local, regional, and global costs and benefits.

CHAPTER 3:

Potential woody biomass resources for California's renewable energy

Principal author: William Stewart

3.1 Introduction

California, like Europe (European Environment Agency (EEA) 2006), is seriously considering a significant increase in the utilization of forest biomass as part of a broader strategy to increase the use of renewable energy. California was one of the first states to promote the utilization of woody biomass to supplement grid based electricity that historically has been supplied by fossil fuels. A significant number of California's biomass power plants are located in forested regions and depend on sawmill residues (e.g. bark, chips, shavings, sawdust) and forest residues (e.g. branches and tree tops collected at the landings) for the bulk of their fuel supply. While a number of the original plants are no longer in operation, the most efficient plants are still in operation, and there are plans to restart a number of idle plants as well as to construct new plants. Many but not all of the plants also provide industrial heat as part of combined heat and power (CHP) units attached to sawmills (California Energy Commission 2009).

Recent European plans predict that forest biomass will make up around half of all new renewable energy that will be developed in the coming decade (Commission of the European Communities 2007). The vast majority of the biomass is projected to come from the more efficient collection of harvest residues and from thinnings conducted as an integral part of sawtimber and pulp chip oriented forest management. In California, an additional significant source of woody biomass could be some of the biomass produced from fire risk reduction projects that involve the harvest and removal of biomass. Some of the harvested volume may be high enough quality to use for sawlogs but much of it will be only be suitable for use as an energy feedstock. Additional woody biomass may come from ecological restoration projects, orchard clearings before replanting, wildland-urban interface fuels reduction projects, and urban forests. These types of projects are designed to accomplish other goals and it is doubtful whether increases in the demand and possibly price for woody biomass would promote a large number of new projects based only on the increased biomass for energy revenue.

3.2 Forestland area by owner, productivity, and legal status

The forestland base by ownership from the Forest Inventory and Analysis (FIA) program (Christensen 2008) provides a useful framework for estimating the area and potential biomass volume available for management actions that could produce woody biomass. The data from the Forest Inventory and Analysis (FIA) of the USDA Forest Service has the advantage of tying both forest area and forest biomass estimates to specific plots where the owners are known (Christensen 2008). The following tables summarize forestland area and average inventory levels by the type of owners, the site quality, and the legal status of the lands.

Table 3 Forestland ownership in California in thousand acres

Owner Class	Unreserved Forest Land		Legally Reserved Forest Land		Total
	Timberland	Unproductive	Productive	Unproductive	
Corporate Private	4,402	338	0	0	4,740
Noncorporate Private	4,593	3,907	0	0	8,500
State and Local	258	211	381	215	1,065
US Forest Service	9,784	2,424	2,626	923	15,757
Other Federal	514	986	993	663	3,156
All owners	19,551	7,866	4,000	1,801	33,218

Source: (Christensen 2008)

To quantify the range of management activity on the 1.9×10^7 acres of timberland, it is necessary to consider different behavioral classes within the various ownership categories and the different types of forest management practices that could be used (**Table 2**). Corporate private forestlands are overwhelmingly managed to maximize value through the sustainable production of wood products. Non-corporate private forests are mainly family forests and have more diverse management approaches. On an acreage basis, approximately $\frac{1}{4}$ of the acres have commercial harvests, $\frac{1}{4}$ of the acres have some degree of vegetation management to reduce risk (primarily fire risk reduction), and $\frac{1}{2}$ of the acres are in a 'let grow' status (sensu Butler 2008). The goals of state and local government forestlands in California are primarily to provide open space, recreation, and habitat value with minimal levels of vegetation management for fire risk reduction, forest health, and public safety. More than half of federal forestlands have no roads and are unlikely for regulatory or practical reasons to ever have any vegetation management activities. Of the roaded areas of federal forestlands, environmental restrictions further limit where vegetation management could be undertaken. Thus in total, less than half the forest land in California could ever be considered to be a potential source of significant amounts of woody biomass. Even when environmental goals such as risk reduction or environmental restoration goals were funded with governmental appropriations, the focus would probably be on the forestlands with moderate, rather than high or low, levels of inventory. The highest inventory sites are mainly in parks, reserves, and wilderness areas. The low inventory sites typically will not have sufficient harvestable volumes that could justify the significant planning and access costs common to all forest management operations in California.

Table 4 Forest inventory levels in California in thousand cubic feet per acre of live tree volume.

Owner Class	Unreserved Forest Land		Legally Reserved Forest Land		Total
	Timberland	Unproductive	Productive	Unproductive	
Corporate Private	2.9	1.0			2.8
Noncorporate Private	3.0	0.8			2.0
State and Local	4.6	1.0	8.5	1.3	4.6
US Forest Service	3.9	0.7	4.5	0.9	3.4
Other Federal	2.0	0.4	5.7	0.8	2.4
All owners	3.5	0.7	5.2	0.9	2.9

Source: (Christensen 2008)

The highest volumes in live trees per acre are in legally reserved forests where no forest management is undertaken but where losses to fires, disease, and insects are substantial. The potential of increased losses to wildfires under future climate scenarios (Westerling, Hidalgo et al. 2006) has been raised as a potential reason to consider new strategies in some areas.

Private landowners in California have lower average forest inventories per acre but higher growth rates and higher harvest rates. Total harvests from both private and public lands in California were flat until the recent slowdown in home construction. The volume from private lands has varied between 87 percent and 94 percent of the total instate harvest over the past decade (California State Board of Equalization 2010). Consumer demand for wood products is increasingly met with imports from Oregon and British Columbia (Western Wood Products Association 2009). As potential interest in increasing the utilization of renewable energy increases in the United States, Canadian government (Climate Change Solutions 2007) and Canadian industries (Tice 2010) are looking at meeting an expanding US market for renewable energy with forest biomass.

3.3 Forest operations that could produce biomass for energy

California's forest practice rules require foresters to 'select systems and alternatives which achieve maximum sustainable production of high quality timber products.' (CA FPR 2010, sec 913, 933, 953). Activities that require environmental permits include timber operations where the products are offered for sale, barter, or trade or when the timberland is to be converted to another land use (CA FPR 2010). Actions covered include a wide range of commercial harvests, commercial thinnings, sanitation salvage or dead or diseased trees, fuel reduction projects where commercially valuable trees are removed, and conversion projects in timberlands. For

any of these operations, some of the lesser value biomass may be left on site to decompose or burn if the delivered prices do not justify the collection and transport.

In terms of total biomass removed from the forest, the high quality timber products such as dimensional lumber and veneer based products such as plywood constitutes less than half of the total volume of trees that were cut across all forest operations. The rest of the harvested woody biomass is logging residues that are often left on site, trees that are chipped or used directly as fuelwood, or sawmill residues. While many of these products are sold for use as other products, greater demand for biomass for renewable energy could theoretically become the major end use for harvested biomass from forests. The following table summarizes annual biomass removals data for the three Pacific Coast forests (California, Oregon, and Washington) and the rest of the United States from the latest inventory of forest resources (Smith 2009).

Table 5 Forest harvest volumes for the Pacific States and the rest of the US in thousand cubic feet per acre of live tree volume.

	thousand cubic feet		Percent of total	Percent of total
	CA, OR, WA	Rest of US	CA, OR, WA	Rest of US
Final timber products (~2/3 of logs)	1,429,163	5,621,531	43%	27%
Sawmill residues (~1/3 of logs)	703,916	2,768,814	21%	13%
Pulpwood and fuelwood	500,619	6,599,768	15%	31%
Logging residues and other removals	706,734	6,172,485	21%	29%
Total harvest	3,340,432	21,162,598	100%	100%

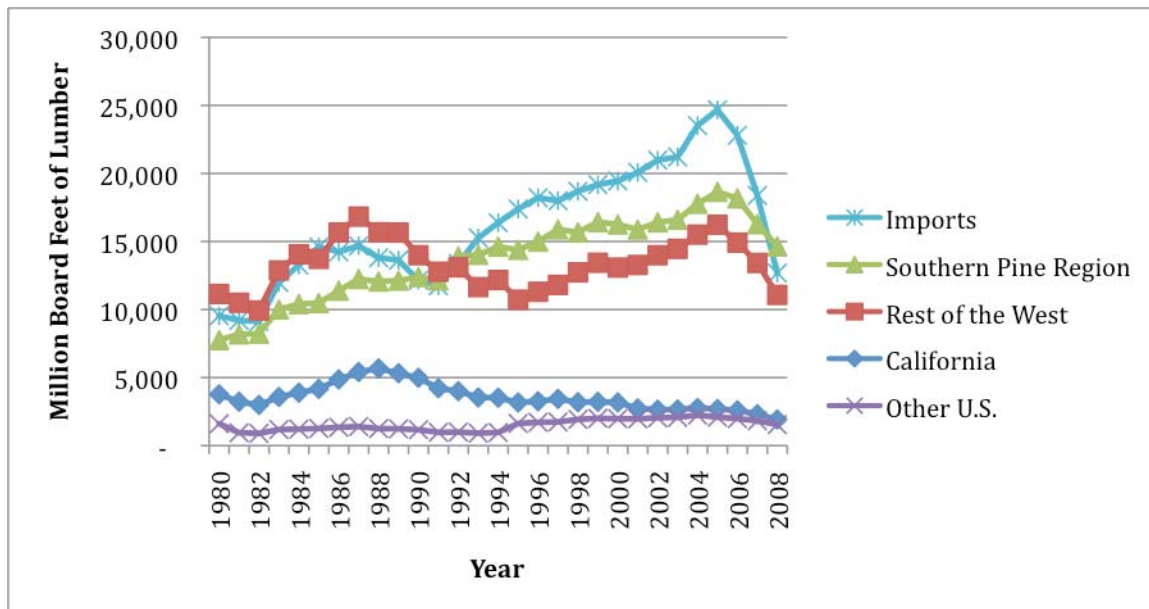
Source: Table 41 from Smith (2009)

Compared to the rest of the United States, California, Oregon and Washington focus more on larger sawlogs and veneer logs and less on pulpwood and fuelwood. When round logs are turned into rectangular lumber and veneers, around one third of the volume that came in as a sawlog ends up in other products. When all the products are considered, only 43% of the harvested biomass in the Pacific Coast is eventually sequestered in long-lived wood products. The other biomass removed from the forest also provide net climate benefits when it substitutes from more GHG emission products such as cement, steel, and plastics but provide less long term carbon sequestration. A considerable fraction of the logging residues are typically left on site where they will rot or burn. These logging residues constitute the single largest potential source of woody biomass that could be used if the demand for renewable energy increased to catch up with state policy goals.

3.3 Potential biomass as a byproduct of lumber production consumed in California

Across the United States and Canada, large volumes of harvest residues are often left in the forest as sawmill residues are usually sufficient to meet the heat and energy needs within the sawmill and woody biomass based electricity is more expensive than coal or natural gas based generation. In some cases, the residues are piled and burned to clear the site for new tree plantings, but in other areas the residues are left to slowly decompose. State forest regulations in Western states often require treatment of the residues to reduce the risk that the additional fuel would increase the intensity of any future wildfire. In most cases, treatments do not require that the biomass be removed from the site. The harvest residues from both thinnings and final harvests represent a large potential supply of woody biomass. Assuming electricity based on renewable sources will be imported to meet future California demands, the supply of these residues will correspond closely to current and projected levels of lumber output. The following figure illustrates a declining trend in California output, cyclical trends in the rest of the West and large increases in lumber imports (with around 90% harvested in Canada) and a steady increase in output from the Southeast United States.

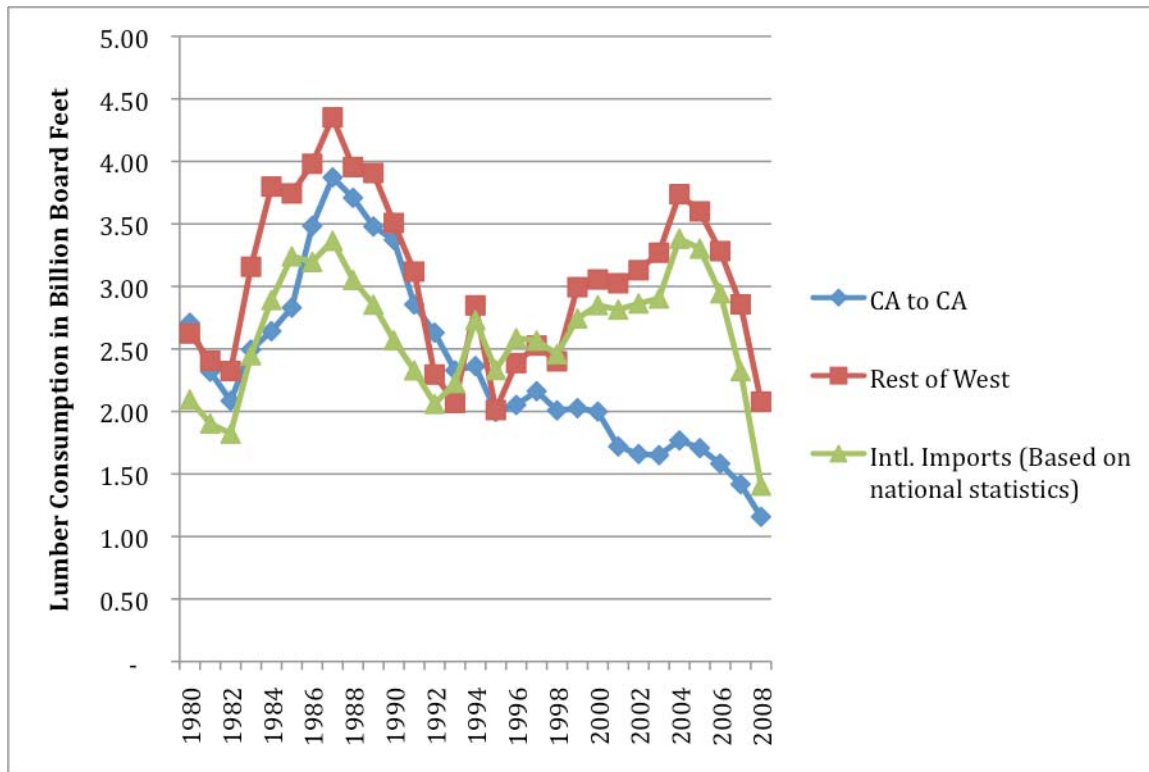
Figure 1 US Softwood Lumber Consumption from the Western Wood Products Association Statistical Yearbooks



Over a period of two housing construction boom and bust cycles, U.S. consumption of softwood lumber has increased. Declines in harvests in California and other western states have been more than made up with increased production from the Southern Pine region and Canada. This suggests that any further reduction in timber harvests in California will simply be balanced by an increased harvest in some other part of North America to meet the increasing demands of U.S. consumers. A more detailed analysis was made by Wear and Murray (2004) who estimated an 84% replacement of the uncut federal lumber after the Northwest Forest Plan from increased harvests in Canada and the Southern Pine region.

The following figure of lumber used in California illustrates the growing role of imported lumber to meet consumer demands in California.

Figure 2 Sources of California Lumber Consumption



Source: (Western Wood Products Association, various)

It is reasonable to assume that increased woody biomass based electricity will come from forests in California, the US Pacific Northwest as well as the Western Canadian provinces. In 2008, California imported 8% of its total electricity from Pacific Northwest (California Energy Commission 2009). These states and the Canadian provinces to the north also provide the majority of sawtimber and other wood products used in California. From the point of view of environmental impacts, a useful metric could be the environmental impact per megawatt hour (MWh) of electricity irrespective of where it is produced along the existing transmission corridors. The similar sets of attributes across the mixed conifer forests across Western North America (e.g. site quality, wildlife habitats, wildfire risks) make it plausible to apply a standard assessment approach for all forest sources of biomass, regardless of what state or province they are located in.

3.4 Harvest products and residues from different types of silviculture

The potential amount of additional biomass from harvest residues will be proportional to volume of timber harvested and the type of silvicultural regime used. The vast majority of the current harvested volume that could be used in California comes from private lands in California, Oregon, and Washington as well as from public and private lands in Canada. In all

regions except California, the majority of the harvested area is done using even aged techniques with mechanical site preparation and replanting. In British Columbia 95% of the area harvested in 2009 was done with clearcutting that usually have reserve units within them (Ministry of Forest and Range Forest Practices Branch, 2010). In California, Oregon, and Washington the current stand structure is noted by the Forest Inventory and Analysis field crews. On private timberlands, the most recent data suggests that even aged stand structures are the dominant structure in Oregon and Washington but represent less than half of area in California.

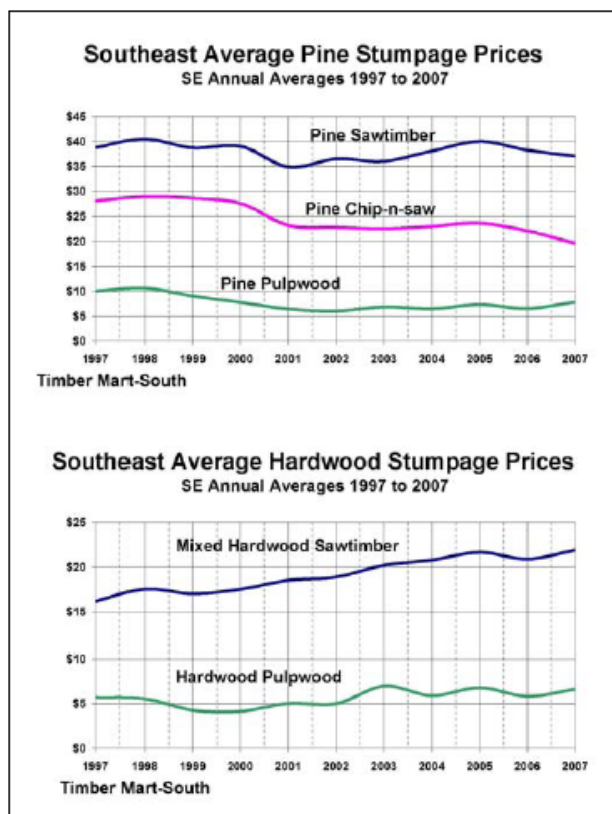
Table 6 Private forest stand structure from FIA field assessments

State	Even aged stand structure	Uneven aged stand structure
California	45%	55%
Oregon	63%	37%
Washington	62%	38%

Source (Christensen 2008)

Biomass harvested from even aged management would occur from commercial thinnings (that could also serve as a fuels treatment) and the final harvests. Biomass harvests from uneven-aged management would occur from periodic harvests in stands with mature trees as well as through fuels treatments. At current prices where biomass based energy competes on price against fossil fueled based energy, the biomass is often not collected and transported as costs exceed revenues in most areas of California. If the price of energy chips increased to equal the value of chips sold for paper pulp (a much higher end value given the low premium for renewable energy in California), most indications are that it would still not be competitive with the market for sawtimber. Since there is no significant market for trees harvested for pulp chips in California, the comparative prices trends from the Southeast United States are used to illustrate the relative prices. The following figures of stumpage prices (the market value of unharvested trees) for sawtimber, pulp, and Pine Chip-n-saw (trees that produce roughly ½ sawtimber and ½ chips) illustrate a fourfold advantage of sawtimber over chips.

Figure 3 Sawtimber, chip-n-saw and pulpwood stumpage prices in the Southeast US



Source: www.timbermart-south.com

Even if the value of biomass stumpage for energy went up to a price in the range offered for pulp chips in the Southeast US or other regions, it would still be far below the value of mature trees for sawtimber. Given that the cost per ton of biomass harvested is higher for smaller trees (Hartsough, 2003), it is unlikely that future prices will induce forest landowners to harvest sites if they had not already planned to conduct a sawtimber oriented harvest.

3.5 California's forest land base and potential for additional biomass for energy harvests

The current and potential supply of woody biomass is closely tied to the goals of landowners or managers. Based on ownership of productive forestland that does not have legal reservations limiting management, there are approximately 10 million acres of private forestland and 10 million acres of federal land potentially available in California. The 13+ million acres of land with less productive forests (e.g. woodlands, shrub dominated forests, low site quality lands) and legally reserved lands are considered unavailable or having only a small ability to provide a sustainable and predictable supply of woody biomass. Within the potentially available lands, corporate private forest land owners have the highest probability of managing for sustainable timber harvests and also producing considerable volumes of biomass as harvest residues and mill residues. The ability of forestland owners or managers to plan and implement large scale

risk reduction projects such as fuels treatment projects depends on their goals and the funding necessary for such projects.

The recent review of land cover changes in California by Sleeter (2010) suggests that fires have been the major change agent affecting California’s forests. An analysis of remote sensing imagery by researchers at the US Geological Survey (USGS) over the 1973 to 2000 period, documented a 3 percent loss in forest cover in the three forest dominated bioregions in California – the Klamath Mountains, Sierra Nevada, and Coast Range. The following table summarizes the area under forest cover (current forests, with recent clearcuts, with recent wildfires), grass and shrub cover, and development. At any one time, around 1.3 percent (s.d. 0.5 percent) of these forested regions was visibly disturbed after harvesting and regeneration and would remain so until the new trees are 5 to 10 years old. The area of forests with evidence of recent wildfires varied considerably between measurements.

Table 7 Land cover in three forested regions in California in square kilometers

Year	Current Forest Cover	Forest+ Mechanical Disturbance (MD)	Forest+MD+ Non-Mechanical Disturbance (mainly fire)	Grass/ Shrub	Developed
1973	87,049	88,205	88,360	18,376	826
1980	86,733	87,291	87,446	19,212	838
1986	86,695	87,660	87,660	19,015	849
1992	85,405	87,211	87,633	18,953	873
2000	84,248	85,361	86,987	19,701	934
Absolute Change 73-00	(2,801)	(2,844)	(1,373)	1,325	108
Percent Change 73-00	-3.2%	-3.2%	-1.6%	7.2%	13.1%

Source: Calculated from Sleeter (2010)

More significant than the cyclical areas of harvest and regeneration has been the large increases in areas marked by non-mechanical disturbance (primarily fire) and the increase in the area covered with shrubs and grasses. Of the 1973 forest area that did not have mature trees or newly planted tree cover in later years, 52% showed evidence of recent wildfire, 47% had grass or shrub cover and 4% had new residential or commercial development. Unlike the shrub and grass regions of California where conversion to developed areas has been more prevalent, very little of the land cover change in forested regions is due to development. Compared to the national trend where forest conversion to residential development is the dominant change agent (Stein, 2009), fire and post-fire revegetation are much more important in California.

An implication from this data is that fire rather than conversion to developed land uses is the most significant factor for the long term reduction in forest cover. In some areas of reserved forests, the carbon storage may have been unnaturally high due to fire suppression and could drop if fire suppression was less effective. For unreserved National Forest lands and private forest lands, greater attention is being played to the potential role of sustainable timber harvests and fuels reduction projects to reduce these possibly avoidable losses of stored carbon from wildfires.

3.6 Estimated potential forest fire risk based on stand structure characteristics

The probability of any acre of forest being burned is strongly influenced by the degree of summer moisture deficit, windy conditions, and lightning and other ignitions. Over the 1995 to 2004 period the annual area of forest burned ranged from 0.90 percent in the Sierra Nevada to 0.24 percent in the North Coast region (Christensen 2008). The figure below illustrates the predicted intensity of wildfires if they occurred in any forest area in California. The red areas are where severe fires that burn all the trees are predicted (active crown fires). The purple areas are where fires are projected to only burn along the surface and kill few if any large trees. Recent studies have suggested that the incidence of fires could increase substantially with climate change (Westerling and Bryant 2008). The potential for increased area of wildfires to reduce forest carbon sequestration (including carbon sequestration benefits of harvestable products) has led to an increased interest in exploring the potential of fuels reduction interventions to reduce the loss of climate benefits before the conditions get worse. The map provides an indication of which areas (red and orange) should have higher priority for fuels treatments (Christensen 2008).

Figure 4 Predicted likely fire type across forest lands where fuels treatment projects could be implemented. From Christensen (2008)

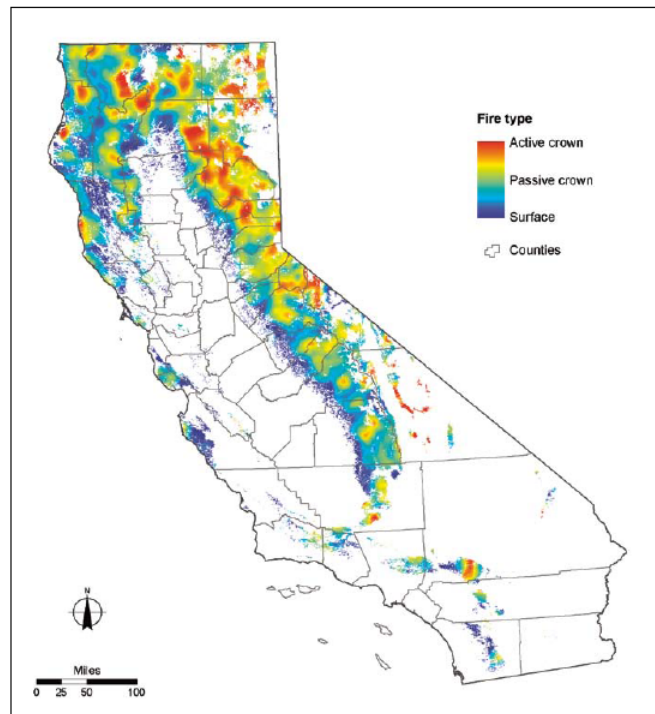


Figure 80—Predicted likely fire type in forested areas using kriging as a modeling method (forest/nonforest geographic information system layer; Blackard et al. 2008).

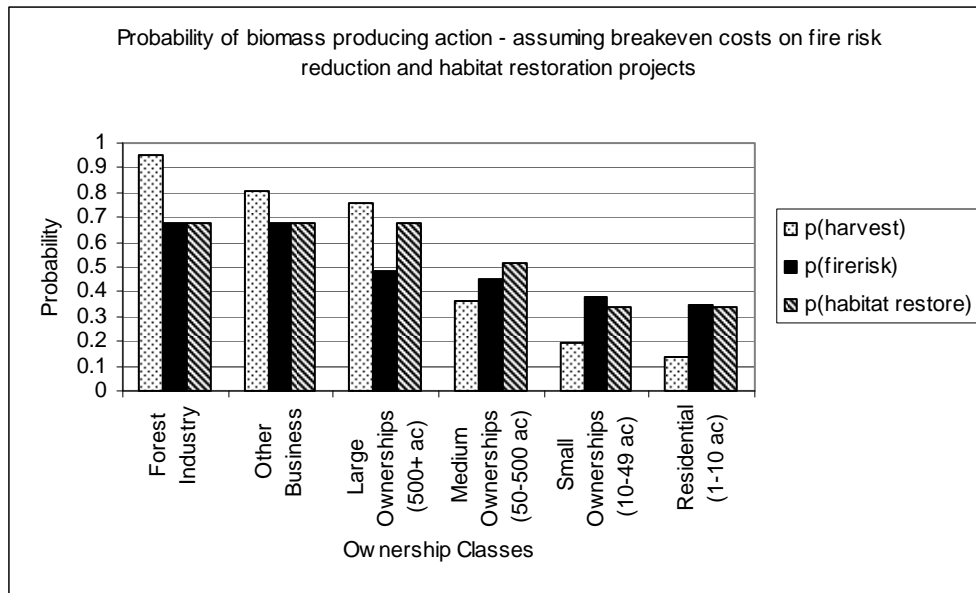
The significant post-wildfire signature on forestland cover changes occurred in spite of California's large and expensive fire suppression program over both public and private lands. A key issue with regard to carbon sequestration is the biomass regeneration trajectory of post-disturbance (mainly fire) forests. Natural progression towards rapidly growing and long-lived trees can be slow without active investments to promote successful regeneration (Zhang, 2008)

The grass and shrub land cover may also be a result of revegetated fire areas. Compared to the area immediately and less immediately following fires, the area with permanent forest cover loss to development was a relatively small component of the change in land cover. Strategies to manage forests where most of the trees were killed in wildfires vary considerably in California. Well-financed private landowners often carry out expensive salvage and reforestation efforts as quickly as they can (Zhang 2008). Public land managers will implement the relevant land management plans to the level that appropriated funds allow them. This may include a range of treatments include harvests, shrub and other vegetation control, and no-treatments (Fettig, McKelvey et al. 2010; McGinnis, Keeley et al. 2010; Zhang in press).

3.7 Estimated interest of different landowners in forest operations that could produce more woody biomass for energy in California

Not all forest landowners within the economic haul distance are interested in undertaking forest management actions that could produce woody biomass. The following figure summarizes the preliminary results of a forest landowner survey of family forest owners in California. For ownerships less than 500 acres in size, the experience and interest in conducting harvests or fuels management projects to reduce fire risk drops considerably. Fuels management projects without a timber harvest component do not produce net revenue and are often not done unless there are grant funds or government appropriations available.

Figure 5 Landowner behavior probabilities for California forestland owners



Source: (Ferranto, et al. (unpublished))

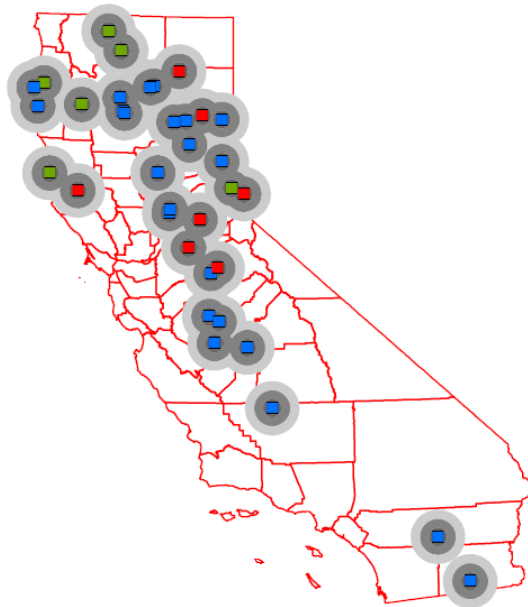
Projects on publicly managed forest lands will be limited more by the lack of government appropriations and the concern that treatments could have negative impacts on other goals such as wildlife habitat rather than by the lack of interest in the managers undertaking projects.

3.8 Existing and proposed energy processing infrastructure

In 2008, California imported 32% of its total electricity with over half of it generated at coal-fired plants (California Energy Commission 2009). The increased demand for energy that meets California’s renewable portfolio standard (RPS) could increase the demand for woody biomass based energy produced in California or in neighboring states. The following figure shows the location of the current, mothballed, and proposed woody biomass to energy plants in California as well as the 20 mile and 30 mile circles around them. Sites within 30 air miles of an energy plant are considered to represent sites for which transportation costs would be less than the plant gate price offered for woody biomass. Some landowners will send biomass more than 30 miles when there are other economic advantages to removing the woody biomass from the site

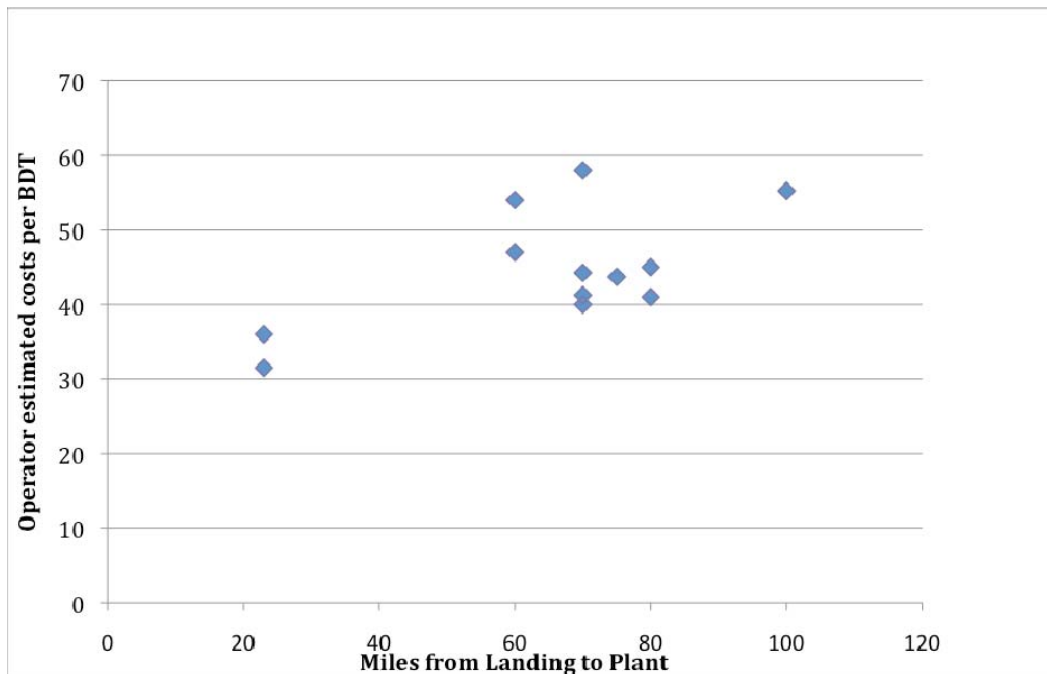
(e.g. cheaper and less risk than pile burning). Even though haul distances greater than 30 miles result in a negative value of biomass at the landing at current prices, the financial penalty for hauling longer distances increases relatively slowly for longer hauls as it usually occurs on high speed highways.

Figure 6 Current (blue), mothballed (red), and proposed (green) biomass energy plants in California



The following figure shows the owner reported loading and delivery costs from 12 biomass harvesting operations in Northern California conducted between 1998 and 2008. The general cost relationship used in BioSum (Fried 2003), one of the many biomass harvest modeling systems, includes costs for loading the chips into the chip vans as well as higher cost per mile for logging roads and lower cost per mile for paved highways. When the delivered prices for biomass were around \$40 per bone dry ton, revenues for sites farther than 30 miles from energy plants typically did not cover transport costs. Since alternative treatment costs of logging residues are not insubstantial, the forest owners had to be willing to integrate the biomass harvest and transport into their overall operation since the biomass component was a financial loss.

Figure 7 Haul cost per bone dry ton for biomass projects in Northern California



Source (Stewart, unpublished data)

3.9 Conclusion

The assessment of forest lands and recent management practices suggests that any increase in woody biomass available for energy production would require market prices that would drive the reallocation of biomass from existing uses (e.g. pulp chips, landscape mulch, firewood) to energy or justify the collection and transport of residues that are currently left in the forest. Harvest residues are a by-product of the existing flow of lumber used in California that is currently sourced in roughly equal proportions from California itself, Oregon and other western states, and western Canada. Biomass could also be produced as a by-product from fuels reduction projects in fire prone and accessible areas in California but the production costs would be higher than for timber harvest residues since some of costs could not be covered by the harvest of more valuable sawlogs. Forestland cover data suggests that forest fires are significantly reducing the forest area and potentially the forest carbon content of California's forests. Although there is increasing evidence that well designed and implemented fuels reduction projects can reduce future fire risk and that the sale of the harvested products can reduce project costs, the goals and constraints of forestland owners or managers limits the potential area where projects could be implemented. The limited number of energy plants that purchase woody biomass to generate renewable electricity increases the effective cost of treatments for forest landowners more than 30 miles from a plant. An expansion in the number and distribution of biomass plants would be needed to provide a significant increase in output. Private investments in new plants will not be forthcoming without more certainty on the quantity and prices for renewable energy on hand and assured long term feedstock supplies on the other hand.

CHAPTER 4:

Nutrient Consequences of Increased Utilization of Woody Biomass for Energy Production

Principal author: Teresa Chuang

4.1 Introduction

Greater utilization of woody biomass has the potential to increase the amount of California's energy that is derived from renewable sources. However, the short- and long-term nutrient consequences that would result from this higher harvest intensity are poorly understood. In evaluating these potential consequences, it is important to consider how the increased bioenergy utilization could affect soil nutrient status. Soil organic matter in forest soils is of interest for its roles in increasing water-holding capacity, maintaining soil productivity, and its role as a source or sink for atmospheric carbon. Soil organic matter is continually added to the forest floor and soil by litter and is also continually broken down by a myriad of microflora and fauna. While soil carbon is not used directly as a nutrient by trees, much of the nitrogen, phosphorous, and sulfur used by trees becomes available as carbon-rich organic matter decays. The carbon rich soil organic matter also improves soil porosity that affects water and nutrient availability. Extremely hot wildfires can consume much of the carbon in both the forest floor and the mineral soil and represents one of the major potential sources of soil carbon loss (Fisher, 2000).

Forest soil scientists have been developing measurement protocols to ascertain the relative risk of forest soils to nutrient depletion (Page-Dumroese et al., 2000; Schoenholtz et al., 2000) as well as conducting pre and post treatment assessments of harvesting on productivity. We surveyed of the knowledge of the nutrient consequences of increased woody biomass utilization from forest harvesting based on forestry work from North America and Scandinavia. We also compare short-rotation woody crops, non-woody perennial crops, and non-woody annual crops on soil productivity. Conclusions regarding knowledge gaps on nutrient cycling for increased bioenergy harvesting from forests are presented after the chapters on soil erosion and silvicultural research.

Assessing the likely time course of nutrient depletion through biomass removals requires estimating inputs to ecosystems as well as the available nutrient stores and the rates of nutrient removals. Available nutrients are difficult to assess, as pointed out by Powers (Chapter 7): operationally defined pools such as exchangeable cations may not correspond to plant-available pools over long time periods. For forest soils in California, nitrogen, phosphorus, potassium, and calcium are the major limiting nutrients for growth (Powers, 1975). Since trees capture carbon from the air rather than from the soil, soil carbon is not considered a direct nutrient but does play a key role in improving the soil quality in terms of water holding capacity, drainage and as a structural anchor for other nutrients. The more recent interest in the role of forest soils as long term carbon storage has increased interest in measuring soil carbon throughout the soil profile.

4.2 Nutrient consequences of increased utilization of currently non-merchantable woody residue produced during timber harvest

4.2.1 Soil nutrient cycling, harvesting, and forests

Biological, physical, and chemical processes all interact to determine soil productivity. A key component of soil productivity is nutrient availability, which is the balance between nutrient supply from atmospheric deposition, weathering of parent material, and decomposition of organic material and nutrient export through removal of organic material and leaching. Forestry practices can affect this balance through harvest intensities and rotation lengths that remove nutrients faster than they are replaced (Vance, 2000). Differences between soils in terms of their nutrient supplies mean that different sites will be able to sustain different levels of nutrient removal. Additionally, species-specific differences in nutrient content, within-tree differences in nutrient distribution, and tree age all need to be considered in evaluating the level and type of biomass removal that is sustainable for a particular forest stand (Janowiak and Webster, 2010).

Much of the research relevant to understanding the nutrient consequences of utilizing currently non-merchantable woody biomass comes from studies comparing the impacts of whole-tree harvesting to stem-only harvesting (Saarsalmi et al., 2010; Wall, 2008). In stem-only harvesting, only the main bole is removed, and significant woody residue from foliage, branches, and noncrop species remain onsite. Numerous studies have shown stem-only harvesting to have a minimal impact on soil nutrient pools, as the non-bole organic material that remains allows for the potential replenishment of soil nutrients (Clinton et al., 1996; Johnson and Curtis, 2001). Depending on the timing and extent of nutrient release, which varies based on residue type and decomposition rate, nutrients may be leached from the site, made available for tree uptake, or retained within the remaining woody biomass. Removal of more of non-merchantable woody residue as is done in whole tree harvesting increases the amount of nutrients taken, but the impact depends on what fraction of total nutrients were in the removed vegetation.

Above-ground nutrient concentrations are generally highest in foliage, followed by fine twigs, branches, and the stem, but vary significantly by species and by point in the growing season (Kimmins, 1977). However, despite higher nutrient concentrations in these smaller size classes, the total amount of nutrients contained within them is generally small compared to the amount contained within the bole of large trees and trees with small canopies; smaller trees, trees with extensive canopy structures, and species with particularly high concentrations of foliar nutrients can be expected to have larger amounts of nutrients in post-harvest woody residue. Even relatively high nutrient export from the site may be modest compared to total site nutrient capital (Vanhook et al., 1982), though not all of that nutrient capital may be plant-available.

In the case of phosphorus, the primary mineral source, apatite, is more readily weathered than the silicates with which it occurs, and its weathering rate is therefore underestimated by methods that assume congruent weathering, such as the sodium denudation rate. Since apatite is a calcium phosphate, the calcium is also potentially more available than previously assumed (Hamburg et al., 2003; Yanai et al., 2005). The most generous estimate of nutrient availability in soils would include the pool of weatherable nutrients. The pool defined as available to

agriculture crops would probably be an underestimate, with the true pool size somewhere between these limits.

In the case of nitrogen, atmospheric inputs can be significant; the soil is not the only source. In fact, in the northeastern US, nitrogen deposition is high enough to sustain biomass removals of nitrogen indefinitely. Clearly, the limiting nutrient will differ depending on location, soil type, and the removal rate. In fire-prone systems, losses due to fire should also be included with the nutrient removals. Where precipitation exceeds potential evapotranspiration (in humid climates, which includes most forests), leaching losses should be included in the mass balance.

Johnson et al. (2008) compared the combined effects of burning and whole-tree harvesting with burning and conventional harvesting in the eastern Sierra Nevada, and found nitrogen removals approximately equal for the two harvesting intensities, but higher removals of P, K, Ca, and Mg in the whole-tree harvested sites. The long-term impact of the removals of the non-N nutrients on overall forest growth can only be captured with follow up measurements.

4.2.2 Measured soil carbon and nitrogen levels in California soils underneath conifer forests, hardwood forests, and conifer and hardwood woodlands

Outside of national parks, reserves, and roadless areas, a significant fraction of California's forests have been harvested for fuelwood or sawlogs for building materials. Data from soil surveys published in Zinke et al. (1986) and Christensen et al. (2008) are summarized in **Table 1** for many of the major tree species in California. Many of these sites have had cycles of harvest and regeneration.

Table 6 Chemical properties of surface mineral soil (0-10 cm) layers by California forest type

Forest type	Data source	Sample size	Organic C (%)	Total N (%)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)
Bigleaf maple	FIA 2001-2005	1	3.82	0.19	2360.03	594.50	357.80
Bigleaf maple	Zinke and Stangenberger	1	3.66	0.131	2200 ± 622	516 ± 203.65	210.6 ± 143.40
Blue oak	FIA 2001-2005	18	2.41	0.20	2125.87	463.05	259.36
Blue oak	Zinke and Stangenberger	10	1.78 ± 0.78	0.16 ± 0.06	2703.14 ± 1202	743.66 ± 357	218.4 ± 106
CA black oak	FIA 2001-2005	9	7.83	0.40	2377.54	239.70	226.40
CA black oak	Zinke and Stangenberger	15	6.02 ± 4.69	0.23 ± 0.14	2201.43 ± 890	281.14 ± 154	243.00 ± 109
Canyon live oak	FIA 2001-2005	18	4.54	0.23	2061.75	182.40	222.02
Canyon live oak	Zinke and Stangenberger	2	4.15 ± 1.94	0.08 ± 0.035	1215.00 ± 643	93.60 ± 30.5	120.9 ± 5.51
Coast live oak	FIA 2001-2005	7	3.83	0.27	2268.31	605.10	270.01
Coast live oak	Zinke and Stangenberger	2	5.17 ± 4.58	0.34 ± 0.34	2965.00 ± 2015	711.60 ± 165	156.00 ± 0
Douglas-fir	FIA 2001-2005	3	5.78	0.29	2030.98	221.97	233.33

Douglas-fir	Zinke and Stangenberger	77	4.29 ± 2.48	0.17 ± 0.10	2357.34 ± 2372	365.67 ± 517	273.95 ± 208
Gray pine	FIA 2001-2005	7	1.89	0.12	1978.33	596.60	228.65
Gray pine	Zinke and Stangenberger	2	2.77 ± 1.64	0.08 ± 0.10	No data	No data	No data
Interior live oak	FIA 2001-2005	8	2.92	0.17	1444.81	198.39	188.67
Interior live oak	Zinke and Stangenberger	19	2.70 ± 1.37	0.13 ± 0.04	1844.44 ± 524	292.00 ± 161	160.33 ± 141
Jeffrey pine	FIA 2001-2005	6	2.63	0.18	1319.39	75.72	208.46
Jeffrey pine	Zinke and Stangenberger	13	3.18 ± 1.40	0.15 ± 0.08	1067.64 ± 1130	860.62 ± 928	101.4 ± 53.6
Juniper	FIA 2001-2005	4	0.80	0.08	1486.24	253.23	158.53
Juniper	Zinke and Stangenberger	2	0.92 ± 0.26	0.08 ± 0.01	160.00 ± 481	414.00 ± 59.3	526.50 ± 138
Lodgepole pine	FIA 2001-2005	10	2.86	0.12	450.04	46.62	90.65
Lodgepole pine	Zinke and Stangenberger	8	6.13 ± 5.57	0.21 ± 0.20	830.33 ± 779	106.40 ± 132	169.65 ± 168
Oregon white oak	FIA 2001-2005	2	3.00	0.14	2424.00	439.10	392.45
Oregon white oak	Zinke and Stangenberger	12	3.03 ± 1.58	0.19 ± 0.12	1781.20 ± 908	232.20 ± 65.4	166.53 ± 97.0
Pacific madrone	FIA 2001-2005	3	3.07	0.15	1037.95	146.51	198.68
Pacific madrone	Zinke and Stangenberger	2	6.77 ± 3.71	0.41 ± 0.34	No data	No data	No data
Ponderosa pine	FIA 2001-2005	6	3.92	0.20	2688.83	265.89	449.95
Ponderosa pine	Zinke and Stangenberger	149	5.14 ± 3.78	0.19 ± 0.12	1581.79 ± 872	220.25 ± 204	269.63 ± 166
Red fir	FIA 2001-2005	4	4.98	0.17	467.58	25.49	109.42
Red fir	Zinke and Stangenberger	20	6.97 ± 4.22	0.23 ± 0.14	687.87 ± 604	39.76 ± 34.3	319.52 ± 150
Tanoak	FIA 2001-2005	13	3.80	0.14	880.33	304.32	220.90
Tanoak	Zinke and Stangenberger	13	4.50 ± 2.45	0.17 ± 0.08	1663.64 ± 1144	356.73 ± 286	334.69 ± 212
White fir	FIA 2001-2005	13	6.81	0.32	2124.62	149.49	255.54
White fir	Zinke and Stangenberger	45	6.90 ± 4.77	0.27 ± 0.24	2204.75 ± 1638	120.49 ± 78.1	251.55 ± 139

Source: (Christensen et al., 2008b; Zinke et al., 1986)

Three key points can be drawn from the data. The first is the large variability in both organic carbon and nitrogen concentrations within samples from the same tree species. An analysis of the plot level data rather than the summary data from Christensen *et al.*, 2008 would have produced similarly large data ranges as those published in Zinke *et al.*, 1986; Zinke and Stangenberger, pers. comm. The second point is the relatively high level of nutrients across nearly all the forest types. The following table summarizes the averages for organic carbon

percent and nitrogen percent for forest species organized by conifer forest, hardwood forest, and conifer and hardwood woodland species. Forest soils under both conifer and hardwood species had similarly high carbon and nitrogen contents while woodland soils have considerably less carbon.

Table 7 Summary of carbon and nitrogen properties of surface mineral soil (0-10 cm) layers by major California forest types

Major forest type	Organic Carbon Percent		Nitrogen Percent	
	Christensen	Zinke and Stangenberger	Christensen	Zinke and Stangenberger
Conifer forest	4.1%	5.1%	0.20%	0.19%
Hardwood forest	4.3%	4.7%	0.21%	0.20%
Woodlands	2.5%	2.6%	0.18%	0.18%

The final point is that carbon and nitrogen concentrations are closely correlated even though there are few nitrogen fixing plants in any of these forest or woodland plant assemblages. The historic removal of the carbon in the boles of the trees and nitrogen in the foliage does not seem to have left any strong evidence of long term nutrient deficiencies in these soils.

Figure 8 Organic carbon percent v nitrogen percent in California forest and woodland soils

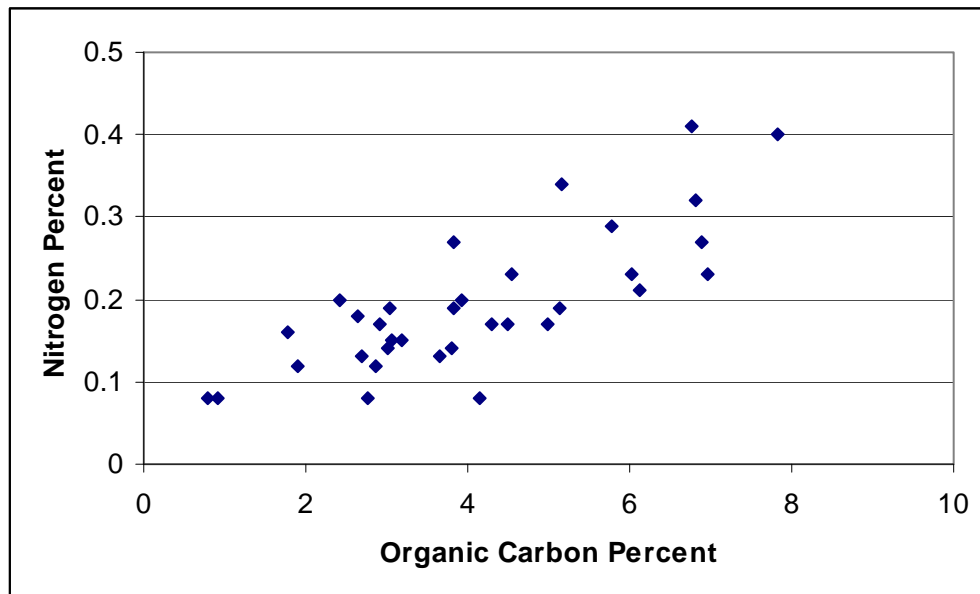


Table 8 Forest carbon in tonnes per hectare for California and Oregon forest types

Forest type (n)	Live tree	Dead tree	Under story	Dead & Down	Forest floor	Soil
Douglas-fir (136)	164.6	9.5	8.5	21.4	35.7	40.1
Ponderosa pine (189)	62.3	2	4.5	10.4	22	41.3
Jeffrey pine (149)	54.4	2.8	4.5	9.5	23.4	41.3
Lodgepole pine (162)	83.2	8.8	11.6	12.9	27	35.2
White fir (203)	114.2	13.9	3.6	20.3	36.6	51.7
Red fir (109)	142.9	14.5	2.6	25.1	39.7	51.7
Redwood (78)	258.4	8.7	5.1	30.3	60.7	53.5
Mixed conifer (1194)	122.5	10.2	2.8	17.2	37.9	49.6
Blue oak (304)	32.6	0.9	14.9	3	30.1	27.6
Canyon live oak (349)	81.1	5.4	8	5.3	30	27.8
Cercocarpus - brush (65)	18.3	2.1	5.6	1.8	30.6	26
Nonstocked (138)	7.2	11.5	5.9	1.5	18.1	35.6
Median	95.1	7.5	6.5	13.2	32.7	40.1
Standard deviation	71.0	4.8	3.7	9.6	11.1	10.0
Douglas-fir , OR USFS (454)	230.4	15.7	6.7	29.1	43.1	94.7
Douglas-fir, OR PVT (599)	91.2	2.2	6.3	19.7	26	95
Douglas-fir, CA (136)	164.6	9.5	8.5	21.4	35.7	40.1

Source: (National Council for Air and Soil Improvement, 2010)

The increased interest in forest carbon storage and changes in the amount of stored carbon has resulted in a significantly expanded effort by the USFS Forest Inventory and Analysis (FIA) program to measure all the carbon pools at all the plots that are measured once a decade in California and in most other states. Based on the most recent FIA databases, GCOLE (NCASI, 2010) calculates carbon pools for different selections of plots. **Table 8** summarizes carbon pools in tonnes per hectare for the major forest types in California as well as for Douglas-fir forests in Oregon.

Figure 9 Live tree carbon v estimated organic soil carbon for California forest types

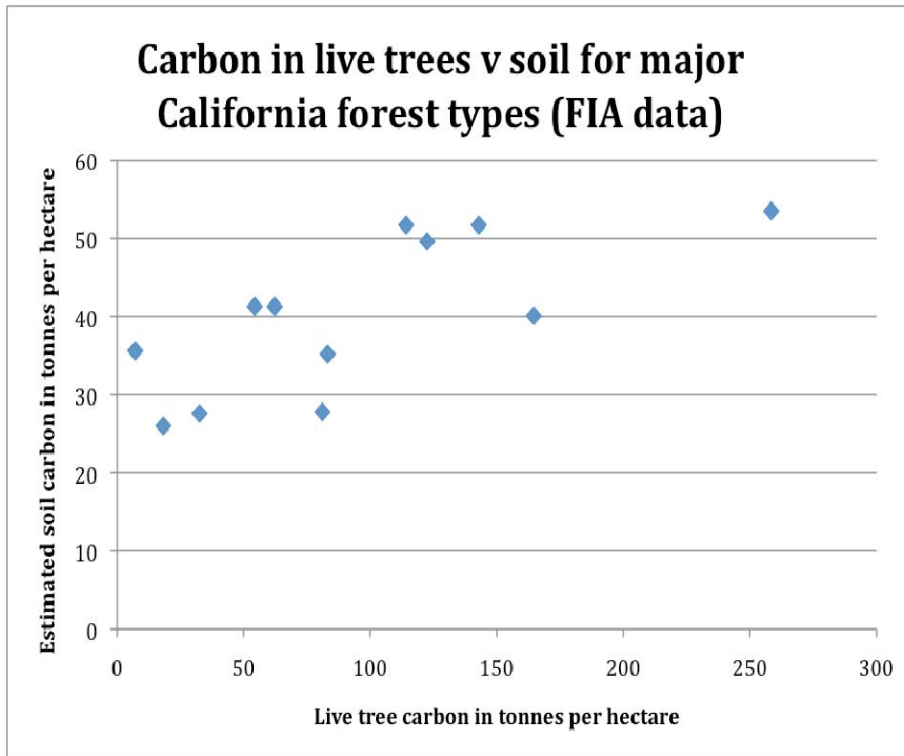


Figure 10 Forest floor carbon v estimated soil carbon for California forest types

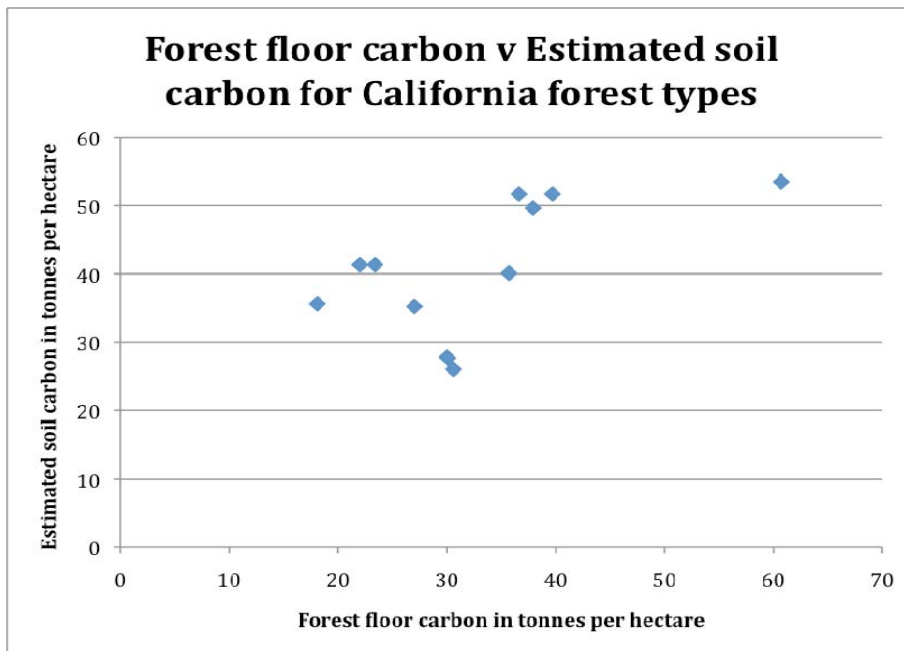
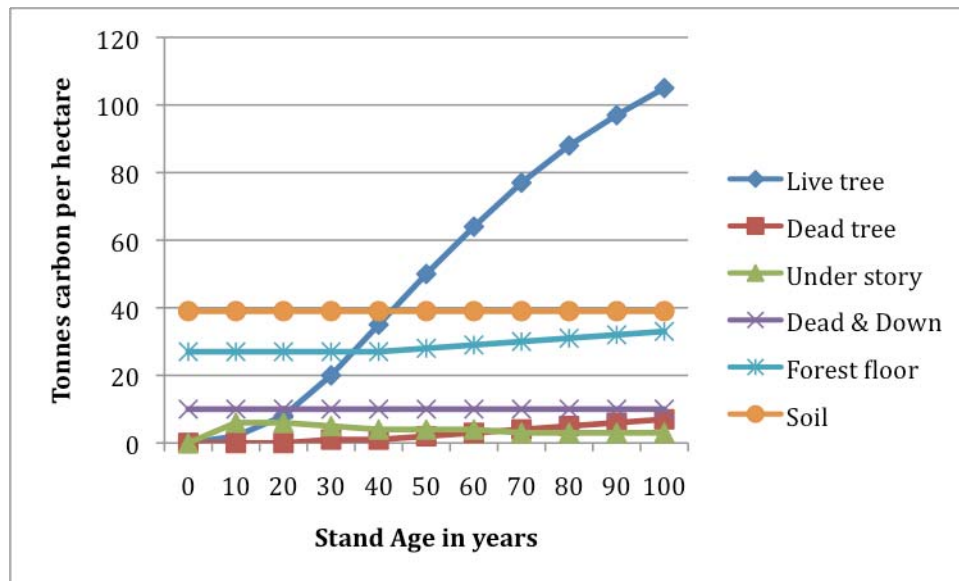


Figure 11 Estimated forest carbon pools over time based on FIA plots for California forests



Source: (National Council for Air and Soil Improvement, 2010)

Forest floor and forest soil carbon amounts were more consistent across forest types in California than the live tree based carbon stores. Compared to the common Douglas-fir forests in Oregon, forest floor carbon in Douglas-fir forests in California were lower than the both forest floor carbon levels on public and private lands. In Oregon, the most intensively managed and younger forests on private land had less than the half the live tree biomass of public lands but equal levels of soil carbon.

It would appear that soil carbon levels in California are more a function of the climate and underlying geology than of any temporal changes from timber harvesting. Changes in residue management and site preparation techniques could reduce carbon storage losses but large scale increases in soil C in forest soils at the project scale would be difficult to measure.

Further work on nutrient cycling and potential depletion from increased biomass removals from the sites should also organize the analysis of plots by the parent rock material and the soil type. Soil survey data will also contain useful information although soil survey data underneath dense forest cover is rarely as accurate as data from agricultural areas. From a nutrient availability perspective, it is the soil amount is important, not just concentration. A deeper, more massive soil contains more nutrients than a shallow soil with the same nutrient availability per unit mass. This is especially relevant in California as many of the more productive forest sites also have very deep soil profiles.

4.2.3 Increased woody biomass utilization in temperate forests of North America and Scandinavia

The majority of the published literature comes from regions outside of California where biomass intensive harvests for pulpwood are more common and where soil nutrient deficits have often been historically recognized. Therefore the published literature can present a biased perspective unless it is based on samples covering the full range of forest sites. The latest round

of the Forest Inventory and Analysis (FIA) data collection involves the collection of a soils data taken to the same national standard. This will allow comparisons over the 10-year return cycles by region, soils/geology, forest type, and silviculture. The initial round of data shown in **Table 8** illustrates some of the general trends for the major forest regions in the United States. Soils in the Pacific West (California, Oregon, Washington) have higher carbon and nitrogen concentrations than regions other than the Northeast. Western forests also have deeper nutrient profiles than Eastern forests but have fewer hardwood and nitrogen fixing trees. The average low and thin carbon and nitrogen concentrations for Southern forests aligns with the many empirical studies documenting the challenges of potential ‘nutrient mining’ from more intensive harvest regimes if they are not accompanied by fertilization.

Table 9 Average soil carbon and nitrogen concentrations in the upper 10 cm in forest soils measured by FIA crews

Region	Carbon percent	Nitrogen percent
Northeast	4.61	0.27
North Central	3.17	0.201
South	2.11	0.108
Interior West	3.14	0.141
Pacific West	3.86	0.173

4.2.4 Southern mixed hardwood forests

From a nutrient cycling perspective, the southern mixed hardwood forests are notable for frequent hardwood resprouting and high humidity levels that contribute to rapid decomposition rates. Together, these characteristics lead to a relatively resilient system even under more intensive harvesting practices, particularly in comparison to northeastern hardwood forests. This has been found in both short and long-term studies, though the majority of work in this system has focused on the effects of clearcutting with woody residue left onsite, and fewer studies have specifically considered the impacts of removing slash during harvest. Abbott and Crossley (1982) found that clear-cut mesic sites with woody residue had higher levels of potassium than either clear-cut xeric sites or the control sites after 1 year. However, levels of calcium, a less mobile element than potassium, did not vary between sites. Similarly, Clinton et al. (1996) found that forest floor nitrogen levels recovered nearly to pretreatment levels within 2 years of cutting and burning, and emphasized the importance of both an intact forest floor and woody debris to ensure both short and long-term contributions of nutrients. Elliot et al (2002) also detailed the relatively rapid recovery of these forests 20 years after conventional clearcutting, though calcium, potassium, and magnesium accumulations were found to be less than that of either nitrogen or phosphorus. Johnson and Todd (1998) specifically compared stem-only harvested sites and whole-tree harvested sites 15 years after treatment and found no signs of deficiency in calcium, potassium, or magnesium or decreased

biomass accumulation in the more intensively harvested sites, though there were higher soil and foliar concentrations of these nutrients in the stem-only harvested sites. Importantly, no differences in soil nitrogen, foliar nitrogen or phosphorus were found between treatments. The authors argue that from a carbon balance perspective, removing woody residue is therefore preferable to leaving it on site when the harvested products continue to store carbon while in use.

4.2.5 Southern loblolly pine plantations

Because the loblolly pine plantations of the southeastern US are its most important source of forest products, there has been much interest in understanding the consequences of utilizing their post-harvest slash for bioenergy. Studies have differed in their conclusions on the effects of removing post-harvest woody residue from these systems, which are characterized by high growth and decomposition rates. Carter et al. (2002) found that both whole-tree harvesting and stem-only harvesting temporarily resulted in significant declines in total soil carbon and nitrogen, but that both treatments recovered to pre-harvest levels within two growing seasons. Similarly, Vitousek et al. (1992) found that after five years, the patterns of nitrogen cycling in whole-tree harvested sites differed minimally from stem-only harvested sites; harvest intensity was observed to have less impact on nitrogen cycling than management practices such as site preparation. Scott and Dean (2006b) found that whole-tree harvesting had a negative effect on biomass accumulation after 10 years, particularly on soils that were relatively unproductive prior to harvest or that had low phosphorus levels. However, phosphorus addition in these systems was successful in increasing biomass. Their conclusions on the impact of woody residue removal on phosphorus cycling differ from those of conclusions of Johnson and Todd (1998) in southern mixed forests in areas where the soils were relatively more fertile.

4.2.6 Northern hardwood forests

Studies on the effects of different harvest intensities on soil nutrients in northern hardwood forests have reached conclusions that vary across the many forest and geological conditions. A number of studies concluded that soil calcium levels in these systems are particularly sensitive to woody residue removal, likely due to high calcium concentrations in oaks. In the case of phosphorus, the primary mineral source, apatite, is more readily weathered than the silicates with which it occurs, and its weathering rate is therefore underestimated by methods that assume congruent weathering, such as the sodium denudation rate. Since apatite is a calcium phosphate, the calcium is also potentially more available than previously assumed (Hamburg et al. 2003, Yanai et al. 2005). The most generous estimate of nutrient availability in soils would include the pool of weatherable nutrients. The pool defined as available to agriculture crops would probably be an underestimate, with the true pool size somewhere between these limits.

Forests in these systems are generally less productive than their southern counterparts and several studies have observed decreased nutrient availability in the years immediately following more intensive harvesting practices. For example, Hornbeck et al. (1990) found that whole-tree clearcutting in these forests caused losses in calcium, potassium, and nitrogen following harvesting and up to 3 years post-harvest; of these elements, nitrogen was predicted to recover most quickly and calcium most slowly. Calcium uptake at one of the study sites was

believed to be high enough to deplete the soil calcium pool to the detriment of future rotations, though the authors note that stem-only harvesting in this system would also have resulted in high calcium losses. Hendrickson et al. (1989) also found nutrient demands to be greater than nutrient inputs from precipitation 2 years post-harvest, and suggested that this could lead to growth declines. In contrast, both Adams and Boyle (1982) and Crow et al. (1991) found relatively rapid recovery in nutrient status in these systems post-harvesting, possibly due to clonal structures in successional vegetation or the confounding effects of wildfire. However, while Crow et al. concluded that whole tree harvesting resulted in only slightly higher nutrient losses than conventional harvesting, Adams and Boyle found that soil calcium and phosphorus levels were significantly higher in treatments that retained woody residue. Long-term effects of woody residue removal in this system remain unknown, though Aber et al. (1978) have predicted that nitrogen availability in the study watersheds in NH would be decreased by shorter rotation lengths and high intensity harvesting based on nutrient budgets in the system.

4.2.7 Scandinavian coniferous forests

Some of the most extensive work examining the potential effects of increased utilization of woody residue comes from Scandinavian forests, generally composed of Scots pine and Norway spruce. The final harvest of mature trees often results in net losses of phosphorus from the site, (Akselsson et al., 2008), but most studies from this region suggest that as a whole, nutrient losses from whole-tree harvesting are only minimally higher than losses from stem-only harvesting. Egnell and Leijon (1997b) suggest that this may be due to the fact that coniferous forests may be able to adjust their nitrogen use efficiency. As a result, the effects of whole tree harvesting on these relatively poorer soils may be less pronounced than in other systems. Where losses did occur, the nutrients with the highest losses appeared to be site-specific. Olsson (1996) found no general impact of removing woody residue on total soil nitrogen. Wall (2008) compared stem only harvesting and whole tree harvesting, and found that of N, P, Ca, Mg, and K, only K represented a major loss in comparison to the original pools of nutrients in the residue. Similarly, Rosenberg and Jacobson (2004) found relatively minor effects of whole tree harvesting on soil chemistry, but found Ca and Mg to be the nutrients with the highest relative losses. Olsson (1999) also detected reduced pools of K, Mg, and Ca after whole tree-harvesting, but generally minor impacts on soil nutrient status. In contrast, Saarsalmi et al. (2010) found significantly lower amounts of total soil nitrogen and calcium in whole-tree harvested sites, and modeling papers by both Hyvonen et al. (2000) and Mercanicova (2005) predicted higher nitrogen amounts in the forest floor of forests with logging residue.

4.2.8 North American boreal forests

Unlike the studies from similar Scandinavian forests, several early studies in this system estimated rates of nutrient export several times higher in whole-tree harvested sites than stem-only harvested sites. Perala and Alban (1982) estimated that up to three times as many nutrients were lost through whole-tree harvesting of mixed aspen-conifer forest due to the particularly high levels of nutrients in aspen bark; Freedman et al. (1986b) had slightly lower estimates in conifer and hardwood estimates ranging from 1-2 times the rate of nutrient loss through more intensive harvesting; calcium removals from the site through either method were considered to be high relative to the total pool of calcium available. However, with the exception of calcium,

only rotations of whole tree harvesting more frequent than 50 years would be a concern. More recently, Palavainen et al. (2004) found elevated levels of phosphorus in runoff from clear-cut forests, suggesting that even when woody residues are retained, those nutrients may not be available to vegetation. Thiffault et al. (2006) indicated that there was no difference in N and K cycling between whole-tree harvested and stem-only harvested sites, but that Ca concentrations were lower in whole-tree harvested sites post-harvest. Peng et al. (2002) modeled nitrogen dynamics under different harvest rotations and results suggest that rotations shorter than 30 years would have a significantly negative effect on productivity.

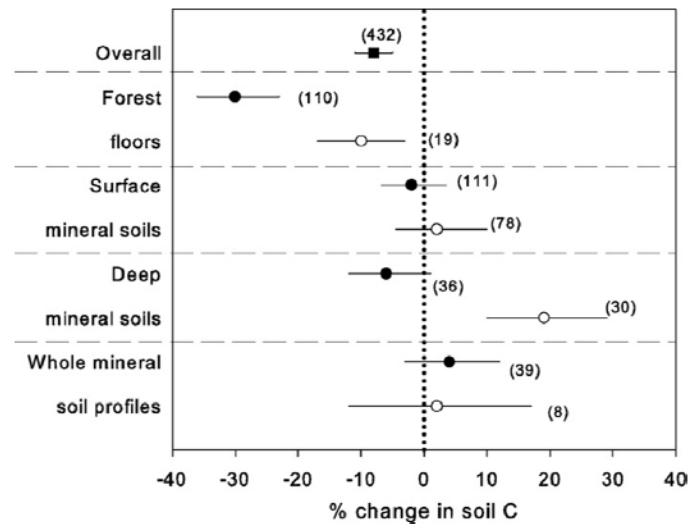
4.2.9 Pacific Northwest conifer forests

For the most part, studies in this system have found minimal impacts of removing woody residue post harvest, possibly because of large apparent nutrient capital in the soil. Little and Klock (1985) concluded that total nutrients removed in Douglas fir and western hemlock residue were small compared to that contained in the bole, and differences in harvest intensity amounted to only 1% of total site N. In the same forest type, Slesak et al. (2010) found that retention of woody debris of any amount had no detectable effect on nutrient levels in foliage or soil available N. Both Ares et al. (2007) and Slesak et al. (2009) found no effect of harvesting intensity on site productivity of Douglas fir plantations. Similarly, in a study of lodgepole pine plantations, Little and Shainsky (1992) found that the whole-tree harvest removal of nitrogen differed from that of bole-only removal by 3 percent, and by less than 1 percent for phosphorus and sulfur. Strahm et al. (2005) did find total N concentrations and leaching flux three times higher in stem-only harvested sites than whole-tree harvested sites, but found that it was still only a small part of the soil N pool.

4.2.10 General conclusions on increased woody biomass utilization in temperate forests

Research on the effects on soil nutrients by retaining woody residue after timber harvest has occurred across a wide variety of temperate forest types. Because of a lack of standardization in approach, individual studies measured different nutrients and different pools of nutrients, and only a few studies looked at long-term nutrient consequences. Taken together, the current body of knowledge suggests that most temperate forests are resilient, at least in the short term. This conclusion is supported by numerous meta-analyses (Johnson and Curtis, 2001; Morris, 1994) that have found, on average, few long-term effects of increased harvesting intensity. In Johnson and Curtis's global meta-analysis, they found whole tree harvesting caused a 6% reduction in A horizon C and N whereas leaving residues on site caused an 18% increase (compared to controls). The positive effect on soil C and N of leaving residues on site seems to be restricted to coniferous species. The increased interest in increasing forest carbon storage as a low cost offset to GHG emissions into the atmosphere has increased interest in how harvesting affects carbon stocks. A recent meta-analysis of 432 soil C response ratios from temperate forest harvest studies around the world concluded that overall forest soil C storage dropped by 8 +/- 3% (Nave et al., 2010). The losses were concentrated in the forest floor and were generally higher in hardwood forests and in sandy Spodosol soils. Nave et al. (2010) also suggested that alternative residue management and site preparation techniques can mitigate or negate these losses.

Figure 12 Soil C changes due to forest harvesting (from Nave et al. 2010)



4.3 Nutrient consequences of utilizing woody biomass from dedicated short-rotation plantations

Short-rotation woody crops, generally defined as high-density plantations of fast-growing tree species with rotation lengths of 1-15 years, represent an alternative renewable bioenergy source to increased woody biomass utilization. Younger trees of all species sequester more carbon than mature trees, and also place higher demands on site nutrients (Blazier and Hennessey, 2008). In combination with shorter harvest rotations, these nutrient demands have led to concerns about the long-term effects of this production methods on site productivity. Evidence from current studies suggests that this production method is intermediate between conventional longer-rotation forestry and conventional agriculture in its impact on soil nutrients. Good site and species selection and effective management practices, the negative soil nutrient consequences of short-rotation woody crops can likely be minimized (Mead, 2005; Ranney and Mann, 1994; Talbot and Ackerman, 2009; Tolbert et al., 2002).

The absolute effect of short-rotation woody biomass crops on soil nutrient status will be the balance between nutrient inputs from atmospheric deposition, litterfall, dead roots, and applied fertilizer and nutrient removals from harvesting, leaching, erosion, denitrification, and runoff (Heilman and Norby, 1998, Federer et al., 1989). Management decisions significantly affect this balance and the amount of nutrient additions required to offset soil nutrient depletion. Species with high litterfall can be expected to return significant nutrients to the soil when grown at rotations longer than 1 year and will decrease the need for nutrient addition (Ericsson, 1994); highest annual nutrient removals are associated with shorter rotation cycles (Adegbidi et al., 2001). Successive rotations at short intervals may result in reduced nutrient availability (Rubilar et al., 2005).

Site selection is also important in determining the relative impacts of these short-rotation woody crops on soil nutrients. From a long-term soil productivity standpoint, plantations

grown on former agricultural land are likely to compare favorably to a tillage-based system. Rotations longer than 1 year can be expected to return more organic material to the soil than agricultural crops, though decomposition rates of woody material will be slower (Baum et al., 2009). Soil erosion rates of short-rotation woody crops are also lower than row crops (Blanco-Canqui, 2010), and the nutrient status of soils of woody crops to compare favorably to previous agricultural crops (Uri et al., 2002). Similarly, most studies have suggested that short-rotation woody plantations are well-suited to marginal lands (Blanco-Canqui, 2010; Keoleian and Volk, 2005). However, one study of a poplar plantation grown on a former pasture of high native fertility showed initial losses of input of soil organic matter (Dowell et al., 2009) and suggests that quantifying initial nutrient status should be performed when selecting sites.

In addition to soil nutrient consequences of short-rotation woody crops, questions have been raised about nutrient runoff and the need to account for fossil fuel-based fertilizers in net carbon calculations. Studies have found that fertilized short-rotation woody crops lead to less nutrient runoff than fertilized row crops (Joslin and Schoenholtz, 1997; Thornton et al., 1998) and at least one study has found no absolute effect of nutrient addition to a willow plantation on groundwater (Aronsson et al., 2000), likely due to management practices that reduce soil erosion through longer rotation lengths and appropriately timed harvests (Kort et al., 1998). Life-cycle analyses that assume short transportation distances find that woody biomass crops are sustainable from an energy balance perspective (Volk et al., 2004) but are substantially improved through the use of non-fossil fuel based fertilizers (Heller et al., 2003; Park et al., 2004).

Together, these studies suggest that woody biomass plantations are a viable bioenergy option, though many uncertainties remain about the long-term effect of sustained nutrient demand from successive rotations. Careful site and species selection, management practices that minimize erosion and runoff, harvests that occur after litterfall, and longer harvest rotations will help to minimize the nutrient additions needed to maintain site productivity. However, fertilization will almost certainly be required, and subsequent rotations may require higher levels of nutrient additions.

4.4 Nutrient consequences of utilizing non-woody biofuels

Non-woody crops represent a bioenergy alternative to tree-based biomass. Most research to date has focused on the perennial grass switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus x giganteus*) (Sommerville, 2010) as a potential source of cellulosic ethanol, and the annual grass corn (*Zea mays*) as a potential source of both grain-based and cellulosic ethanol. Life-cycle analyses have suggested that both bioenergy sources are net carbon sinks (Adler et al., 2007), but management practices greatly affect the degree to which both species, but particularly corn, can be expected to offset greenhouse gas emissions. While both bioenergy crops require some degree of nutrient addition to maintain soil productivity, switchgrass has been observed to have higher productivity, higher nutrient recovery, and lower nutrient requirements than corn (Bransby et al., 1998; Keshwani and Cheng, 2009; McLaughlin and Walsh, 1998). The nutrient consequences of producing both perennial and annual grasses need to be considered (Simpson et al., 2008).

Perennial grasses, like short-rotation woody biomass crops, experience lower rates of erosion, soil organic matter loss, and runoff than annual crops (Sanderson and Adler, 2008). Switchgrass requires lower nutrient inputs than corn, possibly due to evolution under low-N conditions (Thomason et al., 2004), and its efficiency in energy conversion has been estimated to be up to 15 times higher (Mclaughlin and Walsh, 1998). As in all systems that are continuously harvested, input rates of soil organic material are generally not adequate without some level of nutrient addition, and even addition may not offset a long-term decline in soil organic carbon (Reeves, 1997), particularly when harvested more than once a year (Parrish and Fike, 2005; Reynolds et al., 2000). However, when harvested no more than once a year with nutrient addition, effects on soil productivity are expected to be minimal (Thomason et al, 2004).

Increasing amounts of acreage have been put under corn production in recent years for potential use in both grain-based and cellulosic ethanol. As a result, both the nutrient consequences of producing corn as well as the effects of removing corn stover need to be considered. Despite requiring higher rates of nutrient inputs than switchgrass, corn-based ethanol is still expected to offset greenhouse gases (Wilhelm et al., 2004) but retention of some residue on site is key to maintaining at least previous levels of soil productivity. Crop residue removal reduces pools of both soil macro- and micronutrients through direct removal of organic material and higher rates of soil organic material through runoff, though short-term productivity is not always affected (Blanco-Canqui and Lal, 2009). Cover crops and rotations with nitrogen fixing crops can help to minimize soil nutrient losses, as can choice of sites that minimize soil erosion (Gregg and Izaurrealde, 2010). Even with recommended fertilizer and land conservation measures, corn acreage can be a major source of N loss to water (Simpson et al., 2008), and treating increased nitrate concentrations may indirectly lead to higher energy consumptions (Twomey et al., 2010).

Together, these studies suggest that perennial grass- can be net carbon sinks, but that corn production can be expected to have a more negative effect upon soil productivity unless significant amounts of fertilizer are applied. Compared to tree-based biomass, C4 grasses have higher biomass production rates per acre and can be harvested in much shorter rotations. A major advantage of tree-based biomass from natural forests is that the costs of production are typically ascribed to the more valuable sawlogs and pulplogs so that that production costs per ton of biomass can be low.

4.5 Conclusion

Compared to other forests across the United States, California's forests generally have higher nutrient levels and lower evidence of 'nutrient mining' from historical agricultural uses or more intensive harvesting and removal of forest biomass. Forest soil nutrient status has been widely sampled for all forest types and continues to be sampled at the national scale by the US Forest Service Forest Inventory and Analysis (FIA) program and locally by land managers. Site to site variation often overwhelms and forest-type or management history patterns. High intensity short rotation biomass plantations will present a very different situation than natural forests and will require more monitoring of soil nutrient status to maintain productivity. For all forest

types in California, the relationship of soil nutrient losses to wildfires and potential harvest treatments to reduce wildfire impacts remains an area where only limited research results exist.

CHAPTER 5: Soil Productivity and Water Quality Consequences of Biomass Harvests

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5.1 Introduction

As with any forest management or forest conversion process, assessing the long-term sustainability with respect to all forest resources is needed. Ensuring long-term sustainability of biomass harvesting requires maintaining soil productivity and minimizing offsite impacts (Fox, 2000). The aims of this review are to characterize the risks posed by additional biomass utilization on soil and water resources and to provide recommendations for future research. Incentives for biomass harvesting are expected to promote forest management activities that have historically not produced net revenue or value and therefore have been limited in scope or frequency of application. Logging residue and small-diameter trees, which have generally been retained onsite, may be removed. Increasing the intensity and frequency of mechanical impacts and nutrient removals can have consequences for water quality, soil productivity, and future growth of both the trees and other vegetation. All of these potential impacts need to be compared to the potential impacts of hotter and more severe wildfires that could occur without the additional biomass harvest.

5.2 Biomass harvest effects on soil

5.2.1 Physical compaction

The additional removal of forest biomass that does not go out on the sawlog truck may involve no additional in-forest machinery use if done with a feller-buncher that brings whole trees to the landing. In these cases, there will be no additional soil compaction or water quality impacts compared to what was done without the removal of woody biomass from the site. In other cases, the removal of forest biomass during a commercial harvest will involve an additional vehicle movement in the forest to gather the tops, branches, small trees that are left in the forest with or without an additional step of piling them. In these 'two pass' systems, the vehicles will be carrying less weight than occurs when the larger sawlogs are moved. Woody biomass produced in commercial or pre-commercial thinning operations are often masticated in place and can usually be done with lighter weight machinery than is required when full sized sawlogs are harvested. Improvements in technology and practices over the past few decades have significantly reduced the negative impact of harvesting on soil and water resources. Soil compaction reduces soil porosity, which influences gas exchange, nutrient movement, water storage, soil microorganisms, and root growth (Poff, 1996). The potential for compaction is determined by soil attributes like composition (including rock and organic matter content), texture, moisture, and protective cover (Page-Dumroese et al., 2010). There is some concern that biomass harvesting will increase the frequency of stand reentry, resulting in cumulative impacts to soils. Recovery of pre-harvest soil bulk density can take decades. On soils with granitic and

volcanic parent materials in west central Idaho, Froehlich et al. (1985) found that skid trail compaction was still evident 23 years after harvest. Soil compaction resulting from salvage logging on steep slopes could still be measured 70 years later (Landsberg et al., 2003). Amaranthus and Steinfeld (1997) investigated the soil compaction effects of thinning small-diameter (25-50 cm diameter at breast height) Douglas-fir in southern Oregon. Soil bulk density was measured after one, three, and six passes with a small tractor. Bulk density had increased by 7 percent after the third pass, but did not increase significantly thereafter. This small total increase in skid trail compaction may be explained by low soil moisture content at the time of operations, the small size of harvested trees, small size of the harvesting equipment, as well as natural soil characteristics. Other studies have similarly found that most soil bulk density impacts are observed within the first few equipment passes (Cafferata, 1980; Froehlich, 1978; Han et al., 2009).

While few studies have investigated the soil compaction effects of thinning in western forests, research indicates that impacts are largely confined to equipment trails (Page-Dumroese et al., 2010). McIver et al. (2003) compared soil compaction and displacement between two small-diameter tree harvest systems. The mechanical harvest methods included a single-grip harvester coupled with extraction by either a forwarder or a skyline harvesting system. Very little of the harvest area (1.4%) was affected by soil compaction, and compaction was limited to landings and equipment corridors. Soil displacement was more widespread, however, and was often observed adjacent to travel corridors. Onsite woody biomass retention can be used to alleviate the impacts of mechanical harvesting equipment on soils. When limbs and tree tops are positioned on equipment travel corridors as a protective mat, exposure of mineral soil and compaction are reduced (Hartsough et al., 1994; Page-Dumroese, 1993). Whole tree harvesting utilizes small stems and branches rather than leaving them on site for soil protection. Page-Dumroese (1993) observed the protective soil effects with dispersed organic matter retention. The author compared soil compaction with varying levels of biomass removal. Harvests were bole only, whole tree, and whole tree with surface organic matter removal. Harvesting was conducted without impacting study plot soils. Each harvest treatment site was then subjected to a compaction treatment: none, moderate (two passes with a Grappler log carrier), or extreme (four passes with a D-6 Caterpillar tractor). The extreme compaction treatment increased soil bulk density at the surface (0-4 cm depth) for all harvest treatments. However, the high levels of surface organic matter in the high retention treatment protected the lower soil layers from compaction effects, while the other retention treatment plots experienced increased soil bulk density down to at least 16-20 cm. Han et al. (2009) compared cut-to-length and whole tree harvesting impacts on soil compaction. When soil-moistures were high, both harvesting methods resulted in substantial compaction in the equipment tracks. The cut-to-length system compacted soil between the vehicle tracks less than whole-tree harvesting.

Beyond minimizing compaction within equipment trails, many authors promote the use of well-planned systems of designated equipment corridors in order to limit the total area disturbed during harvest (Moghaddas and Stephens, 2008; Page-Dumroese et al., 2010). On flat terrain in northeastern Washington, commercial thinning increased soil bulk density on vehicle trails by 3-15% (Landsberg et al., 2003). When designated equipment trails were far apart (40m),

deviation from trails was more common. On steep slopes, equipment and compaction were more restricted to designated corridors; after harvest, the total area comprised of trails was reduced from 17-57% to 6-27% (level vs. steep terrain).

Utilizing historic skid trails, when available, can help to minimize cumulative soil disturbance from multiple harvest entries. Thinning treatments conducted for the Fire and Fire Surrogate (FFS) study in the Sierra Nevada utilized pre-existing skid trails (Moghaddas and Stephens, 2008). The trails had been established during two commercial harvests that occurred during the 20 years preceding the FFS study. Thinning activities did not increase skid trail soil bulk density.

5.2.2 Mineral soil exposure and soil erosion

Slope steepness, soil characteristics and cover, and rainfall intensity each affect soil vulnerability to erosion (Grigal, 2000). When management activities expose mineral soils, the potential for soil erosion is enhanced. As with compaction, landings, roads, and equipment trails are the primary contributors to surface erosion caused by harvesting (Brown and Krygier, 1971; Fredriksen et al., 1975). Roads and skid trails result in substantial increases in surface erosion relative to background rates (MacDonald et al., 2004). As best management practices and harvesting equipment have improved over time, the documented results from older operations do not necessarily apply to current operations.

As with soil compaction mitigation, limiting the areal coverage of equipment corridors is recommended for limiting post-harvest soil erosion. In British Columbia, the rate of surface soil erosion following merchantable bole-only harvest was doubled when harvest included removal of some additional unmerchantable boles which had been felled during the commercial harvest (Commandeur and Walmsley, 1993). The biomass harvest in this study involved additional areal extent of skid trails and skid roads, and greater soil damage in the form of deep gouges. Site preparation burning that followed harvesting undoubtedly contributed to mineral soil exposure and erosion.

Though the most significant compaction impacts during timber harvest are observed during the first few passes of harvesting equipment, mineral soil exposure may increase with repeated passes. Amaranthus and Steinfeld (1997) observed that although litter cover was largely retained after three passes with a small tractor, substantially more mixing of bare mineral soil and litter could be seen after the sixth trip.

Forest harvesting impacts on soil loss is often addressed within the context of stream sedimentation and water quality. Few studies have measured onsite erosion after harvesting directly. Instead, most assess sediment yields that are collected downslope of the harvest operation. Soil loss and water quality impacts are discussed later in this review.

5.2.3 Forest soil carbon storage and forest management

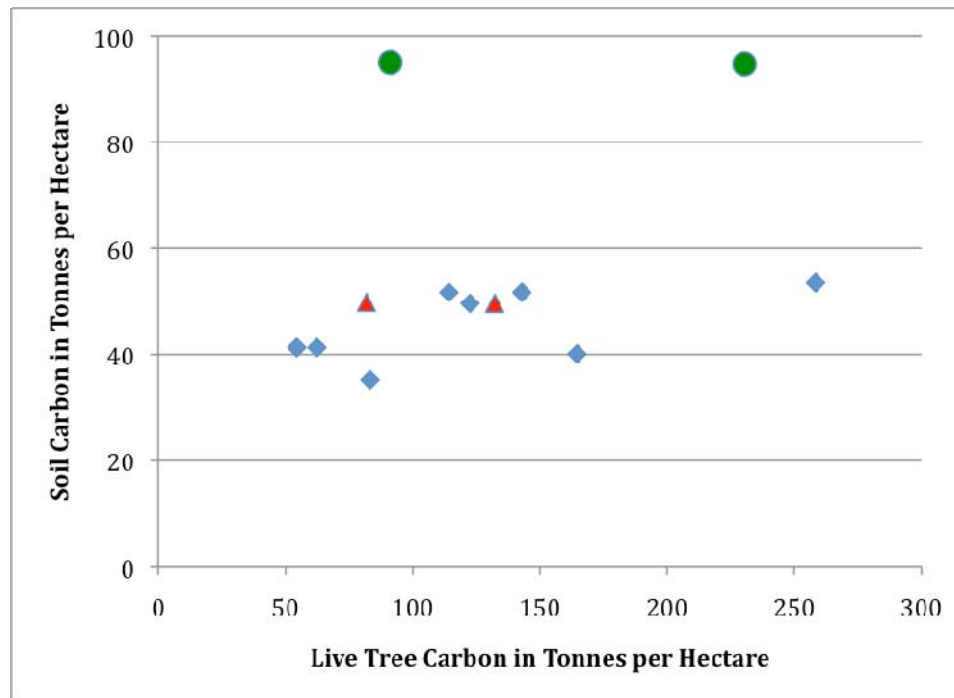
The potential effect on forest soil carbon storage from different approaches to forest management has gained increased attention with the international interest in improving our understanding of terrestrial carbon storage and changes in the rates of increase or decrease. Forest soil carbon is rarely a limiting nutrient for tree growth. While soil carbon is relatively

straightforward to measure, the challenges of accurately measuring the CO₂ emissions from fine roots and microbial decomposition are significant. Full carbon flux measurements of forest soils under different management regimes are relatively rare, illustrate a wide range of conditions, and have not shown a universal pattern to date.

Forest floor carbon increases with the age of trees, dropping branches, and mortality of less competitive trees. Soil carbon storage appears to be weakly correlated with above ground live tree biomass but soil CO₂ fluxes are strongly influenced by fine root and microbial respiration rates of the trees and other vegetation. At the landscape level, it has proved extremely difficult to track belowground C storage and changes in CO₂ fluxes (Liski et al., 2003; Luysaert et al., 2010; Ryan, 2010). Aggregated post-disturbance data from worldwide FLUXNET forest sites show an increase in CO₂ flux in the initial decade following disturbances (Baldocchi, 2008), but it is difficult to disaggregate below ground, forest floor, and standing tree fluxes. Study in pine forests in Mississippi found a small drop in belowground C pools after harvesting with evidence of fairly fast rebound. (Schilling et al., 1999). Harvesting of live trees reduced fine root transpiration and CO₂ flux in Northern Hardwood forests (Peng and Thomas, 2006). Researchers in other Northern Hardwood forests found little change in CO₂ flux with harvesting in sugar maple stands (Stoffel et al., 2010). When dead wood and soil carbon were modeled together, shortening rotations from 120 years to 60 years decreased total carbon storage in the forest while increasing harvested carbon (Johnson et al., 2010).

Figure 13 illustrates live tree and soil carbon estimates from the FIA database as calculated the GCOLE online carbon estimator (National Council for Air and Soil Improvement, 2010). The diamond data points in blue are the average for the major conifer forest types in California. The triangular data points in red are the average of 248 Mixed Conifer plots on private lands on the left and for 905 plots on US Forest Service on the right. The circular plots at the top are the averages for 599 Douglas-fir plots on private lands on the left and 454 plots on US Forest Service land on the right in Oregon. The two main conclusions are 1) that soil carbon concentrations appear to have a negligible relationship to different approaches to forest management (private lands in both states are harvested on shorter rotations and more commonly with even aged systems) and 2) that differences in soil carbon concentrations within California are far less than the differences between California and Oregon. As repeat data is collected at FIA points at ten year intervals (Christensen, 2008), it should be possible to more clearly identify trends and relationships. Given the current research findings and databases, it would appear that the best working hypothesis is that soil carbon amounts are only weakly related to forest management.

Figure 13 Live tree v soil carbon for conifer forest types in California (triangle and diamonds) and Oregon (circles)



5.3 Site productivity

The direct impacts of timber harvest on soils, such as reduced porosity, increased bulk density, and mineral soil exposure can impact future site productivity. Soil compaction may improve (Ares et al., 2005; Powers et al., 2005; Sanchez et al., 2006), reduce (Carter et al., 2006; Powers et al., 2005; Sanchez et al., 2006), or have no effect on tree growth (Carter et al., 2006; Powers et al., 2005). Gomez et al. (2002) observed all three scenarios in the Sierra Nevada, and determined that soil texture was a strong determinant of harvest impacts on early volume growth. Compaction of sandy soils, by reducing large pores sizes, can improve water holding capacity (Ares et al., 2005), improving tree growth.

Removal of site organic matter and its associated nutrients may also adversely affect future productivity if site nutrient status is not managed. The long term sustainability of forest biomass harvesting is governed in part by complex relationships between harvesting and site nutrients which include the magnitude of nutrient removal during harvesting, the rate of nutrient cycling, and the frequency of harvest entries (Kimmins, 1976). Because nutrient concentrations are highest in tree branches, twigs, and leaves than in boles, nutrient removal is disproportionately higher in whole-tree relative to stem-only harvest (Freedman et al., 1986a; Kimmins, 1976; Mann et al., 1988). Increased economic incentives for biomass harvest will promote removal of small diameter trees, woody debris, and tree crowns that are now generally retained onsite.

Evidence of soil productivity decline is difficult to attain, requiring assessment of vegetation growth independent of the potentially confounding influences of climate variability, competition (Mann et al., 1988), variable stocking levels, and disturbance (Powers et al., 1990).

5.3.1 Whole-tree harvesting and whole tree plus forest floor harvesting

A coordinated effort to elucidate forest management impact on productivity, the North American long term soil-productivity (LTSP) experiment (Powers, 1991), includes evaluations of biomass removal. Comparisons of whole-tree harvest with more and less intensive biomass removal systems help to clarify the impacts of removing nutrients contained in organic matter. Ares et al. (2007), an LTSP study, followed Douglas-fir seedling growth after biomass harvesting, which included 4 levels of organic matter removal from bole-only to whole-tree harvest with coarse woody debris removal. Biomass removal had a slight though significant effect on early growth. After 5 years, the whole-tree and whole-tree plus legacy wood removal treatments had reduced stem volume by 5 percent compared with the stem-only removal.

A study of whole-tree and stem-only harvesting in southern U.S. loblolly pine plantations Scott and Dean (2006a) found an average 18% reduction in early biomass production after 7-10 years of growth on most sites. This decline in productivity was strongly related to pre-harvest site productivity and soil P concentration. Small fertilizer additions ameliorated the effects of organic matter removal during whole-tree harvest. Others have similarly found that fertilizer use can reverse the effects of nutrient removals of intensive biomass harvest (Carter et al., 2006; Fox, 2000; Smith et al., 2000). Retention of needles during whole-tree harvest has also been shown to delay the negative growth impacts of whole-tree harvest (Egnell and Valinger, 2003).

While physical soil damage caused by harvesting may be evident early in stand growth (Eisenbies et al., 2005), long-term research is often needed to distinguish more subtle effects of nutrients removal. In a Scots pine plantation, Egnell and Valinger (2003) did not discern a significant reduction in total basal area until 15 years after stand establishment. Divergences in volume growth could only be detected after 9 years of growth, while height differences were seen only during the study's final period, 21-24 years after planting. On productive LTSP sites in Louisiana and North Carolina, loblolly pine stands reached crown closure within 10 years after planting. Intensive biomass removal treatments had no significant impact on stand volume after 10 years of growth. Plant-available P was reduced through biomass removal treatments on these P-limited sites, and the authors noted that it may yet be early to observe the growth effects of nutrient removal (Sanchez et al., 2006).

The sustainability of whole-tree harvest is likely site-specific, and related to initial productivity. In New Zealand, Smith et al. (2000) compared the site productivity impacts of stem-only harvest with slash retention to whole-tree harvest with and without forest floor removal in *Pinus radiata* plantations. The effects of biomass removal varied by location based primarily on-site quality and climate. Forest floor removal negatively impacted diameter growth, but only on N-depauperate sandy soils.

Whole-tree harvest can have large effects on future site productivity. On a nitrogen limited site in Sweden, Egnell and Valinger (2003) found that whole-tree harvest reduced woody biomass

production by 20% compared with conventional stem-only harvest after only 24 years of growth. Site index, as measured by height of the dominant trees at a given age, was reduced in this study by 2 m at 100 years from 24 m.

5.3.2 Thinning

Biomass harvesting for energy production can be accomplished through partial thinning as well as whole-tree clearcutting (DeLuca and Zouhar, 2000). While the soil productivity consequences of whole-tree clear-felling are well-known due largely to recent efforts exploring long-term sustainability of harvesting (e.g. (Powers et al., 2005), a recent review (Page-Dumroese et al., 2010) determined that assessments of thinning impacts across the wide range of western forest conditions are limited. Thinning operations are generally expected to incur less physical damage to soils than stand removal harvests when the same types of technology and practices are used. Harvesting equipment, operator decisions, slash retention, and soil characteristics will all influence soil impacts of thinning. The efforts taken to minimize soil impacts during clear-cutting should be extended to thinning operations. Best management practices (BMPs), such as retaining logging slash on site and restricting harvesting when soil moistures are high, should continue to be utilized. Sites with inherently nutrient-limited and coarse-textured soils are at greatest risk of diminished site productivity due to biomass removal (Page-Dumroese et al., 2010).

Given the challenge of discerning effects of even the most extreme biomass removals (e.g. (Egnell and Valinger, 2003), it seems likely that any reduced long-term productivity caused by partially thinning will be difficult to observe experimentally. As an example, Egnell and Leijon (1997a) established a comparative study of the productivity impacts of whole-tree and stem-only thinning in Sweden. Norway spruce and Scots pine stands chosen to represent a range in site quality were thinned to 21-27% basal area. After 10 years, no significant effect of thinning method on basal area increment could be discerned. The authors noted that long-term effects might differ from the apparently insignificant impacts of nutrient removal during whole-tree thinning.

5.3.3 Stump harvesting

Stump harvesting, while not commonly practiced in California, is elsewhere conducted for biomass energy production, site preparation, and treatment of root rot fungi. Economic incentives for biomass utilization could promote increased use of this treatment type. Hope (2007) observed increases in soil bulk density immediately following stump harvesting treatment, but these effects were short-lived, and bulk density had recovered 9 years after treatment. The impacts of stump removal on tree growth in this study were not pronounced. Post-treatment lodgepole pine and spruce growth were generally not different from the untreated control, except when scarification followed stump removal, lodgepole height growth was enhanced.

Stump removal can successfully reduce future root rot mortality. Studies of stump harvest for treatment of *Phellinus weirii* (Murr.) in the Pacific Northwest (Thies et al., 1994; Thies and Westlind, 2005) indicate increased seedling survival with harvest. A meta-analysis by Vasaitis

and others (2008) found a positive correlation between stand productivity and stump removal from sites infected with root disease through increased height increment and volume growth.

For a more thorough discussion of the ecological impacts of stump removal, see the recent review by Walmsley and Godbold (2010). In summary, with regard to productivity, the results of analyses of the impacts of stump harvest are highly variable, and appear to indicate that effects differ with soil type and tree species considered. Most relevant studies have considered stump removal treatment in stands impacted by insect infestation or disease. There has been little research on the effects of stump harvest in healthy stands, and gains in productivity with treatment are therefore often likely the result of reduced disease and insect impacts.

5.4 Water resource impacts

5.4.1 Sedimentation

Stream sedimentation has been identified as the most serious and widespread water degradation problem associated with timber harvesting (Brown and Binkley, 1994; Croke and Hairsine, 2006). Increased stream turbidity due to sedimentation can reduce feeding and spawning success, reduce photosynthesis by algae, and degrade drinking water quality (Brown and Binkley, 1994). Even when carefully located, constructed and maintained, roads are responsible for most of the sediment associated with logging operations (Beschta, 1978; Grayson et al., 1993). The proper implementation of best management practices designed to avoid offsite impacts of traditional forestry operations can effectively and dramatically reduce watershed impacts (Binkley and Brown, 1993; Brown and Binkley, 1994; Croke and Hairsine, 2006; Grayson et al., 1993; Rice and Berg, 1987; Shepard, 2006). Riparian vegetation buffers have been shown to limit or eliminate the delivery of sediment to stream systems after harvesting (Barling and Moore, 1994; Haupt and Kidd, 1965). A buffer strip 30 feet wide entirely prevented sediment from entering stream channels after logging on the Boise Basin Experimental Forest, while an 8 foot buffer allowed significant sediment delivery to the stream channel (Haupt and Kidd, 1965).

Most previous research addressing stream sedimentation following timber harvest focuses on stem-only clear cutting. The sediment production impacts associated specifically with biomass harvesting techniques will result from decreased onsite biomass retention or partial removal treatments like understory thinning. Few studies address the relative influence of whole-tree and stem-only harvest on sediment yield. Logging slash left behind after harvesting has been shown to reduce the rate of sediment delivery to stream channels (Guy et al., 1993), and whole-tree harvesting may increase stream turbidity when riparian buffers are not maintained (Hornbeck et al., 1986). Investigations of thinning effects are also rare, and most of these address the impacts of partial removal within riparian corridors.

Cram et al. (2007) determined that slope steepness contributes to the likelihood of soil damage during forest thinning. Soils on steep slopes (26-43%) were more vulnerable to damage from logging equipment. When soils sustained only low to moderate disturbance, post-thinning sediment yield was not enhanced relative to untreated sites. Riparian vegetation buffers are known to be effective in shielding streams from sediment delivery from upland harvesting (Barling and Moore, 1994; Lakel et al., 2006). However, the sediment produced by partial

thinning, even in the absence of riparian buffers, may be negligible. Kreuzweiser and Capell (2001) compared three levels of selective harvesting in a hardwood forest in the Upper Great Lakes region. Single-tree, shelterwood, and diameter-limit mechanical harvesting removed 40, 50, and 80-90% of canopy cover, respectively, and no riparian buffers were maintained. For the selection and shelterwood treatments, sediment inputs were strongly linked to roads within the study area; harvesting activities themselves did not contribute measurable sediment inputs. Sediment yields in the high-disturbance diameter-limit treatment units, however, were not related to roads. Instead, sediment inputs were the result of harvest activities. The authors concluded that when selection harvesting of up to 50% canopy removal is carefully conducted, riparian buffers might not be needed to protection streams from sediment delivery. Thinning within riparian corridors generally results in some sediment inputs. Hemstad et al. (2008) observed a 15% increase in fine sediment delivery following riparian thinning in Minnesota. In a mixed boreal forest, riparian thinning reduced basal area by 10-28% (Kreuzweiser et al., 2009). Treatments were coupled with clear cutting of upland areas. Inorganic fine sediment yields increased 3-5 times for one treatment site, though logging did not increase delivery of very fine or organic sediments, and did not impact sedimentation from the other two treatment units

Too few studies exist concerning the impacts of biomass harvesting techniques with modern technology to draw any strong conclusions regarding sediment yields. Even if partial thinning activities have only slight impacts on stream sedimentation, maintenance of riparian buffers and other best management practices are still necessary to mitigate the impacts of roads and landings that are typically the largest sources of project-related sedimentation.

5.4.2 Nutrient concentrations

Binkley and Brown (1993) reviewed the literature regarding forest management effects on stream water nutrient concentrations. In general, forest harvesting was not shown to degrade water quality through altering nutrient concentrations. A brief summary of their review is provided.

High levels of organic matter and high water temperatures reduce levels of dissolved oxygen. While few studies have investigated harvest impacts, generally only large additions of logging debris are capable of significantly depressing oxygen concentrations. Salminen and Beschta (1991) (Binkley and Brown, 1993) reviewed the literature on the timber harvest impacts to stream water concentrations of phosphorus. Generally, timber operations did not significantly increase phosphorus concentration. However, they noted that slash burning could temporarily alter stream water concentrations of phosphorus. Binkley and Brown noted that water degradation from increased stream nitrate ion concentrations was rare, though it has been more frequently documented in the northeastern United States (Dahlgren and Driscoll, 1994; Hornbeck et al., 1986). Stream water nitrogen concentrations were not impacted by timber harvesting in the West. Nitrogen fertilization did not degrade water quality in the Pacific Northwest and British Columbia, while it was noted as a potential problem in some sites in eastern U.S. forests.

5.4.3 Stream temperature

Temperature regulates a number of stream functions including the rate of organic matter decomposition, chemical concentrations, and aquatic invertebrate metabolic processes (Knight and Bottorff, 1981). Many studies have demonstrated the relationship between factors affecting fish species success, including physiological processes (Beschta et al., 1987; Cech et al., 1990), species competitive interactions (De Staso and Rahel, 1994; Taniguchi et al., 1998), and distribution and abundance (Ebersole et al., 2001).

By increasing exposure to solar radiation, forest harvesting increases mean and maximum stream temperatures (Brown and Krygier, 1970; Johnson and Jones, 2000; Macdonald et al., 2003) and diurnal variation (Johnson and Jones, 2000; Macdonald et al., 2003). These effects may be long-lived (Johnson and Jones, 2000) and thermal recovery depends on vegetation response following harvest. It is widely recognized that maintenance of riparian vegetation buffers during clear cutting moderates stream temperature increases (Beschta et al., 1987; Brown and Krygier, 1970; Jackson et al., 2001).

As with sedimentation, research concerning the impacts of thinning is typically conducted within the riparian corridor rather than upland. Macdonald et al. (2003) considered the impact of variable retention harvesting within riparian corridors on stream temperature. The level of vegetation retention initially correlated well with post-harvest stream temperature change. Streams experienced only a 1-2 °C increase following high-retention treatment relative to unharvested units. However, substantial windthrow following harvest reduced standing tree cover in the high retention units, and 4-5 years after treatment, stream temperatures were elevated by 4-6 °C regardless of treatment.

When streamside vegetation is removed, logging slash retention has been shown to mitigate the effects of harvest on stream temperature when large woody biomass provides shade (Jackson et al., 2001; Kibler, 2007). However, these ameliorative effects will diminish as in-stream woody materials decay.

Most research on stream temperature and harvesting has focused on traditional harvest methods where harvest intensities immediately adjacent to streams are constrained and non-commercial logging residues are left on site. The ameliorative effects of riparian buffers are well-established, although some streams have occasionally experienced significant temperature increases after clear cutting even when riparian vegetation was maintained (Moore et al., 2005). Increased biomass utilization of harvest residues would not alter the post-harvest shade levels and there is only a limited probability that the collection would significantly impact stream temperatures.

There is some debate over the relationship between clear-harvesting and subsurface flow temperatures (Moore et al., 2005). The delivery of cold ground water to streams moderates the temperature increases caused by shade removal. Reduced transpiration and interception following harvest could increase groundwater quantity, counteracting the effects of diminished shading. Alternatively, the temperature of shallow groundwater, which is linked to soil temperature, could increase due to reduced canopy cover and increase stream temperature in

turn (Brososke et al., 1997; Moore et al., 2005). This debate is far from settled, however, and does not yet directly address the influences of harvesting technique.

5.4.4 Water yield

The influence of timber harvest on water yield has received substantial treatment in the literature since the 1950s (Bosch and Hewlett, 1982). As a result, the direction and magnitude of water yield response to changes in forest cover is fairly predictable (Bosch and Hewlett, 1982). Forest clearing increases stream flow approximately in proportion to the catchment area harvested in clear cut units. The impact of selection harvesting would theoretically be linearly related to the evapotranspiration of the removed biomass as long as fast growing shrubs did not quickly reoccupy the sites. These effects diminish over time as vegetation recovers (Hibbert, 1966; Rice et al., 2004)

Previous reviews of paired catchment studies suggest that a minimum of approximately 20% of catchment basal area must be removed in order to achieve a perceptible increase in water yield (Bosch and Hewlett, 1982; Stednick, 1996). The response of stream flow to changes in vegetation cover is most influenced by precipitation, post-harvest vegetation growth, and proportion of the vegetation removed. The magnitude of water yield response is greater where precipitation levels are high, however, vegetation regrowth is more rapid in these locations, and the effect of harvest on water yield is relatively ephemeral (Bosch and Hewlett, 1982).

Keppeler and Ziemer (1990) evaluated stream flow data after selective harvesting of 67% of watershed tree volume in northern California. Low flow volume was enhanced by harvesting during the first seven years after harvest by an average of 29%, though this increase was only significant for four of the seven years. Total annual flow increases of 15% on average were detected for 10 years after harvest.

Partial and clear cutting may have similar effects on stream flow. Troendle and King (1987) compared the relative impacts of group selection clear-cutting and partial cutting of large trees (≥ 17.8 cm dbh) in central Colorado within the cold snow zone. Approximately 40% of basal area was removed in each treatment. Partial cutting substantially increased winter snowpack through reduced interception, increasing water yield to a similar degree as in the clearcut harvests.

Most experimental research has focused on clearcutting or partial removal of overstory trees rather than understory thinning (Troendle et al., 2010). Low thinning is unlikely to achieve the requisite 20% basal area reduction that has elsewhere been identified as the minimum necessary to produce a detectable hydrologic impact. Further, it is generally expected that hydrologic recovery after partial removal will be rapid because remnant vegetation will quickly occupy vacated growing space. As a possible exception, partial thinning in the snow zone can potentially enhance stream flows significantly, and these effects may be long-lasting (Troendle and King, 1987). For lower elevation dry forest types, increases in water yield are expected to be minor and ephemeral (Troendle et al., 2010).

5.5 Indirect effects of biomass harvesting on soils and water quality

One of the desired goals of many forest biomass harvests is to reduce the intensity or extent of wildfires that enter the harvested area after the operation. Wildfires can dramatically increase soil erosion rates (Cannon et al., 1998; Helvey et al., 1985) by exposing bare mineral soil, consuming soil organic matter, removing natural sediment dams, and increasing hydrophobic properties. Impacts to water quality include increased water temperature (Amaranthus et al., 1989), peak flows (Robichaud et al., 2000), and stream sedimentation (Ice et al., 2004; MacDonald et al., 2004). On the Eldorado National Forest in the Sierra Nevada, sediment production rates after a severe wildfire rivaled those associated with roads (MacDonald et al., 2004).

In California, biomass harvesting is commonly conducted for wildfire risk reduction. By altering the severity of future wildfires, biomass harvests in the form of fuels reduction treatments may reduce the soil and watershed impacts of fire. The California Biomass to Energy Project (USDA Forest Service, 2010) included a cumulative watershed analysis of modeled silvicultural activities including biomass harvest, and wildfire, at a landscape scale. Over the modeling period of 40 years, treatments reduced wildfire extent and severity. The treatment scenario was also shown to reduce soil erosion compared with the reference, or no treatment, scenario. While harvesting and other treatment activities resulted in some increased sediment production, the no treatment landscape experienced substantially greater watershed impacts due to severe wildfire effects.

5.6 Effects of associated and alternative treatments

While one alternative to biomass utilization is delayed or avoided harvest, continuation of the status quo is a more probable course. Currently, fuel treatments for fire hazard reduction and pre-commercial and commercial harvests often include some onsite treatment of small-diameter trees and logging slash. Low value woody biomass is currently piled and burned, cut and scattered, masticated, and/or treated by broadcast burning. Effects of some post-harvest treatments may be similar to those of biomass harvest. For instance, regardless of the fate of small-diameter biomass, whole-tree harvesting removes much of the above-ground biomass to roadside landings (Hartsough et al., 1994). Other slash treatments, such as mastication, may have substantially different ecological impacts.

5.6.1 Prescribed burning

Managing fire to treat post-logging slash or to reverse the buildup of natural forest fuels can alter soil structure, composition, and organic matter content (Dyrness and Youngberg, 1957; Neary et al., 1999). Organic matter protects soil from erosion from rainsplash impact and maintains soil porosity, promoting water infiltration (DeBano, 1990). Prescribed burning and thinning with burning treatments increase mineral soil exposure more than thinning alone (Gundale et al., 2005; Moghaddas and Stephens, 2007; Moghaddas and Stephens, 2008), though these effects are typically short-lived (Benavides-Solorio and MacDonald, 2005; Gundale et al., 2005). Treatments involving burning can also increase soil water repellency, which prevents soil

wetting and reduces infiltration, promoting runoff (Benavides-Solorio and MacDonald, 2001; DeBano, 1981; McNabb et al., 1989).

The soil impacts of burning vary within and among fires due to variability in weather, fine-scale fuel availability and loading, and soil moisture (DeBano et al., 1979). Low-severity burning can increase nutrients available for uptake by plants (DeBano, 1990; DeBano et al., 1979), however, nutrients released by burning can also be made vulnerable to removal via post-fire erosion and runoff (DeBano et al., 1979). Nutrient volatilization varies with fire intensity (DeBano et al., 1979); N, a nutrient often limiting in western forests, volatilizes at relatively low temperatures (DeBano et al., 1979). Burning also influences soil micro-organisms [e.g. vesicular-arbuscular mycorrhizae, (Klopatek et al., 1988)], though these relationships are still poorly understood.

While burning increases plant-available nutrients by releasing nutrients stored in biomass, combustion volatilizes some portion of nutrients, removing them from the site. A review of fire use in southern pine plantations determined that management of loblolly pine on a 25-year rotation with whole-tree harvesting without site preparation burning would remove an equal quantity of P, K, and Mg and less N and Ca than would bole-only harvesting with burning (Carter and Foster, 2004).

By removing soil organic matter and volatilizing site nutrients, burning could alter site productivity. However, a 40-year study of slash burning following clear cutting in the Cascade Range of Oregon and Washington (Miller and Bigley, 1990) found no effect on site productivity or stocking, though species were unequally affected by burning. Broadcast burning promoted stocking and volume growth of early successional species (Douglas-fir and hardwood species), but negatively impacted other conifer species via removal of advance regeneration. Frequent burning could impair future site productivity, but the relationship between burning and residual tree growth is complex. Peterson et al. (1994) implemented prescribed burning regimes at varying return intervals between 1 and 10 years to determine the impact on tree growth. Short (1- and 2-year) and long (8- and 10-year) intervals reduced basal area increment relative to unburned controls. Intervals of 4 to 6 years, however, did not reduce tree growth during the 13-year study period. On low-fertility sites, the risk to long term productivity may be greatest (Peterson et al., 1994)

The severity of burning is perhaps the most critical determinant of water quality impacts. Low severity burning is not expected to significantly alter water quality (Beschta, 1990). Timber harvesting in the Alsea Watershed Study concentrated slash near streams when riparian buffers were not maintained. Subsequent high-intensity prescribed burning was a likely cause of post-harvest sediment yields (Beschta and Jackson, 2008). Benavides-Solorio and MacDonald (2001) investigated the effects of burning on runoff and erosion following prescribed burning and wildfires in the Colorado Front Range. Due to soil water repellency on burned and unburned plots alike, high severity burning did not increase runoff by a large degree. While sediment yield on plots burned at low severity did not differ from unburned plots, high severity burning increased sediment production by 10-26%. Plots burned at high severity 6 years prior to sampling yielded only double the amount of sediment produced in unburned plots, suggesting that post-fire recovery is fairly rapid. Benavides-Solorio and MacDonald (2001) found that

sediment yield was strongly related to ground cover, but correlated weakly with hillslope and runoff. They noted that fire severity was a better indicator of sediment production than fire type (wildfire vs. prescribed fire).

Benavides-Solorio and MacDonald (2005) assessed post-fire erosion at the hillslope scale, developing a predictive model. Sites burned at high severity yielded sediment at rates several orders of magnitude above that of sites burned at low severity ($0.2\text{--}1.0\text{ kg m}^{-2}\text{ year}^{-1}$ and $0.005\text{ kg m}^{-2}\text{ year}^{-1}$, respectively). Sediment production was best predicted by percentage bare soil and rainfall erosivity, though soil texture, soil water repellency, and fire severity (a categorical variable), were useful explanatory variables as well. For a given fire-severity, post-wildfire sediment yield was higher than sediment production resulting from prescribed burning, likely due to the patchy effects of prescribed fire on ground cover and the relatively high post-fire canopy cover (Benavides-Solorio and MacDonald, 2005).

An alternative to biomass removal of small trees is prescribed fire without mechanical harvesting. Such fires typically reduce stand occupancy and compact soils less than mechanical thinning treatments (Troendle et al., 2010). While some studies have observed increase in water yield after severe burning, low intensity prescribed burns are not expected to greatly augment streamflows (Beschta, 1990).

When woody biomass is utilized for energy, the need for slash treatments involving onsite dispersal of biomass should be reduced. However, one common method of slash treatment, broadcast burning, will continue to follow harvesting. Prescribed fire has benefits in preparing sites for replanting, reducing competition, and reducing surface fuel accumulations for wildfire risk reduction. Removal of forest biomass prior to burning should reduce the negative soil and water quality impacts, because large woody fuels can contribute to high intensity burning and severe soil effects.

5.6.2 Mastication

Mastication, or mechanical shredding, of small diameter understory trees and shrubs is conducted to reduce competition and remove ladder fuels for fire risk reduction. One benefit of this treatment method is onsite nutrient retention, reducing the risk of lowered productivity as a result of nutrient removal. Mastication often involves substantial equipment travel off of designated skid trails. If soils are compacted during mastication activities, the woodchip mulch left behind should offer some protection from rain splash erosion. Mastication was used in a Fire and Fire Surrogate Study manipulation of small diameter (2-25 cm dbh) trees in the Sierra Nevada (Moghaddas and Stephens, 2008). Scattered debris likely buffered soils from compaction during treatment, and mastication was not shown to increase soil bulk density (Moghaddas and Stephens, 2008).

Hatchett et al. (2006) observed few serious physical impacts of mastication on soil or runoff. Significant compaction effects were observed only when soils from the masticator tracks were compared with soils far from the track. It seems these soil impacts are distributed widely rather than concentrated. Compaction was not observed at most soil depths, and was significant only at 10 and 25 cm below the soil surface. Hatchett et al. (2006) also simulated rainfall to assess the

impacts of mastication on runoff. When masticated biomass covered the equipment tracks, bare soil was not increased. When it did not, mastication increased soil exposure by 50%, to 9% total. Bare soil plots produced the most sediment in rainfall trials, and at “normal” rainfall intensity (2.9 in/hr), runoff did not occur in any other plot cover type (e.g. woodchips). At high-intensity (4.7 in/hr), sediment production was higher on woodchip plots than on relatively undisturbed plots, but still only reached 32% of the sediment lost from bare-soil plots.

5.7 Biomass harvesting in shrublands and woodlands

Very few studies consider how biomass utilization in non-forest ecosystems might influence soil productivity and water quality. One exception to this trend regards harvesting of Western juniper (*Juniperus occidentalis* Hook.). Western juniper dominance can reduce understory ground cover, reduce infiltration, promote soil erosion, and alter understory vegetation composition (Bedell et al.1993), but Belsky (1996) found considerably fewer impacts. Juniper expansion into sagebrush steppe communities has generated some research into the soil and water quality consequences of removal treatments. Juniper removal treatments can promote infiltration and reduce soil vulnerability to erosion (Pierson et al., 2007). In central Oregon, Dodson et al. (2006) compared manual and mechanical western juniper harvesting methods. Treatment methods did not differ in their impacts on soil bulk density, but both increased compaction relative to untreated controls. Long-term results are not available to validate the theory that the recovery of grass cover after the juniper removal could potentially improve net infiltration.

Shrublands in Southern California typically occupy steeper terrain than that occupied by Western juniper in Northern California and could involve much greater soil and water impacts from any harvest operations. The lack of markets for shrub biomass, the high per acre cost of operations, and the current high level of erosion risks in Southern California are all reasons for the limited activity to date.

5.8 Conclusion

The potential impacts of additional biomass harvesting on soil productivity, soil erosion, and stream water quality can be assumed to be similar to the impacts of more intensive forest harvesting regimes. Decades of research have led to the development and use of many best management practices (BMPs) to protect soil productivity and water quality. The continued use of appropriate BMPs would appear warranted for any additional biomass harvesting operations. Alternatives to biomass harvesting and removal such as mastication or prescribed burning will have also have impacts related to equipment use. Outside of areas of juniper encroachment on gentle terrain in Northeastern California, there is limited research on the soil and water impacts of biomass harvesting outside of forest types.

CHAPTER 6:

Applying Soil-Related Findings to California Conditions

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The preceding two sections review global experience on whether biomass removal affects forest productivity. Unfortunately, a meta-analysis of the published results from a wide variety of trials in specific soils and forest types that were not designed to provide a statistically valid review of conditions tend to be anecdotal, often contradictory, and limited geographically. Without a statistically valid meta-analysis of well-designed experiments, they convey little beyond those presented three decades ago in a major symposium on the subject (Leaf 1979). The four main points from that symposium were:

- Tree crowns are richer in nutrients than bole wood. Therefore, whole-tree harvesting removes more nutrients than conventional harvests that only remove stems.
- The mass of cation nutrients removed during whole-tree harvesting may exceed those estimated from the cation exchange sites in the upper layers of the soil.
- Consequences of whole-tree removal on future productivity are apt to be greater on poor soils than on richer.
- Treatments that reduce fuel buildup may reduce wildfire risk and severity.

In both Europe and North America, most assessments and projections about future productivity are based on assumed--but unsubstantiated--relationships between nutrient export in biomass and soil nutrient supply (see Abbott and Crossley 1982, Freedman et al. 1986, Hendrickson et al. 1989, Saarsalmi et al. 2010, Switzer and Nelson 1972, Wall 2008). They typically rest on mass-balance models of nutrient supply in the upper soil profile as determined by static measures that overlook the dynamic nature of soil chemical equilibria. The approach is more useful for annual crops to which fertilizer applications are used to address any deficits. Long-term nutrient cycling for a single forest stand over decades and for multiple rotations is far more complex and requires considering slower but significant processes such as additional nutrient availability from decomposing rock layers, atmospheric deposition, and the role of nutrient cycling from tree mortality. The challenge of determining what pools of nutrients are available of the relevant time scales will require more long-term experiments. Furthermore, most predictions that forest productivity will decline from nutrient export lack validation. That is, they lack subsequent measures of forest productivity to test such hypotheses.

6.1 The limitation of mass balance projection methodologies

Most projections of possible productivity loss center on assumed depletion of soil cation nutrients such as calcium (Ca), potassium (K), and magnesium (Mg) as measured by exchangeable ions on soil colloids. That is, that the amount of cation nutrients removed in whole-tree harvesting approaches or exceeds that present on charged exchange sites in the soil.

When this occurs, the concern is that future demand for nutrients will exceed supply and that productivity will decline. The problem with such mass balance projections is the difference between a still photograph and a movie. Cation nutrients in the soil exist in a variety of forms, ranging from those in primary minerals of silicate rocks released only through weathering to those present as very dilute ions in the soil solution. The former are not considered biologically available, while the latter are readily available for uptake. Nutrient cations also exist in intermediate forms, varying from those in weathered secondary minerals (sparingly available) to those on anion exchange surfaces of soil colloids (readily available). By convention (tracing to techniques for annual agricultural crops with high nutrient demand), only readily available cations are measured in soil analyses (Schoenholtz et al. 2000), and results from such analyses rarely if ever correlate with uptake or growth by forest trees (Powers et al. 1998). Undoubtedly, this is because cations in all forms are in a dynamic equilibrium between the source (primary minerals) and those released to cation exchange sites and the soil solution. As cations readily available to tree roots are removed, the equilibrium shifts to higher rates of replacement from supplies which are less available (Markewitz and Richter 2000).

Only rarely are concerns of productivity decline from nutrient removal validated by growth responses. The exceptions are typically in regions where the soils have far less nutrients than those in California. Working with pines on the Southern Coastal Plain, Scott and Dean (2006) reported slight declines in absolute productivity 10 years after whole-tree harvesting. This most certainly reflects the importance of an organic cycling pathway for phosphorus (P), owing to its absolute scarcity in the soil peculiar to the Southern Coastal Plain of the United States because of their peculiar orogeny.

Even if long-term productivity should be diminished as occurs with appreciable topsoil displacement, fertilization can be a cost-effective means to remediate such sites (Miller et al. 1992, Powers et al. 1988). This issue is especially relevant for emerging scenarios that project the increased use of biomass for energy from the agricultural, forest, and marginal lands.

6.2 California vs. the northern hemisphere: climate has affected soil development

Conclusions from the general review of nutritional consequences of biomass removal on soil chemical and physical conditions in Chapters 4 and 5 must be placed in the context of California's unusual soil conditions. Unlike much of North America and northern Europe, California was free of continental glaciation during the Pleistocene. In contrast, all of Canada and much of the central and eastern United States were scoured by glacial ice during the Wisconsin glaciation that began about 85 thousand years ago and ended roughly 11 thousand years before the present. Europe was affected similarly, with continental glaciers extending through the British Isles and as far south as Germany and Poland. In North America, massive ice, generated by the Cordilleran Ice Sheet in western Canada and the broader Laurentide Ice Sheet in central and eastern Canada extended south into Oregon, Idaho and Montana and as far south as southern Missouri. The weight of slowly moving ice, as thick as 3,000 m, scoured existing soils to bedrock and carved the Great Lakes. In its wake were exposed parent rock, stony moraines, and wind-blown loess as far south as the present state of Missouri (Powers et

al. 2005a). In contrast, the moderating influence of the Pacific Ocean and the western jet stream precluded continental glaciers from reaching California and our soils largely were left intact. Here, glaciation was localized, limited to alpine settings and a few deep valleys bordered by mountain range crests such as Yosemite. Thus, California's soils are much older, deeper, and far more fertile than those of glaciated regions of North America and Europe.

While glacial ice did not extend as far south as the present Southern Coastal Plain of the United States, sea level had fallen 30 m or more during the Pleistocene, exposing marine-laid sediments that were structureless and infertile. While sea levels rose during the Quaternary, continental uplift raised the Southern Coastal Plain to its current level. Pines, which had receded along the Gulf Coast into Mexico during the Pleistocene, returned to the Coastal Plain as the climate warmed (Powers et al. 2005a), creating vast expanses of what we know as the southern pine forest on these exposed but relatively infertile soils. Beginning with European settlement in the 17th century, many southern pine forests were cleared and converted to such agricultural crops as cotton, corn, wheat and rice. Eventually, soil fertility was lowered sufficiently by repeated cropping that lands were abandoned and the area called "old fields" returned naturally to forests. Thus, findings from the Coastal Plain forests of the United States must be tempered by the fact that such silty and sandy soils are notoriously infertile due to their orogeny and past land use.

6.3 Organic matter, nitrogen, and productivity

6.3.1 Soil chemical impacts of tree removal

The primary limiting factor of soil fertility controlling growth throughout North America and the world is nitrogen (N). In turn, N is derived from the decomposition of soil organic matter and not from rocks as well as from N fixation from atmospheric deposition. Organic matter's precursor in the soil is decomposing detritus from the forest floor and fine roots of vegetation. Compared with other places, forest soils of California are vast sinks for organic carbon and nitrogen (Post et al. 1985, Zinke et al. 2003). Powers (2002), analyzing a century-old, mixed-conifer forest in the Sierra Nevada, found that slightly more than 600 kg N ha⁻¹ in above-ground biomass. However, this merely accounted for 7 percent of the N in the entire ecosystem exclusive of roots, and that the forest floor contained roughly twice the N as the standing forest.

Because the forest floor is a biologically active reservoir of N, its removal leads to reductions in potential soil N availability as witnessed by several LTSP field experiments in the state. Ten-year findings from four mixed-conifer sites in the Sierra Nevada show little change in potential soil N availability following whole-tree removal, but significant declines in N availability following the removal of the forest floor (Powers et al. 2005b). In general, no productivity differences were found between bole-only and whole-tree harvesting through the first decade of the LTSP study in California (Powers et al. 2005b) and those from later measurements are now being analyzed.

Studies at Blodgett Research Forest in California's Sierra Nevada suggest that soils continue to lose organic carbon for up to 17 years following clearcutting and slash burning (Black and Harden 1995). The probable cause was forest floor consumption during burning. In another

Sierra Nevada study following clearcutting, Fraser et al. (1990) found that soils continued to leach N for up to 17 years until perennial vegetation again dominated the site. As canopies close on developing forests, soil leaching declines, litterfall increases, and organic carbon and N pathways become closed and efficient. However, impacts of massive or repeated removals on future productivity with and without application of N fertilizer are unknown.

Commercial thinning likely has little impact on N stores in the total biomass and soil systems in fertile sites in California. Carlyle (1995), studying *Pinus radiata* plantations, found that thinning did not change total N uptake despite removing about half the basal area. Nutrient leaching was unaffected by thinning as the same absolute uptake simply was shifted to fewer trees. Unfortunately, empirical trials are rare and modeling results often lead to speculation that periodic removal of woody biomass will lead to a permanent system level depletion of nutrients.

While N is the major limiting nutrient, the carbon flux is attracting greater interest with the focus on carbon sequestration. In a chronosequence study of pines planted in California's Volcano Burn on the Tahoe National Forest, Campbell et al. (2009) demonstrated that gains or losses of ecosystem carbon following thinning depended on suppositions made in the model. The upward revision in the amount of soil carbon in US forest soils (Ryan, 2010) is primarily based on modeled results and may not actually represent any improvement in our ability to measure the carbon flux across diverse forest soils.

6.3.2 Soil chemical impacts of understory removal

Many young stands in California--particularly those in the so-called "wildland-urban interface" --have open canopies and contain dense understories of such perennial woody shrubs as manzanita and ceanothus. Such shrubs compete strongly for soil moisture and nutrients, and their biomass may equal or exceed that of the overstory trees (McDonald and Powers 2003, Powers unpublished). Further, they create fuel ladders that put overstory trees at risk to crown fire. Zhang et al. (in press) compared long-term field experiments of ponderosa pine with and without understory shrub control. Those with shrub control were far more capable of withstanding ground fire and were much more resilient to the likely vagaries of climate change. Powers (unpublished) found that shrub biomass in four open pine stands in northern California varied between 20 and 94 Mg ha⁻¹, equivalent to a range in potential energy of between 300 million and 1.3 billion BTU's ha⁻¹. Thus, understory woody fuels are a potential source of biomass energy, and their removal would definitely accelerate overstory tree growth and stand resistance to wildfire (Zhang et al. in press). However, removing dense understories of shrubs also removes a disproportionate mass of above-ground nutrients at a time that stands are developing rapidly and nutrient demand is high (Stein et al. 2010). The differences between harvesting and removing versus harvesting and leaving the shrub biomass in terms of nutrient cycling, fire risks, and costs are not well known.

6.3.4 Soil physical impacts of tree removal

Effects of soil compaction on productivity may be lasting or benign. Soil compaction reduces the volume of large pores that normally drain following wetting. These air-filled "macropores" provide air space for gas exchange and root penetration, and reductions of macroporosity may

create anaerobic conditions in fine soil textures, or improved available water-holding capacity in coarse-textured soils such as those weathered from granite. LTSP studies in California show that compaction generally reduces productivity on clayey soils, but can enhance productivity on sands (Gomez et al. 2002 a, b; Powers 1999, Powers et al. 2005b). Most compaction and surface erosion is associated with logging roads (Beschta 1978), but advances in harvesting equipment can and do alter traffic patterns. While soil compaction clearly can accelerate soil erosion owing to lessened infiltration rates, the presence of a forest floor to break raindrop impact can have a greater effect on reducing soil erosion (Powers 2002).

6. 4 Questions remaining and research needs

6.4.1 Many studies are in place

California is fortunate that many long-term replicated field experiments already are in place (Rabin et al. 2009) that can provide answers to many questions concerning biomass removal. This network of manipulative silvicultural experiments overseen by the Pacific Southwest Research Station is perhaps the most extensive in the West. Work has been underway for approximately two decades to assess the long-term effects of biomass removal on soil chemical and physical properties and fundamental forest productivity. The Long-Term Soil Productivity (LTSP) program was established in 1989 across forested sites in North America, and more than 100 installations are now part of the network (Powers et al. 2005b). The research program is designed to measure forest stands through one full rotation. Research on sequential rotations of trees grown only for energy products would require an even longer time frame. Of these, 12 are in the heart of California's Sierra Nevada mixed-conifer forest type. While the last LTSP report summarized findings through the first decade, another report is expected shortly. The study is meant to continue at least another two decades to the culmination of mean annual volume increment.

Another study involving mechanical treatment of understory shrubs has been in place for five years on four sites in northern California (Powers and Busse 2003). The purpose of the study is to determine how retention or mechanical removals of understory shrubs impacts soil properties, carbon cycling, and the health of the residual forest. Treatments include understory retention, mechanical removal (as might be done for biofuel harvesting), reduction and retention as a chipped surface mulch, and chip retention but incorporation into the surface soil to retain organic carbon and increase soil humus. Findings to date show that prescribed fire can be safely added if shrubs are reduced to chips, and that fire effects on trees and soil properties varies with soil moisture and thickness of the chip layer (Busse et al. 2005). Chipping followed by fire also stimulated seed germination and may encourage invasion of non-native species (Kane et al. 2010). Any treatment reducing shrub density enhances N mineralization, but leaching losses are negligible due largely to California's droughty climate (Stein et al. 2010).

Many long-term trials of vegetation control and thinning already are in place throughout California (Powers et al. 2005c, Zhang et al. 2006, Zhang et al. in press). Many have been followed for decades and, because they are replicated experiments with untreated controls, they could provide important information on how thinning affects total carbon recovery and possible changes in soil fertility.

6.4.2 Important issues remaining

- **Comparing the effects of different combinations of forest harvests and fires (wildfire, prescribed fire, slash burning)** Research results across many projects suggests that the carbon stored in the forest floor is the pool most likely to experience a long term reduction after a harvest or fire and the one where the reduction has long term negative impacts on forest growth. The potential of more wildfire area or the introduction of more prescribed or natural fires could also impacts on the carbon flux that would have long term effects on forest growth and sequestration rates. The paucity of research sites with planned and unplanned fires seriously impedes the generation of insights into this topic.
- **Impacts of increased woody biomass utilization on low productivity sites.** While most woody biomass harvesting guidelines recommend that intensive harvesting be confined to more productive sites, the empirical evidence is mixed, with some studies showing minimal differences between the nutrient effects of whole-tree harvesting and stem-only harvesting on nutrient-poor soils. The LTSP study in California is confined to mixed-conifer forests that—by their nature—are relatively productive sites. Work on varying utilization standards should extend to the ponderosa pine and possible true fir forests where site quality generally is poorer.
- **Impacts of shorter harvest rotation lengths and repeated harvests.** While research suggests that most systems recover quickly from a single episode of more intensive harvesting, uncertainties remain about the impacts of repeated harvests, particularly at shorter rotation lengths when a greater proportion of tree biomass is in nutrient-rich crowns. Coleman et al. (2004) found little difference in soil properties between short-rotation tree plantations and those of other energy crops. But the effect of repeated harvests on sustained productivity remains unknown. As distance between harvest site and processing point is likely to figure in selection of sites for woody biomass utilization, the potential exists to repeatedly deplete nutrient status by returning to previously harvested sites at lower elevations near bioenergy facilities.
- **Alternative species for short-harvest woody rotation.** To date, most energy focused tree research in the U.S. has focused on poplar and willow clones, loblolly pine, sycamore, and sweetgum. With shorter rotation lengths, selection of species best suited to a particular system will help to maximize biomass accumulation as opposed to attempting to plant tree species outside of conditions considered demonstrated to be suitable for use as a commercial species. Eucalyptus plantations are common outside North America and from a nutrient perspective, are suited to California, particularly on marginal land.
- **Better road layout.** During harvesting, well-planned systems of designated equipment corridors and the use of pre-existing trails will minimize the total area impacted by soil compaction and erosion and can help to limit cumulative impacts from multiple harvest

entries. The USDA Forest Service has a standard that no more than 15 percent of a harvest activity area may be in temporary roads. However, this needs to be tested in practice and against alternative trafficking strategies.

- **Mitigative treatments.** Studies are needed to evaluate post-harvest mitigative measures to correct nutrient drain and soil physical properties. While some are in place in the LTSP program, work should expand to poorer sites.
- **Impacts of stump removal.** Stump harvesting, while not commonly practiced in California, is elsewhere conducted for biomass energy production, site preparation, and treatment of root rot fungi (Ranta and Rinne 2006; Eriksson and Gustavsson 2010; Melin, Petersson et al. 2010). Reviews of stump harvesting indicate a need for long-term research addressing effects on site productivity. Most research has focused on stump removal in stands impacted by disease or insect infestation; research on the longer term impacts to healthy stands is lacking (Walmsley and Godbold, 2010).

CHAPTER 7:

Potential Impacts to Biodiversity from Woody Biomass Harvests

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7.1 Defining biodiversity with respect to woody biomass harvesting

Concern over negative impacts on biodiversity from more extensive and intensive removal of forest biomass is a central concern in both Europe (European Environmental Agency 2006, Framstad 2009) and North America (Battles 2001, Titus 2009, Verschuyt 2011). Biodiversity is broadly defined as the variety of living organisms in a given area, but many more specific definitions exist that reflect the vast variety of ecological questions. There are many definitions of biodiversity within the scientific literature and each presents slightly different implications for management and conservation. A simple, comprehensive, and easily operationalized definition of biodiversity is almost impossible to find (Noss 1990). DeLong (1996) and Bunnell (1998) reviewed nearly 90 different definitions of biodiversity, and the variation in use and meaning identified by both papers indicates that there is not a consensus within the ecological community about the concept of biodiversity. For this discussion, biodiversity includes gene, species, habitat, ecosystem and landscape diversity and the processes that sustain these at various spatial and temporal scales (Lindenmayer et al. 2006, Hunter 1990).

DeLong (1996) indicates that biodiversity can be measured in a variety of ways at different scales. A complete assessment of biodiversity at multiple scales is operationally difficult, if not impossible. Whittaker (1972) identifies two scales at which biodiversity can be assessed:

(1) alpha: diversity relating to species richness within a community (1-100 ha)

(Whittaker 1972, Kimmins 1999).

(2) beta: diversity relating to differentiation of communities along habitat gradients (100-10,000 ha) (Whittaker 1972, Kimmins 1999).

Within these spatial scales identified by Whittaker (1972), diversity can be assessed at the genetic, species, taxonomic, habitat, and ecosystem levels through time (Kimmins 1999, Table 1).

Table 10 Common measures of biodiversity used at alpha and beta scales

Measure	Definition
Genetic	the diversity of genotypes within a species in the area of interest.
Species	the number of species in the area of interest (species richness), and the relative abundance (e.g., common, average, or rare) of the different species in the area (species evenness)
Taxonomic	the number of genera, families and higher taxa
Structural	the diversity in the vertical structure (e.g., the number of different canopy layers (trees of different heights) and understory layers (e.g., shrubs, herbs, mosses)) of the plant community, and the horizontal diversity (the spatial patchiness) in structure. The diversity of plants and animals of different life forms (e.g., trees, shrubs, herbs, mosses, evergreen deciduous plants; herbivores, carnivores and detritivore animals)
Functional	the diversity of different functional groups (ecological guilds) in the area (e.g., shade tolerant or shade intolerant plants; fast growing and slow growing plants; plants that are nutrient-demanding or tolerant of low nutrient availability; seed feeding or leaf feeding herbivores; fungal feeding or bacterial feeding soil animals.)
Temporal	the degree of change over time in all the other measures.

Source: Adapted from (Kimmins 1999)

Franklin et al. (1981) recognized three primary attributes of ecosystems that are fundamental determinants of biological diversity: composition, structure, and function. Composition refers to the presence and abundance of plant and animal species present in an ecosystem; function includes how various ecological processes occur and the rates at which they take place; and structure refers to the spatial arrangement of various physical components of the ecosystem (Franklin et al. 1981). These attributes encompass multiple spatial and temporal scales. Conclusions about biodiversity within an area are dependent upon the components of biodiversity assessed and the scale at which those assessments are made.

7.1.1 Why is biodiversity important?

The maintenance of biodiversity during woody biomass harvests, at all spatial and temporal scales, is important for the continued provision of goods and services from California's wooded ecosystems (Purvis and Hector 2000). The biodiversity of California forests, woodlands and shrublands plays an important role in sustaining ecosystem function, resiliency and adaptability (i.e. nutrient cycling, carbon sequestration, watershed functions, site productivity, cleansing of the air and water). Additionally, Californians derive benefits from the direct consumption of raw materials and products produced by the biologically diverse wooded ecosystems (i.e. timber, energy and fuels, food, non-timber products). Ecosystem services and products are essential components of California's social and economic landscape.

The protection of biodiversity and the services/products ecosystems provide are often central goals of sustainable land management. Biodiversity losses are associated with the fragmentation, degradation and conversion of habitats. These losses ultimately impact the ecosystem's function and resilience (Naeem et al. 1994, Fischer et al. 2006, Tilman 1999).

7.2 Measuring biodiversity

7.2.1 Use of indicators

Biodiversity is often measured using indicators, relatively easily measured elements of the ecosystem that correlate well with most elements of biodiversity (Lindenmayer 1999, Lindenmayer et al. 2000, Hagan and Whitman 2006). The most common indicators of biodiversity at the species level can be divided into two broad categories: (1) biological or taxon-based indicators, and (2) stand- and landscape-level structure based indicators (Lindenmayer et al. 2000). Biological indicators include individual species, species guilds, and measures of species richness, abundance and evenness; while structure based indicators include measures of structural complexity, composition, connectivity, and heterogeneity (Lindenmayer et al. 2000). Niemi and McDonald (2004) present a good overview of the development and use of ecological indicators.

Countless biological indicators have been proposed, each with their own set of limitations and justifications. Macro-invertebrates have long been used as biological indicators of the health and condition of aquatic ecosystems. Maleque et al. (2006) suggest the use of arthropods as ideal indicators of forest biodiversity and ecosystem integrity. Small mammals, such as mice and voles, have also been proposed as potential indicators of sustainable forest management (Pearce and Venier 2005). Similarly, there are many structural indicators that can be used to estimate biodiversity. Patterns of coarse woody debris accumulation, distribution and decomposition have been used to estimate the biological diversity of fungi, beetles, and terrestrial vertebrates (e.g. Stokland 2001, Juutinen et al. 2006, Maguire 2002).

7.2.2 Concerns with using indicators

The use of indicator species has been criticized in the context of forest management-related issues (Landers et al. 1988, Noss 1990, Niemi et al. 1997, Dale and Beyeler 2001). It is important to understand the general limitations inherent in the use of biodiversity indicators (Lindenmayer 1999). The selection of inappropriate indicators or spatial scales during analyses of biodiversity could lead to a lack of scientific understanding, poorly informed management decisions, and a false sense of ecological sustainability (Lindenmayer et al. 2000, Hagan and Whitman 2006, Noss 1990, Guynn et al. 2004). Failing and Gregory (2003) identify ten common "mistakes" in the development and use of forest biodiversity indicators ranging from failing to define objectives to oversimplifying spatial and temporal biodiversity trade-offs.

Because of the complexity inherent in biodiversity, a set of complimentary indicators should be used during an assessment of biodiversity (Noss 1990). Noss (1990) explores how the components of an ecosystem described by Franklin et al. (1981) (composition, function and structure) are connected and develops a hierarchical concept for assessing biodiversity based on

the use of multiple indicators across spatial and temporal scales. A single indicator will not be capable of “measuring” biodiversity across multiple temporal and spatial scales (Noss 1990).

Lindenmayer et al. (2000) includes a list of suggestions for dealing with the uncertainty associated with the conservation of biodiversity in managed forests: (1) establish biodiversity reserves managed primarily for conservation of biodiversity, (2) use multiple structure-based indicators to assess how management practices affect structural complexity, habitat connectivity, and heterogeneity, (3) use multiple conservation strategies at multiple spatial scales, and (4) use an adaptive management approach to monitor the efficacy of the indicators being used.

7.3 Biodiversity and woody biomass harvests

In comparison to the vast body of scientific literature concerning biological diversity and conservation, the literature available on the impacts of woody biomass harvests on biodiversity is limited. Some research has been done in Sweden’s boreal forests looking at the impacts of intensive slash management and whole tree harvests on biological diversity, but studies from forest ecosystems more similar to California are limited (Jonsell 2007, Jonsell et al. 2007, Nitterus et al. 2007, Rudolph and Gustafsson 2005). Two major biodiversity concerns related to woody biomass harvests are associated with: 1) conversions of native forestlands, woodlands, and shrublands to short rotation woody crop plantations, and 2) intensive woody biomass harvests from native ecosystems that result in extensive alterations to habitat conditions, including fragmentation and loss (Cook et al. 1991, Hesselink 2010).

7.3.1 Structural elements potentially affected by woody biomass harvests

Biodiversity impacts are associated with changes to ecosystem structure, composition, and function at both the stand- and landscape-level (Noss 1990, Franklin et al. 1981). The type and amount of woody biomass removed for bioenergy production will determine the severity of these changes. In forest, woodland and shrubland ecosystems, the structural components typically harvested or manipulated during a woody biomass harvest include:

- (1) Dead and downed wood (pre-existing) and harvested generated slash:
 - Snags
 - Coarse woody debris (logs, stumps and other woody material >3” diameter)
 - Fine woody debris (leaves, needles, branch tips, forest floor, and other woody material less than 3” diameter)
- (2) Understory shrub and herbaceous layers, non-merchantable trees
- (3) Wildlife trees (decaying live trees, cavity trees, mast producing trees).

7.3.2 Dead and downed wood

Abundant literature demonstrates the importance of dead and downed wood for wildlife and biodiversity. (See Harmon et al. 2004, Freedman et al. 1996, Brown et al. 2003, Hagan and Grove 1999, Hunter 1990, Laudenslayer et al. 2002, and McComb 2008 for reviews of woody debris functional roles). The dead and downed wood components of wooded ecosystems provide the basis for food and cover resources for many wildlife species. Dead wood can take the form of

standing snags, stumps, fallen logs, broken off tops and limbs, twigs and the forest floor (duff, litter, organic layers). This dead wood pool is often broken up into three categories: (1) snags, standing dead trees (2) coarse woody debris includes the logs, stumps and other woody material greater than 3 inches diameter, and (3) fine woody debris includes leaves, needles, branch tips, forest floor and other woody material less than three inches diameter (Harmon et al. 2004, Laudenslayer et al. 2002).

Coarse woody debris provides habitat for invertebrates, fungi, microorganisms, some of which aid in the decomposition process (Hunter 1990, McComb 2008). Amphibians and reptiles use logs and stumps for cover and microclimate control (Aubry 1988, Szaro et al. 1988, Butts and McComb 2000). Logs also provide cover, nesting sites, and travel corridors for a wide range of small mammal species (Bowman et al. 2000, Carey and Harrington 2001, Manning and Edge 2009). Some species of bats and ground nesting birds use coarse woody material as roost or nest sites (Campbell et al. 1996, Hayes 2003, Waldien et al. 2003, Tobalske et al. 1991). If the hollow log is large enough, forest carnivores (fishers, martins, bears) may utilize the space for denning and resting needs (Spencer et al. 1983, Purcell et al. 2009, Bull and Heater 2000, Bull et al. 2000). Fine woody debris is very important in the cycling of nutrients within forested ecosystems as it decomposes quickly and contains a high proportion of the nutrients found in woody plants (Harmon et al. 2004). While coarse woody debris eventually decomposes, the process is slow and the amount of resulting available nutrients is generally low in comparison to decomposing fine woody material (See chapter on nutrient cycling).

Both coarse and fine woody debris play an important role in maintaining slope stability, reducing the impact of raindrop erosion, and slowing surface runoff (Laudenslayer et al. 2002). Logs and branches that find their way into aquatic ecosystems can alter the rate of flow, create pools and riffles, and provide habitat for aquatic species (Wooster and Hilton 2004).

Snags, standing dead trees, are an essential habitat component for wildlife in forest ecosystems, especially for cavity-using birds, bats, and mammals. Raphael and White (1978) estimate that about 31 percent of bird species and 32 percent of mammal species living in the forests of the Sierra Nevada use snags for nesting or denning, foraging, roosting, perching, or hunting. In a separate study of nesting and foraging habitat selection by cavity-nesting birds, Raphael and White (1984) found 72 percent of nests in snags. The relative value to wildlife (and biodiversity) of an individual snag is related to the size (diameter and height), tree species, age and condition (time standing since death), and location (habitat context) (Raphael and White 1978, Raphael and White 1984, Freedman et al. 1996, Thomas et al. 1979).

7.3.3 Understory tree, shrub and herbaceous layers

The understory tree, shrub and herb layers are important habitat components from the point of view of many wildlife species. The functional role of these vegetative layers is primarily food production, whether directly through vegetative material or mast, or indirectly through larger food webs (Hagar 2007). These layers add structural and functional diversity to forest stands, thereby increasing wildlife habitat values and biodiversity. Many wildlife species depend on non-coniferous vegetation for food resources, including a wide variety of grasses, herbs, shrubs and hardwood trees (Hagar 2007). Wildlife species also depend upon these understory

vegetative layers for resting and escape cover. While relationships between wildlife and understory vegetation are well established, the degree of dependence of species on small trees, shrubs and herbs is not well documented in the scientific literature (Hagar 2007, Beedy 1981).

Since biodiversity measures should also include plant species abundance, richness and evenness, the mere presence of understory vegetation increases the biodiversity value of a stand. Battles et al. (2001) suggests opening up growing space in forest stands can result in an increase in understory species richness. The composition of understory vegetation varied among all silvicultural treatments analyzed, indicating that both the level of biomass removal and the post-harvest practices (site preparation activities) influence understory vegetation establishment (Battles et al. 2001). The differences in plant communities tended to reflect the seral stage of the overstory, with clearcut stands containing a higher proportion of early-seral and invasive species than the reserve stands, which had more natives and late-seral associates (Battles et al. 2001). It is clear, understory vegetation is very important for wildlife habitat and biodiversity and harvest practices have the ability to influence the plant species composition, abundance and richness.

7.3.4 Wildlife trees

There are several categories of forest trees that perform a variety of essential habitat functions and often serve as structural indicators of biodiversity: (1) decaying live trees; (2) trees with cavities, broken tops, and mistletoe brooms; and (3) mast-producing trees. Decaying live trees provide habitat for insects and fungi, which are important food sources for foraging birds and mammals. When decaying live trees die, their biomass is added to the dead wood component of the forest. The tree may remain standing (snag) or fall to the ground (log), either way it adds to the structural complexity within the stand and holds values for biodiversity conservation. The process of wood decay is extremely important for ecosystem function, structure, and composition (Laudenslayer et al. 2002, Lofroth 1998, Hagen and Grove 1999, Harmon et al. 2004). The essential ecosystem services provided by dead wood change throughout the decay process (habitat, nutrient cycling, structure, etc.) (Harmon et al. 2004).

Cavity trees, and trees with growth deformities, provide nesting and denning habitat for a variety of forest birds and mammals. While some cavities may have natural origins (broken top or branch, fire scar), the majority of cavities are created by a group of species known as “primary cavity excavators”. Primary cavity excavators, such as pileated woodpeckers, perform the essential role of creating cavities that are used by secondary cavity nesters (McComb 2008). Secondary cavity nesting species use pre-existing cavities and do not excavate their own. Primary cavity excavators and secondary cavity users include invertebrate, bat, bird, and mammal species (Bull et al. 2000, McComb 2008, Harmon et al. 2004, Freedman et al. 1996). It has been estimated that 20-40% of the birds in any given forest community could be dependent upon cavities to meet some habitat need (Hunter 1990). The majority of cavity-using species are secondary cavity users. The number of cavities used by an individual varies widely among species, but it is often greater than one (McComb 2008). Species often have specific requirements for the size of the tree/cavity.

Mast-producing trees provide a key food resource for many wildlife species. Mast includes hard fruits (acorns and nuts) and soft fruits (berries and drupes). These food resources are typically energy/nutrient dense and significant components of many species diets.

7.3.5 Measuring impacts of structural elements

Type, severity, and duration of biodiversity impacts depend upon the level of modification or removal of these structural elements during biomass harvests. It will be important to consider the length of time between biomass harvests, as cumulative impacts from repeated removal are likely but not addressed in the literature. If biomass harvests are frequent enough (i.e. occurring more than once a rotation) the quantity and quality of woody biomass pools will likely decline over time. Impacts to biodiversity can be expected to increase as these habitat structures are removed and altered within a stand and across the landscape.

7.4 Common guiding principles for biodiversity conservation

7.4.1 Connectivity

Connectivity is the linkage of habitats, communities, and ecological processes at multiple spatial and temporal scales (Lindenmayer et al. 2006, Fischer et al. 2006, Lindenmayer et al. 2008). Connectivity is important for maintaining viable wildlife populations. Highly isolated plant and wildlife populations are more vulnerable to extirpation or extinction. Corridors have been proposed as mechanisms to enhance or maintain landscape connectivity, but their effectiveness is much debated (Simberloff and Cox 1987, Simberloff et al. 1992, Noss 1987, Beier and Noss 1998). Connectivity can be measured for habitats, landscapes, and ecological processes, and while these concepts are interrelated they are not synonymous (Lindenmayer and Fischer 2007). Connected habitats allow species to adapt to changes in habitat distributions through migration and dispersal (e.g. by recolonizing extirpated patches, etc.). Connectivity at both the habitat and landscape levels is important for maintaining ecological processes (i.e. trophic relationships, hydrologic and nutrient cycles) (Lindenmayer and Fischer 2007).

Habitat fragmentation is another term used in conservation biology that can be thought of as the process by which connectivity becomes disrupted (With et al. 1997). Fragmentation often occurs through the loss of habitat, but also results from changes in habitat configuration (Fahrig 2002, Fahrig 2003). Quantitative measures of habitat fragmentation often include at least one of the following (all four would be ideal): (1) reduction in habitat amount, (2) increase in number of habitat patches, (3) decrease in sizes of habitat patches, and (4) increase in isolation of patches (Fahrig 2002). It is difficult to examine the effects of habitat fragmentation independent of habitat loss, and the studies that have attempted to do so conclude that the effects associated with habitat fragmentation are generally much weaker than those associated with habitat loss (Fahrig 2002, Fahrig 2003, Fahrig 1997). Empirical studies suggest that the effects of habitat fragmentation are as likely to be positive as they are to be negative, while the effects of habitat loss are almost always negative (Fahrig 1997, Fahrig 2002, Fahrig 2003).

7.4.2 Stand structural complexity

Managed landscapes, such as industrial forestlands or grazed oak woodlands, demonstrate structural differences from their non-managed/natural counterparts (Perry 1998, Hansen et al. 1991). The most noticeable difference from a biodiversity conservation standpoint is the lack of within stand structural complexity. The types of structural attributes and their spatial arrangement within a stand contribute to complexity and wildlife habitat. Habitat alterations that reduce stand structural complexity often result in changes to the local biodiversity. Intensively managed stands often lack vertical and horizontal complexity present in habitats supporting high levels of biological diversity (Fridman and Walheim 2000, Perry 1998). Multiple layers, large living and dead trees, uneven age structure, gaps, plant species diversity, variable patterns in stem locations, and dead and downed wood contribute to the three-dimensional structure of a stand.

Wildlife species are more likely to find suitable habitat and/or travel corridors in harvested areas in which structural elements are retained (Fischer et al. 2006, Lindenmayer et al. 2008, Lindenmayer et al. 2006). Regenerating stands often lack the structural complexity associated with highly diverse wildlife and plant populations. Residual structural complexity in harvested stands may provide “life-boat” functions in which species are able to persist in an otherwise unsuitable habitat. Dead and downed wood in a forested ecosystem is an especially important structural element as it provides essential habitat functions for a diverse group of wildlife species (Freedman et al. 1996, Harmon et al. 2004, Hunter 1990). The community of wildlife associated with snags or logs varies over time as the structural characteristics of these dead wood elements change. Harvest residues, such as stumps, limbs and slash, when left on site also contribute to ecological processes (i.e. nutrient cycling, soil development).

7.4.3 Landscape heterogeneity

Intensive land management practices are responsible for homogenizing the spatial and temporal structure of forests, woodlands, and shrublands (Franklin et al. 2002, Hansen et al. 1991, Perry 1998). Harvesting, both of standing trees and other biomass, tends to reduce the structural complexity of a forest stand. If these activities are conducted over a broad spatial extent, then we face the likelihood that forested landscapes will trend towards increased homogeneity. As valuable wildlife habitat is lost, biodiversity also declines. Unlike human disturbances, natural disturbances are more likely to leave biological legacies and create a more variable, patchy distribution of habitats across a landscape. Spatial heterogeneity across a landscape is essential for the maintenance of biodiversity as it insures there are a variety of environmental conditions capable of supporting diverse wildlife populations (Lindenmayer et al. 2006, Hunter 1990).

Therefore, it is very important to consider the landscape context of biomass harvests. The green-up regulations in the California Forest Practice Rules require foresters to consider their proposed harvests in a landscape context (CA FPR 2010). Adjacent harvests cannot take place until regeneration requirements have been met. Without this rule clearcuts could be placed next to each other, effectively increasing the size and intensity of landscape modification beyond socially acceptable levels. It will be important for land managers to use a similar

approach when considering the impacts of woody biomass harvests. The landscape-level impacts from the reduction of heterogeneity at the stand-level ultimately depend upon the surrounding forest conditions (Wilson and Puettmann 2007). The landscape context of a woody biomass harvest and its impact on spatial heterogeneity must be included in the assessment of impacts. Discussion of the landscape-level, cumulative impacts associated with woody biomass harvests is lacking in the scientific literature.

There are areas within a landscape where biomass harvesting may be especially detrimental to biodiversity. These areas of special management concern such as rare habitats, wetlands and riparian corridors, or sensitive soils often have high biodiversity values and should be entered with great care (Fischer et al. 2006, Patel-Weynand 2002). Maintaining regional biodiversity requires the protection and maintenance of rare and threatened habitats (Probst and Crow 1991). Riparian zones are known to provide ecosystem functions such as sediment filtration, erosion control, and most importantly wildlife habitat (Sabo et al. 2005, Thomas 1979, Olson et al. 2007). Local and regional biodiversity will benefit by maintaining riparian corridors as significant landscape features (Naiman et al. 1993). Reducing the intensity of harvest or even excluding activities within these special management areas would function to preserve the structural complexity of these habitats and increase the spatial heterogeneity across the landscape.

7.4.4 Range of natural variability

Spatial and temporal variability within an ecosystem results from natural and human disturbances such as wildfire and forest harvest on the underlying physiographic, climatic and geological patterns. Practitioners of sustainable resource management often use natural variability concepts to inform decisions that influence maintaining/enhancing biodiversity. The reasoning behind natural variability concepts is the assumption that understanding the historical range of environmental conditions helps managers assess the potential impacts of their actions on the current ecological conditions and processes (Landers et al. 1999, Lindenmayer et al. 2006). Defining the range of natural variability can be difficult and will depend upon the reference period selected (i.e. pre-European settlement) (Landers et al. 1999, Kaufmann et al. 1994). Because the current ecosystem conditions (global climate change) and disturbance patterns (fire suppression and forest harvest) are almost certainly different than the historical conditions used in defining the reference period, the applicability of natural variability concepts may be limited. In general, biomass harvests that push stand structure outside the historic range of conditions are more likely to have negative impacts on biodiversity and ecosystem function.

Maintenance of variability within an ecosystem is essential for biodiversity conservation and ecosystem functions. This is emphasized by the use of the range of natural variability concepts. Historically, ecosystems experienced a range of natural disturbance events at various intensities and intervals. These natural disturbance patterns resulted in variability within stands and across landscapes. When biodiversity is a management goal, is important that human disturbances vary in terms of size and intensity in order to increase complexity and heterogeneity (Wilson and Puettmann 2007) or to mimic natural disturbances as closely as

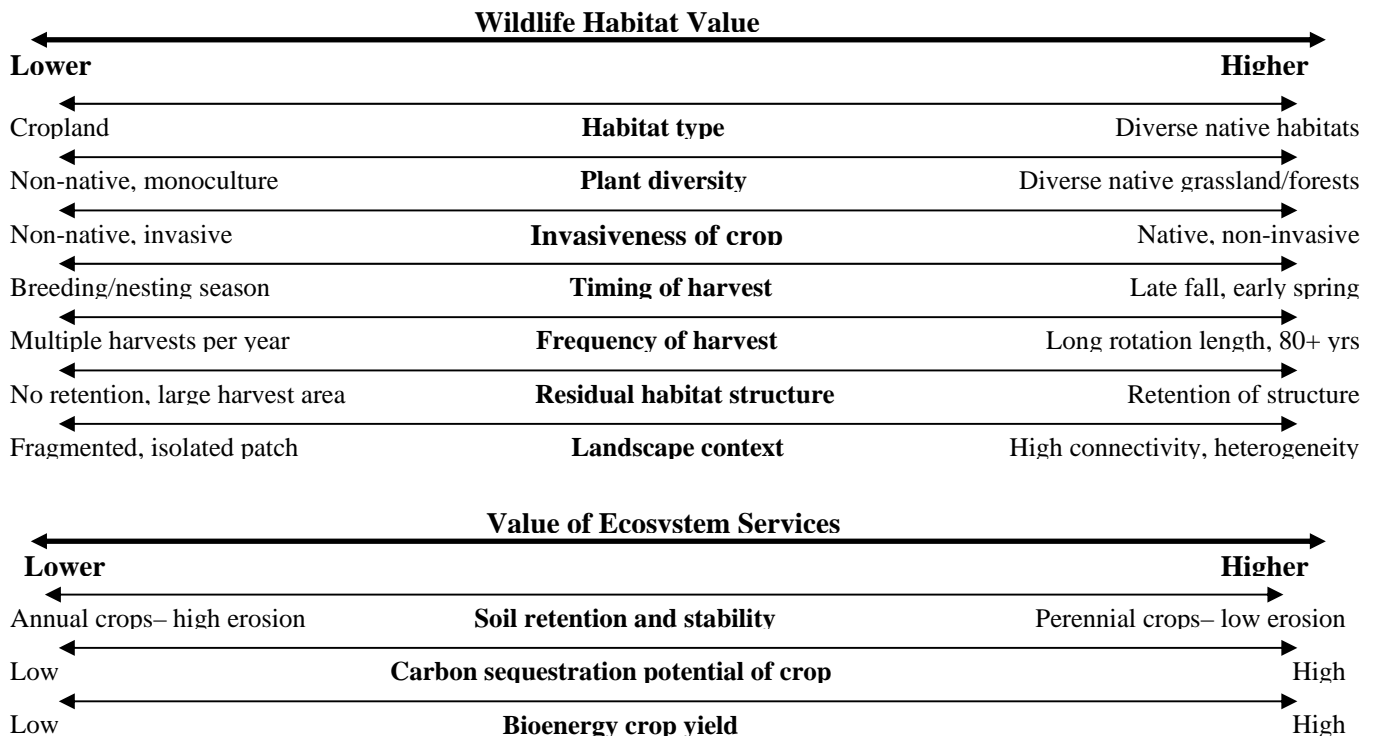
possible. Individual disturbances can either increase or decrease biodiversity, depending upon the spatial and temporal scales being considered. In general, the highest levels of biodiversity are associated with ecosystems subjected to intermediate frequencies, scales, and intensities of disturbance (Carnus et al. 2006, Kimmins 2004, Petraitis et al. 1989).

7.5 Biodiversity implications of short rotation woody crop plantations

The impact on biodiversity from short rotation woody crop (SRWC) plantations ultimately depends upon the land use being replaced, crop management practices, type of woody crop used, and the soil, water, and nutrient characteristics of the site (Joslin and Schoenholtz 1997, Fargione et al. 2009, Tolbert and Wright 1999, see **Figure 1**). Bioenergy plantations can often provide increased habitat and biodiversity when established on marginal agricultural or other degraded lands (Carnus et al 2006, Janowiak and Webster 2010, Cook and Beyea 2000, Lindenmayer and Hobbs 2004, Willyard and Tikalsky 2006, Fargione et al. 2009). The perceived gains to biodiversity result from increased vertical and horizontal complexity associated with the establishment of woody trees and shrubs. Landscape level impacts to biodiversity depend upon the placement of SRWC plantations and the surrounding land uses (Christian et al. 1998, Carnus et al. 2006). Benefits to wildlife and biodiversity are likely where SRWC plantations increase spatial heterogeneity, habitat diversity and connectivity across the landscape (Fargione et al. 2009, Carnus et al. 2006).

SRWC plantations can have negative impacts as well. The introduction of exotic, invasive species into adjacent native habitats is a serious concern for biodiversity and ecosystem functionality (Fargione et al. 2009). The water requirements of some of woody biomass crops may disrupt local hydrologic processes and fertilizer/pesticide use may pollute and degrade aquatic resources (Fargione et al. 2009, Shepard 2006). The most obvious negative impacts to biodiversity occur when native forests, woodlands, or shrublands are replaced with SRWC plantations (Stephens and Wagner 2007, Fargione et al. 2009). These impacts are likely to be severe because SRWC plantations have less structural complexity and habitat value than the native woody ecosystems (Janowiak and Webster 2010, Stephens and Wagner 2007,). Like most intensively managed plantations, SRWC plantations will likely have a more uniform structure than natural stands, with very little competing understory vegetation or dead and downed wood accumulation. While there are management opportunities to increase the biodiversity of plantations, the main goal of SRWC plantations is maximum production of biomass for energy consumption (Carnus et al. 2006, Hartley 2002, Kerr 1999). The use of SRWC plantations can help meet the expected increase in demand while alleviating the pressure to produce and harvest woody biomass from California's forests, woodlands and shrublands (Carnus et al. 2006). A careful use of SRWC plantations on degraded agricultural and pasture lands may be congruent with woody biomass production and biodiversity conservation goals.

Figure 14 Factors influencing wildlife habitat value and ecosystem services of bioenergy crops



Adapted from (Fargione et al. 2009)

7.6 Conservation measures: retention targets

The development recruitment targets for structural elements such as large snags, logs, and coarse woody debris that would otherwise not be replaced under an intensive biomass harvesting regime requires both an assessment of the current densities as well as insights into the relationship of the density of structural elements to populations of desired species. Few studies have attempted the difficult task of quantifying the amount of dead and downed wood/biological legacies necessary to maintain wildlife populations and biodiversity (Brown et al. 2003, Graham 1994). It is difficult to interpret and apply the results of these studies as they are site specific and focus on a single species or subset of the entire forest fauna population. Maintaining biodiversity will require a broad approach that seeks to provide structural diversity within stands and heterogeneity across landscapes.

Rule based approaches to biodiversity conservation often lack flexibility by applying a fixed target or limited range (on optimum, mean, or minimum) across a variety of areas (Bunnell and Huggard 1999). Bunnell and Huggard (1999) warn against any rule, policy or guideline that prescribes the same management activity (level of retention) everywhere, concluding that such practices will inevitably lead to homogeneity within a system and reduced biodiversity. Hagan and Whitman (2006) discuss the establishment of retention targets, concluding the process is often weakly based in science. However, quantitative retention targets are commonly used to insure minimum levels of essential habitat structures are maintained within managed

landscapes. Conservation efforts may be more successful if targets are set at the landscape-scale and focus on the quantity, quality and spatial distribution of various habitat elements (Ranius and Fahrig 2006, Bunnell and Huggard 1999, Bunnell and Johnson 2000). Redford et al. (2003) and Angelstam et al. (2003) suggest using multiple conservation targets across varying spatial scales as a way to protect both individual species (endangered/threatened) and the ecological processes that sustain them.

7.6.1 Dead and downed wood retention

Increased demand for woody biomass may lead to economic values for woody material that was previously non-merchantable (dead and downed wood, understory trees, etc.). This new market will probably result in more intensive forest management in the Sierra Nevada. If rotations shorten and biomass harvests occur at both intermediate and regeneration cuts, the accumulation of dead and downed wood will likely be reduced (Ranius and Fahrig 2006, Raphael and White 1978). Because of the importance of these structures for the maintenance of biodiversity and wildlife population, woody biomass harvesting guidelines requiring retention of dead and downed wood may be necessary (Angelstam et al. 2003). Providing for the replacement of snags and decomposing downed wood may also be necessary. Large snags are very valuable for wildlife and biodiversity, as they provide different habitat functions for many species over their long duration on the landscape (Raphael and White 1984). Intensive management may lead to fewer trees reaching the large diameter classes necessary for the production of these valuable snags and logs.

7.6.2 Biological legacies

Impacts to biodiversity from woody biomass harvests may be mitigated by the quantity and quality of the structural components left on the landscape. Often termed biological legacies, these retained structures can include green trees, snags and cavity trees, understory vegetation, CWD/FWD, etc. The maintenance of these structures within a stand has been shown to be beneficial to wildlife and biodiversity (Mazurek and Zielinski 2004, Kerr 1999, Fischer et al. 2006, Hansen et al. 1991). Whether dispersed across the stand or retained in clumps, biological legacies increase structural complexity, habitat values and biodiversity. It is important to consider the various spatial scales used by wildlife with different home ranges and distribution capabilities. Harvests that increase within-stand variability through legacy retention can provide important habitat features across multiple scales (Wilson and Puettmann 2007). Simple stand-level prescriptions that do not include residual woody structures will almost certainly fail to produce the necessary spatial variability required for the maintenance of biodiversity across a landscape.

7.7 Conclusions

The effects of woody biomass harvests on biodiversity are highly variable and influenced largely by the species of interest and the spatial and temporal scale being evaluated. A comprehensive set of indicators could be used to assess biodiversity at the landscape scale given the interaction of natural events (e.g. fires, drought), new projects, and results of historic or ongoing land cover change. Immediately post-harvest, impacts at the site-level may be more acute than impacts at the stand- or landscape-scales, but effects are likely to evolve over time

depending on landscape context. Lindenmayer et al. (2006) and Fischer et al. (2006) developed a set of guiding principles for biodiversity conservation that could help managers mitigate the negative effects of biomass harvesting on biodiversity. With respect to the incremental impact of more woody biomass removals, the maintenance of dead and down wood is widely considered to be area with the greatest impact. The effectiveness of indicators or principles should be independently assessed after a number of years.

The use of short rotation woody crop (SRWC) plantations for the purpose of growing bioenergy crops has been suggested as an alternative to harvesting woody biomass from native forest systems. The potential biodiversity consequences of purpose grown energy crops ultimately depends upon the land use being replaced by the plantation.

The maintenance recruitment of structural elements such as large green trees and snags, logs, and coarse woody debris that would otherwise not be replaced under an intensive biomass harvesting regime is an issue of critical concern for biodiversity and food webs related to these elements. Few studies have attempted the difficult task of quantifying the amount of dead and downed wood/biological legacies necessary to maintain wildlife populations, and more work is needed to identify critical threshold levels. It is difficult to interpret and apply the results of these studies as they are site specific and focus on a single species or subset of the entire forest fauna. Maintaining biodiversity will require a broad approach that seeks to provide structural diversity within stands and heterogeneity across landscapes.

CHAPTER 8:

Potential Impacts to Wildlife from Woody Biomass Harvests

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8.1 Introduction

Wildlife is defined to include all the flora and fauna of a place (Hunter 1990). The impacts of woody biomass harvests on wildlife are variable and depend upon the timing, frequency, intensity and spatial extent of the harvest. The majority of impacts will be associated with habitat manipulation, fragmentation, and loss (Fahrig 2003). Harvesting activities can be disruptive, especially during breeding and nesting seasons, care should be taken to avoid harvests during these important periods. The direct loss of species is often greatest for plants, but small mammals and forest-floor dwelling organisms can also be killed. The potential effects of biomass harvests on wildlife species should be considered within the context of species (1) distribution and abundance, (2) migratory and dispersal characteristics, (3) habitat associations, and (4) potential responses to changes in habitat (Pilliod et al. 2006).

There are few, if any, scientific studies of the impacts of woody biomass harvesting on wildlife. Most of the existing research has focused on the impacts of slash removal on ground-dwelling beetles and soil organisms (Bengtsson et al. 1997, Castro and Wise 2009, Gunnarsson et al. 2004, Jonsell et al. 2007, Nitterus et al 2007). Relationships between wildlife species and various habitat elements likely to be harvested during woody biomass operations (i.e. dead and downed wood, understory vegetation) have been established within the scientific literature. The following discussion of potential impacts to wildlife from woody biomass harvests draws heavily from these studies.

8.2 Wildlife habitat

California's forests, woodlands, and shrublands are home to thousands of wildlife species. Those assemblages of plants and animals that tend to co-occur frequently constitute habitat types. Every species has its own habitat requirements dictated by the scale at which the landscape is perceived and used. This makes generalizations about the impacts of habitat manipulations very difficult and often inappropriate. Plants, fungi and microorganisms often have limited mobility across spatial and temporal scales as compared to small mammals or birds. Site-level impacts to wildlife from biomass harvests will depend upon the level of alteration to essential habitat elements and the species under consideration.

8.2.1 Habitat selection by wildlife

The selection of habitat by an individual species is often described in a hierarchical fashion consisting of four levels (McComb 2008, Johnson 1980, Orians and Wittenberger 1991). The first-order selection of habitat is defined by the species' geographic range. Knowing where, within the species range, the biomass harvest is located can help in the assessment of impacts.

Habitat of lower quality is often found near the periphery of a species' geographic range as compared to the ideal habitat conditions often present in the center of a species distribution (McComb 2008). Harvests in lower quality habitats will likely have greater impacts, especially if essential habitat elements are manipulated or removed.

Home ranges define the second-order selection of habitat and vary in size with the body mass and feeding habits of the species (McComb 2008). There is variation in home range size between individuals, but in general smaller species tend to have smaller home ranges. The home range size of a species will help in determining the potential impacts from a harvest. Species with large home ranges, such as the California mountain lion, experience fewer impacts from a single harvest operation as the majority of their home range is unaltered. Impacts will be much greater for species with home ranges that closely match the size of, or are smaller than the biomass harvest unit (Hagar 2007). For these species, their entire territory may be modified.

The quantity and quality of habitat elements vary within a species' home range. The third-order selection of habitat is the use of patches that meet a species' cover, reproduction and/or feeding requirements. It is important to consider the impacts of biomass harvests on the spatial heterogeneity within a stand. These patches, within a stand, contain habitat elements that provide essential functions (i.e. decomposing logs or trees with cavities). These essential habitat elements used by the species for feeding, cover, and reproduction define fourth-order habitat selection (McComb 2008). Biomass harvests that remove/alter these habitat patches will severely impact the wildlife species dependent upon their existence. Retention of habitat patches and essential habitat elements within a harvested stand will increase heterogeneity in the understory and benefit wildlife (Pilliod et al. 2006, Carey and Harrington 2001).

Resource managers often use these wildlife-habitat relationships to inform management decisions and assess potential impacts. The impacts to wildlife from biomass harvests are typically assumed to be determined by the level of manipulation of structural components and the sizes, numbers and arrangement of residual habitat elements. The habitat quality of a site increases with high levels of vertical and horizontal complexity, the presence of understory vegetation, dead and downed wood, cavity trees, and a well developed forest floor (McComb 2008, Hunter 1990, Bunnell et al. 1999, Hagar 2007, Carey and Harrington 2001). Biomass harvests should seek to retain some of this complexity within the stand to meet wildlife conservation goals.

8.3 Essential habitat elements

Each species has a specific set of habitat elements that fulfill essential feeding, reproduction, or cover requirements. A structurally complex stand is more likely to contain these essential elements, and therefore habitat of higher quality. One of the striking differences between natural and managed landscapes is the level of uniformity and lack of structural complexity present in intensively managed stands (Hagar 2007, Hansen et al. 1991, Thompson et al. 2003). Impacts will vary depending upon the species of concern and the habitat requirements met by the removed/manipulated elements. Woody biomass harvests will most likely remove/manipulate the following habitat elements:

- Dead and downed woody debris
 - Snags
 - Coarse woody debris (logs, limbs, stumps, and other woody material >3" diameter)
 - Fine woody debris (leaves, needles, branch tips, forest floor, and other woody material less than 3" diameter)
- Understory vegetation layers
 - Herbs
 - Shrubs
- Non-merchantable, understory trees

8.3.1 Dead and downed wood

The dead and downed wood component of terrestrial and aquatic ecosystems has been shown to provide essential habitat for many species of wildlife (McComb 2008, Hagan and Grove 1999, Hunter 1990, Harmon et al. 2004, Laudenslayer et al. 2002, Maser and Trappe 1984). Snags and logs in various stages of decay, offer habitat for one-quarter to one-third of the forest dwelling vertebrates (Bunnell et al. 1999). In general, downed wood provides cover for breeding and dispersal for amphibians, reptiles, and ground-dwelling mammals, while snags or dying trees provide nesting, roosting and denning habitat for birds, bats, and small mammals (Harmon et al. 2004, Hagar 2007). Fine woody debris, in addition to providing cover, is an important energy and nutrient source for soil decomposers (bacteria, fungi, invertebrates) (Harmon et al. 2004). A large body of literature indicates that the habitat value of dead and downed wood increases with larger diameters (e.g. Hagar 2007, Raphael and White 1984, Harmon et al. 2004, Bunnell et al. 1999).

The size, amount and distribution of dead and downed wood within a stand depend upon the pattern of natural and human disturbance (Spies et al. 1988, Harmon et al. 2004). Wind, fire, insects, disease and direct competition often add dead and downed wood into a system at different timescales. Forest harvests produce a pulse of CWD/FWD in the form of mostly small diameter trees, tops and limbs, and foliage. Currently this material left in the forest to decay or burned in slash piles. As biomass harvests focus on removing this material, dead and downed wood pools are likely to decrease on intensively managed landscapes over time. The immediate effects of removal, combined with the cumulative effects of lower levels of dead and downed wood recruitment could result in serious impacts to wildlife.

The persistence of dead wood on a landscape is determined by the diameter and species of trees, climatic conditions and disturbances (Harmon et al. 2004, Harmon et al. 1987, Spies et al. 1988). Larger logs and snags tend to persist longer than smaller ones (McComb and Laudenslayer 1999, Harmon et al. 2004). Decay rates vary by species and whether or not the woody material is in contact with the forest floor. Moist forests (summer rain) often have higher rates of decomposition and smaller dead wood pools than drier areas.

Dead and downed wood provide spatial and temporal habitat connectivity when left undisturbed during/after harvests. Forest management activities often result in large changes to the vegetation structure of a stand and the habitat it provides (i.e. clearcuts). Retained logs

and snags provide essential habitat and travel corridors for species within these altered sites (Harmon et al. 2004). Some species of amphibians, cavity-nesting birds, forest carnivores, reptiles, and small mammals use highly decayed stumps in forested habitats (Butts and McComb 2000, Bull and Holthausen 1993, Bull et al. 2001).

Stump harvesting is not a common practice in the United States. Some studies have looked at the impacts of removing stumps on root diseases and seedling regeneration in Douglas-fir forests of Oregon, Washington and Canada (Thies and Nelson 1988, Thies and Westlind 2005). Walmsley and Godbold (2010) published a literature review of the environmental impacts associated with stump harvesting for bioenergy production. Stump harvests have the potential to provide benefits (fuel source, root disease control, site preparation, etc) or result in serious negative environmental impacts (compaction, erosion, loss of organic matter, soil productivity declines, loss of habitat) (Walmsley and Godbold 2010). Stumps may be an important source of structure and habitat in forest stands that have been harvested for woody biomass. By including stumps in woody biomass harvests, the amount of deadwood in a harvested stand will be reduced and the environmental impacts of woody biomass harvests will likely increase (Walmsley and Godbold 2010).

8.3.2 Understory vegetation- herbs, shrubs and non-merchantable trees

Floristic diversity, often lacking in intensively managed stands, is important habitat for a wide array of wildlife species (Hagar 2007, Carey and Johnson 1995, Bunnell et al. 1999). While the structure and composition of the dominant vegetation plays an important role in defining available habitat, the quantity and quality of understory vegetation determines the available feed and cover for the majority of wildlife species. The understory herbs, shrubs, and hardwood trees provide essential cover and food resources for invertebrates, small mammals, birds, and ungulates (Hagar 2007, Bunnell et al. 1999). Wildlife species are often described as having associations with particular stand development stages. While early seral associates are often found in newly regenerating stands, with open canopies and bushy vegetation, they also occur with great regularity in older stands as long as the necessary understory cover is present (Hagar 2007). Wildlife species presence and abundance tends to be highly correlated with the structural characteristics present, and not the stand age (Bunnell et al. 1999). Therefore, the retention of some essential habitat structures during a biomass harvest, such as dead and downed wood and understory vegetation, would help maintain wildlife populations.

Understory vegetation is often controlled in intensively managed forest stands, so that the period of herb and shrub dominance is shorter than in naturally regenerating stands. In general, shrubs and hardwood trees cover has declined across intensively managed landscapes because it is considered competing vegetation and slows growth of crop trees. The presence of herbs and shrubs is determined by openings in the canopy and higher level of light availability in the understory. Some biomass harvests may be associated with increased canopy openings and available light resulting from overstory tree removal, therefore opening resources for understory vegetation. However, in general, biomass harvests will likely have negative impacts on understory herbs, shrubs and trees by removing or disturbing this vegetation if present.

8.4 Impacts to wildlife from woody biomass harvests

8.4.1 Plants

The most obvious impacts to plants from woody biomass harvests include removal and damage. Non-merchantable trees will be targeted for removal during harvests as well as woody shrubs. Understory vegetation that is not removed, such as grasses, herbs, and flowers, will likely be crushed or damaged during the harvest activity.

Dead and downed wood often functions as growing substrates for vascular plants, lichens, mosses, and fungi. Several important factors influence likelihood and success of plants growing on dead and downed wood: tree species, decay state, size and distribution (Harmon et al. 2004, Bunnell et al. 2002). Nurse logs provide moist microclimates beneficial to regenerating seedlings and understory plants (Harmon et al. 2004, Laudenslayer et al. 2002). Fungi and bacteria play essential roles in the decomposition of dead and downed wood and facilitate nutrient cycling within the ecosystem. In a study of the impacts of slash harvests in boreal clearcuts in Sweden, Astrom et al. (2005) found significant changes in the species composition and richness of liverworts, bryophytes, and mosses. Approximately 33 percent of the liverwort species disappeared from stands where slash was harvested (Astrom et al. 2005).

8.4.2 Invertebrates

Many terrestrial invertebrates use dead or dying wood to meet their habitat requirements for feeding, breeding and shelter (Harmon et al. 2004). Different species of invertebrates require dead and dying wood in various forms of decay. Some invertebrates use and consume the wood directly while others graze upon the fungi decaying the wood or prey upon invertebrates (Harmon et al. 2004). The microclimatic conditions maintained by large pieces of dead and downed wood are especially important during the dry summer months. In the summer, slugs, snails, centipedes, and earthworms, often present in the soil and litter layer, move into the moist, cool microclimates associated with dead and downed wood (Harmon et al. 2004). Carpenter ants, yellow jackets, termites, carpenter and honey bees use dead wood for nest sites. Bark beetles, such as the mountain pine beetle, are important actors in the dead wood cycle as they often attack dying trees and kill them. Wood boring insects quickly colonize the newly dead wood. The activity of these groups opens up the dead wood for use by other invertebrates and decay associates (fungi) (Harmon et al. 2004). Invertebrates associated with dead and downed wood are an important component of many vertebrates' diets (small mammals and birds). Biomass harvests that significantly reduce the amount of dead and downed wood may have impacts that appear higher up in the food chain (Bunnell et al. 2002).

A study looking at the impacts of logging slash removal from clearcuts on soil organisms in Sweden found a significant reduction in the populations of different soil macro-arthropods and concluded that continued removal of slash would likely result in long-term decreases in the abundances of many soil animal groups (Bengtsson et al. 1997).

Gunnarsson et al. (2004) studied the impacts of logging slash removal on beetle populations in Swedish forests. Species abundance and richness differed significantly between the sites with logging slash and sites without (Gunnarsson et al. 2004). The sites with logging slash retained

had significantly greater species abundance and richness, leading Gunnarsson et al. (2004) to conclude that extensive slash removal leads to impoverished species richness, at the local scale. Nitterus et al. (2007) found no difference in overall beetle abundance between clearcuts with different slash treatments. Slash removal did cause a compositional shift in beetle populations, with more generalist species present in clearcuts that had been harvested for slash (Nitterus et al. 2007). Nitterus et al. (2007) conclude that removal of slash may have long-term effects on the composition and structure of beetle communities, resulting in greater abundance of generalist beetle species.

Castro and Wise (2009) studied the impacts of fine woody debris addition to/removal from the forest floor on litter-dwelling spiders in unmanaged forests. Spider density within plots where fine woody debris (FWD) was removed was 30% lower than the spider density within control plots (Castro and Wise 2009). The results of this study may not be representative of the impacts associated with FWD removal from younger, managed stands (Castro and Wise 2009).

8.4.3 Herpetofauna (Amphibians and Reptiles)

Amphibians include species with diverse life histories, habitat preferences, and means of dispersal. While this diversity makes generalizations about the impacts of woody biomass harvest difficult, the available literature shows that a large proportion of amphibians are heavily dependent upon dead and downed wood for a variety of functions (Harmon et al. 2004, Corn and Bury 1990, Aubry 2000, Aubry et al. 1988, Raphael 1988, Bury 1983, Butts and McComb 2000). Besides providing cover and protection from predation, dead and downed wood maintains moist, cool microclimates that buffer more dramatic stand-level moisture and temperature changes (James and M'Closkey 2003, Welsh and Lind 1988). Many salamander species are associated with the presence of dead and downed wood (Corn and Bury 1990, Aubry 2000). Reptiles are common in California's grasslands, shrublands, oak woodlands or open forests (Pilliod et al 2006, Bury 2004). Stumps, logs, and snags provide cover and maintain suitable microclimates for snakes and lizards (James and M'Closkey 2003, Waldien et al. 2003).

8.4.4 Birds

The scientific literature on birds and their habitat associations with dead and downed wood and understory vegetation is extensive (e.g. Raphael and White 1984, Laudenslayer et al. 2002, Thomas 1979). Cavity nesting birds can make up a large proportion of the total bird species in a forest stand. The number of cavity nesting birds within a stand varies with the stand's development stage and depends upon the number, size, species, and state of decay of the dead and dying trees. Cavity nesting birds are often placed in one of two categories: primary cavity excavators or secondary cavity nesters (McComb 2008). Woodpeckers and other primary cavity excavators provide an essential service to many wildlife species by excavating cavities in dead and dying trees (Pilliod et al 2006, McComb 2008). Secondary cavity nesting birds, bats, and mammals unable to excavate dead wood, depend upon these cavities for nesting and roosting cover (Hagar 2007, Harmon et al. 2004, McComb 2008).

The size of the dead or dying tree will determine which species may use it. Cavity nesting birds generally select snags with larger than average diameters for nesting (Carey 1989, Mannan et al. 1980, Raphael and White 1984). Larger species require snags with larger diameters as well. The

state of decay may play an important role in determining the habitat value of snags for cavity nesting birds as slightly decayed snags are easier to excavate. The habitat value of snags changes over time with the decay process. Again, larger snags are often preferred because they last longer on the landscape. It will be important to limit disturbance to snags and retain as many as possible during woody biomass harvests.

The feeding habits of many birds depend upon a well developed understory with herbs, shrubs, deciduous trees and dead and downed wood (Hagar 2007). The seeds and fruits produced by understory plants are often a major source of food for birds. Insects, both flying and terrestrial, are also very common components of bird diets. Snags and logs are heavily utilized as feeding sites for insectivorous birds (Harmon et al. 2004, Raphael and White 1984). Seavy et al. (2008) found lower abundances of shrub associated species in chaparral stands that had been masticated.

8.4.5 Raptors

Raptors are highly mobile predators that frequent diverse habitats. Raptors prey upon small mammals and birds that hide in understory vegetation and dead and downed wood. Biomass harvests that remove these habitat structures may expose greater quantities of prey, making feeding easier for raptors (Pilliod et al 2006). In general, it is important to maintain the habitat structures used by small mammals and birds in order to insure a stable population capable of supporting a large bird of prey (snags, logs, coarse woody debris, some understory vegetation, etc). Large trees and snags are important resting and nesting habitat structures for many large birds of prey, including the Northern Goshawk (Greenwald et al. 2005).

8.4.6 Bats

Many species of bats locate roosting sites within large, moderately decayed snags with cavities and under the bark of large trees (Pilliod et al. 2006, Bunnell et al. 2002, Lofroth 1998, Campbell et al. 1996, Brigham et al.1997, Ormsbee and McComb 1998, Waldien et al. 2000, Weller and Zabel 2001, Hayes 2003). Bats use different structures for roosting throughout the day that may help in thermo-regulation (Hayes 2003, Campbell et al. 1996, Vonhof and Barclay 1996, Ormsbee and McComb 1998, Weller and Zabel 2001). Roost structures are often tall and occur in gaps, openings or areas of low canopy closure (Hayes 2003, Vonhof and Barclay 1996, Waldien et al. 2000, Campbell et al. 1996). Biomass harvests that reduce the quantity and quality of snags will likely impact bat species. Several species of bats are known to use large stumps with cracks and crevices within clearcuts, especially when preferred roosting sites (snags) have been removed (Waldien et al. 2003, Vonhof and Barclay 1997, Waldien et al. 2000, Hayes 2003). Night roosting sites are used for resting, energy conservation, social interaction, consumption and digestion of food and are often man-made structures, caves, large logs or snags with cavities (Hayes 2003).

Bats often use open habitats for feeding more intensively than dense forests. The types of vegetation within a forest stand will influence the insect populations present and therefore the food supply for bats. Biomass harvests that remove the majority of herb and shrub cover within a stand could be detrimental to insect populations and bats. If biomass harvests result in homogeneous forest structures across the landscape lacking in understory vegetation and dead wood (mainly snags) bat populations will likely decline (Hayes 2003). In general, scientific

studies of bat populations are lacking and make it difficult to assess the impacts of biomass harvests on bat species (Hayes 2003).

8.4.7 Small mammals

The habitat associations between small mammals and dead and downed woody debris are well established in the scientific literature (Harrington and Nicholas 2007, Bunnell et al. 1999, Laudenslayer et al. 2002, Harmon et al. 2004, Freedman et al. 1996, Thomas 1979, Butts and McComb 2000, Carey and Harrington 2001). Logs and coarse woody debris provide perching platforms and escape runways. Loose bark provides cavities for hiding and thermal cover. Food availability for small mammals increases as invertebrates and fungi colonize the dead wood material and aid in decay. A given species may use dead and downed wood to meet all, several, or one of its life requirements (feed, cover, reproduction, etc). The abundance of small mammals using dead wood is directly related to the quantity and quality of logs, limbs, stumps, and snags in the system. Herbaceous and shrub cover are sometimes associated with small mammal presence (Carey and Harrington 2001, Carey 1995, Carey and Johnson 1995, Carey et al. 1999). Biomass harvests that remove or disturb dead and downed wood and understory vegetation layers will result in lower habitat quality and smaller small mammal populations (Butts and McComb 2000, Carey and Harrington 2001).

There is disagreement in the literature about whether or not small mammals preferentially use logs with high levels of decay (and fungi) (Maser et al. 1978, Ure and Maser 1982, Maser and Trappe 1984, Hayes and Cross 1987, Bowman et al 2000). Bowman et al. (2000) suggests that small mammal use logs differently, depending upon the state of decay, but the level of use did not vary with decay class. Highly decayed logs have a greater presence of fungi, a common and important food source for many small mammal species (Maser et al. 1978, Carey et al. 1999, Pyare and Longland 2001, Ure and Maser 1982). Woody biomass harvests may remove or damage these important structures. Frequent harvests may significantly reduce the quantity of dead wood with high levels of decay as there would not be sufficient time between harvests for decay to develop.

8.4.8 Ungulates

The most common group of hoofed animals in California's wooded ecosystems is deer (*Odocoileus spp.*). There are also native and introduced species of elk, sheep, and pigs. All species are associated with abundant forage, including herbs, grasses, shrubs, and hardwoods. These species also tend to have large home ranges that include patches of dense forest canopy for cover and open thickets of shrubs for browsing, resting and fawning. The associations that exist between ungulates and dead and downed woody debris are weak. Deer and elk will use the upslope side of logs for bedding sites (Maser et al. 1979). Large amounts of woody debris distributed across harvested sites act to deter deer and elk from browsing (Maser et al. 1979, Bergquist et al. 1999). Increased removal of woody debris may open the stands up for more browsing by ungulates. Woody biomass harvests that reduce the quantity and quality of browse and cover available within a stand and across the landscape will likely have negative impacts on ungulate species.

8.4.9 Carnivorous mammals

Large, carnivorous mammals are rare (relative to plants and smaller animals) in forest, woodland, and shrubland habitats in California. Mammals found in California include the mountain lion (*Felis concolor*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), black bear (*Ursus americanus*), fisher (*Martes pennanti*) and American martin (*Martes americana*). Important habitat elements for these large mammals include dead and downed wood and understory shrub and tree cover within and adjacent to mature forest stands. Large diameter logs and snags with cavities are often used for denning and resting (Maser et al. 1979, Bull and Heater 2000). Spencer et al. (1983) found martens preferred above snow resting sites in large snags and live trees, and undersnow resting sites in coarse woody debris and stumps. Fishers prefer large diameter trees with mistletoe brooms and snags with cavities for resting and denning sites (Purcell et al. 2009). Bull et al. (2000) found 41% of black bears using hollow logs or snags/trees with large basal cavities as denning sites in northeastern Oregon.

Common feeding habits for bears and martens include foraging within dead and downed wood for invertebrate and vertebrate prey (Maser et al. 1979, Sherburne and Bissonette 1994). Bears are known to prey on colonies of termites and carpenter ants present in downed logs and stumps (Harmon et al. 2004). Understory vegetation plays an important role in providing cover and food (berries) (Arthur et al. 1989, Sherburne and Bissonette 1994). Because these mammals have such large home ranges the impacts associated with a single biomass harvest would be negligible. However, the cumulative impacts to carnivorous mammals from biomass harvests may be serious if dead and downed wood and understory vegetation (i.e. reduction in prey populations, forage and denning habitat) is significantly reduced across the landscape.

8.5 Management of wildlife at the landscape-scale

There are two main categories of wildlife conservation approaches: those that focus on maintaining single species and those that focus on maintaining ecosystem patterns and processes (Tracy and Brussard 1994, Franklin 1993). The metaphor of fine filters and coarse filters is often used to describe these two complementary strategies for maintaining wildlife populations (Hunter 2005). There is considerable debate within the scientific literature about the most effective method for wildlife conservation (Lambeck 1997, Tracy and Brussard 1994, Roberge and Angelstam 2004).

8.5.1 The “fine filter” approach

The fine filter approach to wildlife conservation focuses on rare or specialized species that may not find adequate protection associated with large scale reserves or more general strategies (Hunter 1990). Species-specific approaches to wildlife habitat management are particularly common for species with special management status (i.e. endangered, threatened, rare) (Lambeck 1997). Special rules and management practices have been developed to protect species that have been identified as being especially vulnerable to habitat alteration (see Endangered Species Act, ESA 1973). Species-specific retention targets for essential habitat elements are used to ensure the continued provision of critical habitat. Species-based approaches have been criticized for being too slow, expensive, and incapable of preserving ecological processes and essential habitats (Franklin 1993, Orians 1993, Walker 1995). Fine filter

approaches can address the needs of only a few species, and should be used in combination with other management techniques to ensure viable populations of all wildlife species are maintained, not just the endangered, threatened or rare (Hunter 1990, Shaffer 1981)

8.5.2 The “coarse filter” approach

The coarse filter approach to wildlife conservation is based on the concept of protecting entire ecosystems, mainly through the use of reserves and the maintenance of ecological processes (Hunter 1990). Franklin (1993) and Walker (1995) discuss the importance maintaining landscape patterns and processes for wildlife conservation. Such approaches can be particularly useful for the conservation ecosystems and species that are not well understood, such as invertebrates and bacteria (Franklin 1993, Walker 1995). Orians (1993) suggests ecosystem approaches to conservation are more likely to include protection for wildlife species that are not rare, threatened or endangered. Criticisms of the ecosystem approach include issues with defining ecosystems and processes for conservation and paralyzing complexity (Tracy and Brussard 1994). Coarse filter approaches may not provide adequate protection for rare, threatened, or endangered species and habitats. Fine filter approaches can “catch” those species that “slipped” through the coarse filter (Hunter 1990).

8.5.3 Hybrid approaches

Wildlife will benefit most from a conservation strategy that optimally combines both fine filter and coarse filter approaches (Hunter 1990). Lindenmayer et al. (2006) propose five guiding principles for biodiversity and wildlife conservation that focus on maintaining landscape connectivity, heterogeneity, and structural complexity. While the recommendations focus on sustaining ecological processes, Lindenmayer et al. (2006) recognize the importance of managing stands to sustain species and sensitive habitats. Villard and Jonsson (2009) agree with the general recommendations presented in Lindenmayer et al. (2006) but conclude that such recommendations require knowledge of individual species habitat requirements. Species of management interest will have an important role in determining any conservation strategy or retention target (Villard and Jonsson 2009).

8.5.4 Retention targets

It may be necessary to develop provisions for the recruitment of structural elements such as large snags, logs, and coarse woody debris, which would otherwise not be replaced under an intensive biomass harvesting regime (Lambeck 1997, Franklin 1993). Few studies have attempted the difficult task of quantifying the amount of dead and downed wood/biological legacies necessary to maintain wildlife populations ((Hunter and Bond, 2001; Hunter, 1990; Hunter, 2005), Ranius and Fahrig 2006). The results of these studies are site specific and focus on a single species or subset of the entire forest fauna population. Hunter (2005) suggests an approach that focuses on conserving critical structural elements and ecological processes of ecosystems is particularly appropriate for working landscapes, such as forests, woodlands and shrublands harvested for woody biomass. Dead and downed wood retention targets would be an example of this conservation approach. Lambeck (1997) suggests using a multi-species approach, similar to the concept of umbrella species, in which a suite of focal species are selected whose habitat requirements encompass the needs of the majority of species present.

Retention targets for dead and downed wood could then be developed to reflect the requirements of these representative species (Lambeck 1997).

8.5.5 Habitat fragmentation and loss

The impacts on wildlife at the site of an individual biomass harvest will be determined by the size and intensity of the harvest and types of structural elements removed. The surrounding, untreated forest (matrix) can provide habitat for those species with dispersal capability. As more and more forest stands are harvested for biomass the level of dead and downed wood and understory vegetation may be significantly reduced across the landscape, resulting in more homogeneous understory conditions. Spatial heterogeneity, at both the stand- and landscape-levels, is important for the maintenance of wildlife populations (e.g. Lindenmayer et al. 2006, Carey and Harrington 2001, Harmon et al. 2004, Freedman et al. 1996).

The spatial and temporal distribution of biomass harvests within a landscape will determine the level of habitat fragmentation and loss experienced by the local wildlife (Fahrig 1997, Thompson et al. 2003). Habitat fragmentation is a landscape-level process that includes both the loss and breaking up of continuous habitats into smaller habitat patches surrounded by unsuitable conditions (Fahrig 2003). Fahrig (2003) concludes that habitat loss has large, consistently negative effects on wildlife populations, whereas habitat fragmentation is at least as likely to have positive effects as negative effects. Habitat fragmentation is likely to occur as biomass harvests are implemented across the landscape. The spatial arrangement of these harvests will determine the type and amount of cumulative impacts (Thompson et al. 2003). The intensity of removal, the types of habitat structures removed and the frequency of harvest will determine how permanent the effects are. If biomass harvests do not allow for the retention and/or recruitment of large snags and logs in various states of decay, impacts to wildlife may be serious (Raphael and White 1984, Ranius and Fahrig 2006).

Several studies suggest there are critical thresholds in habitat fragmentation that vary with habitat type and wildlife species (Andren 1994, Andren 1999, Fahrig 2002, Franklin and Forman 1987, Monkkonen and Reunanen 1999). Species ability to cope with fragmentation depends upon the distance between suitable habitat fragments, dispersal capability, and the conditions of the matrix (Andren 1999). Species with large home ranges will likely be able to move to a more suitable habitat patch during and after a biomass harvest more easily than limited dispersers. As greater proportions of the landscape are harvested for biomass, habitats become more fragmented and the impacts from each additional harvest may be magnified. It is important to remember that the effects of habitat fragmentation resulting from biomass harvest are limited temporally, and will change over time as the habitat conditions recover (Monkkonen and Reunanen 1999).

8.6 Conclusions

The impacts of woody biomass harvests on wildlife are variable and depend upon the timing, frequency, intensity and spatial extent of the harvest. The majority of impacts will be associated with habitat manipulation, fragmentation, and loss. There are few scientific studies that look at the site-specific impacts of woody biomass harvests on wildlife, and even fewer at the

landscape scale. Species specific analyses are necessary to fully understand the potential impacts of woody biomass harvests on wildlife.

Many wildlife species depend upon dead and downed wood structures and understory vegetation, but few studies attempt to quantify the critical thresholds that are necessary to maintain viable wildlife populations. The impacts on wildlife at the site of an individual biomass harvest will be determined by the size and intensity of the harvest and types of structural elements removed. The spatial arrangement of biomass harvests will determine the cumulative impacts. The surrounding, untreated forest (matrix) can provide habitat for those species with dispersal capability. The intensity of removal, the types of habitat structures removed and the frequency of harvest will determine how permanent the effects are.

The maintenance of residual habitat structures during woody biomass harvests will be important for achieving habitat conservation and wildlife protection goals. Care should be given to developing retention guidelines that reduce the impacts to wildlife. These guidelines must be informed by the results from empirical studies of woody biomass harvests and their impacts to wildlife. Strict retention guidelines that recommend the same level of woody biomass retention across the landscape may lead to unwanted homogeneous conditions.

CHAPTER 9:

Using the California Wildlife Habitat Relationship model to predict the impacts of increased harvest residue collection

Modeling the Impacts to Wildlife from Woody Biomass Harvesting in Sierran Mixed Conifer, Blue Oak Woodland, and Mixed Chaparral habitats of Northern California

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9.1 Introduction

Concerns about rising energy costs, global climate change related to greenhouse gas emissions, and catastrophic wildfires have resulted in a renewed interest in the use of woody biomass from California's forest, woodland, and shrubland ecosystems for bioenergy generation. The potential environmental impacts associated with increased utilization of woody biomass from natural ecosystems are not fully understood. In particular, the effects of woody biomass extraction on wildlife populations and biodiversity are largely unaddressed in the scientific literature. The extraction of woody biomass from California's forests, woodlands and shrublands may impact wildlife, especially where essential habitat structures are removed from the landscape (Janowiak and Webster 2010).

Since the mid-1970s, wildlife habitat-relationship models have been used by resource managers and land use planners to assess impacts of management decisions on wildlife communities (Airola 1988). More specifically, wildlife habitat-relationship models are often used to estimate changes in habitat suitability resulting from alterations to habitat structure and connectivity (Beck and Suring 2009). The California Wildlife Habitat Relationship (CWHR) system contains information on, and habitat-relationship models for 694 regularly occurring species of amphibians, reptiles, birds, and mammals (CWHR 2008). In California, CWHR has been used by state and federal agencies to assess impacts to wildlife associated with proposed land uses (e.g. Biomass to Energy, Nechodom et al. 2008). Private timber companies operating in California are required to use CWHR when writing sustained yield and timber harvest plans (CA FPR 2010).

The primary objective of this analysis was to model woody biomass harvests, with and without structural retention, in the Sierran mixed conifer, blue oak woodland, and mixed chaparral habitats to quantify changes in species richness and habitat suitability scores.

9.2 Methods

9.2.1 California Wildlife-Habitat Relationship (CWHR) system

The California Wildlife Habitat Relationship (CWHR) system currently contains habitat-relationship models for 694 wildlife species regularly occurring in California (CWHR 2008). CWHR uses a standardized habitat classification system containing 59 habitats, structural stages, and 124 habitat elements to predict species presence and habitat suitability ratings

(Airola 1988, Mayer and Laudenslayer 1988). For each structural stage, ratings of high, medium, low, or not used are given for reproduction, cover, and feeding habits (Airola 1988). Average habitat suitability scores are also reported. Habitat elements are rated according to their importance in determining the use of a habitat by a species for breeding, feeding, and resting (Airola 1988). While species presence and habitat suitability scores are determined by the habitat type and structural stage, essential habitat elements must also be present for the model to predict occurrence (Airola 1988). CWHR has its sources of error and limitations but it represents the best existing information on the habitat relationships of California vertebrates and is commonly used to model wildlife-habitat relationships for California species (Garrison and Lupo 2002, Garrison and Standiford 1997, Block et al. 1994, Garrison 1994, Purcell et al. 1992).

9.2.2 Selecting the study area

We were interested in assessing the potential impacts to wildlife species of biomass harvest in forest, woodland, and shrubland habitats across California. In order to simplify the analysis, we decided to focus the impact assessments on habitats within Shasta and Tehama counties. Three habitats were identified as having woody biomass production potential: Sierran mixed conifer (SMC), blue oak woodland (BOW), and mixed chaparral (MCH).

9.2.2 Selecting evaluation species

Impacts from biomass harvesting were assessed by selecting wildlife species that represent diverse habitat needs and uses for reproduction, feeding and cover habits. Following the methodology described in Garrison and Standiford (1997), a single condition query was conducted for all 18 habitat stages in the SMC habitat type within Shasta and Tehama counties. Species occurring at all times of the year were included. 62 special habitat elements were determined to be absent from study area, including manmade structures, aquatic, physical and agricultural edges. A species detail report was produced with 169 species of amphibians, reptiles, mammals and birds predicted to occur in our study area. The same process was used to develop an initial list containing 159 species for the MCH habitat type. Instead of recreating the Garrison and Standiford (1997) BOW evaluation species list, we used the list as published.

In order to focus the impact assessments on species primarily associated with the habitats of interest (SMC and MCH), species were eliminated if they met one or more of the following criteria (Garrison and Standiford 1997): (1) species primarily associated with aquatic habitats, (2) species primarily associated with habitats other than SMC or MCH, (3) species with distributions not including the study area (Shasta and Tehama counties), (4) non-native species associated with human habitation, and (5) species *without* arithmetic average habitat suitabilities ≥ 0.66 (medium habitat suitability) for at least one of the 18 SMC or 13 MCH habitat stages. CWHR species life history reports were consulted during the elimination process. 95 species remained on the SMC list and 54 species remained on the MCH list. The majority of species removed from both lists met criteria #5.

Using the scoring system described in Garrison and Standiford (1997), the two lists of remaining species were ranked according to the following criteria:

(1) CWHR-predicted sensitivity to differences in canopy cover.

This was determined by using the difference in CWHR predicted, arithmetic-average habitat suitability values between SMC habitat stages with < 40% canopy cover (open canopies) and stages with \geq 40% canopy cover (closed canopies) (i.e. a two condition query). Species received a score of 3 (high sensitivity) when the model output showed a change of 2 suitability classes (H for open canopies and L for closed canopies). Species received a score of 2 (moderate sensitivity) when the model output showed a change of 1 suitability class (M for open canopies and H for closed canopies). Species received a score of 1 when the model did not predict a change in suitability class (M for open and M for closed). Species with score of 2 or 3 were categorized as preferring open or closed canopy conditions depending upon which cover condition had the greatest average suitability value. Species with a score of 1 were categorized as having no preference.

(2) The level of overlap between the species geographic distribution and the range of SMC/MCH in California (1=no or low overlap; 2=moderate overlap; 3=high overlap)

(3) Whether or not the species breeds in the SMC/MCH (0=no; 1=yes),

(4) Whether or not the species has special legal status, such as harvest, threatened, endangered, or special concern (0=no; 1=yes).

A maximum score of 8 was possible, though no species ranked that highly. Scores ranged from 2 to 7 for species on both the SMC and MCH lists. A threshold of scores \geq 6 was used to further reduce the SMC and MCH evaluation species lists. Species with scores below the threshold were eliminated. The preliminary SMC species list contained 35 species, while the MCH list contained 24 species.

These preliminary species lists were then sent to several wildlife biologists and species experts for review (Peter Stine and Ryan Burnett, personal communication 2010). Several deletions and additions were suggested and the evaluation species lists were finalized. We are confident that the species selected for evaluation are appropriate and include diverse habitat uses/needs. Most importantly, these species lists should be able to capture impacts associated with habitat alteration from woody biomass harvesting.

9.2.3 Biomass harvest simulations

Habitat, structural conditions and special habitat elements are the determinants of species presence and habitat suitability values within the CWHR system (Airola 1988). Therefore the development of realistic initial and post-harvest habitat descriptions is an important component of the CWHR impact assessment process. Experts were consulted, and a total of 12 initial and post-harvest habitat conditions were developed for Sierran mixed conifer, blue oak woodlands, and mixed chaparral habitats in Shasta and Tehama counties (Rick Standiford and Bill Stewart, personal communication 2010).

Sierran mixed conifer

Biomass harvests within the Sierran mixed conifer would likely be associated with other forest management activities, such as pre-commercial thinning or regeneration treatments. These activities occur within different structural stages. Three different initial and post-harvest habitat conditions were developed for the SMC habitat in an attempt to capture the impacts associated with different types of biomass harvest in both even-aged and uneven-aged silvicultural systems. Initial and post-harvest habitat conditions were developed for a pre-commercial thin, clearcut, and single-tree selection using the CWHR vegetation classification system described in Mayer and Laudenslayer (1988):

(1) *Pre-commercial thin, canopy is opened but quadratic mean diameter remains unchanged.* The initial condition (**4D**) is characterized by small trees (11-24" dbh) with dense canopy closure (60-100%). The post-harvest condition (**4M**) is characterized by small trees (11-24" dbh) with moderate canopy closure (40-59%).

(2) *Clearcut regeneration, canopy is removed and seedlings establish.* The initial condition (**5D**) is characterized by medium/large trees (>24" dbh) with dense canopy closure (60-100%). The post-harvest condition (**1**) is characterized by the presence of tree seedlings less than 1" dbh.

(3) *Single-tree selection, canopy remains closed but canopy layers are removed and the quadratic mean diameter is reduced.* The initial condition (**6**) is characterized by a multi-storied, closed canopy stand of large trees. The post-harvest condition (**4D**) is characterized by small trees (11-24" dbh) with dense canopy closure (60-100%).

Blue oak woodlands

Blue oak woodlands would likely experience biomass harvesting in association with firewood cutting. It was decided that a residual oak stand would likely remain after a biomass harvest, so no "clearcut" operations were modeled. Two partial cuttings, resulting in different post-harvest conditions, were modeled in an attempt to capture a range of potential wildlife impacts. The initial condition (**3M**) for both treatments is characterized by pole sized trees (6-11" dbh) with moderate canopy closure (40-59%). The harvest prescriptions and post-harvest conditions are described:

(1) *Heavy thin, canopy is greatly reduced and the quadratic mean diameter increases.* The post-harvest condition (**4S**) is characterized by small trees (11-24" dbh) with sparse canopy closure (10-24%);

(2) *Light thin, canopy is slightly reduced and the quadratic mean diameter remains unchanged.* The post-harvest condition (**3P**) is characterized by pole sized trees (6-11" dbh) with open canopy (25-39%).

Mixed chaparral

Biomass harvesting within shrubland habitats would most likely consist of the complete removal of woody biomass on site. No partial harvests were modeled within the mixed chaparral habitat. It was assumed that biomass harvests would occur in stands of mature

shrubs when woody biomass volumes are greatest. The initial habitat condition (3D) is characterized by mature shrubs (1-25% canopy decadence) with dense canopy closure (60-100%). The post-harvest condition (1) is characterized by the presence of shrub seedlings and sprouts.

9.2.4 Special habitat element lists

The CWHR system uses the presence/absence of rated habitat elements to further assess the likelihood of occurrence within a modeled habitat (Airola 1988). While special habitat elements have no influence on species' habitat suitability scores, essential elements must be present in order for species to be present. Upon review of the special habitat elements, it was determined some of the 124 special habitat elements should be excluded from the 12 modeled initial and post-harvest conditions (mainly manmade structures, aquatic, physical and agricultural edges). Two element exclusion lists were developed for each post-harvest condition in an attempt to determine if there were impacts associated with the removal of coarse woody debris, logs, snags, and trees with habitat values (cavities, loose bark, broken tops). The second post-harvest element exclusion list differs from the first in that it retains some habitat elements for wildlife: slash, large (rotten and hollow); snags, all size classes (sound); trees, with broken live top/cavities/loose bark.

Table 11 The number of special habitat elements excluded from initial and post-harvest conditions in the Sierran mixed conifer CWHR model runs

Habitat condition	Number of excluded elements
Initial (4D)	57
Pre-commercial thin (4M)	76
Pre-commercial thin (4M) w/retention	62
Initial (5D)	56
Clearcut (1)	79
Clearcut (1) w/retention	64
Initial (6)	55
Single-tree (4D)	75
Single-tree (4D) w/retention	62

Table 12 The number of special habitat elements excluded from initial and post-harvest conditions in the blue oak woodland CWHR runs

Habitat condition	Number of excluded elements
Initial (3M)	54
Heavy thin (4S)	73
Heavy thin (4S) w/retention	62
Light thin (3P)	73
Light thin (3P) w/retention	62

Table 13 The number of special habitat elements excluded from initial and post-harvest conditions in the mixed chaparral CWHR model runs

Habitat condition	Number of excluded elements
Initial (3D)	77
Harvest (1)	84
Harvest (1) w/retention	82

9.2.5 Assessing species impacts

Using the CWHR system's two condition query, habitat value comparison reports were generated for 12 biomass harvest scenarios. Average habitat suitability for all evaluation species were calculated using an arithmetic mean for both initial and post-harvest conditions. Several methods can be used to evaluate the impacts of habitat changes on wildlife species, changes in wildlife species richness and habitat suitability values were selected for this analysis.

Species richness is the number of wildlife species that occur at a site (Peet 1974, Sanjit and Bhatt 2005). A change in species richness can be used as a simple measure of wildlife community response to habitat alteration. The habitat value comparison report indicates changes in species richness and identifies species that no longer find suitable habitat within the post-harvest condition.

Changes in habitat suitability values resulting from habitat alteration are included in the habitat value comparison reports. Two different measures of significance were applied: (1) *rating class*, a method in which a difference of one or more average habitat suitability values between conditions was considered significant (i.e. a change from 0.33(L) to 0.66(M) would be a significant difference); and (2) $\geq 22\%$ *difference*, a method in which a difference in average habitat values of 22% or more between conditions was considered significant (i.e. a change from 0.66(M) to 0.44(M)) (Garrison 1994).

9.3 Results

9.3.1 Sierran mixed conifer

The 42 evaluation species (appendix: Table 7) included representatives from all vertebrate groups (excluding fish), with birds and mammals making up the majority of the list. A wide variety of breeding substrates and feeding habits are represented in the evaluation species. 11 species had a rating score of 7, 24 species had a rating score of 6, 6 species had a score of 5, and Cassin's finch had a score of 1. The 7 species with scores below the threshold were added by expert reviewers (Peter Stine and Ryan Burnett, personal communication 2010). The majority of evaluation species used trees/snags as a preferred breeding substrate. The feeding habits were diverse, with species feeding primarily on invertebrates, plant material, small mammals, or birds. Ten species were predicted by CWHR to prefer open canopies ($\leq 39\%$ canopy closure), 20 species were predicted to prefer closed canopies ($\geq 40\%$ canopy closure), and 12 species were assigned habitat suitability values that indicated they had no preference.

The evaluation species showed varied responses to the different biomass harvest prescriptions. The pre-commercial thin treatment produced 21 significant changes in species habitat suitability values, with 8 species having positive and 13 species having negative responses. The pre-commercial thin treatment produced habitat conditions that the model predicted unsuitable for 12 species. These 12 species no longer found suitable habitat because essential habitat elements were removed during the harvest. Interestingly, there was very little predicted difference in the number of significant changes between the pre-commercial thin and the pre-commercial thin with retention. The Northern Saw-whet Owl was the only species to be affected by the retention of additional habitat elements. The overwhelming majority of retained habitat elements did not produce species responses, indicating that the elements retained were not essential for the presence of the evaluation species. The difference between the two measures of significance was small (Table 14).

The clearcut treatments produced the largest number of significant changes out of all 6 biomass harvests modeled in the SMC. Forty species were predicted to have a significant change in habitat suitability between the initial and post-harvest condition. Thirty-three of those changes were predicted to be negative and 24 species were predicted to have no suitable habitat. Two species not predicted to find suitable habitat in the initial condition, the calliope hummingbird and the purple martin, were predicted to have habitat suitability values greater than zero in the post-harvest condition. Therefore the change in species richness between the two conditions was -22 species. The model predicted no difference in the response of the evaluation species between the clearcut and clearcut with retention post-harvest conditions except for the Northern Saw-whet Owl. This indicates the special habitat elements excluded in both post-harvest conditions were essential to the 23 species no longer finding suitable habitat. The difference between the two measures of significance was small. The $\geq 22\%$ difference measure of significance resulted in 39 significant changes between the initial and clearcut with retention condition (Table 15).

The predicted species impacts from the single tree selection treatments showed a little more variability than the previous model runs. Twenty species were predicted to have a significant change in habitat suitability between the initial and post-harvest condition. Sixteen of those significant changes were predicted to be negative. The predicted change in species richness between the two conditions was -13. This number drops by one when habitat elements are retained and the Northern Saw-whet Owl is added to the list of species finding suitable habitat in the single-tree selection with retention condition. Again, the Northern Saw-whet Owl is the only species with a predicted change in occurrence between the single-tree selection and single-tree selection with retention conditions. The difference between the two measures of significance was more noticeable between the initial and both single-tree selection post-harvest conditions. In both cases, the number of unaffected species was predicted to be greater under the $\geq 22\%$ difference measure (Table 15).

Table 14 Number of significant changes in habitat suitability values using both measures of significance (rating scores and $\geq 22\%$), and change in species

		# of Significant Changes in Habitat Suitability Values						Change in Species Richness
		Positive		Negative		Unaffected		
Habitat	Treatment	Rating scores	$\geq 22\%$	Rating scores	$\geq 22\%$	Rating scores	$\geq 22\%$	
SMC	Pre-commercial thin (4D to 4M)	8	9	13	13	21	20	-12
SMC	Pre-commercial thin (4D to 4M) w/retention	8	9	12	12	22	21	-11
SMC	Clearcut (5M to 1)	7	6	33	34	2	2	-22
SMC	Clearcut (5M to 1) w/retention	7	6	33	33	2	3	-21
SMC	Single tree (6 to 4D)	4	2	16	15	22	25	-13
SMC	Single tree (6 to 4D) w/retention	4	2	15	13	23	27	-12

9.3.2 Blue oak woodlands

The 21 evaluation species (appendix: Table 8) included representatives from all vertebrate groups (excluding fish), with birds and mammals making up the majority of the list. A wide variety of breeding substrates and feeding habits are represented in the evaluation species. The species rating scores ranged between 4 and 9, with the acorn woodpecker, mourning dove and the wild turkey having the highest scores and the western fence lizard having the lowest. The majority of evaluation species used trees/snags with and/or without cavities as a preferred breeding substrate. The feeding habits were diverse, with species feeding primarily on invertebrates, vertebrates, or plant material. Nine species were predicted by CWHR to prefer open canopies ($\leq 39\%$ canopy closure), three species were predicted to prefer closed canopies

($\geq 40\%$ canopy closure), and eight species were assigned habitat suitability values that indicated they had no preference.

The predicted species impacts varied slightly between the four woody biomass harvests modeled in the Blue Oak woodlands. There were more significant, positive changes predicted in the two (heavy and light) harvests that retained habitat elements. Evaluating the heavy harvests first, 12 significant changes were predicted between initial and post-heavy harvest conditions (11 with element retention). Seven species were predicted to no longer find suitable habitat in the post-harvest condition, while the western meadowlark's average habitat suitability score increased from 0 to 1. When habitat elements were retained in the post-heavy harvest condition, the number of species predicted to no longer find suitable habitat dropped to 4. The predicted species richness changed by -6 species between the two conditions, but was only -3 when habitat elements were retained. The retention of special habitat elements had a positive effect on the Northern Screech Owl, acorn woodpecker, and the ash-throated flycatcher. Present in the initial condition, the Northern Screech Owl, acorn woodpecker, and the ash-throated flycatcher were predicted to not find suitable habitat in the post-harvest condition. However, the retention of habitat elements in the second post-harvest condition made the habitat suitable and their occurrence likely. There was no difference between the two measures of significance when evaluating habitat changes between the initial and both post-heavy harvest conditions (Table 16).

There were slightly fewer predicted significant changes between the initial and post-light harvest conditions. Eight of the eleven significant changes predicted were negative. However, when habitat elements were retained the number of significant negative changes drops to 5. Seven species were predicted to no longer find suitable habitat in the post-light harvest condition (5 with element retention). The predicted change in species richness was the same as that predicted during the heavy harvest runs, -6 without and -3 with habitat element retention. The retention of habitat elements had a positive effect on the same three species as in the heavy harvest condition: Northern Screech Owl, acorn woodpecker, and the ash-throated flycatcher. The retention of habitat elements allowed these species to find suitable habitat where they did not find suitable habitat before. There was a noticeable difference between the two measures of significance (Table 16).

Table 15 Number of significant changes in habitat suitability values using both measures of significance (rating scores and $\geq 22\%$), and changes in species richness resulting from 4 biomass harvest treatments in the blue oak woodland habitat type

		# of Significant Changes in Habitat Suitability Values						Change in Species Richness
		Positive		Negative		Unaffected		
Habitat	Treatment	Rating s	$\geq 22\%$	Rating s	$\geq 22\%$	Rating s	$\geq 22\%$	
BOW	Heavy harvest (3M to 4S)	4	4	8	8	9	9	-6
BOW	Heavy harvest (3M to 4S) w/retention	6	6	5	5	10	10	-3
BOW	Light harvest (3M to 3P)	3	2	8	11	10	8	-6
BOW	Light harvest (3M to 3P) w/retention	5	3	5	8	11	10	-3

9.3.3 Mixed chaparral

The 25 evaluation species (appendix **Table: 9**) included representatives from all vertebrate groups (excluding fish), with birds and mammals making up the majority of the list. A wide variety of breeding substrates and feeding habits are represented in the evaluation species. The species rating scores ranged between 4 and 7, six species receiving rating scores of 7 and the wren tit having the lowest score. The majority of evaluation species used the surface or shrubs as a preferred nesting or denning sites. The feeding habits were diverse, with species feeding primarily on invertebrates, vertebrates, or plant material. Seven species were predicted by CWHR to prefer open canopies ($\leq 39\%$ canopy closure), nine species were predicted to prefer closed canopies ($\geq 40\%$ canopy closure), and seven species were assigned habitat suitability values that indicated they had no preference.

There was no difference in the number of predicted significant changes between initial and both post-harvest conditions. The retention of habitat elements did not change the list of species predicted to occur in either of the post-harvest conditions. This indicates that there were essential habitat elements removed during both biomass harvests. In both model runs, the change in species richness was predicted to be -9. There were 19 predicted significant changes, 15 of which were negative. The $\geq 22\%$ difference measure of significance suggests slightly more negative impacts than the ranking measure, as 17 species show negative responses to the treatments (Table 17).

Table 16 Number of significant changes in habitat suitability values using both measures of significance (rating score and $\geq 22\%$), and changes in species richness resulting from 6 biomass harvesting treatments in mixed chaparral habitat type

		# of Significant Changes in Habitat Suitability Values						Change in Species Richness
		Positive		Negative		Unaffected		
Habitat	Treatment	Rating s	$\geq 22\%$	Rating s	$\geq 22\%$	Rating s	$\geq 22\%$	
MCH	Harvest (3D to 1)	4	3	15	17	4	3	-9
MCH	Harvest (3D to 1) w/retention	4	3	15	17	4	3	-9

9.4 Discussion

Differences between initial and post-harvest habitat conditions were predicted for all 12 biomass harvests. While some species were predicted to benefit from the change in habitat condition resulting from biomass treatments, most species were predicted to experience reductions in their average habitat suitability scores. Many of the species experiencing significant, negative changes in suitability found the post-harvest conditions completely unsuitable. Upon further inquiry into the model, it was determined these species were not predicted to occur because of missing essential habitat elements, not because the habitat and stand structural stage held no suitability value. For example the black-tailed jackrabbit, an evaluation species for the mixed chaparral habitat, was predicted to have an average habitat suitability of 0.22 in the initial mature, dense chaparral stand. Post-harvest, assuming all habitat elements were present, the average habitat suitability score should increase to 1. However, the biomass harvests modeled in the mixed chaparral included the removal of two essential habitat elements (shrub and herbaceous layers) and thus eliminated the black-tailed jackrabbit from the list of species predicted to occur.

The CWHR system produces lists of occurrence and average habitat suitability scores based upon the geographic location, habitat type, structural stage (canopy closure and QMD) and habitat elements designated in the query. While habitat type and structural stage are the most influential in predicting the habitat suitability score, essential habitat elements must also be present in order for species to be predicted to occur. In an attempt to capture the effects associated with the exclusion of essential habitat elements, all biomass harvests were modeled using two lists of excluded elements. Only four species, across all 12 model runs, responded to the difference in excluded elements between runs: Northern Saw-whet Owl in the SMC and Northern Screech Owl, acorn woodpecker, and the ash-throated flycatcher in the BOW. The most common essential elements that were manipulated during the modeled biomass harvests resulting in unsuitable habitat included: subcanopy layers- trees, shrubs, and herbs; shrubs, trees with cavities and loose bark, and trees $>11''$ dbh.

It is expected that some of the impacts of woody biomass harvests will be associated with the manipulation and removal of the dead and downed wood in an ecosystem. Coarse and fine

woody debris and snags are known to play important roles in providing cover, feeding and breeding substrates for many wildlife species (Harmon et al. 2004, Laudenslayer et al. 2002, Hagan and Grove 1999, Spies et al. 1988). It may be important to develop retention targets for these categories of dead wood, so that ecosystem processes can continue and sufficient habitat exists to support viable wildlife populations (Janowiak and Webster 2010, Bunnell and Johnson 2000, Angelstam et al. 2002). No species within the CWHR system require the presence of logs, CWD/FWD (large and small categories of slash), snags (i.e. these special habitat elements are not rated as essential). Instead, these dead and downed wood elements are often secondarily essential (i.e. they are essential but can be replaced by some similarly functioning element). The coarseness of the model limits our ability to detect impacts on wildlife from the removal/manipulation of dead and downed wood.

Another shortcoming of this modeling approach is the emphasis that is placed on short term, snapshot impacts resulting from habitat alteration. Ecosystems are dynamic, plants grow and wildlife species are mobile. It is important to remember that the impacts discussed above last only as long as the habitat remains in that condition. This analysis could be supplemented by a dynamic vegetation model that “grows” the 12 post-harvest conditions over time. This would allow for an assessment of impacts over time, starting immediately post-harvest and continuing into some future stand condition. One could potentially determine the length of wildlife impacts and change in magnitude of those impacts over time.

When assessing the potential impacts of habitat manipulation, it is important to consider the landscape context. In California, it is unlikely 1000s of continuous acres will experience biomass harvest of the same intensity at the same time. Instead, smaller habitat patches will be treated within a matrix of untreated forest, woodland or shrubland habitats. At this time, CWHR does not have the capacity to take into account patch size or adjacency during its model predictions. The CWHR users guide states that “areas larger than 1,000 acres are most appropriate for assessment with the CWHR system” (Airola 1988). Using the system for site level impact predictions, while one of the major stated uses of the system, is subject to the errors and limitations inherent in the model. All habitat suitability values are reported assuming adequate amounts of habitat are available to support the species of interest (Airola 1988). A species’ likelihood of occurrence within a habitat patch is often driven by the home range size (i.e. territory) of that species. Species with large home ranges (i.e. raptors, mammal carnivores) are not often limited by patch size and can move freely into adjacent habitats that provide adequate cover or food. The Cooper’s hawk was not predicted to occur in the BOW post-harvest condition because of a missing essential habitat element (tree layer). Since the Cooper’s hawk’s home range is much larger than a typical harvest area, it will likely be able to find that habitat element in adjacent uncut areas. To say a Cooper’s hawk would be unable to use the harvested area may be oversimplification, especially once the harvested site is evaluated in the larger landscape context.

9.5 Conclusions

Essential habitat elements that are often manipulated during biomass harvesting can result in unsuitable post-harvest habitat: subcanopy layers- trees, shrubs, and herbs; shrubs, trees with cavities and loose bark, trees > 11" dbh. The wildlife impacts of removing logs, large and small slash (CWD/FWD), snags, elements often manipulated during biomass harvesting, are not captured by CWHR.

Dynamic vegetative modeling is needed to see how long the predicted impacts on wildlife species last, and how those impacts change in magnitude over time. A model in which the user can designate the amounts of special habitat elements present each habitat condition is necessary to provide more accurate predictions. In the CWHR system, either habitat elements are present in the amount necessary or absent.

A model with the capacity to evaluate the impacts on wildlife communities associated with the manipulation of CWD/FWD, logs, and snags would be very useful during the development of dead and downed wood retention guidelines. The harvesting of a dense, mature chaparral stand for biomass objectives would most likely result in overall negative impacts on the associated wildlife community, at least in the short term. The retention of special habitat elements and untreated areas during biomass harvests would likely mitigate some of the predicted impacts on wildlife communities.

9.6 Evaluation Species lists

Table 17 Ranking scores, canopy cover preferences, and reproduction/feeding habits of the 42 evaluation species used in an assessment of impacts from woody biomass harvests in the Sierran mixed conifer habitats of Shasta and Tehama counties

Common Name	Scientific Name	Rating Score ¹	Cover Sensitivity Score ²	Preferred Canopy Cover	Primary breeding substrate	Primary feeding habits
Allen's chipmunk	<i>Neotamias senex</i>	6	2	Open	trees/snags	herbivorous
American martin	<i>Martes Americana</i>	7	2	Closed	cavities in trees/snags	mostly carnivorous
Band-tailed pigeon	<i>Patagioenas fasciata</i>	6	1	No preference	trees	acorns and fruits
Black bear	<i>Ursus americanus</i>	6	1	No preference	hollow trees/snags with cavities	omnivorous
Brown creeper	<i>Certhia Americana</i>	6	2	Closed	behind loose bark	invertebrates
California mountain kingsnake	<i>Lampropeltis zonata</i>	6	1	No preference	surface, little known	lizards; snakes; birds and eggs; small mammals

Calliope hummingbird	<i>Stellula calliope</i>	7	3	Open	tree	nectar; insects; sap
Cassin's finch	<i>Carpodacus cassinii</i>	4	1	No preference	tree	seeds, buds, insects, berries
Chipping sparrow	<i>Spizella passerine</i>	6	2	Open	tree	insects/spiders ; grasses/forbs
Common ensatina	<i>Ensatina eschscholtzi</i>	6	2	Closed	surface	invertebrates
Coyote	<i>Canis latrans</i>	6	2	Open	cavities	omnivorous
Dark-eyed junco	<i>Junco hyemalis</i>	6	2	Open	surface	insects; spiders; arthropods; seeds; fruits
Deer mouse	<i>Peromyscus maniculatus</i>	6	1	No preference	surface with cover	seeds; fruits; insects; fungi; leaves
Douglas' squirrel	<i>Tamiasciurus douglasii</i>	7	2	Closed	cavities in trees/snags	omnivorous
Dusky flycatcher	<i>Empidonax oberholseri</i>	5	1	No preference	tree or shrub	flying insects
Ermine	<i>Mustela erminea</i>	6	1	No preference	surface with cover	carnivorous
Fisher	<i>Martes pennanti</i>	7	2	Closed	hollow trees/snags, cavities	mostly carnivorous
Golden-crowned kinglet	<i>Regulus satrapa</i>	6	2	Closed	trees	invertebrates
Gray fox	<i>Urocyon cinereoargenteus</i>	6	1	No preference	cavities	omnivorous
Hammond's flycatcher	<i>Empidonax hammondi</i>	7	3	Closed	tree	flying insects
Hermit thrush	<i>Catharus guttatus</i>	6	2	Closed	tree, occasionally on ground	invertebrates; berries; fruits; seeds
Hermit warbler	<i>Dendroica occidentalis</i>	5	1	No preference	tree	insects and spiders
Macgillivray's warbler	<i>Oporornis tolmiei</i>	5	3	Closed	shrub	mostly insects
Mountain chickadee	<i>Poecile gambeli</i>	5	1	No preference	tree cavities	insects and spiders; seeds and plant material
Mule deer	<i>Odocoileus</i>	7	2	Open	surface	plants, acorns,

	<i>hemionus</i>					fruits
Nashville warbler	<i>Vermivora ruficapilla</i>	6	2	Open	surface	invertebrates
Northern flying squirrel	<i>Glaucomys sabrinus</i>	7	2	Closed	tree/snag	omnivorous
Northern goshawk	<i>Accipiter gentilis</i>	7	2	Closed	tree	mostly birds
Northern saw-whet owl	<i>Aegolius acadicus</i>	6	2	Closed	tree/snag cavities	small mammals; birds; arthropods
Olive-sided flycatcher	<i>Contopus cooperi</i>	7	2	Closed	tree	flying insects
Pileated woodpecker	<i>Dryocopus pileatus</i>	6	2	Closed	tree/snag	carpenter ants, wood-boring beetles
Purple martin	<i>Progne subis</i>	6	2	Closed	tree	flying insects
Red-breasted sapsucker	<i>Sphyrapicus ruber</i>	6	2	Open	tree/snag cavities	insects (ants); sap/cambium; berries and fruits
Rubber boa	<i>Charina bottae</i>	6	1	No preference	surface with cover	small mammals; lizards
Sooty grouse	<i>Dendragapus fuliginosus</i>	7	2	Closed	surface	conifer needles; leaves; fruits; buds; flowers; seeds;
Spotted towhee	<i>Pipilo maculatus</i>	5	2	Open	surface	seeds, insects, invertebrates, berries, acorns
Steller's jay	<i>Cyanocitta stelleri</i>	6	2	Closed	tree	omnivorous
Townsend's solitaire	<i>Myadestes townsendi</i>	6	2	Open	stream bank, stump	invertebrates
Western gray squirrel	<i>Sciurus griseus</i>	7	2	Closed	tree/snag cavities	fungi; nuts; acorns; fruits
Western tanager	<i>Piranga ludoviciana</i>	6	2	Closed	tree	invertebrates; fruit
Western wood-pewee	<i>Contopus sordidulus</i>	5	1	No preference	tree	flying insects
Winter wren	<i>Troglodytes troglodytes</i>	6	2	Closed	tree/snag cavities	invertebrates

1Results of numeric ratings for four criteria, including cover sensitivity score.

2 Numeric rating for CWHR-predicted sensitivity to differences in blue oak tree canopy cover (1 = no difference, 2 = difference of 1 CWHR rating class, 3 = difference of >2 rating classes).

Table 18 Ranking scores, canopy cover preferences, and reproduction/feeding habits of the 21 evaluation species used in an assessment of the impacts from woody biomass harvests in the blue oak woodland habitats of Shasta and Tehama counties

Common name	Scientific name	Rating score ¹	Cover sensitivity score ²	Preferred canopy cover	Primary breeding substrate	Primary feeding habits
Acorn woodpecker	<i>Melanerpes formicivorus</i>	9	2	open	tree cavities	acorns, fruits, invertebrates
Ash-throated flycatcher	<i>Myiarchus cinerascens</i>	7	2	open	tree cavities	invertebrates
Bushtit	<i>Psaltriparus minimus</i>	6	1	no preference	trees/shrubs	invertebrates, seeds, fruits
California ground squirrel	<i>Spermophilus beecheyi</i>	6	2	open	subsurface	invertebrates, seeds
Cooper's hawk	<i>Accipiter cooperii</i>	8	2	closed	trees	vertebrates
Dusky-footed woodrat	<i>Neotoma fuscipes</i>	7	1	no preference	surface	plants, acorns, fruits
Common ensatina	<i>Ensatina eschscholtzii</i>	7	2	closed	subsurface	invertebrates
Gopher snake	<i>Pituophis melanoleucus</i>	6	2	open	subsurface	vertebrates
Gray fox	<i>Urocyon cinereoargenteus</i>	7	2	open	trees, cavities, cliffs, rocks	omnivorous
Mourning dove	<i>Zenaida macroura</i>	9	2	open	trees	seeds
Mule deer	<i>Odocoileus hemionus</i>	8	2	open	surface	plants, acorns, fruits
Pacific-slope flycatcher	<i>Empidonax difficilis</i>	7	2	closed	trees	invertebrates
Red-tailed hawk	<i>Buteo jamaicensis</i>	7	1	no preference	trees, cliffs	vertebrates
Western bluebird	<i>Sialia mexicana</i>	7	2	open	tree cavities	invertebrates, fruits
Western fence lizard	<i>Sceloporus occidentalis</i>	5	1	no preference	surface	terrestrial invertebrates
Western gray squirrel	<i>Sciurus griseus</i>	7	1	no preference	trees	acorns, nuts, seeds, fruits
Western meadowlark	<i>Sturnella neglecta</i>	7	3	open	surface	invertebrates, seeds
Western	<i>Otus kennicottii</i>	6	1	no	tree cavities	invertebrates,

screech-owl				preference		vertebrates
Western scrub-jay	<i>Aphelocoma californica</i>	7	1	no preference	trees/shrubs	acorns, fruits, invertebrates
White-breasted nuthatch	<i>Sitta carolinensis</i>	7	1	no preference	tree cavities	invertebrates, seeds, fruits
Wild turkey	<i>Meleagris gallopavo</i>	9	1	no preference	surface	invertebrates, seeds, acorns, plants

1Results of numeric ratings for four criteria, including cover sensitivity score.

2Numeric rating for CWHR-predicted sensitivity to differences in tree canopy cover (1 = no difference, 2 = difference of 1

CWHR rating class, 3 = difference of >2 rating classes).

Table 19 Ranking scores, canopy cover preferences, and reproduction/feeding habits of the 23 evaluation species used in an assessment of impacts from woody biomass harvests in the mixed conifer habitats of Shasta and Tehama counties

Common name	Scientific name	Rating score ¹	Cover sensitivity score ²	Preferred canopy cover	Primary breeding substrate	Primary feeding habits
Black-tailed jackrabbit	<i>Lepus californicus</i>	7	2	Open	surface	grasses and forbs
Blue-gray gnatcatcher	<i>Poliophtila caerulea</i>	6	2	Closed	shrub or tree	insects, spiders
Brush rabbit	<i>Sylvilagus bachmani</i>	6	1	No Preference	cavities in surface	grasses, forbs
Bushtit	<i>Psaltiparus minimus</i>	6	2	Closed	shrub or tree	invertebrates, seeds, fruits
California thrasher	<i>Toxostoma redivivum</i>	6	2	Closed	shrub or tree	insects, spiders
California towhee	<i>Pipilo crissalis</i>	6	1	No Preference	shrub or tree	seeds, insects, fruits
Coyote	<i>Canis latrans</i>	6	1	No Preference	cavities	omnivorous
Deer mouse	<i>Peromyscus maniculatus</i>	6	1	No Preference	surface with cover	seeds, fruits, leaves, fungi, insects
Fox sparrow	<i>Passerella iliaca</i>	7	3	Closed	surface	seeds, insects
Gopher snake	<i>Pituophis catenifer</i>	6	2	Open	below surface	mammals, birds
Gray fox	<i>Urocyon cinereoargenteus</i>	7	2	Closed	cavities	omnivorous
Mountain lion	<i>Puma concolor</i>	6	2	Closed	caves, cavities, and thickets	carnivorous; mule deer make up 60-80% of diet

Mountain quail	<i>Oreortyx pictus</i>	6	1	No Preference	surface	foliage, buds, acorns, fruits, seeds
Mule deer	<i>Odocoileus hemionus</i>	7	2	Closed	surface	plants, acorns, fruits
Orange-crowned warbler	<i>Vermivora celata</i>	7	3	Closed	surface or shrub	mostly insects
Ringneck snake	<i>Diadophis punctatus</i>	6	2	Open	below surface	earthworms, salamanders
Ringtail	<i>Bassariscus astutus</i>	6	2	Open	cavities, below surface	carnivorous
Spotted towhee	<i>Pipilo maculatus</i>	7	2	Closed	surface with cover	seeds, insects, invertebrates
Striped racer	<i>Masticophis lateralis</i>	6	1	No Preference	little is known, on surface	vertebrates
Striped skunk	<i>Mephitis mephitis</i>	6	2	Open	cavities and crevices	omnivorous
Western fence lizard	<i>Sceloporus occidentalis</i>	6	2	Open	surface	terrestrial invertebrates
Western harvest mouse	<i>Reithrodontomys megalotis</i>	6	2	Open	surface	omnivorous
Wrentit	<i>Chamaea fasciata</i>	4	1	No Preference	shrub	insects, berries, spiders

1Results of numeric ratings for four criteria, including cover sensitivity score.

2Numeric rating for CWHR-predicted sensitivity to differences in tree canopy cover (1 = no difference, 2 = difference of 1 CWHR rating class, 3 = difference of >2 rating classes).

CHAPTER 10: The Potential for Biomass Harvesting in California Forests to Reduce Future Tree Mortality from Wildfire, Insects, and Pathogens

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10.1 Introduction

California's forests experience high levels of mortality from wildfire, insects, and pathogens. Fuels reduction treatments to reduce wildfire hazard are a commonly used tool of land managers in reducing the incidence of forest mortality. Fuel treatments share many practical similarities with another silvicultural practice: biomass harvesting. Biomass harvesting involves the collection of limbs, tops, small-diameter trees, and logging slash left behind by traditional timber harvesting operations followed by chipping and transporting to a facility that uses the fuel to generate renewable energy. Fuel treatments remove potential wildfire fuels including the small-diameter trees that would carry a fire into the forest canopy and the surface fuels, such as logging slash, that increase fire intensity, with the focus of creating a more fire-resistant stand structure. This review addresses the potential for fuel treatments that employ biomass harvesting techniques to reduce losses to some of the most important agents of tree mortality in the western United States: wildfire, bark beetles, and forest pathogens.

Many stands in California have regenerated after historic harvests during a century of fire exclusion. This past management allowed uncharacteristically high levels of fuels and vegetation to accumulate in forests that once experienced frequent low-severity fires. A large proportion of these stands are now susceptible to passive and active crown fire (Christensen et al., 2008a). Passive crown fire occurs when individual trees or groups of trees torch; in an active crown fire, the flaming front encompasses all fuels from the surface of the forest floor to the upper canopy (Scott and Reinhadt, 2001). Crown fires can produce high levels of tree mortality and challenge containment efforts.

Fuel treatments alter potential fire behavior by changing the arrangement and quantity of fuels available for burning. Small trees, shrubs, and shade-tolerant trees with crowns extending to the forest floor all act as ladder fuels that can carry fire into the forest canopy. High levels of surface fuels, which include duff, litter, and woody debris, increase the intensity of a potential fire. Biomass harvesting of the fuels that compose these pools can be an effective tool for fire hazard reduction. For instance, removal of small trees helps prevent torching of individual trees and groups of trees, while utilization of the tops and limbs of large-diameter trees harvested for timber prevents a post-harvest increase in surface fire hazard.

On public lands in the United States, biomass removal is increasingly viewed as a potential tool for addressing fire hazards (Barbour, 2008). As **Table 21** illustrates, fire hazards vary with land ownership, and federal lands in California have a higher risk of crown fire than either state or private lands. The proceeds from selling forest biomass harvested for fuels reduction can be

used to offset the costs of conducting treatments. The in-forests costs of biomass harvests increase when the terrain is steep and the distance to the landing is long. The chipping costs, haul costs on logging roads, and haul costs of paved highways are also significant. Operators estimate that biomass harvesting on moderate terrain with haul distances of less than 30 miles can produce revenues that are greater than the direct costs. When collection costs to the landing are greater or the haul costs are longer, the cost of treatments needs to be weighed against the potential risks from leaving large amounts of forest fuels in the harvested forest.

Table 20 Estimated fire type by forest land owner Category in California

Ownership (million acres)	Fire Type			
	Surface	Conditional Surface	Passive Crown	Active Crown
National Forest (15.6)	52%	15%	24%	9%
Other Federal (3.1)	57%	14%	19%	10%
State (1.1)	70%	12%	11%	7%
Private (13.2)	70%	9%	17%	4%

Source: Christensen (2008). Percentages based on Forest Vegetation Simulator - Fire and Fuels Extension (Reinhardt and Crookston, 2003) simulations under severe weather conditions.

On private forestlands in California and neighboring states, biomass harvests are not subsidized and are typically undertaken only when they provide long-term economic benefits to landowners (Daugherty and Fried, 2007). Since the gross revenue required for a break-even operation are fairly significant in California, where mountainous terrain is common and regulatory costs per project are high, biomass harvesting is usually conducted as part of a commercial harvest and where an energy plant is within a practical hauling distance. On Crown lands in Canada, biomass removal is more often associated with the silvicultural goals of long-term lease-holders or more recently, to remove large volumes of beetle-killed trees (Kurz 2008; Dymond, Titus et al. 2010).

The high costs and low returns of fuels reduction treatments have historically limited their application, despite high and increasing costs of fire suppression on public lands in the United States (Donovan and Brown, 2005). The inclusion of biomass energy in renewable energy portfolios could raise the value of forest biomass and potentially increase the areal extent of treatments where hazard reduction is a driving goal of land managers. The scale of the risks, the ability to identify areas of high risk where management interventions could be effective, alternatives to biomass harvests, and the potential outcomes without intervention all need to be considered when selecting management strategies. Of course, treatments do not affect fire hazard in isolation. If reducing forest mortality is a goal of management, the influence of treatment activities and post-treatment stand structure on future insect and pathogen incidence must also factor into decision-making.

10.2 Reducing wildfire hazards with biomass harvests, alternative fuel treatments, and managed wildfires: overview of key themes

The importance of the link between forest fuels and wildfire characteristics is well known (Anderson, 1974; Rothermel, 1983; Rothermel, 1991). The quantity and arrangement of fuels are the only leg of the “fire behavior triangle” that can be directly influenced by management (Agee, 1996), and numerous studies have shown the potential for fuels management to modify wildfire behavior and impacts (Cram et al., 2006). Agee and Skinner (2005) provide four basic principles for creating effective fuel treatments. Treatments should reduce surface fuels, increase the height to the canopy, decrease canopy density, and retain large trees belonging to fire-resistant species.

Traditional thinning prescriptions used in managing commercial timber encompass a wide range of activities that may or may not reduce the risk of future losses to wildfire. Thinning young, dense stands is known as precommercial thinning because the harvested biomass often has no commercial value. Precommercial thinning is commonly employed by private timber owners to concentrate resources in fewer trees, improving the growth rates of remaining individuals. This silvicultural practice is typically conducted to meet economic objectives and may have little impact on wildfire hazard. A fire burning in a young plantation can produce high levels of mortality across a wide range of tree densities because these stands often have vertically and horizontally continuous canopies through which a fire can easily spread. Removing a minor fraction of the larger trees with value as timber as well as many smaller trees is known as commercial thinning. While stand density and canopy fuel continuity are reduced in a partial harvest, thinning may actually exacerbate fire hazards if slash created by the operation is left untreated (Cram et al., 2006; Weatherspoon and Skinner, 1995). Further, the harvest of sawlog-diameter trees alone may not address ladder fuel hazards. The impact of any thinning treatment on fire hazard depends on the entire post-treatment fuel profile, including surface, ladder, and canopy fuels.

Biomass harvest is defined here as the removal of low value woody biomass, such as small-diameter trees, logging slash, and tree tops and limbs, that is not merchantable in traditional timber markets. Thinning techniques similar or identical to those used in biomass harvesting have been used to moderate potential wildfire behavior for some time. Small-diameter understory trees act as ladder fuels that carry surface fire into the canopy, increasing crown damage and post-fire mortality. Understory thinning removes these ladder fuels, increases the proportion of trees within larger diameter classes, and reduces stand density. Understory thinning has greater effects on fire behavior than selection or crown thinning alone (Agee and Skinner, 2005; Graham et al., 1999). Biomass harvesting for fuels reduction can also include utilization of the tops, limbs, and other material produced during the harvest of large trees for timber. Biomass utilization of these activity fuels (fuels produced by harvesting operations) may minimize the need for or decrease the costs associated with follow-up treatments like prescribed burning which are commonly used to reduce the fire hazards associated with high surface fuel loads.

Historically, there has been a mismatch between the economic costs and wildfire risk incentives of fuels reduction. The society-wide costs of large wildfire events are dispersed across forest land owners and their neighbors, public firefighting agencies, and the wider community. While the benefits of effective fuels management would accrue to all parties, landowners typically bear the cost of project implementation alone. Based on a cost-benefit analysis that includes only the private costs associated with a future wildfire, a land owner may not choose to treat low-value biomass, yet treating these fuels is often critical to modifying wildfire behavior. Since there is no immediate cash flow from reducing future risk of loss to wildfire, it is not uncommon that the removal of ladder fuels and logging slash is far more limited than would be recommended to significantly reduce future fire risks.

Experimental evaluation of thinning treatments is inherently challenging, given the probabilistic nature of wildfire events and the impracticality of implementing one's own wildfire "treatments." Consequently, empirical studies are usually based on opportunistic data collection following a chance wildfire occurrence, ideally where pre-fire vegetation and fuel conditions have recently been inventoried. The ability to draw firm conclusions from these opportunistic studies may be hindered by a lack of pre-fire data, randomization, and replication (Roccaforte and Fulé, 2008). Computerized fire behavior and effects models simplify comparisons of fuel treatment scenarios under varying fire weather conditions and through time, but they are by necessity simplifications of reality. A discussion of computer-based model limitations is provided in section 10.3.

10.2.1 Stand-scale studies of forest thinning and wildfire hazard

Fuel treatments at the scale of an individual forest stand are intended to moderate the local behavior and effects, such as tree mortality levels and soil damage, of a potential future wildfire. The effectiveness of a given thinning treatment depends on a host of factors including harvest severity, understory response to treatment, the impact of harvest activities on stand structure and surface fuel loads, the length of time between treatment and wildfire occurrence, fire weather conditions, and site factors like topography.

One uncertainty in designing thinning treatments concerns the degree of biomass removal needed to accomplish fire hazard reduction goals. A light thinning may not sufficiently remove ladder fuels or impact fire intensity, and if the residual vegetation quickly responds to reoccupy vacated growing space, the effects of treatment may be short-lived. In contrast, treatments that substantially reduce canopy cover can exacerbate fire danger through their effect on the understory microclimate and vegetation. Overstory thinning can increase solar radiation, windspeeds, and air temperatures (Ma et al., 2010; Whitehead et al., 2006) and have been shown to promote understory vegetation growth (McConnell and Smith, 1965). Further, using fire in combination with thinning can increase seedling density (Moghaddas et al., 2008) and stimulate shrub seed germination (Kane et al., 2010).

In a modeled comparison of thinning effects, all removal treatments reduced the potential for torching and crown fire behavior, and the most severe removal treatments produced the greatest reductions in crown fire hazard (Fulé et al., 2001). The gains in fire hazard reduction from heavy thinning may also outlive those of more moderate thinning treatments. Fiedler and

Keegan (2003) assessed fuel treatment effects on crown fire hazard in dry ponderosa pine and dry mixed conifer forests of New Mexico by comparing three harvest prescriptions: low thinning, a commercial thin with retention of trees larger than 41 cm (16 in) in diameter at breast height (dbh), and a more complex restoration treatment that maintained a diverse structure and preferentially removed late successional species. All treatments retained 50 ft²/acre basal area. Stand growth following treatment was projected 30 years into the future using the Forest Vegetation Simulator (Crookston, 1990; Stage, 1973; Van Dyck, 2001). All treatments reduced fire hazard as measured by crowning index, but the commercial thin and restoration treatments had more substantial and longer-lasting effects on fire hazard. After 30 years, crown fire could occur in low-thinned stands with 37 mph wind speed, while crowning in the more heavily thinned stands would require wind speeds in excess of 56-57 mph. It should be noted that wind speeds as high as 37 mph are likely to occur very infrequently, however, these results indicate a relatively low potential for crown fire initiation following the restoration and commercial thinning treatments (Cruz and Alexander, 2010).

While forest thinning may inhibit crown fire spread and/or torching activity, increased surface fuel levels can lead to high severity fire effects if treatment residues are not removed (Fulé et al., 2001; Keyes and Varner, 2006; Raymond and Peterson, 2005; Stephens, 1998). An assessment of fuel treatment effectiveness during the 2007 Angora Fire, which burned in the Lake Tahoe Basin, underscores the importance of treating activity fuels. Safford et al. (2009) evaluated thinning treatments that included pile burning of logging slash. As a general rule, treatments dramatically reduced bole char height, crown scorch, torching, and post-fire mortality. Exceptions included treatments located on steep slopes where slash piles had not been burned before the wildfire. Thinning followed by pile burning also significantly reduced burn severity in the Rodeo-Chediski Fire in Arizona (Strom and Fulé, 2007): while only 5% of overstory trees outside of treatment areas survived, approximately half of trees within the treatment units survived.

Broadcast burning is commonly paired with thinning to address the surface fuel buildup associated with harvesting. Thinning with prescribed fire, and to a lesser extent thinning alone, significantly reduced post-wildfire mortality in dry eastside pine stands of the Blacks Mountain Experimental Forest in northern California (Ritchie et al., 2007). When prescribed burning was used to treat surface fuels, post-wildfire survival increased from 1-11% in untreated stands to 80-100% in treated stands. In one case, prescribed burning prevented the wildfire from carrying into the treatment interior. In contrast, when crown material from harvested trees was retained and scattered on site, post-wildfire survival rates were reduced relative to other treated stands. Prichard et al. (2010) similarly found that thinning followed by prescribed fire greatly reduced mortality from a wildfire in the Okanogan-Wenatchee National Forest, while thinning alone had only minimal effects.

Treatment prescriptions that include surface fuel treatments like broadcast burning are predicted to be most effective in reducing wildfire indices like rate of spread, fireline intensity, and post-fire mortality (Fulé et al., 2001; Stephens, 1998; Stephens and Moghaddas, 2005). However, treating surface fuels adds to the costs of fuel treatment (Hartsough et al., 2008), and the use of prescribed fire is often limited by air quality restrictions, narrow burn windows, the

liability associated with the risk of escape, and inadequate staffing (Bradley et al., 2006). A biomass removal technique, whole-tree harvest, holds potential for fire hazard reduction, though it is still largely untested in this capacity. Traditional chainsaw harvests transport only tree boles to the landing and leave limbs and tops scattered across the harvest site. Whole-tree harvesting conveys much of this biomass to the landing where it can be burned in piles, left to decompose, or transported off site. Whole-tree harvesting reduces the cost of logging slash removal for biomass utilization, may minimize the need for subsequent treatment of logging slash, and should reduce the risks associated with prescribed burning because lower levels of activity fuels should translate into reduced fireline intensity.

Few studies have empirically evaluated the ability of whole-tree thinning to reduce fire hazards. Whole-tree thinning 4-5 years prior to the 1994 Cottonwood Fire on the Tahoe National Forest in California greatly reduced crown scorch and fire severity relative to untreated sites (Pollet and Omi, 2002). In a modeling effort for Yosemite National Park, Stephens (1998) assessed the effects of whole-tree harvesting of small to intermediate trees. While this biomass removal treatment greatly reduced predicted fireline intensity, area burned, and scorch height under 95th percentile weather conditions relative to the untreated control, a follow-up prescribed burn was required to prevent torching and spotting. In this study, it was assumed that the pre-treatment fuelbed would be unaffected by treatment. However, whole-tree harvesting operations will add to surface fuel loads, though to a lesser degree than bole only harvests, and prescribed fire may be needed to reduce wildfire intensity and severity. The 2002 Biscuit Fire burned several fuel treatment plots in a mixed-evergreen forest with a mixed-severity fire regime in the Coast Range of southwestern Oregon. The high levels of fine woody debris created by whole-tree thinning led to substantially higher levels of mortality relative to untreated areas (80-100% and 53-54% mortality, respectively). In the same study, a thinning and underburning treatment preceding the wildfire by one year resulted in only minimal mortality (5%) because the wildfire was unable to spread into the treatment area (Raymond and Peterson, 2005).

A recent comparison of fuel treatment methods by Reinhardt et al. (2010) reinforces many of the themes discussed in this section. Using FFE-FVS (Reinhardt and Crookston 2003) to model the effects of a suite of biomass treatment methods on potential fire behavior, Reinhardt et al. simulated treatments for mature ponderosa and lodgepole pine stands representative of the Northern Rocky Mountains. Primary biomass removal methods included commercial thinning, understory thinning, and no thinning; secondary slash treatment included whole-tree yarding, mastication (mechanical shredding of small trees and understory vegetation), or no treatment; in addition, prescribed burning was simulated for each thinning and slash treatment combination. The modeling effort included projection of changing fire risk over time as post-treatment vegetation recovery transpired. Predicted wildfire-induced tree mortality was decreased from the untreated scenario by all treatment methods except for the commercial thinning/no prescribed fire combination. The influence of slash treatment type on fire potential appeared to diminish within approximately 10 years. Prescribed fire effects were longer lasting, and could still be observed at the end of the 60-year simulation period. The authors stated that while biomass removal can generally be expected to have an effect on potential fire behavior,

the effects of thinning with prescribed fire might outlast those of whole-tree yarding and mastication. The relative impacts of treatment combinations on future fire and fuel characteristics varied by stand, indicating that a context of place is a critical factor in guiding treatment method selection.

10.2.2 Landscape-level fuel treatment assessments

Stand-scale studies of fuel treatment effects on wildfire behavior and tree mortality generally cannot assess the influence of treatments on the probability of wildfire occurrence or fire size. Given the inherent difficulty in replicating and directly testing the influence of fuel treatments on fire behavior and effects, most landscape-scale studies are based on computer modeling rather than field sampled data.

Collins et al. (2010) modeled a network of understory thinning treatments on a northern Sierra Nevada landscape using the FFE-FVS system. The analysis evaluated the relative effects of varying diameter-limit thinning treatments on conditional burn probability: the probability of burning by wildfire with >2 m flame lengths, given input weather conditions and random fire ignitions allowed to spread for a given period of time. Understory thinning removed the smallest-diameter trees up to a given diameter threshold (30.5-76.2 cm dbh [12-30 in]) until the treatment achieved a pre-selected canopy cover (40-60%). Surface fuels were then removed with pile-and-burn treatments. 17% of the landscape was treated under each thinning scenario and an additional 8% of the total area was treated using a different method, either mastication of small trees and shrubs or prescribed fire. Vegetation growth was projected for treated and untreated stands for ca. 30 years, and fires were simulated at each 10-year timestep. The impacts of fuels reduction extended beyond treatment boundaries, and impacted burning across the landscape. Average conditional burn probability (flame length > 2 m) was substantially reduced by understory thinning for the first 20 years post-treatment. After 10 years, the lowest diameter limit (30.5 cm [12 in]) produced only a small increase in canopy base height relative to the untreated scenario, while increasing the diameter limit from the intermediate (50.8 cm [20 in]) to the highest level (76.2 cm [30 in]) had only a modest impact on canopy base height. The differences in canopy structure did not produce clear divergences in landscape-level conditional burn probability, however. One cited explanation for this incongruity is low initial canopy cover, near the level of treatment targets.

California's Biomass to Energy (B2E) Project, funded by the California Energy Commission, assessed the ability of whole-tree and biomass harvesting to alter wildfire characteristics on a landscape scale in the northern Sierra Nevada. The Project's scope included simulated treatment of 30% of the public and private landscape over a 40-year period. Vegetation treatments included a variety of forest management prescriptions intended to represent industrial, private, and public land ownership priorities. Vegetation change and forest management activities were simulated, and wildfire areal extent and severity were projected. The study estimated that over the 40-year simulation period, wildfire extent was reduced 22% from the no treatment scenario. The percentage of the area burned by high severity wildfire was also reduced (USDA Forest Service, 2010). While such large scale modeling efforts may be our

best option for evaluating complex landscape level fuel treatment alternatives, they require many simplifying assumptions and are difficult to validate empirically.

10.3 Limitations of Computer-Based Models

Computer simulations facilitate fuel treatment comparisons, assessments of changing fire hazards as vegetation develops and fuels accumulate after treatment, and landscape-scale evaluations of treatment size and placement. Management recommendations are frequently based on the projected impact of simulated treatments on fire behavior. However, a review of several widely used fire behavior models found inherent biases that can lead to underpredictions of the likelihood of crown fire initiation in the post treatment stands and by extension, exaggerated fuel treatment benefits (Cruz and Alexander, 2010).

There are many quasi-process based fire models such as the Forest Vegetation Simulator's Fire and Fuels Extension (FVS-FFE), BehavePlus, NEXUS, FARSITE, FlamMap, ArcFuels, and the Wildland Fire Decision Support System (WFDSS). Empirical studies have produced a much broader range of outcomes than are predicted by models, which often rely on stylized representations of the fuel complex. For most situations, default parameters must be altered so that a calibrated model will produce realistic outputs. The important role of expert calibration is crucial to consider when applying model results toward broader policy or financial decisions.

The FFE-FVS modeling system is widely used in evaluating both the initial changes in fire behavior and effects produced by a fuel treatment or timber harvest and the longer-term impacts as the treated stand develops. Because several studies cited in this chapter base their findings on the FFE-FVS system, the model's limitations merit some further discussion. The system couples the Forest Vegetation Simulator (FVS)(Wycoff et al., 1982), an assemblage of forest growth models, with the Fire and Fuels Extension (FFE), which tracks forest fuel accumulation and decay, snag dynamics, and includes a fire model that projects fire behavior and effects. The model assigns surface fuel models based on overstory conditions when the surface model cannot be independently verified. One limitation of the system is that while FVS typically projects growth and mortality on a 10-year cycle, FFE employs a 1-year timestep (Reinhardt and Crookston, 2003). As a result, relatively continuous processes such as changing passive crown fire hazard appear to develop in discrete intervals. Users often keep model projections in sync by reporting simulation results at the 10-year timestep, or some multiple thereof (Collins et al., 2010; Hurteau and North, 2009; Johnson et al., 2007; Reinhardt et al., 2010).

Some geographic variants of FFE-FVS, including those relevant to California, do not explicitly model natural regeneration. Instead, a user must provide estimates of the number, species, and frequency of tree seedling establishment events. As ingrowth is a critical determinant of ladder fuel hazard, the choices made by model users may have important consequences for projected fire behavior and effects. Collins et al. (2010) found that without any simulated regeneration, canopy base height increased over time. This result is contrary to expected canopy development following thinning in Sierran mixed conifer forests, where ingrowth of shade-tolerant species typically lowers canopy base height over time, increasing crown fire hazards. For stands in the

Sierra Nevada, Collins et al. (2010) used a random number generator to select the number of seedlings establishing during each FVS cycle. Based on recommendations from local forest managers, modeled regeneration was set to favor shade-tolerant species.

FFE dynamically tracks fuel loading and the relative contribution from particle size classes by tracking inputs from live and dead trees as well as management activities, and decay rates that simulate the passing of biomass from one size class to another. Fuel loads are used to select one or more predefined fuel models, which are in turn used by the fire submodel to determine potential fire behavior and effects (Reinhardt and Crookston, 2003). Johnson et al. (2007) noted that the default rate of decomposition in FFE-FVS is unrealistically high for many forest types, and is not sensitive to location-specific variables such as aspect and elevation. Further, FVS does not include growth models for non-tree understory vegetation, though this fuel component is an important contributor to fire behavior, and some fuel models are partly defined by a large component of live understory fuels. In their simulation study, Collins et al. (2010) concluded that fuel model selection by FFE was invalid, in part because both crown fire activity and conditional burn probability in untreated stands actually diminished over the simulation period. Both Collins et al. (2010) and Seli (2008) developed their own fuel model selection logics in lieu of the FFE method in their simulation studies of fuel treatment effects on wildfire. As the projection period increases, model predictions become less reliable. Though their simulation of fuel treatments and fire behavior spanned 60 years, because of the diminishing reliability caused by long-term growth projections Reinhardt et al. (2010) restricted their statistical analyses to the 10-year post-treatment results.

10.4 Alternative fuel reduction methods

Biomass harvesting could reduce the use of other treatment methods that are now commonly included in fuels reduction prescriptions. Utilization of small diameter trees, for instance, could supplant mastication of these ladder fuels. Piling and burning of logging slash may be unnecessary if these fuels are instead removed and sold to biomass-based energy plants. Each method for treating forest fuels has a corresponding influence on potential fire behavior as well as associated costs.

Fuel treatment alternatives to biomass harvest are divided into two categories. One major alternative to biomass harvest involves onsite retention of woody fuels. Small-diameter trees are cut or masticated, and fuels are scattered and either left to decay or burned in a prescribed fire. Fire-only treatments, alternatively, do not involve mechanical manipulation of forest fuels. Instead, fuels are combusted and some vegetation is killed.

10.4.1 Slash retention treatments

Mastication is a mechanical method for reducing shrub and ladder fuel hazards by shredding understory vegetation and small trees. By redistributing aerial fuels to the surface, mastication reduces canopy fuel loading and continuity but increases surface fuelbed depth, loading, and continuity (Bradley et al., 2006; Kane et al., 2009; Kane et al., 2010; Reiner et al., 2009; Stephens and Moghaddas, 2005). Because these heavy surface fuel loads represent a wildfire hazard, prescribed burning is often used as a follow-up treatment to mastication.

Although prescribed fire can mitigate the surface fuel additions created by mastication, the high levels of fuel can produce high severity effects even under the relatively moderate weather conditions typical of controlled burns. Shrub and small tree mastication in a black oak/knobcone pine woodland in northern California greatly increased surface fuel loading, which contributed to high surface fire intensity and flame lengths during spring prescribed fires (Bradley et al., 2006). Residual overstory trees experienced high levels of post-burn mortality. In contrast, prescribed burning did not kill any overstory trees in unmanipulated plots.

Mastication impacts the potential for crown fire ignition by increasing the height to live crown base (Kobziar et al., 2009; Stephens and Moghaddas, 2005). Mastication treatments in a Sierra Nevada pine plantation decreased tree spacing and crown fuel continuity, but greatly increased surface fuel loading (Kobziar et al., 2009). As a result, the treatments reduced crown fire spread potential but increased flame lengths and torching risk. The modeled high intensity surface fire produced high levels of post-fire mortality even under moderate fire weather conditions. The mastication treatment increased predicted wildfire intensity and mortality relative to the untreated stand. Commercial thinning with mastication of small-diameter trees in a north-central Sierra Nevada mixed conifer forest reduced predicted fire intensity and post-fire mortality relative to untreated sites. However, prescribed fire used alone and in combination with thinning had a greater impact on fire behavior and effects (Stephens and Moghaddas, 2005).

As with mastication, cutting and scattering of ladder fuels increases surface fuel loads. In a modeling assessment of fuel treatment methods (Stephens, 1998), a cut and scatter treatment increased fireline intensity, average heat per unit area, area burned, and scorch height relative to an untreated control. Passive crown fires were predicted under 95th percentile weather conditions, and spotting and crowning occurred even under moderate (75th percentile) conditions. When a cut and scatter treatment was followed by prescribed burning, treatment effectively reduced crown scorch relative to untreated stands, but only somewhat reduced another measure of severity, bole char (Cram et al., 2006).

The studies summarized here emphasize that when mechanical treatments that retain high levels of biomass on-site are followed in short order by prescribed or wildfire, the impacts to residual vegetation may be severe. Further, prescribed burning of masticated fuels can promote shrub response, which may be counterproductive from a fuels management standpoint (Kane et al., 2010). However, if enough time elapses between treatment and burning to allow substantial surface fuel decomposition, these risks may diminish (Fahnestock and Dieterich, 1962; O'Connell, 1997).

10.4.2 Prescribed burning

Prescribed fire influences subsequent surface fire spread by reducing fuelbed continuity, the quantity of fuels available for combustion, and the resultant potential fireline intensity. The ability of prescribed-fire-only fuel reduction treatments to reduce wildfire severity has been widely documented (Cumming, 1964; Davis and Cooper, 1963; Finney et al., 2005; Mitchell et al., 2009; Moore et al., 1955; Pollet and Omi, 2002; Stephens and Moghaddas, 2005; Wagle and Eakle, 1979).

Though broadcast burning can dramatically reduce surface fuels and surface fire spread (Ritchie et al., 2007), low intensity prescribed fire will rarely affect a significant reduction in canopy bulk density because it will not directly kill large-diameter trees (Fulé et al., 2002; Stephens and Moghaddas, 2005). Fulé et al. (2002) implemented thinning with prescribed fire and fire only treatments to assess their relative impacts on potential wildfire behavior. The fire only treatment reduced canopy base height and killed some small diameter trees, but overall produced the smallest reduction in stand density and basal area. The treatment had only moderate impacts on estimated crown fire hazard. In an observational study, Pollet and Omi (2002) compared sites previously treated with thinning and prescribed burning to others treated with prescribed fire alone, and which were subsequently burned by wildfire. While all treatments reduced crown scorch and fire severity relative to untreated sites, it appeared that the prescribed fire only treatment had a less substantial impact than treatments that included mechanical removal of fuels. The authors inferred that mechanical thinning allows managers more control over post-treatment conditions, such as stand density and tree diameter distribution.

10.4.3 Managing wildfires for fire hazard reduction

The use of managed wildfires to reduce future wildfire hazards, until recently termed *wildland fire use for resource benefits*, has been described as “the other treatment option” (Black, 2004). Under current federal wildland fire policy guidelines, wildfires can be managed for multiple objectives, including goals similar to those of prescribed fire and other standard fuel treatments: increasing forest resilience by reducing accumulated fuels and limiting the severity of subsequent wildfires. For example, four managed wildfires burning across an altitudinal gradient in Grand Canyon National Park reduced ladder fuels and tree density, and shifted species composition toward fire-tolerant species (Fulé and Laughlin, 2007).

One potential advantage of using wildfires to reduce fuels is cost. On a per acre basis, managing wildfires for resource benefits may be cheaper by an order of magnitude than either mechanical thinning or wildfire suppression (Black, 2004). Few studies have quantified the impacts of this “passive” management, but compared with the more controlled effects of mechanical and prescribed fire treatments, relatively high levels of mortality and patches of high severity fire effects can be expected (Fulé and Laughlin, 2007). It is important to point out that the potentially larger cost of using wildfire as a fuel reduction tool is the potentially very high costs associated with escapes that then require very expensive suppression efforts and the potential damage to other assets and resources.

10.4.4 Benefits and challenges of alternative fuel reduction methods

Fuel treatment methods such as mastication and prescribed fire can reduce future fire risk without requiring transport of forest biomass offsite. Yet the potential economic benefits of this source of renewable energy go unrealized when biomass is combusted or left to decay, and there are drawbacks associated with each treatment type. Mastication can create more fire-resistant stand structures, but it can also increase the risk of high severity fire in the years before masticated biomass substantially decomposes. Multiple prescribed fire treatments may be required to attain a fire-resistant stand structure, because initial burns may not sufficiently thin

stands and dead fuels from trees killed by burning will accumulate over time, increasing fire hazards (Skinner, 2005). Prescribed fires can also kill large-diameter trees (Agee, 2003). Mechanical methods afford managers more control over post-treatment stand structure.

10.5 Biomass harvesting and forest health: connections to insects and disease

The exclusion of low-intensity wildfire and logging of fire-resistant species that has produced high fire hazards in many western forests has also created stands susceptible to insect and pathogen mortality (Ferrell, 1996; Wickman, 1992). A key information gap is how biomass harvesting and other management interventions might influence forest biomass losses to insects and disease. The following sections provide an overview of relevant literature.

10.5.1 Effects of biomass harvesting on tree resilience

Historic management of dry western forests, including fire suppression and timber harvest, has altered landscape-scale composition and structure, and increased the frequency of late-successional species (Hessburg et al., 1994). As a result, many contemporary western forests are denser and more homogeneous, and more susceptible to high severity wildfire as well as biotic agents of disturbance, like root-rotting fungi and bark beetles (Covington et al., 1994; Hessburg et al., 1994).

Reducing stocking levels can improve the health of the remaining trees by reducing competition for limited resources, improving their ability to resist insects and pathogens. However, harvesting operations can increase the susceptibility of the remaining trees to insect attack and pathogen infection through stem wounds and damage to root systems caused by mechanized equipment (Filip et al., 2010). Harvesting may also attract insects through increasing host material abundance and host volatiles (Fettig et al., 2006; Six et al., 2002) and create infection courts for root disease (Witcosky et al., 1986). Reducing stand density, however, can make stands more resistant to agents of disturbance by improving vigor (Feeney et al., 1998; Mitchell et al., 1983) and by reducing the risk of high severity wildfire (Fulé et al., 2001; Pollet and Omi, 2002). In treating stands, care must be taken to avoid creating new forest health problems or making existing problems worse.

The inverse relationship between site occupancy and tree vigor is well documented. Metrics of tree health, such as growth rate and water stress, are negatively correlated with high levels of competition (Kolb et al., 1998; Zausen et al., 2005). Vigor, in turn, is linked with the ability of trees to resist biotic agents of mortality (Christiansen et al., 1987). Resistance mechanisms like resin flow and foliar toughness are positively correlated with vigor and negatively correlated with stocking levels (Kolb et al., 1998). Fiddler et al. (1989) and Kolb et al. (1998) each compared tree mortality between thinning and unthinned stands in northern California. Reducing stocking levels reduced mortality from biotic agents, namely mountain pine beetle (*Dendroctonus ponderosae*) and annosus root disease (*Heterobasidion annosum*), by 86 to 100%. Other studies have similarly found that thinning to improve vigor created stands with reduced incidence of tree mortality (Waring and Pitman, 1985).

10.5.2 The potential of biomass harvests to reduce future losses from bark beetle outbreaks

Forest thinning influences bark beetle (Coleoptera: Cuculionidae, Scolytinae) habitat by altering microclimate conditions, levels of suitable woody biomass, and tree susceptibility to attack. Changes in microclimate resulting from density reduction, such as light intensity, wind speeds, and temperature (Amman, 1989), influence beetle activity, fecundity, and phenology (Amman and Logan, 1998).

Harvest of understory trees could improve stand resistance to attack by improving the vigor of remaining trees. Reducing stand density can increase defensive resin flows (Kolb et al., 1998; Matson et al., 1987; Wallin et al., 2008), bark thickness (Matson et al., 1987), phloem thickness (Matson et al., 1987; Zausen et al., 2005), diameter growth (Filip et al., 1995), and photosynthetic efficiency (Waring and Pitman, 1985) and reduce water stress (Zausen et al., 2005). Several studies have demonstrated the relationship between stand density and subsequent susceptibility to bark beetle attack (Kolb et al., 2007; McGregor and Oakes, 1987). Wallin et al. (2008) observed no bark beetle colonization attempts following thinning/prescribed burn treatments in Arizona. When aggregation pheromone lures were used, colonizations were most successful in the untreated control plots and least successful in the most heavily thinned plots. During epidemic levels of bark beetle attack in western Montana, partial cutting of lodgepole pine stands greatly reduced losses to insect mortality (McGregor and Oakes, 1987).

In the literature, consideration of stand density reduction is frequently concerned with the impacts of burning on insect attack. Prescribed burning reduces the availability of some host materials, namely logging slash and other woody debris. However, prescribed fire may weaken trees, and has been shown to increase tree mortality from bark beetle attack relative to thin-only treatments. While increases in lethal attacks following prescribed burning have been widely documented, the total losses due to beetle attack are generally small in magnitude (<10% of trees) (Breece et al., 2008; Fettig et al., 2008; Youngblood et al., 2009).

The influence of prescribed fire on post-treatment bark beetle mortality is likely related to burn severity. Fettig et al. (2010) compared insect-caused mortality following Fire and Fire Surrogate (FFS) study treatments in northern California. Prescribed burning alone significantly increased mortality attributable to bark beetles over thinning alone and combined thinning and burning treatments. Post-burn mortality from beetles was concentrated in the small diameter classes, and totaled only 9% of trees. In contrast, at a FFS study site in northeastern Oregon, thinning and burning treatments increased beetle-induced mortality relative to fire only and thinning only treatments (Youngblood et al., 2009). The cut-to-length harvesting system employed in this study retained tree tops and branches onsite. As a result of these activity fuels, surface fire severity was highest when thinning preceded burning. Though increases in lethal attacks following prescribed fire have been widely documented, the total losses due to beetles are generally small in magnitude (<10% of trees) (Breece et al., 2008; Fettig et al., 2008; Youngblood et al., 2009). Burn severity is frequently identified as an important predictor of bark beetle presence (Bradley and Tueller, 2001; Six and Skov, 2009; Sullivan et al., 2003; Youngblood et al.,

2009). In contrast, Schwilk et al. (2006) found no significant relationship between secondary insect mortality and bole char or scorch height.

Slash produced during density reduction treatments can lead to *Ips* beetle outbreaks in standing trees. Depending on activity fuel characteristics (e.g. arrangement and size) and other factors like treatment timing and overstory shading of fuels, density-reduction treatments intended to reduce tree mortality from some bark beetle species may increase susceptibility to other species (Hayes et al., 2008). While the magnitude of residual tree mortality was small, chipping of small-diameter trees significantly increased bark beetle-induced mortality relative to lop and scatter treatments in California and Arizona (Fettig et al., 2006). Hayes et al. (2008) found that *Ips* spp. exhibited a strong preference for logs of specific lengths and diameters. Beetle attack and emergence density were positively related to log length, and beetles exhibited a preference for logs of intermediate diameter (15-20 cm [6-8 in]). However, thinning treatments that removed merchantable logs and retained logging slash had no influence on bark beetle-caused mortality in western Montana (Six and Skov, 2009) and northeastern Oregon (Youngblood et al., 2009).

Slash disposal techniques influence bark beetles as well as predator populations. In a study of post-thinning pine engraver (*Ips pini*) activity in western Montana, the beetles colonized scattered ponderosa pine slash preferentially to piled slash. However, bark beetle natural enemies exhibited a similar preference for scattered biomass (Six et al., 2002).

Climate change is expected to promote bark beetle epidemics in many western forests if winter frosts become less effective in reducing surviving beetle populations (Waring et al., 2009), and insect outbreaks can be severe enough to convert forests from carbon sinks to sources (Kurz et al., 2008). Based on this review, biomass harvesting in the form of thinning small-diameter understory trees should be expected to reduce stand susceptibility to bark beetles, provided appropriate activity fuel treatments are also undertaken. Many of the observed increases in bark beetle incidence following density reduction treatments are associated with significant onsite retention of woody biomass. Where prescribed fire is used as a follow-up treatment to biomass harvest, minimizing logging slash through utilization should moderate post-thinning fire severity and the number of trees weakened by fire. While prescribed fire can produce low levels of bark beetle-induced mortality in the short run, some losses should be accepted in light of the high risk of large scale insect outbreaks in dense and structurally homogeneous contemporary landscapes.

10.5.3 Forest pathogens

Predicting how forest thinning associated with biomass harvesting will affect the incidence of tree disease is not a straightforward matter. While logging damage to tree boles and roots, the creation of stumps, and soil compaction promote the spread of some pathogens, reducing stocking levels may improve host resistance. Targeted thinning of infected trees will theoretically produce stands with fewer pathogens and faster-growing trees, but there is little empirical data to validate this hypothesis. Rippy et al. (2005) reviewed the literature for conifer root diseases common in western forests as related to fuel treatments. They noted that few studies specifically address fuel treatment impacts on root disease, and based management

recommendations on available studies in addition to pathogen biology and plant pathogen science. This summary is based largely on their review.

The sensitivity and response of root disease fungi to forest management activities depend on the host and pathogen species concerned and on site-specific factors such as species composition, soil characteristics (texture, water-holding capacity) and compaction, management history, and availability of fungal inoculum (Rippy et al., 2005). Root diseases can be managed by altering host species composition, including removal of susceptible species and increasing host diversity. The importance of avoiding damage to residual trees from logging equipment or soil compaction is frequently emphasized in the literature because wounds and damaged root systems act as points of entry for fungal spores and their insect vectors (Rippy et al., 2005).

Attempts to improve stand health with mechanical thinning are based on the hypothesis that reduced competition should improve tree vigor and resistance to infection. In a 20-year study of precommercial thinning impacts, *Armillaria* root disease mortality in mixed-species plantations in Oregon and Washington was not impacted by treatment, though crop tree basal area growth was positively influenced by thinning (Filip and Ganio, 2004). Entry et al. (1991) found that stands that had undergone thinning prior to inoculation with *Armillaria ostoyae* experienced lower infection rates than unthinned stands. Precommercial thinning in a central Oregon ponderosa pine stand significantly reduced leave-tree mortality from *Armillaria* root disease and increased basal area growth, though not diameter growth (Filip et al., 2009) These studies provide limited evidence that forest thinning could improve vigor and pathogen resistance.

One measure of tree vigor is the speed of wound occlusion. Filip et al. (1995) artificially wounded tree stems in northern Oregon to assess the ability of thinning to speed wound closure. In this study, thinning improved tree vigor in ponderosa pine, grand fir, and lodgepole pine, and diameter growth in grand fir and lodgepole pine. Wounds tended to occlude faster in thinned portions of stands, though this trend was only significant for lodgepole pine. Stem decay largely due to *Heterobasidion annosum* was extensive in grand fir stands, but no decay was observed in lodgepole or ponderosa pine. Thinning with fertilization successfully reduced grand fir stem decay in a similar study of wound closure in southern Oregon (Filip et al., 1992).

The relationship of forest management to black stain root disease (*Ophiostoma wagneri*) underscores the need for consideration of disease-specific impacts. Twelve years after precommercial thinning a Douglas-fir stand in the north coast of California, black stain infection was found on 18 of 23 subplots, and did not occur in any of 6 unthinned subplots (Harrington et al., 1983). In Oregon Douglas-fir plantations, the incidence of black stain root disease was associated with roadsides and skid trails, and was more commonly found in precommercially thinned than unthinned plantations (Hessburg et al., 2001). The authors recommended minimizing site disturbance and direct damage to trees during precommercial thinning. For root disease fungi that are vectored by beetles, scheduling harvesting activities to avoid beetle emergence and flight periods has also been advocated (Hessburg et al., 2001).

The limited studies that have evaluated forest management impacts on root diseases indicate that context is a critical when considering thinning treatments for pathogen management.

Thinning may improve growth rates and reduce the incidence of mortality caused by *Armillaria* root disease, but silvicultural operations can promote the spread of other pathogens, like black stain fungi. In all cases, minimizing damage to residual trees and forest soils is advisable.

10.5.4 Interactions between agents of forest mortality and the role of vegetation management

Biomass harvesting will not influence forest health threats in isolation. Mortality agents have complex interactions that can be influenced by forest management. Root diseases can predispose trees to insect attack, and conversely, beetles create infection courts and vector pathogenic fungi (Rippy et al., 2005). Fire, too, can promote root pathogens (Sullivan et al., 2003). Bark beetles are attracted to trees under attack by other bark beetle species (Fettig et al., 2004). Bark beetle epidemics influence future wildfire hazards (Bebi et al., 2003; Jenkins et al., 2008) and likewise, wildfires affect future stand susceptibility to bark beetle attack (Bebi et al., 2003; Kulakowski and Veblen, 2006). Management will influence agents of forest mortality both individually and in concert.

Bark beetles are an important agent of post-wildfire mortality. As observed for prescribed burning, post-wildfire beetle-caused mortality is positively correlated with fire severity measures such as crown injury (McHugh et al., 2003). Bark beetles can kill trees with relatively low levels of fire injury, and which might have otherwise survived a wildfire (McHugh et al., 2003). Trees apparently uninjured by wildfire can also be killed during post-fire beetle outbreaks (Amman and Ryan, 1991).

Wildfires promote subsequent bark beetle mortality, and bark beetle epidemics may influence future wildfires. Lynch et al. (2006) observed that a mountain pine beetle outbreak preceding the 1988 Yellowstone Fires by 13-16 years increased the likelihood of burning, though a more recent outbreak had no influence on burn probability. Bigler et al. (2005) similarly found that stands previously attacked were more likely to burn at high severity. Others have shown reduced likelihood of burning following insect attack (Kulakowski et al., 2003; Veblen et al., 2000). The variability in these findings is likely the result of timing (Lynch et al., 2006). Bark beetle attacks create periodic increases and decreases in forest fuel quality and availability, as well as attendant stand susceptibility to burning (Jenkins et al., 2008).

Interactions between agents of disturbance in western forests are numerous. When planning forest management activities to address losses from an individual agent, managers should consider the potential impacts on others as well.

10.6 Conclusions and recommendations for future research

Many forests in California are susceptible to damage from wildfire, insect outbreaks, disease agents, and drought. As a result, high levels of tree mortality (Ferrell, 1996) and morbidity (Christensen et al. 2008) are commonly observed. This review focused on the potential for woody biomass harvesting to address forest health concerns, along with comparisons to alternative methods of treatment. The following is a summary of findings and existing knowledge gaps. Given the scope of the challenges and the diversity of ecological conditions in

California, a coordinated set of experimental projects located across a representative set of conditions will be needed to complement ongoing and preexisting modeling efforts.

- As a general rule in dry forests, reducing stand density improves the vigor of residual trees, thereby promoting resistance to pathogen-, insect-, and fire-induced mortality. Reducing crown fuel continuity and ladder fuel hazard by harvesting small-diameter understory trees reduces the potential for high severity crown fire while removing relatively little biomass in larger trees. More focused research on the physical effects and cost effectiveness of alternative approaches that could be used in California is necessary before promoting new investments or cost-share programs to increase the level of biomass harvest in the state.
- Activity fuel treatment after partial cutting reduces post-harvest wildfire hazards (Weatherspoon and Skinner, 1995). Fuel treatment alternatives to biomass harvest that retain high levels of woody debris onsite, such as mastication, can increase potential wildfire intensity and severity in the short term. Because this small-diameter material is a target for biomass utilization, biomass harvest can minimize post-thinning fire hazards.
- Few studies have experimentally investigated the potential for biomass harvesting to influence wildfire behavior and effects. Comparisons with other fuel treatment techniques such as chainsaw harvest and prescribed burning would help to inform forest management decisions. Differences in costs as well as slope limitations for mechanical equipment can significantly affect the potential area eligible for treatment.
 - Mastication treatments reduce wildfire hazards and minimize risks to soil and water resources. Biomass and associated nutrients are retained onsite, helping buffer soils from compaction, runoff, and productivity impacts of harvesting. However, mastication can produce high levels of surface fuels, and if a wildfire occurs before significant decomposition has occurred, high severity effects may result. The risks and benefits, as well as the costs of woody biomass retention should be evaluated against those of biomass removal.
- Many of the observed increases in *Ips* beetle incidence following thinning treatments are associated with retention of woody slash. Biomass harvesting, which removes much of this potential beetle habitat, should be expected to deter rather than promote beetle incidence. Where prescribed burning is used as a follow-up treatment to biomass harvest, minimization of logging slash through utilization should moderate fire severity and the number of trees rendered susceptible to beetle infection by fire damage.
- Studies that investigate the consequences of common fuels reduction techniques for tree susceptibility to root disease are rare. There is a clear need for research into the long-term effects of fuels management on incidence of tree disease, in part because the impacts of treatment may be slow to manifest. The impacts of prescribed burning and the combination of thinning with burning treatments are especially poorly understood (Rippy et al., 2005).
- Forest thinning can influence mortality from root diseases by promoting host vigor and resistance, wounding trees and damaging root systems, or disturbing forest soils. Management activities should be planned and conducted with regard to context: the presence

and identity of pathogens, stand composition, and management history should be considered. Minimizing residual tree injury should be integrated into biomass management strategies.

- The relationships between factors governing the risk of biotic and abiotic disturbance in forests are complex (Jactel et al., 2009). However, some management considerations relevant to a given agent of tree mortality are common to others. Forest thinning, for instance, can reduce both potential wildfire severity and stand susceptibility to bark beetle attack.

CHAPTER 11: Existing State Woody Biomass Harvesting Guidelines

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11.1 Introduction

There has been growing national interest in using woody biomass from forests, woodlands, and shrublands to meet renewable energy demands and reduce the risk of catastrophic wildfires. Most existing forest practice rules and best management practices (BMPs) do not directly address the extraction of woody biomass or waste materials from forests for energy generation objectives. Increased demand for woody biomass may result in conflicts between various resource values (i.e. the woody material harvested during biomass operations also serves as wildlife habitat and aids in nutrient cycling). A few states have attempted to address these potential conflicts by developing woody biomass harvesting guidelines that specify the amount of woody debris retention appropriate for maintaining biodiversity, wildlife habitat, soil productivity, and water quality.

In 2009 reviews of the existing woody biomass harvest guidelines were published: *An Assessment of Biomass Harvesting Guidelines* by the Forest Guild (Evans and Perschel 2009), and *Energy from Woody Biomass: A Review of Harvesting Guidelines and a Discussion of Related Challenges* by Dovetail Partners, Inc. (Fernholz 2009). The Fernholz (2009) report includes a discussion of some of the challenges and opportunities related to woody biomass harvesting, existing biomass harvesting guidelines, and international experiences. The Evans and Perschel (2009) report was recently updated to include a more thorough review of the rules and regulations affecting woody biomass harvesting in the forests of the northeast, existing state biomass harvesting guidelines, policies and guidelines from Canada and northern Europe, and certification systems and other biomass-related organizations (Evans et al. 2010). Five common themes were identified within the woody biomass harvesting guidelines: dead and downed wood, wildlife and biodiversity, water quality and riparian management zones, soil productivity, and silvicultural applications (Evans et al. 2010). A set of general recommendations for the development of future biomass guidelines is presented at the end of the report (Evans et al. 2010).

This chapter will review the common themes identified in Evans et al. (2010) and found within the existing state woody biomass harvesting guidelines. A brief discussion of the experiences in Canada and northern Europe is also included. Six states have functioning woody biomass harvesting guidelines, and several more are beginning the process of guideline development. California regulators may find a review of these existing woody biomass harvesting guidelines informative as they begin the guideline development process. Understanding the ecological and economic differences between California and the states with existing guidelines will be important so that recommendations found in other state guidelines can be evaluated within the context of California's environment.

11.1.1 Woody biomass definitions

Some confusion exists about what is meant by woody biomass, as seen in the various definitions used in the six existing state biomass harvest guidelines and the scientific literature. Before any guidelines are developed in California, clear and appropriate definitions are needed. In this review, woody biomass will be defined to include any woody vegetation removed for energy objectives, including pre-existing fine woody² and coarse woody debris³, logs⁴, stumps⁵, snags, understory vegetation (shrubs and non-merchantable small-diameter trees), tops and limbs from merchantable trees, and larger trees that cannot be sold for lumber (i.e. deformities). Merchantable trees removed for the production of lumber or other added value forest products are not included in this definition of woody biomass.

11.1.2 States with woody biomass harvesting guidelines

Maine, Minnesota, Missouri, Michigan, Pennsylvania, and Wisconsin have already developed woody biomass harvesting guidelines that attempt to minimize environmental impacts by addressing concerns about long-term site productivity, and biodiversity and wildlife habitat alterations. The majority of this chapter will review the content of these six woody biomass harvesting guidelines. Copies of these state guidelines are available online:

11.1.3 Maine

Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine (Benjamin 2010)

(http://www.maine.gov/doc/mfs/pubs/biomass_retention_guidelines.html)

11.1.4 Minnesota

Biomass Harvesting on Forest Management Sites (MFRC 2007a)

The Minnesota Forest Resources Council (MFRC) also developed a set of guidelines for woody biomass harvesting from brushlands and open lands.

Woody Biomass Harvesting for Managing Brushlands and Open Lands (MFRC 2007b)

(http://www.frc.state.mn.us/documents/council/site-level/MFRC_forest_BHG_2001-12-01.pdf)

11.1.5 Missouri

Missouri Woody Biomass Harvesting Best Management Practices Manual (Enyart 2008)

(<http://mdc4.mdc.mo.gov/Documents/18043.pdf>)

² (FWD) Any woody material 0.01-3" diameter (CWHR V8.2)

³ (CWD) Any woody material 3-10" diameter (CWHR V8.2)

⁴ Any woody material greater than 10" diameter (CWHR V8.2)

⁵ Any snag less than 10 feet tall (CWHR V8.2)

11.1.6 Michigan

Michigan Woody Biomass Harvesting Guidance (MI DNRE 2010)

(http://www.michigan.gov/documents/dnr/WGBH_321271_7.pdf)

11.1.7 Pennsylvania

Guidance on Harvesting Woody Biomass for Energy In Pennsylvania (PA DCNR 2008)

(http://www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf)

11.1.8 Wisconsin

Wisconsin's Forestland Woody Biomass Harvesting Guidelines (Herrick et al. 2009)

(<http://council.wisconsinforestry.org/biomass/pdf/BHG-FieldManual-lowres090807.pdf>)

11.1.9 States in the process of developing woody biomass harvesting guidelines

Massachusetts, Maryland and Vermont are beginning the process of developing woody biomass utilization programs and harvesting guidelines. Oregon has conducted a review of its forest practice rules and the existing scientific literature on the impacts of woody biomass harvests and decided no new guideline development was necessary (Behan and Misek 2009).

11.1.10 Massachusetts

In late 2009, Massachusetts Department of Energy Resources (DOER) selected the Manomet Center for Conservation Services of Plymouth to lead a team of consultants to study issues related to biomass sustainability and carbon policy (EOEEA 2009). Consultants from the Forest Guild, Pinchot Institute for Conservation, the Biomass Energy Resource Center and others will produce a report analyzing the role of forests in carbon sequestration and the net greenhouse gas effects of woody biomass harvesting and utilization as a substitute for fossil fuels (i.e. biopower/biofuels) (EOEEA 2009). The report will also include a discussion of how carbon sequestration in forests managed specifically as biopower/biofuel energy plantations can be influenced through public policy, guidelines, and regulations (EOEEA 2009). Massachusetts DOER is expected to issue new regulations for biomass power facilities upon the release of the report (EOEEA 2009).

In May 2010, the Forest Guild Biomass Guideline Working Group published *Forest Biomass Retention and Harvesting Guidelines for the Northeast*. This report was prepared as part of the Biomass Sustainability and Carbon Policy Study commissioned by the Massachusetts Department of Energy Resources. The guidelines contained within the report were designed to be used with any existing best management practices (BMPs) or state-based biomass harvesting guidelines (FGBWG 2010). The report begins by defining sustainability, biomass, and down woody material and then presents general guidelines for biomass retention and harvesting for all forest types in the northeast (FGBWG 2010). Scientific justification of the suggested biomass harvesting guidelines is provided within the report. Unlike any existing forest harvesting or woody biomass harvesting guidelines, the Forest Guild's report includes recommendations for the management of carbon (FGBWG 2010). The section on carbon management includes a discussion of elements to include including in carbon impact analyses of woody biomass

harvests (FGBWG 2010). Because the United States has not signed the Kyoto Protocols, this is just one of many non-binding suggestions on how to address the climate impacts of using forest biomass to reduce fossil-fuel based energy. The latest International Energy Agency report reaffirms their accounting principle of “excluding combustion of biomass (considered as non-emitting CO₂ based on the assumption that the released carbon will be reabsorbed by biomass regrowth, under balanced conditions)” (International Energy Agency, 2009) since the European member countries all measure forest growth rates far in excess of harvest rates and have strict forest regulations.

11.1.11 Maryland

Stakeholders in the state of Maryland are currently working with the Pinchot Institute to develop a set of biomass harvesting guidelines (PIFC 2009). A steering committee, consisting of representatives from the Maryland DNR-Forest Service, Maryland Energy Administration (MEA), Maryland Forestry Association, academic and research interests, environmental and conservation organizations, is working with the Pinchot Institute to define what constitutes sustainable bioenergy in Maryland (PIFC 2009). Estimates of available biomass will be made to determine if there is enough feedstock to sustain wood-based bioenergy facilities without adversely affecting other resource values (PIFC 2009).

11.1.12 Vermont

Vermont is just beginning the process of developing woody biomass harvesting guidelines. In 2009, the Vermont General Assembly established a Biomass Energy Development Working Group (BEDWG) tasked with developing a sustainable biomass industry (BEDWG 2010). Over the next three years, the BEDWG will produce three reports addressing recommended fiscal and regulatory incentives for the use of local biomass for energy production; recommended biomass harvesting guidelines; and recommended standards and policies for renewable energy from local biomass (BEDWG 2010). The first interim report was published in January 2010 summarizing the Working Group’s activities thus far. No formal recommendations, standards or guidelines have been developed as of January 2010.

11.2 Examining existing state woody biomass harvesting guidelines

All six existing state biomass harvesting guidelines make some recommendations about dead and downed wood, wildlife and biodiversity, water quality and riparian zones, soil productivity and silvicultural applications. Learning from the experiences of other states, California should develop guidelines that address all of those categories using scientific justifications and a process that allows for public input and collaboration.

11.2.1 Dead and downed wood

Dead and downed wood is an important structural component in forested ecosystems. Its functional role is constantly changing as it decomposes over time. In addition to providing essential habitat for a variety of mammal, bird, amphibian, reptile, invertebrate, and plant species, dead and downed wood plays an important role in nutrient cycling (Harmon et al. 2004, Freedman et al. 1996, Brown et al. 2003). The amount of dead and downed wood present in intensively managed forest stands is often much less than the amount present in unmanaged

stands (Harmon et al. 2004, Freedman et al. 1996, Hansen et al. 1991, Franklin et al. 1981). This is a result of increased fiber utilization during forest harvests, salvage operations, slash disposal and site preparation (Graham et al. 1994).

Most of the existing state guidelines include specific rules about the amount of woody biomass to be retained on site. Each state has requirements for the retention of logs and snags (of various sizes and decay class), forest floor, stumps, and pre-existing coarse woody and fine woody debris. In addition to leaving all pre-existing woody debris when possible, the six state guidelines suggest leaving between 15 to 33% of woody debris generated during harvest. These retention guidelines are not supported by references to scientific literature and it is difficult to discern where such retention percentages were obtained.

There have been a few studies that have attempted to quantify the amounts of dead and downed wood needed to maintain wildlife populations or communities (e.g. Brown et al. 2003, Graham et al. 1994, Ranius and Fahrig 2006). While these studies recognize that the habitat value of dead and downed wood is influenced by the spatial arrangement, species, and state of decay, the suggested retention targets only focus on the amount of dead wood to be retained (Bunnell et al. 2002, Ranius and Fahrig 2006).

Brown et al. (2003) suggests there are different optimum levels of coarse woody debris retention depending upon the resource values being managed and the forest type. The optimal range of coarse woody debris left on site results from a balance between level of acceptable fire risk and the quantity needed for soil productivity and wildlife habitat (Brown et al. 2003). Brown et al. (2003) suggests that 5-20 tons/acre for warm dry forests and 10-30 tons per acre for other, cooler forests would best meet resource needs. These recommendations should be modified when other factors are considered including, quantity of pre-existing fine woody fuel, diameter of coarse woody debris, landscape level volumes, and ecosystem restoration objectives (Brown et al. 2003). For example, high levels of fine fuels and/or warm dry climates would likely reduce the optimum range for coarse woody debris (Brown et al. 2003). Graham et al. (1994) also conducted a study of optimum woody debris loads in western forests (Idaho, Montana, and Arizona). Graham et al. (1994) suggest the optimum amount of organic matter on the forest floor should fall within the range 6.9-39.7 tons per acre depending upon forest type, with coarse woody debris making up 25-50% of this material. Their recommendations were based on what they perceived to be the levels needed to maintain forest productivity as determined by organic matter and ectomycorrhizae relationships (Graham et al. 1994). Since other studies have tested such recommendations and found that deviation from the guidelines often had no impact on productivity (Powers et al. 2005), long term field trials in the specific forest types of interest are warranted.

Please review Chapter 7: *Potential Impacts to Biodiversity from Woody Biomass Harvests* and Chapter 8: *Potential Impacts to Wildlife from Woody Biomass Harvests* for a more detailed review of the relevant scientific literature. See **Table 3** for a summary of dead and downed wood management recommendations in existing state biomass harvesting guidelines.

11.2.2 Wildlife and biodiversity

Existing regulations in California explicitly state that woody biomass harvests should not be allowed to reduce biological diversity within stands or across the landscape through the reduction of suitable wildlife habitat (Article 9, CA FPR 2010). The maintenance of structural complexity within stands harvested for woody biomass is critical to achieve wildlife habitat and biodiversity conservation goals (Fischer et al. 2006, Lindenmayer et al. 2008, Lindenmayer et al. 2006, Franklin et al. 2002). It is well demonstrated that wildlife habitat and biodiversity are closely linked to the quantity, quality and spatial distribution of dead and downed wood within a stand and across the landscape (Freedman et al. 1996, Harmon et al. 2004, Franklin et al. 2002). The six existing state biomass harvest guidelines indicate an awareness of these relationships and require the retention of some portion of the dead and downed wood profile. Additionally, the state guidelines recommend the retention of biological legacies such as mast producing hardwoods, trees with cavities, pockets of understory vegetation and green trees. The existing biomass harvesting guidelines agree on the importance of avoiding harvests within sensitive sites, or sites supporting sensitive wildlife species. These include areas of high biodiversity and/or high conservation value such as riparian zones, wetlands, meadows, old-growth forests, etc.

Minnesota's and Pennsylvania's guidelines suggest biomass harvests can be used to create or maintain important wildlife habitats that are lacking within a stand (MFRC 2007a, PA DCNR 2008). Biomass harvest operations can increase browse production by creating openings in the canopy that allow for herbaceous understory plant development and seedling regeneration (PA DCNR 2008). Both Wisconsin's and Michigan's guidelines suggest leaving additional woody debris in stands with low levels of woody debris prior to biomass harvests for wildlife and biodiversity conservation goals (Herrick et al. 2009, MIDNRE 2010).

Habitat loss and fragmentation are the two main threats to biodiversity (Fahrig 2003). The effects of habitat fragmentation are inconsistent, as some species benefit from an increase in edge habitat while others are negatively impacted (Fahrig 2003). The effects of habitat loss on wildlife and biodiversity are almost always negative (Fahrig 2003). Biomass harvests from managed landscapes may result in both habitat loss and fragmentation, especially if land is converted to short rotation woody crop plantations (Janowiak and Webster 2010). Conversion of natural or managed forests to short rotation woody crop plantations will most likely result in simplified stand structures and reductions in wildlife habitat and biodiversity (Stephens and Wagner 2007, Carnus et al. 2000, Janowiak and Webster 2010). Missouri's guidelines recommend avoiding the conversion of natural forests to plantations, because of the associated biodiversity consequences (Enyart 2008).

The maintenance wildlife habitat and biodiversity within stands and across landscapes will require guidelines that promote vertical and horizontal structural complexity through the retention of biological legacies (Fischer et al. 2006, Lindenmayer et al. 2008, Lindenmayer et al. 2006, Franklin et al. 2002). Additionally, guidelines must address acceptable levels of biomass harvest in sensitive areas (soils, habitats, etc). Systematic conservation planning generally uses spatially explicit targets for different biodiversity elements as a way to ensure maintenance of

adequate habitat and wildlife populations (Margules and Pressey 2000). The most effective biodiversity conservation targets are quantitative and operational (Margules and Pressey 2000). Bunnell and Huggard (1999) suggest rule based guidelines that prescribe fixed targets or limited ranges for optimal retention of biological legacies may not be the best mechanism for achieving biodiversity conservation goals. Retention targets that seek to maximize biological diversity and wildlife habitat at one scale will inevitably lead to homogeneity across the system as the same rule is applied everywhere (Bunnell and Huggard 1999). Redford et al. (2003) suggest the use of multiple conservation targets across varying spatial scales that address the maintenance of both individual species and ecological processes.

Please review Chapter 7: *Potential Impacts to Biodiversity from Woody Biomass Harvests* and Chapter 8: *Potential Impacts to Wildlife from Woody Biomass Harvests* for a more detailed review of the relevant scientific literature. See **Table 4** for a summary of wildlife and biodiversity management recommendations in existing state biomass harvesting guidelines.

11.2.3 Water quality and riparian zones

Most states with biomass harvesting guidelines have existing regulations specifying the establishment of riparian management zones and the types of activities allowed within. While these regulations are referenced within the state biomass harvest guidelines, some states choose to include specific recommendations for the protection of water quality during biomass operations. Maine, Minnesota and Missouri recommend retaining dead and downed wood structures used for erosion control/soil stabilization (Benjamin 2010, MFRC 2007a, Enyart 2009). Pennsylvania's guidelines focus on water quality issues related to road design, function and placement (PADCNR 2009). The harvesting of biomass from within riparian management zones is generally limited in the six existing state biomass harvesting guidelines. Michigan's guidelines refer to the 2009 Sustainable Soil and Water Quality Practices on Forest Land (IC 4011) manual for specific recommendations about riparian management zones, road placement and management, and soil and sedimentation (MIDNRE 2010).

Shepard (2006) concludes that water quality Best Management Practices (BMPs) developed for conventional forestry will most likely provide adequate protection of water quality when applied during woody biomass harvests. In particular, the use of riparian buffers during woody biomass harvests is expected to minimize sediment delivery into streams, rivers and lakes (Shepard 2006, Barling and Moore 1994). High rates of fiber utilization expected during woody biomass harvests may reduce the nutrient capital of treated areas (Reijnders 2006, Tritton et al. 1987, Kimmins 1976). Shepard (2006) suggests more frequent fertilization may be required under some intensive bioenergy systems. Water quality BMPs may need to be adjusted to ensure any additional fertilizer inputs into the system are not transported into adjacent streams, rivers and lakes (Shepard 2006). Water quality BMPs developed for conventional forest harvests may not offer sufficient protection in short rotation woody crop plantation systems as fertilization/pesticide use and frequency of soil disturbance will increase to levels with greater similarity to annual agricultural crops (Shepard 2006).

Please review Chapter 5: *Soil Productivity and Water Quality Consequences of Biomass Harvest* for a more detailed review water quality concerns and of the scientific literature. See **Table 5** for a summary of water quality and riparian management zone recommendations in existing state biomass harvesting guidelines.

11.2.4 Soil productivity

Most states with woody biomass harvesting guidelines already include protection measures for the maintenance of soil productivity within existing forest practice rules and guidelines. Minnesota's biomass harvesting guidelines refer uses to the General Timber Harvesting Guidelines section on soil productivity, but then goes on to provide specific suggestions for biomass harvests (MFRC 2007a). Maine recommends retaining all dead and downed wood but directs users to its Biodiversity Guidelines for more detailed recommendations (Benjamin 2010). Michigan's guidelines refer to the 2009 Sustainable Soil and Water Quality Practices on Forest Land Manual (IC 4011) for specific guidelines related to maintenance of soil productivity (MIDNRE 2010).

Intensive biomass extraction may alter site productivity through nutrient losses and changes to nutrient cycles (Thiffault et al. 2010, see reviews in Richardson et al. 2002 and Roser et al. 2008). The retention of fine woody debris is thought to be especially important for the maintenance of soil productivity as this material decomposes quickly and contributes to the nutrient cycle (Harmon et al. 2004). Most existing state biomass harvesting guidelines recommend retaining the fine woody debris (leaves, needles, twigs), the forest floor, litter layer, stumps and root systems. Maine's, Minnesota's, Missouri's, Michigan's, and Wisconsin's guidelines include recommendations based upon the soil types, with poor, shallow, sandy soils being classified as less suitable for biomass harvest (Benjamin 2010, MFRC 2007a, Enyart 2008, MIDNRE 2010, Herrick et al. 2009). Pennsylvania and Minnesota address the impacts of roads and landings on soil productivity (PADCNR 2009, MFRC 2007a).

Changes to the physical structure of the soil during woody biomass harvests may impact productivity (Page-Dumroese et al. 2010). Soil compaction can reduce porosity and increase bulk density, though the impacts of compaction vary between soil types and can be negative, positive or neutral (Page-Dumroese et al. 2010).

Please review Chapter 4: *Nutrient Cycling Consequences of Woody Biomass Harvesting*, Chapter 5: *Soil Productivity and Water Quality Consequences of Biomass Harvest* and Chapter 6: *Applying Soil-Related Findings to California Forests* for a more detailed review of the relevant scientific literature. See **Table 6** for a summary of soil productivity conservation recommendations in existing state biomass harvesting guidelines.

11.2.5 Silviculture

Most states with biomass harvesting guidelines recognize the potential to use woody biomass harvests to achieve a variety of silvicultural goals including density control and growing space allocation during intermediate treatments, site preparation and regeneration, salvage operations, maintenance of forest health, and fuels reduction treatments. Some states have used their biomass guidelines to make recommendations about post-stand conditions that are not

directly related to woody biomass harvesting. Missouri's guidelines include specific recommendations about the number and spacing of retained trees during a biomass harvests associated with pre-commercial and commercial thinning operations (MFRC 2007a). Pennsylvania's guidelines stress the importance using woody biomass harvests to achieve residual stand condition goals (PADCNR 2008). Wisconsin suggests leaving approximately 5% of the area being salvage harvested in untouched reserve patches that include dead and downed wood, cavity trees, and green trees when possible (Herrick et al. 2009). Wisconsin and Missouri mention the use of prescribed fire after biomass harvests to achieve site preparation or fuels management objectives (Herrick et al. 2009, MFRC 2007a). Michigan's and Wisconsin's guidelines suggest woody biomass harvests could be used to eradicate invasive/exotic species (MIDRE 2010, Herrick et al. 2009).

Minnesota warns that biomass harvests may have the potential to cause swamping, where the removal of woody vegetation temporarily increases the wetness of the site due to decreased transpiration (MFRC 2007a). Swamping can be a problem during the establishment of regenerating seedlings and Minnesota's guidelines recommend retaining some live vegetation in wet sites (MFRC 2007a).

Minnesota, Missouri, and Pennsylvania recommend against re-entry into recently harvested stands for the purpose of removing biomass (MFRC 2007a, Enyart 2008, PADCNR 2008). It is recommended that a stand not be re-entered once regeneration has been established (MFRC 2007a, PADCNR 2008). Upon re-entry, erosion control measures should be reestablished and slash piles that demonstrate use by wildlife species should be avoided (MFRC 2007a, PADCNR 2008).

Please review Chapter 10: *The Potential for Biomass Harvesting in California Forests to Reduce Tree Mortality from Wildfire, Insects and Pathogens* for reviews of relevant scientific literature. See **Table 7** for a summary of silvicultural recommendations in existing state biomass harvesting guidelines.

11.3 California and woody biomass guideline development

11.3.1 California Forest Practice Rules 2010

California has an extensive set of forest practice rules that regulate management activities on state and private lands. Woody biomass harvests are not explicitly regulated under the existing law; however, there are mandates about the treatment of slash and snags that would be applicable to a biomass harvest. The CA FPR contain rules addressing allowable silvicultural treatments, harvesting practices and erosion control, site preparation, watercourse and lake protection, hazard reduction, and wildlife protection practices that would apply to woody biomass harvests that remove merchantable trees (CA FPR 2010).

Fuel hazard reduction treatments are of particular importance in California because of the increasing number of catastrophic wildfires experienced each summer. The California Forest Practice Rules include guidelines that are focused on reducing fire risk and require the modification of live and dead fuels during fuel treatments (Article 7: Hazard Reduction, CA FPR 2010). Treatment of surface and ladder fuels, including logging slash and debris, brush,

small trees, and deadwood, that could promote the spread of wildfire is specifically address in the CA FPR. Rules about appropriate vertical and horizontal spacing between fuels, maximum depth of dead ground surface fuels (9 inches), and reduction of standing dead fuels are included (CA FRP 2010). Slash treatments are required after nearly every forest management operation.

11.3.2 California Woody Biomass Harvesting Guideline Development

Evans et al. (2010) reviewed the various guideline development processes used by Maine, Minnesota, Missouri, Michigan, Pennsylvania and Wisconsin. The guideline development process will be an important determinant of the specific recommendations included in any biomass harvesting guideline document. Ample public participation and stakeholder involvement during all phases of guideline development may lead to greater public acceptance of the final product (Evans et al. 2010). Minnesota's, Missouri's, and Wisconsin's development process included a technical committee with broad representation from the forestry and conservation communities, as well as public comment periods. Pennsylvania's guidelines were developed entirely in-house and borrow extensively from Minnesota's guidelines. Maine's and Minnesota's biomass harvesting guidelines include fairly extensive literature reviews.

As California begins the process of developing woody biomass harvesting guidelines a thorough review of the CA Forest Practice Rules 2010 should be conducted to identify any potential gaps in resource protection. If the CA FPR sufficiently address the issues related to woody biomass harvests (in particular coarse woody debris retention) then there may be no need for new guidelines. Independent monitoring of a sample of completed projects could provide the necessary basis to determine whether new guidelines would be beneficial.

California has a variety of wooded ecosystems, in addition to forestlands, that may be suitable for woody biomass harvests. Harvesting operations in oak woodlands and chaparral communities are not subject to regulations found within the CA FPR (CA FPR 2010). Even if the CA FPR are revised to include specific regulations about woody biomass harvests, it will be necessary to develop a secondary set of guidelines specific to biomass harvests in oak woodlands and chaparral communities. Minnesota's Forest Resource Council developed a second set of guidelines specific to woody biomass harvesting on brushlands and open lands (MFRC 2007b). The MFRC 2007 brushland guidelines include discussion of water quality and riparian management zones, reserve areas and wildlife/biodiversity, soil productivity, timing and location of operations (MFRC 2007b).

A review of the existing state biomass harvesting guidelines may be helpful as California begins the process of developing new woody biomass harvesting guidelines. Understanding how different states address the potential for woody biomass harvests to impact wildlife and biodiversity, water quality, and soil productivity can be informative, but direct appropriation of suggestions or recommendations may not be appropriate. Forests in the northeastern and lake states regions of the United States are different from the forests, woodlands and shrublands of California (see Table 21 below). Woody debris retention requirements appropriate for forests in Maine, Minnesota, Missouri, Michigan, Pennsylvania, and Wisconsin may not be appropriate in California due to the much drier summer conditions and resulting wildfire risks.

Table 21 Summary of key differences between California and eastern states with biomass harvesting guidelines

		States with biomass harvesting guidelines						
By State		CA	ME	MN	MO	MI	PA	WI
Average summer rainfall ¹ (June, July and August)		0.7 in.	9.9 in.	11.9 in.	11.7 in.	9.9 in.	12.3 in.	12.3 in.
Forest Composition ²	Hardwood	18.2%	44%	67%	92%	68%	90%	73%
	Softwood	81.8%	56%	33 %	8%	32%	10%	27%
By Region		Pacific Coast	North					
Wood products ³	Pulpwood	5.6%	39.4%					
	Sawlogs	70%	38.4%					
	Fuelwood	12.6%	18.9%					

1. NCDC U.S. Climate Normals (<http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl>)

2. 2007 Net Volume of Hardwood/Softwood Growing Stock (Table 18 and Table 19, Smith et al. 2009)

3. 2006 Volume of Roundwood Products Harvested in U.S. by Region (Table 39, Smith et al. 2009)

Many of the retention guidelines designed to address a potential increase in biomass harvesting in eastern states are designed around guidance to leave a percentage of the initial amounts of different types of biomass such as standing dead trees and downed wood. While such guidelines are relatively easy to apply by operators, the ecological value applying percentage retention guidelines developed in other forest types is not guaranteed. The following comparisons from FIA tables for common western and eastern forest types illustrate very large differences between states and forest types.

Table 22 Forest carbon in metric tonnes per hectare for common Eastern US and Western US forest types

Forest type, state (number)	Live tree	Dead tree	Under story	Dead & Down	Forest floor	Soil
Maple/beechn/birch, ME (1135)	61.5	2.4	2.3	5.8	26.6	69.8
Maple/beechn/birch, MI (1672)	74.1	3.4	3.3	7.6	27.8	134.9
Maple/Beechn/Birch, PA (507)	91.6	2.4	2.3	7.6	28.4	70.1
Oak/Hickory, MI (637)	70.9	3.5	3.0	7.5	7.9	97.3
Oak/Hickory, PA (434)	98.2	1.2	2.7	7.7	8.8	53.2
Eastern White Pine, ME (112)	79.6	2.1	3.0	6.1	13.2	78.1
Mixed Conifer, CA USFS (905)	132.2	11.7	3.1	18.2	38.5	49.6
Mixed Conifer, CA PVT (248)	81.8	3.8	5.5	13.2	35.1	49.8
Douglas-fir, OR USFS (454)	230.4	15.7	6.7	29.1	43.1	94.7
Douglas-fir, OR PVT (599)	91.2	2.2	6.3	19.7	26.0	95.0

6 Eastern Forests Average	79	3	3	7	19	84
2 California Mixed Conifer Average	107	8	4	16	37	50
2 Oregon Douglas-fir Average	161	9	7	24	35	95

Western forest types in the sample had roughly twice as much dead tree and dead and down woody biomass as the Eastern forests. In high fire risk sites, maintaining a high percentage of the initial loads may not be the most effective strategy. Guidelines for California that are guided by statewide inventory data, fire risk assessments and experimental trials will probably be more effective than starting with guidelines developed in very different forest types.

10.4 Other biomass harvesting guidelines

Other countries, such as Sweden, Finland, and Canada, have long histories with, and well developed literature on the impacts of woody biomass extraction for energy and fuel objectives. The following section briefly reviews woody biomass guidelines found in other countries.

11.4.1 Canada

In February 2008, 140 people gathered in Toronto for a workshop titled *The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies*. The goal of the workshop was to identify the gaps in what is known about the environmental impacts of increased woody biomass utilization and begin the process of developing sustainable biomass removal guidelines and policies (Titus et al. 2008a). In Canada, there has been nearly 30 years of research on the impacts of removing slash on ecosystem processes (e.g. soil productivity and biodiversity), which should be an important resource during the development of biomass harvesting guidelines (Titus et al. 2008b, Mallory 2008).

While many of the Canadian provinces have laws regulating forest harvests and mandating protection of ecosystem services such as biodiversity, few have guidelines specific to woody biomass harvesting (Evans et al. 2010, Fernholz 2009). Nova Scotia began the process of guideline development by forming a multi-stakeholder biomass committee comprised of representatives from the Nova Scotia Department of Energy, Department of Natural Resources and the forest products industry (Ralevic et al. 2008). In addition to developing biomass harvesting guidelines, this committee is assessing the potential sources for sustainable bioenergy production (Ralevic et al. 2008). Ontario forest management and harvest policies (Crown Forest Sustainability Act and Section 6.2 of the 2010 Stand and Site Guide) provide guidance on woody biomass harvests. Harvest of stumps and below ground biomass for bioenergy production is not allowed (OMNR 2010). Forest biofiber is defined to include only trees; merchantable, unmerchantable, and salvaged (OMNR 2010). The majority of woody debris must remain on site post-biofiber harvest, including boles, branches, roots, bark, leaves, needles, and debris (OMNR 2010). The province did mandate monitoring, adaptive management and a policy review in 2013 (ECO 2009). In 2008, British Columbia adopted the BC Bioenergy Strategy aimed at helping the Province achieve its goal of becoming electricity self-

sufficient by 2016 (Campbell et al. 2008). The BC Strategy focuses on developing bioenergy conversion technologies and demonstration projects while utilizing forest residues and bark beetle-killed trees (Campbell et al. 2008). While biomass harvesting guidelines were not included in the Bioenergy Strategy, British Columbia has the Forest and Range Practices Act (FRPA) and its regulations that govern the harvest activities on Crown forestlands (FRPA 2010).

New Brunswick developed woody biomass harvest guidelines in response to the increasing demand for low-quality fiber (slash and non-merchantable stems) and sustainability concerns. New Brunswick's guidelines begin by defining forest stands that are eligible and ineligible for biomass harvest (NB DNR 2008). This determination is made by a NB Department of Natural Resources approved GIS-based decision support model that calculates the total nutrient supply for a forest stand using the soil type, bedrock type, atmospheric nutrient deposition and tree nutrient content (NB DNR 2008). Forest composition and growth rate are incorporated into the model to determine the nutrient demands of the stand. Eligible sites are those that demonstrate minimal site nutrient loss post-harvest, assessed over an 80 year period (NB DNR 2008). To limit re-entry, all biomass is to be removed from the site within one operating year to limit re-entry (NB DNR 2008).

11.4.2 Europe

Many European countries have been working on the topic of utilizing forest biomass for energy production for years, and the amount of literature available from Europe is quite extensive. In addition to the governmental reports and guidelines produced by individual countries, there has been much collaboration between European countries. An example of the extent of work on the topic of woody biomass utilization is the *Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on the Baltic and Nordic Region* (Röser et al. 2008). This 262 page book details the European experience to date and includes a chapter on the existing country and international organizations recommendations. *Chapter 7: Review of Recommendations for Forest Energy Harvesting and Wood Ash Recycling* includes a discussion of the environmental guidelines and recommendations, and the technical, logistical and economic considerations of woody biomass utilization in Denmark, Finland, Sweden, Lithuania, and the United Kingdom (**Table 2**, Stupak et al. in Röser et al. 2008). The Evans et al. (2010) report also includes a detailed review of the development and contents of woody biomass harvesting guidelines from Sweden, Finland, Denmark and the United Kingdom.

In 2006, the European Environment Agency published *How much bioenergy can Europe produce without harming the environment?* (Wiesenthal et al. 2006). In order to determine the sustainable amount of forest biomass technically available for energy production a set of European scale environmental criteria were developed. The main criteria were: (1) no intensification of use on protected forest areas (11.7% of European forests are protected), (2) foliage and roots are always left on site (20% of total aboveground biomass), (3) the extraction rate for residues from stem and branches is limited according to the suitability of the site, (4) 5% increase in protected forest area for each member state, and (5) 5% standing volume retained on site (Wiesenthal et al. 2006). A residue extraction suitability map of Europe and acceptable extraction rates were produced based on these environmental criteria and the potential for soil erosion, compaction

and nutrient depletion (Wiesenthal et al. 2006). The maximum extraction potential for forest residues (excluding foliage) from highly suitable sites was set at 75% (50% for moderately and 15% for marginally suitable sites) (Wiesenthal et al. 2006). The report also includes discussion of the amount of technically available biomass from the agricultural and waste sectors. The authors conclude that significant amounts of biomass are available within Europe even with strict environmental constraints. (Wiesenthal et al. 2006).

Table 23 Overview of topics included in recommendations, guidelines and informational materials from Denmark, Finland, Sweden, and the United Kingdom and international organizations (Stupak et al. 2008)

Sources for Table 23 (Stupak et al. 2008): A. Danish Forest Agency (1985), B. Pedersen & Hald (1996), C. Centre for Biomass

Topic	Denmark			Finland		Sweden						United Kingdom		International			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
SFM, certification, C&I, legislation									x							x	
Soil fertility (nutrients, erosion)	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
Soil organic matter (C-storage, leaching)	x		x			x	x		x	x		x				x	
Wood production	x			x		x	x		x	x						x	
Biodiversity and wildlife				x	x	x	x	x	x	x	x	x	x		x	x	
Insect pests, fungi	x	x		x	x	x	x	x	x	x	x						
Hydrology, water quality, streams and lakes					x	x	x		x	x		x			x	x	
Landscape, archeology, culture and leisure				x	x	x			x	x		x					
Nature conservation									x				x				
Silviculture	x	x		x	x					x		x	x		x		
Stump harvesting	x			x		x				x					x		
Production costs, sales and economy		x	x		x								x		x		

Technology (2002), D. Nurmi & Kokko (2001), E. Koistinen & Äijälä (2005), F. Egnell et al. (1998), G. Skogsstyrelsen (2001), H. National Board of Forestry (2002), I. Energimyndigheten (2006), J. Egnell et al. (2007), L. Samuelsson et al. (2007), M. Nisbeth et al. (1997), N. British Biogen (1999), O. Richardson et al. (2002), P. Emilsson (2006), Q. Vares (2006)

A recent analysis in Fennoscandia (Scandinavia plus Finland) on increased biomass harvesting summarized the potential effects on biodiversity, landscape amenities and cultural heritage values (Farmstad, 2009). The strong cultural heritage related to the decline of agricultural lands in a region with settled agriculture that goes back for centuries is different than conditions in California. In relation to the three goals, they rated the following practices as generally acceptable or having the potential for serious negative effects in terms of biodiversity, landscape amenities or cultural heritage values.

Acceptable in most cases

- Harvesting of logging residues when appropriate measures to protect biodiversity are taken
- Harvesting of biomass from power line corridors and along roads
- Harvesting of bushes and trees from marginal farmlands

Having the potential for serious negative effects

- Harvesting of stumps
- Intensification of silviculture in natural forests
- Harvest of biomass from currently non-commercial forests
- Increase use of woody vegetation on culturally significant agricultural lands

The numerous reports from Europe after a decade of the intensification of the use of biomass for renewable energy illustrates the challenges that California and the United States will also face as we begin to reduce our dependence on fossil fuels for energy. While the ecological and social situations are unique, this study highlights the close links between the two sets of values and the importance of considering whether increased biomass harvesting would substantially alter the existing landscapes.

11.5 Forest Guild Recommendations for State Level Biomass Guidelines

Evans et al. (2010) developed the following list of recommendations for states beginning the process of drafting woody biomass harvest guidelines:

- Develop guidelines that are based on the scientific literature and rigorous field based research. There are hundreds of journal articles that address the environmental impacts associated with increased woody biomass utilization. There are opportunities to implement field based research projects where there are gaps in the literature.
- Guideline development should allow for ample stakeholder input.
- Define important terms, such as “woody biomass,” clearly. It will be necessary to differentiate between “biomass” (all organic material in the forest) and “woody biomass for energy” (the component of a forest harvest that was once waste/non-merchantable and now harvested for energy). It must be clear what components of the ecosystem are included in the “woody biomass” definition, and therefore regulated under future guidelines.
- Woody biomass harvesting guidelines should be informed by the local ecology (climate, forest cover, natural disturbance regimes, etc). California’s climate, forest cover types, and forests products are substantially different from those states that have developed woody biomass harvesting guidelines. While it may be tempting to borrow from the

work that has been done in the Northeast and Lake States, these guidelines were not developed for California's forests or Mediterranean climate.

- Guidelines should be developed to include rules concerning water quality, soil productivity, wildlife habitat and biodiversity, dead and downed wood, and silvicultural applications. Just as California has regionally specific Forest Practice Rules, these woody biomass harvest guidelines should also be developed to match regional conditions.
- Dead and downed wood (coarse woody debris, fine woody debris, logs, stumps, and snags) typically has more wildlife and biodiversity values than newly created harvest residues. Improved data on these relationships is necessary if specific retention targets for different categories of dead wood (existing and harvest generated CWD/FWD, forest floor, logs, stumps and snags) are to be developed. The level of dead wood retained after a woody biomass harvest can have a significant impact on wildlife habitats and nutrient cycling. In the more fire-prone forest types in California, the persistence of dead and downed wood will be strongly affected by fire regimes that can consume much of this biomass over decades.
- Woody biomass harvest guidelines must be operational and congruent with existing forest practice rules. In general, newly created harvest residues have higher energy values and are easier to collect than pre-existing dead and downed wood in forest stands. Since collection methods will not always be able to sort between new and pre-existing biomass, guidelines should be based on desired post-treatment retention levels given fire risks and regeneration requirements.
- The development of empirically based guidelines specific to woody biomass harvests in woodlands and shrublands may be necessary, as these vegetation cover types are structurally different from most industrially managed forests.

11.6 California woody biomass harvesting guideline recommendations

11.6.1 Dead and downed wood

Retention guidelines developed for California's forests and wooded ecosystems should take into account the ecological processes of dead and down wood accumulation and decay specific to a Mediterranean climate regime. During the dry, hot summer months, dead and downed woody material dries out, reducing decay rates and increasing fire risk. Requirements to retain such material for wildlife and soil productivity goals must be balanced with the increased fire risk.

Dead and downed wood retention guidelines should be informed by the best available science including experimental results that compare treatments to no treatment. Functionally viable levels of woody debris will likely vary between ecosystems, ecological processes of concern (nutrient cycling), species of conservation concern, and spatial scales of analysis. It may also be important to address how the retained dead and downed wood structures are distributed

across the landscape. Some species benefit from clumped distributions, while other prefer dispersed structures.

The most effective retention targets to implement are quantifiable and operational (Margules and Pressey 2000). Periodic evaluations are necessary to assess their ecological effectiveness. Requiring the retention of some number of bone dry tons of biomass is operationally difficult. Per acre retention requirements may not be the most effective mechanism for achieving optimal levels of dead and downed wood within a stand and across the landscape (Bunnell and Huggard 1999). Because of the variability in the level of dead and downed wood needed to sustain ecological processes and wildlife populations, the scientific merit of single optimal retention target may not be established (Hagan and Whitman 2006). Risk assessment could be used to determine optimal retention targets- “if we set target X (and meet it), we will face the probability of Y of still losing that service” (Hagan and Whitman 2006).

11.6.2 Wildlife and biodiversity

Woody biomass retention guidelines developed for California must carefully consider the type, amount and distribution of structural elements required by native wildlife species. The elements most often harvested during woody biomass operations are those that are very important for wildlife habitat: dead and downed wood, understory vegetation, hardwoods, trees with cavities, etc. It may be necessary to develop guidelines for the retention of some amount of the forest floor, litter layer, coarse/fine woody debris, stumps, logs, and snags (of various size and decay classes). It will be important to identify and study species of special concern (Federally and/or state listed rare, threatened, endangered) that depend upon dead and dying wood for some essential life habits.

11.6.3 Water quality and riparian zones

California, like the six states reviewed, has water quality and riparian management zone requirements written into the Forest Practice Rules. There is little indication that these existing guidelines would not be sufficient to protect water quality during woody biomass harvests (Shepard 2006). It may be appropriate to address the type and amount of woody biomass removal allowed from riparian buffer strips. Since coarse woody debris plays important structural and functional roles within aquatic ecosystems, it will be necessary to maintain structures that will eventually end up in the stream or river (Harmon et al. 2004).

11.6.4 Soil productivity

While California’s Forest Practice Rules already include provisions for the protection of soil productivity, it may be necessary to include recommendations about the retention of fine woody debris and the forest floor. Additionally, it may be important to address uprooting vegetation and stump harvesting as both of these practices are very disruptive to the soil profile and result in increased erosion potential (Walmsley and Godbold 2010). Following Maine’s, Minnesota’s, Missouri’s, and Wisconsin’s lead, guideline developers may choose to look at California soil types and identify nutrient poor and/or highly erosive soils that could be unsuitable for intensive biomass harvesting.

11.6.5 Silviculture

As the guideline development process begins in California, it will be important to consider how woody biomass harvests fit into the current Forest Practice Rules. It will be necessary to acknowledge the potential for woody biomass harvests to achieve a variety of silvicultural goals, including fire risk reduction and slash management. It will also be important to address the acceptable amounts of biomass harvest during salvage operations. California may find it necessary to develop guidelines that specifically address re-entry into harvested sites for the purpose of harvesting/collecting woody biomass. Multiple entries into a harvest area may result in cumulative site impacts associated with compaction, erosion, rutting, disturbance to retained structures and regeneration. Minnesota, Missouri, and Pennsylvania recommend against re-entry into harvested stands for the purpose of removing biomass (MFRC 2007a, Enyart 2008, PADCNR 2008).

Table 24 Summary of dead and downed wood retention targets from states with existing biomass harvesting guidelines

	Dead and Downed Wood	Citation
Maine	<ul style="list-style-type: none"> • Retain as many snags as possible • Retain as much pre-existing FWD and CWD as possible • Retain litter layer, stumps, roots intact as much as possible 	Benjamin 2010; Flatebo et al. 1999; Elliot 2008
Missouri	<ul style="list-style-type: none"> • Retain a minimum of 33% of the harvest residue • Retain as much FWD as possible • Retain woody debris from multiple tree species and size classes, with an emphasis on larger structures • Avoid removing all CWD • Retain 6-12 snags, depending upon vegetation type 	Enyart 2008
Minnesota	<ul style="list-style-type: none"> • Retain the forest floor, litter layer, root systems, stumps • Retain as much pre-existing CWD/FWD and logs as possible • Retain all snags when possible, if cut leave on site • Retain approximately 30% of harvest residue (leave 20% of harvest residue with 10-15% additional FWD coming from incidental breakage) 	MFRC 2007
Michigan	<ul style="list-style-type: none"> • Retain approximately 17-33% of the harvest residues (tops, limbs less than 4' diameter) • Retain more debris in stands with little woody debris prior to harvest • Retain as much pre-existing CWD as possible • Avoid removal of the forest floor, litter layer, stumps and roots. 	MI DNRE 2010
Pennsylvania	<ul style="list-style-type: none"> • Retain 15-30% of harvest residues • Retain slash during conventional timber harvests • Retain 2-5 non-merchantable logs per acre • Retain 1-5 snags per acre 	PA DCNR 2008
Wisconsin	<ul style="list-style-type: none"> • Retain and limit disturbance to pre-existing CWD/FWD • Retain 10% of harvest residues (tops and limbs <4" diameter), an additional 10-15% FWD is expected from incidental breakage 	Herrick et al. 2009

	<ul style="list-style-type: none"> • Do not remove the forest litter layer, stumps, and/or root systems • Retain snags based on guidelines found in WI DNR Silviculture Handbook, chapter 24 • The ultimate goal is to maintain 5 or more oven dry tons of FWD per harvested acre 	
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Table 25 Summary of wildlife and biodiversity retention targets from states with existing biomass harvesting guidelines

	Wildlife and Biodiversity	Citation
Maine	<ul style="list-style-type: none"> • Refer to Biodiversity and the Forests of Maine: Guidelines of Land Management for general stand-level recommendations and specific guidelines for special habitat areas • Retain as much dead wood as possible (FWD/CWD/logs, snags) • Retain some green wildlife trees (trees with cavities and rot) • Retain some mast-producing trees (hardwood species) • Retain biological legacies in clumps and buffers 	Benjamin 2010; Flatebo et al. 1999; Elliot 2008
Missouri	<ul style="list-style-type: none"> • Avoid harvests in High Conservation Value Forests (HCVF) • Retain mast producing trees of various species and size classes • Retain 7-25 den trees and 6-12 snags per acre • Avoid “hard edges,” by creating a gradual transition into harvested areas • Consider creating travel corridors in large harvests (40 acres +) 	Enyart 2008
Minnesota	<ul style="list-style-type: none"> • Review existing leave tree and snag retention guidelines (in MI <i>General Guidelines and Timber Harvesting</i>) • Retain 20% of shrubs and small trees, cut and left on site • Retain all snags possible; avoid harvest activity in leave tree clumps • Avoid biomass harvests within sites where endangered or threatened plant or animal species are known to exist • Retain slash piles that show evidence of use by wildlife 	MFRC 2007
Michigan	<ul style="list-style-type: none"> • Avoid/limit biomass harvesting in areas of high conservation value/sensitive sites • Avoid biomass harvesting near state and federally listed threatened, endangered, or species of greatest conservation need • Retain CWD and snags from various size and decay classes, and tree species • Refer to Within-Stand Retention Guidance (IC 4110) for more information about wildlife habitat retention 	MI DNRE 2010
Pennsylvania	<ul style="list-style-type: none"> • Protect sensitive habitats (springs, vernal pool/ponds, riparian zones, cliffs, caves) • Protect cavity trees, snags, and food-producing shrubs and vines • Develop specific management plans for unique areas • Avoid disturbing endangered, threatened or rare species, practices should protect and enhance habitat 	PA DCNR 2008

Wisconsin	<ul style="list-style-type: none"> • Refer to WI DNR Silviculture Handbook for specific recommendations and quantitative guidelines for the retention of reserve trees, wildlife trees, and snags • Retain a variety of mast producing trees and shrubs • Do not harvest from sites where federal or state endangered or threatened species are known to exist or are discovered • Protect High Conservation Value Forests (HCVF), sensitive ecosystems, and species of greatest conservation need 	Herrick et al. 2009
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Table 26 Summary of water quality protection measures from states with existing biomass harvesting guidelines

	Water Quality and Riparian Management Zones	Citation
Maine	<ul style="list-style-type: none"> • Refer to the existing <i>Water Quality BMP Manual</i> for specific recommendations about water quality protection • Minimize disturbance to forest floor • Woody biomass may be used to control water flow, prevent soil erosion, and/or stabilize exposed soil; these structures may be left in place after harvest 	Benjamin 2010; Flatebo et al. 1999; Elliot 2008
Missouri	<ul style="list-style-type: none"> • Refer to the <i>Missouri Watershed Protection Practice</i> booklet • Streamside management zones, of at least 50 feet in width, should be used on all perennial and intermittent streams • Retain at least 33% of trees in the stream management zone (SMZ), 40 sq.ft. of basal area • Avoid use of heavy equipment, cable yard if necessary • Retain most of the vegetation within the SMZ 	Enyart 2008
Minnesota	<ul style="list-style-type: none"> • Refer to <i>2005 MFRC General Guidelines and the Voluntary Site-Level Forest Management Guidelines</i> for specifics on maintaining water quality through the use of filter strips and water diversion, and protection of wetlands. • Avoid removing biomass from riparian management zones or within 25ft of a dry wash (some roundwood harvesting is acceptable following existing guidelines) • Install temporary erosion control devices 	MFRC 2007
Michigan	<ul style="list-style-type: none"> • Refer to the 2009 Sustainable Soil and Water Quality Practices on Forest Land Manual (IC 4011) for specific recommendations about harvest activities and mitigation practices in riparian management zones, stream crossings, wetlands. • Michigan's <i>Woody Biomass Harvesting Guidance</i> does not specifically address water quality protection measures related to woody biomass harvests 	MI DNRE 2010
Pennsylvania	<ul style="list-style-type: none"> • Comply with all provisions of Chapter 102 and Chapter 105 of the Clean Streams law and Dam Safety and Encroachments Act • PA DCNR's guidelines include a general discussion of stream crossings and road, skid trail, and landing design/placement. • Riparian buffers should provide adequate protection; avoid contaminating water courses/bodies with soil, chemicals, and/or petroleum • Operations should occur when soils are dry or frozen 	PA DCNR 2008

Wisconsin	<ul style="list-style-type: none"> • Refer to WI DNR Best Management Practices (BMPs) for Water Quality. • Wisconsin's <i>Forestland Woody Biomass Harvesting Guidelines</i> do not specifically address water quality protection measures related to woody biomass harvests 	Herrick et al. 2009
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Table 27 Summary of soil productivity protection measures from states with existing biomass harvesting guidelines

	Soil Productivity	Citation
Maine	<ul style="list-style-type: none"> • Retain the litter layer, stumps and roots as intact as possible, except where necessary during site preparation • Retain as many tops and branches as possible on low fertility sites, sallow soils, coarse sandy soils, poorly drained soils, steep slopes, and other erosion-prone sites 	Benjamin 2010; Flatebo et al. 1999; Elliot 2008
Missouri	<ul style="list-style-type: none"> • Lengthening rotations and/or using uneven-aged management will encourage soil fertility • Retain a minimum of 33% of the harvest residue • Avoid skidding on shallow soils and steep slopes • Avoid grazing recently harvested areas 	Enyart 2008
Minnesota	<ul style="list-style-type: none"> • Refer to <i>2005 MFRC General Guidelines and the Voluntary Site-Level Forest Management Guidelines</i> for specifics related to soil productivity • Avoid biomass harvesting on ombrotrophic, organic soils deeper than 24 inches; aspen/hardwood cover types on shallow soils (8 inches or less to bedrock) • Do not remove the forest floor, litter layer, and/or root system • Roads, skid trails, and landings should occupy no more than 1-3% of the site • Avoid additional biomass harvests from erosion-prone sites; install erosion control devices • For shallow soils and droughty sands, consider retaining 33% or more of the FWD post-harvest 	MFRC 2007
Michigan	<ul style="list-style-type: none"> • Refer to the 2009 Sustainable Soil and Water Quality Practices on Forest Land Manual (IC 4011) for specific guidelines related to maintenance of soil productivity • On shallow, nutrient poor soils, consider leaving additional residue (more than 33%) 	MI DNRE 2010
Pennsylvania	<ul style="list-style-type: none"> • Minimize soil compaction and rutting by matching operating techniques and season of operation to soil types and moisture levels • Minimize the soil disturbance through careful design and placement of landings, roads, and skid trails • Do not contaminate soils with equipment fuels or chemicals 	PA DCNR 2008
Wisconsin	<ul style="list-style-type: none"> • Do not harvest FWD on shallow soils (bedrock within 20 inches of surface) • Do not harvest FWD on dry, nutrient-poor, sandy soils • Do not harvest FWD on soils classified as dysic Histosols (wetland soils with 16 inches organic material, nutrient-poor and low pH). 	Herrick et al. 2009

	<ul style="list-style-type: none"> • Retain the forest litter layer, forest floor, stumps, and/or root systems 	
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Table 28 Summary of silvicultural recommendations from states with existing biomass harvesting guidelines

	Silviculture	Citation
Maine	<ul style="list-style-type: none"> • Maine’s <i>Woody Biomass Retention Guidelines</i> do not include silvicultural recommendations related to woody biomass harvesting 	Benjamin 2010; Flatebo et al. 1999; Elliot 2008
Missouri	<ul style="list-style-type: none"> • Avoid damaging crop/leave trees • Avoid re-entering stands; biomass harvests should occur during sawlog harvests • Avoid high grading; specific recommendations about crop tree numbers and spacing are included • Avoid converting natural forests into plantations • Biomass harvests can be used as part of a salvage operation • Biomass harvests can be used to enhance aesthetics 	Enyart 2008
Minnesota	<ul style="list-style-type: none"> • Refer to <i>MFRC Timber Stand Improvement</i> for additional guidelines related to stand improvement activities • Refer to <i>MFRC General Guidelines</i> for recommendations about post operational activities • Avoid re-entering stands, especially if planting/regeneration treatments have occurred • Biomass harvests can be used to accomplish fuels reduction goals • Examples of how biomass harvests can help accomplish management objectives: avoided swamping, site preparation/regeneration, browse deterrent, bark beetle management, thinning 	MFRC 2007
Michigan	<ul style="list-style-type: none"> • Focus on the residual stand structure during intermediate harvests • Biomass harvests can be used to control/remove invasive or exotic plant species • Biomass harvests can be used to reduce hazard trees within recreational areas and fire risk • Biomass harvests can be used to achieve salvage and sanitation goals 	MI DNRE 2010
Pennsylvania	<ul style="list-style-type: none"> • Avoid high grading; focus on the residual stand structure • Avoid re-entering harvested stands • Biomass harvests can be used to accomplish salvage and sanitation goals • Avoid converting natural forests to short rotation woody crop plantations, appropriate SRWC practices are mentioned briefly • Guidelines address regeneration, residual stand conditions, aesthetics, as restoration treatments as they relate to woody biomass harvests 	PA DCNR 2008

Wisconsin	<ul style="list-style-type: none">• Biomass harvests can be used to achieve site preparation, invasive/exotic plant removal, fuel reduction treatments, and restoration goals• Biomass harvests can be used during salvage and sanitation operations; 5% of the area should be left unsalvaged	Herrick et al. 2009
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CHAPTER 12:

Woody Biomass and Sustainable Forest Management Certification Systems

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12.1 Introduction

As various states and countries have been developing individual guidelines, there has been an international movement to develop principle, criteria, and indicator based sustainability certification systems for biomass production and utilization. While voluntary or mandatory state biomass harvests guidelines encourage the use of sustainable practices during biomass harvests, they do not offer third-party certification that such practices are implemented. The following section provides an introduction to the major sustainable forest management certification systems and discusses if and how they address woody biomass harvests. Also included in this section is a brief review of two sustainable biomass crop certification systems: Roundtable on Sustainable Biofuel (RSB) and Council on Sustainable Biomass Production (CSBP). The work of international biomass and bioenergy organizations, such as the IEA Bioenergy, is also reviewed.

12.2 Sustainable forest management (SFM) certification systems

Currently there are no sustainable biomass production certification systems for forest, woodland, or shrubland ecosystems. It can be informative to review how, if at all, existing forest management certification systems have addressed sustainability concerns related to the harvest of logging residues and non-merchantable woody biomass removals for bioenergy production. Since the early 1980's a number of different sustainable forest management certification systems have emerged worldwide. While the specifics of each certification system are varied, there are few major similarities: 1) all systems seek to achieve the same objective of sustainable forest management, 2) all certification systems require participating organizations to meet the a set of sustainability standards and pass an audit by an accredited third-party certifying body, 3) all systems recognize issues associated with environmental, social, and economic sustainability, and 4) many systems comply with International Standards Organization (ISO) rules for standard-setting and third party verification. The major forest certification systems present in North America include Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), Sustainable Forestry Initiative (SFI), Canadian Standards Association (CSA), American Tree Farm System/American Forest Foundation (ATFS/AFF).

12.2.1 International SFM umbrella certification systems

There are two main umbrella forest certification organizations: Forest Stewardship Council International (FSC-IC) and Programme for the Endorsement of Forest Certification International (PEFC). Both organizations review and endorse national certification standards that meet their sustainability standards. These organizations require national standards to be developed

through an open and transparent process with broad stakeholder involvement and consensus. Both certification schemes depend upon credible third-party assessments of forest practices benchmarked to a pre-determined set of standards. In order for a national standard to be endorsed by either FSC-IC or PEFC, it must include principles, criteria and indicators that encompass a full range of forest sustainability concerns: environmental, economic, and social.

12.2.2 Forest Stewardship Council (FSC) International (<http://www.fsc.org/about-fsc.html>)

FSC International is an independent, non-governmental, non-profit organization that was established to promote sustainable forest management. Organizations seeking FSC certification must comply with the FSC-IC developed standards and procedures. The standard-setting process begins within the FSC-IC organization but is meant to be transparent and inclusive of interested stakeholder groups. The FSC-IC Principles and Criteria form the basis of all national level FSC standards. These 10 principles and 56 criteria describe the rules for how forests are to be managed sustainably for social, economic, and environmental values. For the first time, FSC-IC is conducting a full review of the Principles and Criteria. Any changes that result from this review will directly impact the FSC-US national indicators and the 9 regional standards in use by FSC accredited forests in the United States. The FSC-IC requires that national and regional standards are reviewed at least every 5 years, and the FSC-US is concluding this process. (Council_on_sustainable_biomass_production(CSBP), 2009) FSC-IC offers accreditation of sustainable forest management standards, chain of custody standards, and certifier organizations.

12.2.3 Programme for the Endorsement of Forest Certification (PEFC) schemes (<http://www.pefc.org/>)

PEFC is the world's largest forest management and chain of custody certification system, with about 560 million acres managed in compliance with the PEFC's Sustainability Benchmark. Similar to FSC-IC, PEFC endorses national certification systems that are developed independently and prove compliance with the PEFC's Sustainability Benchmarks. The PEFC's Sustainability Benchmarks consist of globally recognized principles, guidelines and criteria that were developed by a multi-stakeholder process requiring engagement and consensus from international and inter-governmental bodies as well as other interested parties. Unlike FSC-IC, PEFC does not develop these standards directly. The PEFC Sustainability Benchmark consists of over 300 globally accepted criteria and is the basis against which all national certification systems are assessed during PEFC endorsement. In addition to criteria about biodiversity, ecosystem services, and workers rights, the PEFC Sustainability Benchmark requires national level standards to be developed following a specific multi-stakeholder process that ensures forest sustainability concerns are addressed at regionally appropriate levels. Each PEFC endorsed national standard must undergo a multi-stakeholder review every five years. PEFC offers certification of forest management practices as well as a chain of custody certification. Three major North American certification programs are PEFC endorsed: Sustainable Forestry Initiative (SFI), American Tree Farm System/American Forest Foundation (ATFS/AFF), and Canadian Standards Association-National Sustainable Forest Management System (CAN/CSA-Z809).

12.3 Sustainable forest management (SFM) certification systems on public and private lands in the United States

In the United States, certification was first applied to private, industrial forestlands as a way to publicly demonstrate a commitment to sustainable forest management and produce a certified wood product. As of 2007, the amount of forestland certified under a SFM system in the United States was only 13% (Pampush 2008). The majority of certified forestland is in private, industrial ownerships. Non-industrial family forests and public lands remain largely uncertified (Pampush 2008).

Several state forest systems in the US have pursued certification, including Pennsylvania, Wisconsin, New York, Maine, Indiana, and Washington. Many of these states are certified under both SFI and FSC. Because public land management is very different from industrial forest management, SFI and FSC have specific requirements for public lands seeking certification (SFI 2010, FSC-US 2003). There is more emphasis on public involvement and resource planning during the auditing process of public lands (Sample et al. 2007). SFM certification of public lands is often less about producing a certified wood product, and more associated with demonstrating commitment to ecological, social and economic values (Hansen et al. 2006, Sample et al. 2007).

The question of whether or not the USDA Forest Service should seek certification for National Forest System (NFS) lands has been debated for several years and remains unresolved. The issues associated with certifying NFS lands are complex. While the Forest Service encourages responsible forest management, they have not wanted to endorse, or be perceived to endorse, any particular certification program (Sample et al. 2007). In 2005, the Forest Service joined with the Pinchot Institute to explore the potential benefits and costs of NFS certification (Sample et al. 2007). Auditors conducted third-party assessments of five national forests to determine how well Forest Service management aligns with the SFI and FSC certification system requirements. While actual certification by FSC or SFI was not a goal or possible outcome of this study, the evaluations were designed to simulate the auditing process (Sample et al. 2007). Participating national forests met or exceeded many of the requirements of SFI and FSC, especially in the areas of resource planning and public engagement (Sample et al. 2007). There were several major non-conformances that were common to most forests, including: 1) inadequate road maintenance and decommissioning, 2) inadequate monitoring of non-timber forest products and wildlife, 3) unaddressed forest health issues related to a backlog in vegetation management, 4) old-growth protecting and management issues, and 5) inadequate monitoring and compliance with worker safety requirements and training (Sample et al. 2007). Compared to private firms that have been certified under FSC or SFI, the Forest Service has a much lower ratio of revenue per acre and is less able to cover all the necessary costs associated with either certification system.

The SFI 2010-2014 Standard includes specific requirements for public land management organizations seeking certification, found under Objective 18 (SFI 2010). In addition to the FSC Principles and Criteria, National Indicators and Regional Standards, FSC-US has a Federal Lands Policy that consists of three sets of threshold standards that have to be met before

certification audits can proceed on any federal ownership in the U.S (FSC-US 2003). The first threshold is willing landowner participation in the certification process (FSC-US 2003). The second threshold makes certification of NFS lands difficult as it demands public consensus about timber harvesting and other major resource management practices on forestlands (FSC-US 2003). The USDA Forest Service is required to manage NFS lands for a wide range of services and benefits including watershed protection, recreation, timber production, and the protection of rare and endangered species and habitats. FSC-US acknowledges there is a lack of consensus about the appropriate management approach on federal lands and USDA Forest Service lands in particular (FSC-US 2003). FSC-US will determine if/when there is sufficient public consensus necessary for certification (FSC-US 2003). Once the first two threshold are met for a given federal ownership type (e.g. U.S. Department of Defense), specific national indicators for that ownership type will be developed by the FSC-US with opportunities for regional and national stakeholder input (FSC-US 2003). Currently the U.S. Department of Defense and the U.S. Department of Energy are the only federal ownership types that have developed FSC-US national standards.

12.4 North American SFM certification systems and woody biomass harvesting

Sustainable forest management certification systems were initially developed to address growing international concern about deforestation in the tropics. Over the last two decades, certification systems have been developed for and applied in temperate and boreal forest types. Since these SFM certification systems were developed to certify a wide range of forest cover types, ownerships and harvest treatments and objectives, their standards do not contain guidelines specific to the harvest of woody biomass for bioenergy. Instead, it is expected that this new forest management activity will be executed in line with the existing standards. All SFM certification systems have standards pertaining to the maintenance of ecosystem functions. Often these standards explicitly require the retention of understory vegetation, den and cavity trees and snags, and dead and downed wood for wildlife habitat, biodiversity, and soil nutrient cycling goals. Woody biomass harvests on SFM certified lands would have to maintain some structures on the landscape. The level of retention that is appropriate and necessary is not explicitly addressed in SFM certification standards, as it will vary with site and region specific ecological factors. Many of these certification systems can be considered outcome focused, as they do not dictate the specifics how forests should be managed or harvested. Instead, a variety of management approaches can be used while still meeting the certification standards.

The following is an analysis of the major SFM certification systems in North America as they relate to woody biomass harvest:

12.4.1 Sustainable Forestry Initiative (PEFC endorsed)

<http://www.sfiprogram.org/sfi-standard/sfi-standard.php>

SFI just completed the review and adoption of its new 2010-2014 Standards that are organized around 14 core principles of sustainable forest management. These principles are made operational through the 20 objectives, 39 performance measures and 114 indicators that address

the specific requirements/practices necessary to achieve and maintain SFI certification. SFI is endorsed by PEFC, and this new 2010-2014 Standard will be submitted for review to PEFC International. While woody biomass harvests are not explicitly addressed, the new 2010-2014 Standard contains language that supports bioenergy feedstock development.

Objective 1 of the 2010-2014 Standard requires program participants to draft forest management plans that ensure long-term forest productivity and yield, as well as other non-timber forest products, such as *bioenergy feedstock production* (1.1.1.h, SFI 2010). As with all sustainable forest management certification systems, SFI requires program participants to insure their forest management practices protect and maintain forest and soil productivity. The correct use of erosion control measures is important, as well as creating post-harvest conditions that are conducive to maintaining productivity. In particular, the SFI Standard mentions scientifically informed retention of down woody debris and vigorous trees to meet productivity goals (2.3, SFI 2010).

The SFI 2010-2014 Standard includes specific objectives about the maintenance of wildlife habitat and biological diversity. Participants are expected to implement stand- and landscape-level measures that promote a diversity of habitat types, successional stages, and the conservation of forest wildlife (terrestrial and aquatic flora and fauna). In particular, the SFI Standard requires participants to develop and implement criteria, guided by regionally appropriate scientific information, to retain stand-level wildlife habitat elements such as snags, stumps, mast trees, down woody debris, and den and nest trees (4.1.4, SFI 2010).

The SFI 2010-2014 Standard also includes a section on minimizing waste and ensuring efficient utilization of forest products consistent with other SFI Standard objectives (Objective 7, SFI 2010). It is in this section that woody biomass harvests for bioenergy production are addressed most directly. Participants must consider the economic, social and environmental concerns (nutrient values, fire hazard) associated with management and utilization of harvest residues (7.1.1.a, SFI 2010). Additionally, participants should explore alternative markets for underutilized species and low-grade wood, such as bioenergy markets (7.1.1.d, SFI 2010).

The SFI Standard also includes a forestry research, science, and technology objective in which participants are expected to support forest research to improve forest health, productivity and sustainable management of forest resources, and the environmental benefits and performances of forest products. The ecological impacts of bioenergy feedstock removals on productivity, wildlife habitat, water quality and other ecosystem functions is just one of the many topics identified in the SFI Standard (15.1.1.f, SFI 2010).

12.4.2 American Tree Farm System/American Forest Foundation (PEFC endorsed) (http://www.treefarmssystem.org/cms/pages/26_19.html)

The American Tree Farm System (ATFS) is a program of the American Forest Foundation's Center for Family Forests and is the world's oldest sustainable forestry certification program. Currently, ATFS has certified 24 million acres of privately owned forestland in 46 States. In comparison to other SFM certification systems, ATFS is structured to meet the needs of small forestland owners seeking certification. ATFS has established standards and guidelines based

on the American Forest Foundation's Standards of Sustainability for Forest Certification. Property owners must meet these standards in order to become a Certified Tree Farm, including the development of a management plan and an inspection by an ATFS volunteer forester every five years.

ATFS certification requires landowners to develop a written management plan that addresses the management objectives, desired forest conditions, and proposed activities. It is suggested landowners consider, describe and evaluate the biomass and carbon resources on their lands. These plans must address forest health, soil, water, wood and fiber production, threatened and endangered species, special sites, invasive species, integrated pest management and high conservation value forests (1.1.2, ATFS 2009).

It is important that ATFS participants follow all relevant federal, state and local laws, regulations and ordinances, which would include the California Forest Practice Rules. The rules related to air, water and soil protection in the ATFS Standard require forest owners to meet or exceed practices prescribed in State Forestry Best Management Practices (BMPs) (4, ATFS 2009). While the conservation of fish, wildlife and biodiversity on forestlands are important components of the ATFS system, there are no biomass retention guidelines in the Standards document. Instead forest owners are expected to work with local natural resource agencies to identify and conserve threatened or endangered habitats and species (ATFS 2009). ATFS participants are expected to protect and manage for sites that demonstrate unique historical, archeological, cultural, geological, biological or ecological value (7, special sites, ATFS 2009). Forest harvest activities, including woody biomass harvests for bioenergy, should be implemented carefully or avoided in these special areas. ATFS participants located in states with mandatory woody biomass harvest guidelines are expected to comply with these rules (ATFS 2009).

12.4.3 Canadian Standards Association (CSA Z809 SFM Standard) (PEFC endorsed) (http://www.csa-international.org/product_areas/forest_products_marking/Default.asp?language=english)

The Canadian Standards Association (CSA) is a non-profit organization that focuses on the development of standards and certifications for a wide range of products and activities. In 1994, a multi-stakeholder volunteer technical committee was developed with representatives from four major stakeholder groups, professional/academia, general interest, government, and industry, for the purpose of developing a Sustainable Forest Management standard for Canada. After a public review process the draft Standard is sent to the independent Standards Council of Canada for final approval. As of June 2007, about 59% of certified Canadian forests had been certified under the CSA Z809 SFM standard.

The CSA Z809 consists of six criteria and 14 elements and core indicators adopted from the criteria for sustainable forest management developed by the Canadian Council of Forest Ministers. The CSA Standard conforms to ISO standards for environmental management systems and standard setting. Like other SFM certification systems, the CSA Standard includes requirements for management plans, commitment to CSA Z809 and SFM, public participation,

performance measures and targets, independent third-party audits, and monitoring and improvement (CSA Z809 2008). Additional certifications available in Canada include the internationally recognized PEFC Annex 4 for a chain of custody certification for forest based products and CSA Z804-08 for SFM on woodlots and small area forests (CSA Z809 2008).

The conservation of biological diversity by maintaining integrity, function, and diversity of living organisms and their habitats makes up the first criterion of the CSA Z809 Standard. The elements and indicators of this criterion address the importance of retaining structures on the landscape, using the range of natural variation and disturbance patterns to inform management, and protecting habitats for all native wildlife species. Dead and downed wood is identified as a habitat element that is particularly important for the maintenance of wildlife habitat and biodiversity (CSA Z809 2008). Management of protected areas or areas of special biological or cultural values must be carefully considered, and may not be appropriate for most forest operations.

The second criterion deals with maintaining ecosystem condition and productivity and requires public discussion of biomass utilization opportunities and concerns (CSA Z809 2008). The appropriateness of salvage logging and biomass retention, following forest disturbances such as blow downs, disease/insect mortality or wildfire must be part of the public discussion (CSA Z809 2008). A.6.3.2.4 suggests that an organization that intends to remove woody biomass for energy or other purposes should develop clear operational guidelines for the sustainable removal of biomass from forests (CSA Z809 2008).

Criterion three addresses the conservation of soil and water resources and mentions retention of downed woody debris as an indicator of sustainable soil management practices (3.1.2, CSA Z809 2008). Woody debris should be managed by leaving both dead and live trees, as well as logs and stumps during forest harvests (CSA Z809 2008). Participating forestland owners need to consider the economic and social benefits of timber and non-timber goods and services coming off their lands and the ways in which management can contribute to the sustainability of local communities (Criterion 5, CSA Z809 2008).

12.4.4 Forest Stewardship Council- United States, Pacific FSC International endorsed) (http://fscus.org/standards_criteria/index.php)

In the United States there are nine regional standards that have been developed based on the FSC-IC Principles and Criteria. In an attempt to capture the regional variation in forest types and management regimes, each regional standard has a unique set of indicators that are used to assess the sustainability of forest management operations. The FSC-US is required by FSC International to review its regional standards every five years. The most recent review recommended that the FSC-US adopt a single National Standard that incorporates regional variations, "notes of intent" for clarification on what each standard is meant to achieve, and the development of specific family forest standards (small and low-intensively managed forests, "SLIMF" policy). The reviewers indicate that a single National Standard would improve interpretation, auditability, implementation and consistency in FSC-US certification across the United States.

In November 2009, FSC-US sent its final draft of a National Forest Management Standard to FSC-International for final approval. While final approval of the Draft 8.1 National Standard by FSC-IC is expected at any time, the nine FSC-UC regional standards currently determine compliance and certification. Both the Draft 8.1 National Standard and the Pacific Coast regional standard are structured around ten core principles that address compliance with laws, social and economic responsibility, benefits and services from the forest, environmental impact, management plans, monitoring and assessment. There are many similarities between the two standards as they both use the same Principles and very similar criteria. The Draft 8.1 Standard offers more explanation of each criteria and indicator, including discussions of intent and implementation. Substantial revision to Principle 6 and its criteria and indicators in the Draft 8.1 Standard has resulted in a clearer presentation of the rules, their intent and guidance for meeting the standards as compared to the current Pacific Coast standard. The following is a discussion of the proposed FSC-US Draft 8.1 Standard, as it relates to woody biomass harvests.

Principle 5 concerns benefits derived from the forest and encourages efficient use of a forest's multiple products and services, including commercially harvested non-timber forest products (NTFP, i.e. woody biomass for bioenergy) (FSC-US Draft 2009). FSC-US Draft 8.1 requires forest management activities to be economical viable, taking into account the full environmental and social costs of the operation. Measures should be in place to optimize the use of harvested forest products, including the exploration of product diversification where appropriate and consistent with management objectives and FSC principles and criteria (5.2.b FSC-US Draft 2009). Additionally, forest management should minimize the loss and/or waste associated with harvesting and on-site processing operations. "Waste" consists of damage or underutilization of harvested products, except when slash is left on site to maintain woody debris, nutrient cycling, and other ecological functions (C5.3, 5.3.a FSC-US Draft 2009). Forest management should strive to diversify economic uses of timber and non-timber forest products and services. This includes evaluating existing and emerging markets for non-timber forest products, such as woody biomass for energy (5.4.a FSC-US Draft 2009). The rate of harvest of forest products (NTFPs including woody biomass) cannot exceed the sustained yield harvest level calculated for a particular harvest unit. The calculation of the SY harvest level must consider the effects of repeated harvests, across multiple rotations or entry periods (C5.6, 5.6.a FSC-UC Draft 2009).

FSC-US Draft 8.1 Standards seek to maintain the ecological functions and integrity of the forest by conserving biodiversity, water and soil resources, and unique ecosystems and landscapes (principle 6, FSC-US Draft 2009). Assessments of the potential environmental impacts at both the site- and landscape-level must be completed using best available scientific information prior to any forest operation, including harvests of NTFPs. Based upon the findings of the assessment, measures should be developed and implemented that avoid or minimize the potential impacts identified (C6.1, 6.1.b, 6.1.c FSC-US Draft 2009). Criteria 6.3 attempts to address a full range of biodiversity conservation concerns using eleven landscape- and stand/site-level indicators. There are no indicators that are specific to biomass harvests or whole tree harvesting within this criterion. Instead, these harvests are assumed to be addressed in the discussion of other types of removals. These indicators include rules about maintaining diverse wildlife habitats, vertical/horizontal structures, viable wildlife populations, riparian

zones, native vegetation, etc. Woody biomass harvests must be conducted in such a way as to maintain adequate habitat for species associated with large and/or decaying trees and dead wood (6.3.f FSC-US Draft 2009). Retention of live and dead vegetative structures is important for the maintained of biological diversity and required by FSC-US Draft 8.1 when even-aged systems and/or salvage harvests are used (6.3.g.1 FSC-US Draft 2009). Indicator 6.3.g.1.a requires that 10-30% of pre-harvest basal area is retained within harvest openings larger than 6 acres. Regeneration harvest blocks in even-aged stands must be no larger than 60 acres, with an average size of 40 acres or less (FSC-US Draft 2009). FSC-US Draft 8.1 Standard includes the following dead and downed wood retention guidelines for even-aged systems in the Pacific Coast region: 1) dry regions, about 10 tons of debris per acre may be sufficient, while in wetter areas 20 tons of debris may be more appropriate; 2) debris is to be well distributed spatial and by size class, with at least 4 large pieces per acre (20" in diameter by 15 feet in length); 3) snags are well represented by size, species and decay class, with three to ten snags per acre (averaged over 10 acres); and where necessary 4) vegetation is retained around these dead wood structures to maintain microclimate conditions (6.3.g.1.b, 6.3.g.1.c FSC-US Draft 2009).

In forest types that are fire-adapted and/or at risk of wildfire, fuels management practices should be developed and implemented (FSC-US Draft 2009). Since woody biomass harvest treatments effectively treat fuels, they may be appropriate management activities under this indicator (6.3.i FSC-US Draft 2009). The protection of soil and water resources during forest operations is addressed by indicator 6.5.c. This is identified as being a particularly important indicator during woody biomass and whole tree harvests. The amount and frequency of the removal of fine and coarse woody debris must not reduce soil productivity, function, and habitat. All decisions must be informed by research and objective data (6.5.c. FSC-US Draft 2009).

Riparian areas require specific protection and harvesting/management activities are limited with in stream management zones (SMZ). Conversions of natural forestlands to plantations or non-forest land uses are not allowed under the FSC-US Draft 8.1 Standard, except in very limited circumstances (C6.10, 6.10.a FSC-US Draft 2009). The development of woody biomass plantations in natural or semi-natural forest stands would not be allowed under the FSC-US Draft 8.1 Standard. Certification of plantations requires the compliance with Principles 1-9, found in the FSC-US Draft 8.1 and Principle 10 Draft 7.4. The Draft 7.4 includes rules about what constitutes a plantation, size limitations, adjacency and regeneration, biological legacy retention requirements, native species plantings, forest restoration, forest health, etc (FSC-US Draft 7.4 2009). Sufficient woody debris and other organic matter must be retained within plantations to ensure adequate soil structure and nutrient cycling (10.6.e. FSC-US Draft 7.4 2009). These rules would reduce the woody biomass available for harvest from plantations (FSC-US Draft 7.4 2009).

12.5 Biomass energy crop certification programs

The production of woody biomass is not limited to residues removed from natural forests, woodlands, and shrublands. There is increasing interest in using marginal agricultural lands (e.g. abandoned or marginal agricultural fields, former Conservation Reserve Program lands)

for the production of biomass from short rotation woody crop plantations. These biomass-for-energy plantations are not likely to seek or obtain sustainable forest management certification, even if forest tree species are being grown. Instead, there have been several biomass energy crop certification systems developed to address sustainability concerns with plantations and purpose grown bioenergy crops.

While some of the sustainability issues associated with biomass-for-energy plantations are similar to those associated with forest management, such as the maintenance of soil and water resources, there are other concerns that are particular to purpose grown bioenergy crops. A major sustainability issue, never addressed in SFM certification programs, is food security and the conversion from food crops to bioenergy crops on cultivated lands.

12.5.1 Roundtable on Sustainable Biofuels (RSB)

(<http://cgse.epfl.ch/page84341.html>)

In November 2009, after three years of global stakeholder discussions, the Roundtable on Sustainable Biofuels released the RSB Principles & Criteria for Sustainable Biofuels (RSB-STD-20-001), an international standard for sustainable production and processing of biofuels. Version One of the RSB standard includes the Principles and Criteria, a guidance document, compliance indicators. The standard seeks to certify sustainable biofuel operations along the entire supply chain and identifies four types of operators subject to different requirements: feedstock producers, feedstock processors, biofuel producers, and blenders. It is expected that the RSB standard will become fully operational in 2010, and begin to offer certification of biofuel production and processing.

The RSB standard includes twelve principles that address sustainability issues associated with legality, planning and monitoring, social responsibility, greenhouse gas emissions, food security, biodiversity conservation and environmental impacts, use of technology, and waste management. While there are some similarities between the RSB Standard and sustainable forest management certification systems, the requirements for greenhouse gas emission accounting and maintenance of food security are unique to biofuel certification. Lifecycle greenhouse gas emissions of both the feedstock and biofuel must be calculated using the RSB lifecycle GHG emission methodology, and demonstrate a significant reduction in GHG emissions as compared to fossil fuels (principle 3, RSB 2009). Participants are required to complete environmental and social impact assessments (ESIAs) and identify if biofuel production would negatively impact land, water, labor and infrastructure resources needed for local food security (principle 6, RSB 2009).

Areas such as natural habitats and riparian zones that have been identified as containing conservation values can not be converted to biofuel production, unless management practices maintain or enhance the conservation value (principle 7, RSB 2009). Ecological corridors and riparian buffer zones should be established in order to maintain water quality and habitat connectivity (7.c, 7.d, RSB 2009). Plant species used in the production of biofuel cannot be highly invasive. Management plans must include monitoring systems that check for plant

establishment and mitigation actions (eradication, containment, or management) in case of establishment beyond the operations boundaries (7.e, RSB 2009).

Soil productivity, function and structure must not be degraded by biofuel crop production (principle 8, RSB 2009). Similar to statements found in SFM certification standards, the RSB standard specifically prohibits the use of forestry (and agricultural) residues from feedstock production that results in long-term degradations to soil productivity and structure (8.a.1, RSB 2009). Impacts to water quality and availability resulting from biofuel operations must be considered in the ESIA process. Biofuel operations must be water efficient and employ recycling systems that limit demands from local water resources (9.b, RSB 2009). Principle 10 requires producers and processors along the supply chain to minimize their air pollution emissions from biofuel operations.

12.5.2 Council on Sustainable Biomass Production (CSBP)

(<http://www.csbp.org>)

In 2007 the Council on Sustainable Biomass Production (CSBP) was established to develop a voluntary standard that would provide guidance on and certification of sustainable biomass and bioenergy production. Managed by the Meridian Institute and Heissenbuttel Natural Resources Consulting, CSBP hopes to establish itself as an independent, non-profit corporation sometime in 2010. The Council's membership consists of biomass production and bioenergy companies, environmental groups, and representatives from academia. The USDA FS and Agricultural Research Service provide technical support, as well as the US EPA and US DoE. In 2009, CSBP published a draft standard for Sustainable Biomass Production, which is currently going through public comment and revision. CSBP hopes to have a finalized standard for Sustainable Bioenergy Production, including both biomass production and biofuel/biopower production by December 2012.

CSBP intends to consult with existing SFM certification systems (SFI, FSC-US, ATFS, and PEFC) to see how well the CSBP Standard aligns with these programs, and identify any significant gaps between the programs. If there is consistency between the CSBP standard and existing programs, CSBP would like to develop some mechanism that would allow those certified under SFM programs to associate their products with CSBP, and those certified by CSBP to associate their products with SFM certification systems. Those certified under existing SFM programs are concerned that dual certification under both SFM and CSBP standards would be redundant and cost prohibitive. CSBP is working to make sure their Standards are science based, focused on sustainable biomass production and harmonized with the international RSB Principles & Criteria for Sustainable Biofuels.

The Draft CSBP Sustainable Biomass Production Standard is organized around nine core principles. These principles are similar to those found in the RSB Principles & Criteria for Sustainable Biofuels and other SFM certification programs and include: water, soil, biodiversity, socio-economic wellbeing, greenhouse gas emissions, continuous adaptation of standards as new science emerges, and planning and monitoring (CSBP Draft 2009). The Draft CSBP Sustainable Biomass Production Standard offers two levels of certification: Silver and Gold.

Both certifications require participants to undergo a third-party audit and meet the rules established by the principles, criteria and indicators of the CSBP Standard. Participants certified at the Gold level use production practices that significantly enhance environmental and socio-economic conditions beyond the baseline standards established by the Silver-level.

12.6 European and international efforts concerning biomass certification

There are many international organizations and initiatives that are working to advance sustainable bioenergy as part of the solution to growing global energy demands and climate change. The Food and Agriculture Organization (FAO) of the United Nations runs the Sustainable Wood Energy Systems (SWES) program that works to strengthen international capacity to produce sustainable wood energy while mitigating climate change (FAO-SWES 2009). The Bioenergy and Food Security Criteria and Indicators (BEFSCI) project, funded by FAO, aims to develop principles, criteria and indicators for sustainable bioenergy production that maintains food security (BEFSCI 2010). A preliminary review of seventeen existing bioenergy and food security initiatives was completed and includes regulatory frameworks, voluntary standards/certification schemes, and scorecards (BEFSCI 2010). FAO released the International Bioenergy Platform (IBEP) in 2006 as a mechanism for organizing sustainable bioenergy development across energy, agriculture and environment sectors. The IBEP is expected to provide expertise and advice for governments and private operators formulating bioenergy policies and strategies and facilitate international exchange and collaboration of bioenergy research, development and deployment (IBEP-FAO 2006).

Other international organizations addressing sustainable bioenergy production and use:

- Global Bioenergy Partnership (<http://www.globalbioenergy.org/>)
- European Commission: Directive on renewable energy and EU Biomass Action Plan (http://ec.europa.eu/energy/renewables/bioenergy/national_biomass_action_plans_en.htm)
- International Energy Agency (IEA) and IEA Bioenergy (<http://www.ieabioenergy.com/>)

12.6.1 IEA Bioenergy

(<http://www.ieabioenergy.com/Index.aspx>)

The International Energy Agency (IEA) was established during the oil crisis of 1973-74 and acts as an energy policy advisor to 28 Member Countries and the European Commission. As the energy markets have evolved, the IEA has become less focused on a sustained oil supply and more concerned with alternative energy technologies, market reform, and climate change. IEA is mandated with developing energy policy that insures energy security, economic development, and environmental protection. In 1978, the IEA created IEA Bioenergy, an international organization charged with improving cooperation and information exchange between 22 member countries with national bioenergy research, development and use programs. National experts from research institutions, government, and industry work

together with experts from other member countries on a variety of Tasks including research and development of biomass resources, supply systems, conversion technologies, end products and sustainability guidelines and standards.

The IEA Bioenergy Member Countries are currently working on 12 diverse Tasks, the results of which will be informative during the development of California's biomass-for-energy market. Each Task produces multiple deliverables including reports, technical presentations, workshops, and publications. Additionally, each Member Country participating in the Task produces a country report that summarizes their national experience in relation to the Task objectives. Many of these resources are available on the IEA Bioenergy website and associated Task pages. Over 360 notes and publications from IEA Bioenergy can be accessed through the international journal of *Biomass and Bioenergy*. Tasks are not completed in isolation from each other; collaboration of experts working on different Tasks is common.

Task 40: Sustainable International Bioenergy Trade (Active)

The core objective of this Task is to support the development of a sustainable, international, bioenergy market through analysis of supply (local and global), biomass/bioenergy certification initiatives, trade/market/demand dynamics, transport and logistics, and outreach and dissemination (Faaij and Schouwenberg 2010). In 2010 a background document, *Initiative in the Field of Biomass and Bioenergy Certification*, was published and includes an overview and update on biomass and bioenergy certification initiatives and systems (van Dam 2010). This 330 page background document reviews over 70 different initiatives and certification systems from around the world and was used to inform the van Dam et al. (2010) paper, *From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning* (submitted to the Journal of Renewable and Sustainable Energy Reviews).

Task 30 and Task 31: Biomass for forestry (Completed)

Two recently completed Tasks are especially relevant to the discussion of biomass from natural forests and plantations:

1. Task 30: Short Rotation Crops for Bioenergy Systems
 - a. <http://www.shortrotationcrops.org/>
2. Task 31: Biomass Production for Energy from Sustainable Forestry (which includes Task 18: Conventional Forestry Systems for Bioenergy)
 - a. <http://www.ieabioenergytask31.org/>

The objectives of these Tasks are: to share, analyze, synthesize, disseminate and promote scientific knowledge and technical information leading to the economically and environmentally sustainable production of biomass for energy from short rotation crops (Task 30) and integrated forestry systems (Task 31+Task 18). Numerous presentations and publications are available detailing the work completed by Member Countries on these Tasks (e.g. Smith and Thiffault 2008, Lattimore et al. 2009, Richards et al. 2007). *Bioenergy from Sustainable Forestry: Guiding Principles and Practices*, published in 2002, is a compilation of work

completed by international experts working on Tasks 18 and 31. The book provides general principles for biomass production from natural forests and plantations in the context of environmental, economic, social sustainability (Richardson et al. 2002). While the publication does include discussion of sustainable short rotation woody crop production it is not the focus of the book.

12.6.2 The European Union and biomass certification

There is great interest in the development and implementation of an international European biomass utilization framework that would include minimum sustainability criteria in the form of a sustainable biomass production certification system. In 2008, the Biomass Technology Group (BTG) published a comprehensive report that explores the possibilities for an EU based biomass certification system (Vis et al. 2008). The report begins by reviewing the main activities and viewpoints of various European bodies, EU Member States, NGOs, international organizations, etc. on the development of biomass sustainability criteria (Vis et al. 2008). The majority of the document is dedicated to an analysis of existing sustainable forest management and purpose-grown bioenergy crop certification systems, as well as certification systems used in the power sector and systems related to emissions trading (Vis et al. 2008). The authors of the BTG report address the technical and non-technical barriers of biomass certification, including a discussion of the costs of biomass certification (Vis et al. 2008). The work included in the BTG report goes beyond what is presented here and is a very rich resource for those interested in certification system analysis and development.

Vie et al. (2008) suggest using existing forest certification systems (e.g. FSC or SFI) as examples when developing EU biomass sustainability criteria. While current forest certification systems include a number of criteria applicable to biomass harvesting, no system takes into account greenhouse gas balances or carbon stocks (Vis et al. 2008). Vis et al. (2008) recommend developing comprehensive sustainability criteria, including carbon and greenhouse gas balances, for a large number of biomass types.

The authors conclude that obligatory biomass certification cannot cover all aspects of sustainable biomass production because of WTO regulations (Vis et al. 2008). It is recommended that the EU develop minimum criteria to be used as a starting point towards the sustainable use of biomass (Vis et al. 2008). Ideally, these minimum criteria and other EU initiatives will create the conditions necessary for the development voluntary biomass certification systems (Vis et al. 2008). It is recommended to leave the establishment and operation of certification systems to the market (Vis et al. 2008).

12.8 Conclusions

Since the early 1980's a number of different sustainable forest management certification systems have emerged worldwide. Currently there are no sustainable biomass production certification systems for forest, woodland, or shrubland ecosystems. A review of how existing forest management certification systems have addressed sustainability concerns related to the increased utilization of logging residues and non-merchantable woody biomass removals for bioenergy production highlights the opportunities and challenges of focusing on what is

typically a by-product of another production system. While the specifics of each certification system are varied, there are few major similarities: 1) all systems seek to achieve the same objective of sustainable forest management, 2) all certification systems require participating organizations to meet the a set of sustainability standards and pass an audit by an accredited third-party certifying body, 3) all systems recognize issues associated with environmental, social, and economic sustainability, and 4) most systems follow, or plan to follow the International Standards Organization (ISO) rules for standard-setting and third party verification.

There are two main international umbrella forest certification organizations: Forest Stewardship Council- International (FSC-IC) and Programme for the Endorsement of Forest Certification (PEFC). Both organizations review and endorse national certification standards that meet their sustainability standards. FSC-IC develops their sustainability standards in-house, while PEFC uses a Sustainability Benchmark consisting of over 300 globally accepted criteria developed by an international multi-stakeholder process.

The major sustainable forest management certification systems in North America include: Forest Stewardship Council-US (FSC-US), Sustainable Forestry Initiative (SFI), American Tree Farm System/American Forest Foundation (ATFS/AFF), and Canadian Standards Association-National Sustainable Forest Management System (CAN/CSA-Z809). As of 2007, only 13% of the forestland in the United States was certified under a sustainable forest management system (Pampush 2008). The majority of certified forestland is in private, industrial ownership while non-industrial family forests and public lands remain largely uncertified (Pampush 2008).

Public land management is very different than industrial forest management, as state and federal land is often managed for a variety of objectives/uses. State lands often have fiduciary responsibilities to produce revenue for define state funded programs such as education while federal lands are managed according to changing Congressional legislation and Executive Branch policies. SFI and FSC-US have specific requirements for public lands seeking certification (SFI 2010, FSC-US 2003). Several state forestry systems have pursued certification including Pennsylvania, Wisconsin, Maine and Washington. The question of whether or not the USDA Forest Service should seek certification for National Forest System (NFS) lands has been debated for years and remains unanswered (Sample et al. 2007). The U.S. Department of Defense and the U.S. Department of Energy are the only federal ownership types that are certified under a SFM system.

Since SFM certification systems were developed to certify a wide range of forest cover types, ownerships and harvest treatments and objectives, their standards do not contain guidelines specific to the harvest of woody biomass for bioenergy. Instead, it is expected that this new forest management activity will be executed in line with the existing standards. All SFM certification systems have standards pertaining to the maintenance of ecosystem functions. Often these standards explicitly require the retention of understory vegetation, den and cavity trees and snags, and dead and downed wood for wildlife habitat, biodiversity, and soil nutrient cycling goals. The level of retention that is appropriate and necessary is not explicitly addressed in SFM certification standards. Many of these certification systems can be considered

outcome focused, as they do not dictate the specifics how forests should be managed or harvested. Instead, a variety of management approaches can be used while still meeting the certification standards.

The production of woody biomass is not limited to residues removed from natural forests, woodlands, and shrublands. There is increasing pressure to use marginal lands (e.g. abandoned or marginal agricultural fields, former Conservation Reserve Program lands) for the production of biomass from short rotation woody crop plantations. These biomass-for-energy plantations are not likely to seek or obtain sustainable forest management certification, even if forest tree species are being grown. Instead, there have been several biomass energy crop certification systems developed to address sustainability concerns with plantations and purpose grown bioenergy crops: Roundtable on Sustainable Biofuels (RSB) and Council on Sustainable Biomass Production (CSBP).

There are many international organizations and initiatives that are working to advance sustainable bioenergy as part of the solution to growing global energy demands and climate change. The Food and Agriculture Organization (FAO) of the United Nations has several programs in place that seek to strengthen international capacity to produce sustainable bioenergy while mitigating climate change, protecting food security (BEFSCI 2010, IBEP-FAO 2006, FAO-SWES 2009). The IEA Bioenergy working group of the International Energy Agency (IEA) provides organization and structure to a collective effort of 23 member countries working on bioenergy research, development and demonstration. The work of IEA Bioenergy is organized into 12 active Tasks, which have objectives and multiple deliverables. Three Tasks specific to biomass and forestry systems (Task 31, 30, and 18) have been completed. Task 40 is particularly relevant to this discussion as one of its objectives is to review biomass/bioenergy certification initiatives and their potential impact on the development of a sustainable, international bioenergy market. Vis et al. (2008) prepared a report that explores the possibilities for an EU based biomass certification system. The authors suggest using existing forest certification systems as examples when developing EU biomass sustainability criteria, while also specifying the need to address carbon and greenhouse gas balances (Vis et al. 2008). It is recommended that the EU develop minimum criteria to be used as a starting point towards the sustainable use of biomass, leaving the establishment and operation of certification systems to the market (Vis et al. 2008).

CHAPTER 13:

Conclusions

13.1 Scale, strategy, and site issues

This section synthesizes the findings of the literature reviews and draws conclusions regarding the current state of knowledge regarding the potential environmental impacts of increased utilization of woody biomass to meet California's energy demands. It also identifies the key information gaps most relevant to California.

First, it is necessary to consider the scale at which the environmental impacts of potentially increased biomass utilization are assessed. While the driving rationale for utilizing more biomass for energy is to reduce fossil fuel consumption and global concentrations of greenhouse gases, the focus on the environmental impacts is mainly on local impacts (Ryan 2010). If woody biomass utilization patterns follow current patterns of wood products or energy use, the full environmental impacts need to be tracked at four different levels – 1) global, 2) trading regions (Canada, Alaska, and neighboring states for California), 3) processing regions (sites within 100 miles of a biomass to energy facility), and 4) local sites. Changes in the relative prices of different sources of energy, different end uses for woody biomass, and different transportation costs and processing efficiencies could substantially change where there will be increased utilization of woody biomass to meet the energy needs of California. Global atmosphere does not care where or who produces GHGs. Therefore California must consider the positive and negative impacts within our total supply region, not just the operations in California.

Second, a surprisingly large fraction of the research articles and reports drew major conclusions based on simplifying and often untested assumptions concerning the management goals and strategy of the landowners. Unlike forest ownership in regions such as the Southeast US where most productive forestland is privately owned and managed for wood products (Haynes 2003), the strategies of forest owners in California are far more diverse. More than half of all forest and woodlands are in federal ownership with much of that legally or operationally zoned out of any significant degree of vegetation management. Wildfires rather than timber harvesting is the dominant factor controlling carbon fluxes and storage. Within the privately owned lands, over half is owned by families who have some of the lowest rates of vegetation management among the western states (Butler 2008). This suggests that around one quarter of California's forestlands will be managed to maximize the financial value of the forest inventory and the land but that numerous other goals of the owners will play a large role in deciding forest management strategies on the rest of the lands. For example, the increased collection and transport of logging residues is a money-losing activity given the long distances from most forest sites to energy plants. Private forest owners with long term financial interests in future timber harvests have proved willing to undertake such activities while public ownerships and most family forests limit biomass harvests to projects where government grants have been available. The greatest potential for new woody biomass production could come from family and government owners who are currently less engaged in timber production but new incentives or policy directives would probably be necessary.

One of the challenges of drawing conclusions from such a large body of published work from worldwide temperate forests is that each site-based study had a specific combination of biophysical and management characteristics which qualify its generalizability to a broader set of conditions. For example, much of the research from forests in the Eastern United States are from areas where the soils are less fertile than the deep, unglaciated soils of California; where summer rainfall is plentiful, and where wildfire risks are considerably less than in California. The ratio of biomass removed by harvests to biomass compared to that removed from wildfires is much higher in sites such in the Southeast US than it is in the Western US. On a ton for ton basis, the atmospheric impact of the biomass removals is far greater when the biomass is not burned and used to substitute for fossil fuel based emissions. In addition many place-based studies implicitly compare harvest and non-harvest at that site scale but ignore the fact that consumer demands for products or energy will be met with imports from other sites. The “leakage” effect, in carbon accounting parlance, is significant when global forest carbon inventories and emissions are considered.

Regarding the environmental impacts in forests, woodlands, and grasslands in California and the neighboring states that could potentially provide energy generated from forest based biomass, key information gaps remain even after these detailed literature reviews.

13.2 Nutrient cycling, soil and water quality, impacts and soil-related productivity

While specific nutrient deficiencies have been noted in many sites in North America and Europe subject to intensive forest harvest regimes, documented and measurable declines in forest site productivity on sites in California or sites similar to California appear rare. Current best management practices for managing soil fertility, soil carbon, and soil erosion have addressed most of the problems that had been noted in field results before 2000. There is a gap in research sites on lower productivity sites, especially in forests with a large hardwood component. The existing system of long term experimental sites is weak in a number of areas where future biomass harvests could be an issue. There is relatively little known about the nutrient and soil fertility issues of short rotation tree crops. It is possible that genetically improved species could be more productive in marginal sites that are not currently under forests cover. Increased harvested biomass volumes could also require greater attention to road and road layouts that would receive greater use as well as appropriate mitigative treatments. Finally, the potential of stump removal for biomass utilization has been noted as an area of potential concern regarding nutrient and carbon cycling.

13.3 Wildlife and biodiversity

Based on biomass harvests related to thinning and logging residual removal, the probable impacts were assumed to be reductions of understory vegetation and smaller diameter/canopy trees in some sites. These are wildlife resources that are rarely in deficit at a regional level, but can be deficit at scales important to some wildlife populations. There could also be additional removal of some of the existing dead and downed woody debris. The literature review pointed out that there are many different metrics for assessing wildlife habitats and more general

biodiversity conditions. In California, the mixed pattern of forest ownership, the diversity of forest-types, stand ages and conditions, and the influence of significant disturbances such as fire essentially guarantee a diverse landscape, diverse management opportunities and wildlife habitats. This is quite different than forested areas like the Southeast US or the Douglas-fir plantations of the Pacific Northwest where a new forest management practice could be applied across a high percentage of the landscape at one time. The application of new site-specific or forest-specific wildlife habitat and biodiversity precautionary measures could be based on statistical relationships between forest attributes and wildlife values. The more significant measures should be tested on sites where treatments and control plots can be implemented.

13.4 The potential for biomass harvesting in California forests to reduce future tree mortality from wildfire, insects, and pathogens

Across much of the public forests in California, wildfires rather than timber harvesting is the primary driver of carbon fluxes and storage. Some fuels treatment projects to reduce the potential losses to wildfires could generate considerable amounts of collectable biomass. After the collection of logging residues that have been historically left on-site, the biomass created by risk reduction activities represents another potentially significant source of additional biomass that could be used for energy production. Even when in-forest harvest and collection costs are ignored, the value of biomass at the landing is less than zero for sites more than 30 miles away from a biomass plant. Given this, biomass removal needs to be justified based on the reduction in future risks to valued forest attributes such as future timber harvested, reduced wildfire emissions, protection of key wildlife habitats, or protection neighboring residential areas. A number of studies that measure the differential impact of wildfires moving into treated and untreated areas have demonstrated the benefits of treatments that involved the removal of considerable volumes of low or negative value forest biomass. More recent modeling in California of post-treatment fire behavior concluded that it should be possible to implement effective treatments at reasonable costs. The information gap is to implement and measure projects and coordinate the research addressing wildlife, soils, and water quality. The evidence for investing in relatively expensive treatments to reduce future losses from insects and pathogens is more ambiguous than for fire risk reduction projects.

13.5 The role of best management practices, regulations, certification, and market forces in achieving higher standards.

Woody biomass harvesting guidelines and regulations in North American and Europe vary widely. They are usually a subset of broader forestry guidelines or regulations. The recent increase in the scale of market demand for more woody biomass for energy has led many US states, Canadian provinces, and European nations to bring together regulators, resource managers, and operators to develop new guidelines. The relatively low value of biomass that had not previously been harvested has limited the interest of landowners to operate in steep, remote or other high cost sites. The wide range of forest conditions and potential sources of woody biomass reduces the potential value of simply transferring specific guidelines or regulations from one area to another. Market based branding and certification systems such as SFI, CFSA, and FSC are used in the United States for lumber and paper products where the

consumer can see the certification. They are less commonly used for commodities that are not directly purchased by consumers.

13.6 Overarching conclusion

While the utilization of forest residues for renewable energy is often considered to be a source of considerable climatic benefits (e.g. Fargione et al., 2008; Searchinger, 2009), long term site and regional research in California is limited, especially outside of the mixed conifer forests. There is a need for the increased use of results from comprehensive research sites to ensure that the data supported conclusions woody biomass use in California and elsewhere are applied where they are applicable. Combining empirical research results and modeling results often results in a situation where the results are a function of the assumptions rather than of the results of statistically robust experiments. Recent publications have reaffirmed the value of utilizing the full range of plot data to draw unbiased conclusions across landscapes. This is true for wildlife (Marcot et al., 2010), current carbon inventories (Duane et al., 2010), future carbon inventories under disturbance (Zhou, 2010), and expanding bioenergy markets (Polyakov et al., 2010; Stennes et al., 2010).

The major environmental concerns addressed in the literature and in recent guidelines are 1) protecting long term soil productivity, 2) minimizing harvest related erosion and water quality impairment, 3) and maintaining important wildlife habitat and biodiversity elements across the larger landscape. Based on historic patterns and future opportunities, increased production will probably continue to be a by-product of timber production in western states and Canadian provinces as well as from fuels treatment and other projects in California.

Much of the published literature and guidelines to limit the negative environmental impacts of pulpwood or biomass for energy harvests are based on experiences in the Eastern United States and Europe, areas with very different soils, tree species, and wildfire regimes than California. These guidelines typically recommend higher residual biomass retention fractions of the original biomass that are not necessarily appropriate for California's fire adapted forest ecosystems where biomass accumulation and production has naturally been reduced by periodic wildfire. Long-term experiments in California's mixed conifer forests show no loss of long term productivity from biomass harvesting but there are few results from other forest types, woodlands or shrublands. The potential loss of some of the size classes of live trees, snags, and downed wood from wildfires, other disturbances, or biomass harvests could have negative effects on wildlife habitats and biodiversity. However, the current predictive tools have limited effectiveness in measuring impacts of different approaches. Key information gaps could be reduced by implementing and evaluating long-term experimental wildlife habitat and forest productivity projects across a greater range of forest types - especially where treatments and wildfires interact. Significant portions of such a network are in place on US Forest Service and University research forests and research plots but additional work is necessary to address new biomass harvesting specific questions and hypotheses.

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