RESTORING OAK HABITATS IN THE SOUTHERN WILLAMETTE VALLEY, OREGON: A MULTI-OBJECTIVE TRADEOFFS ANALYSIS FOR LANDOWNERS AND MANAGERS

by

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Restoring oak habitats is an emerging conservation priority in Oregon's Willamette Valley. Both private and public landowners face multiple challenges to conservation and restoration of oak habitats, including a lack of knowledge about the potential tradeoffs and constraints for achieving multiple priorities on a given site. This study simulated 25 alternative oak habitat restoration scenarios to develop estimates of outcomes related to six different restoration priorities: costs, income potential, habitat value, scenic quality, fire hazard reduction potential, and time requirements. Model results indicated that initial land conditions strongly influence a landowner's ability to optimize among these different priorities. To assist landowners with decision-making, model estimates were organized into a digital decision matrix that communicates advantages and tradeoffs associated with each alternative scenario. In doing so, it aims to help landowners choose restoration goals that better meet their broader needs and objectives.

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TABLE OF CONTENTS

Chapter Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

LIST OF GRAPHS

Graph Page

CHAPTER I

INTRODUCTION

Oak dominated habitats in Oregon's Willamette Valley have been shaped by human activity for thousands of years (Agee 1993, Boyd 1999). As in other parts of the world, Native cultures perpetuated them through regular burning for reasons including food production, safety, resource development, transportation, and aesthetics (Boyd 1999). As a result, oak habitats are maintenance dependant; they require human interaction for their health, diversity, and long-term existence. Speaking of this mutual relationship in reference to California's oak ecosystems Helen McCarthy (1993) notes "The people need the plants in order to live, but the plants also need the people; they need people to gather their seeds, and leaves, and roots, and to talk and sing and pray to them." Because of this mutual dependence, the cessation of human ignited fires around the middle of the 19th century precipitated the decline of many oak communities. At the same time, numerous plant and animal species dependent on the spatial and compositional qualities of specific oak habitats began to decline too (Fuchs 2001, Vesely and Rosenburg 2010). For these and other reasons described below, Willamette Valley oak habitats and associated grasslands have become one of the most endangered ecosystems in North America (Noss et al. 1995). Understanding the causes of the decline of oak habitats provides insight into the processes required for their conservation, and to obstacles to their restoration.

The general patterns of forest succession in oak habitats are well documented (Agee 1993). In the absence of fire, increasing numbers of Oregon white oak, *Quercus garryana*, begin to fill in open oak savannas. Where oaks grow more densely, less fire tolerant but faster growing species such as Douglas-fir, *Pseudotsuga menziesii*, eventually overtop and kill the shade-intolerant oaks. As the canopy closes native grasses and forbs important to the historic bio-diversity of oak habitats begin to decline and shift to herbaceous species more common to forests.

In addition to the forest succession that results from fire suppression, the total amount of land that oak habitats once covered is shrinking as a result of land conversion. Human land uses such as agriculture, forestry, and urban development all compete for the land that oak once dominated (Hulse et. al. 2002). On those lands that have not been lost to land conversion or habitat succession, non-native species proliferation poses an increasing threat to the composition of oak ecosystems (Oregon Conservation Strategy 2006). Many non-native invasive species can quickly dominate oak ecosystems—suppressing native species and altering ecological processes. Consequently, depending on the source, anywhere from 0-10% of the open oak savannas and 30% of the oak woodlands that existed in 1850 remain in the Willamette Valley today (Hulse et al. 2002, Oregon Conservation Strategy 2006).

Challenges to oak habitat conservation on private land

Compounding the problem of oak habitat loss in the Willamette Valley is that 96% of all land is privately owned. Since public lands make up only 4% of the total land area, and much of this is on higher elevations that never were oak habitat, the vast majority of remnant oak habitat is located on private land (Oregon Conservation Strategy 2006). Many private landowners face considerable financial and social pressure to keep their land economically productive (Fischer 2004). In some cases, remnant oak habitat is in direct competition with agricultural production, such as on dry south-facing slopes where wine grapes grow as well as oaks. As a result of this pressure on private land, adapting restoration practices to the needs of private landowners is essential to preserving it as a functioning habitat type (Vesely and Tucker 2004, Oregon Conservation Strategy 2006).

Private landowners encounter multiple challenges to restoring oak ecosystems on their property. Challenges include a lack of knowledge about restoration methods and options; a lack of funding to do the work; fear of government regulation, and a lack of awareness about the societal and personal benefits of restoration (Fischer 2004, Fischer and Bliss 2008). On the other hand, landowners have the potential to receive benefits from restoration including the pride of land stewardship, increased wildlife habitat, increased biodiversity, potential income, improved aesthetics, and reduced wildfire hazard (Vesely and Tucker, 2004). Many landowners seek these and other tangible benefits of conservation but also prioritize their autonomy in accomplishing them (Fischer and Bliss 2008). Landowners recognize tradeoffs between cost, habitat quality, and regulatory risks to working with government partners as important factors relevant to their restoration decision-making. Tools that can assist landowners with navigating these tradeoffs may be important to facilitating their restoration goals. Garmon (2006) states "Private landowners are unlikely to be willing to initiate restoration efforts on their lands if substantial uncertainty exists about restoration and management strategies and costs. Clearly, decision-making tools to help landowners and managers navigate these complex issues would be highly valuable." In part, this analysis is intended to reduce the uncertainty about tradeoffs to restoration that Garmon highlights, while supporting landowner's autonomy, by providing information that can support clearer decision-making.

Fischer and Bliss (2008) outlined a framework for understanding the various motivations of private landowners in restoring oak habitats. Applying the behavioral and policy research of Schneider and Ingram (1990) to Willamette Valley landowners, they identified five sets of tools that motivate restoration: authority tools, capacity tools, incentive tools, learning tools, and symbolic tools. Learning tools seek to harness landowners' knowledge of the constraints to habitat conservation in order to develop solutions. Authority tools, which rely on regulation to incentivize action, have historically been the tools of first resort for conservation, but they frequently conflict with landowners' desire for autonomy in pursuing restoration goals. Capacity tools build landowner's ability to restore by providing education, technical information, assistance, and financial resources. Incentive tools rely on the provision of various financial rewards and/or relief from regulation to motivate action. Lastly, symbolic tools reward a sense of stewardship and pride in being a part of a worthwhile outcome (Figure 1).

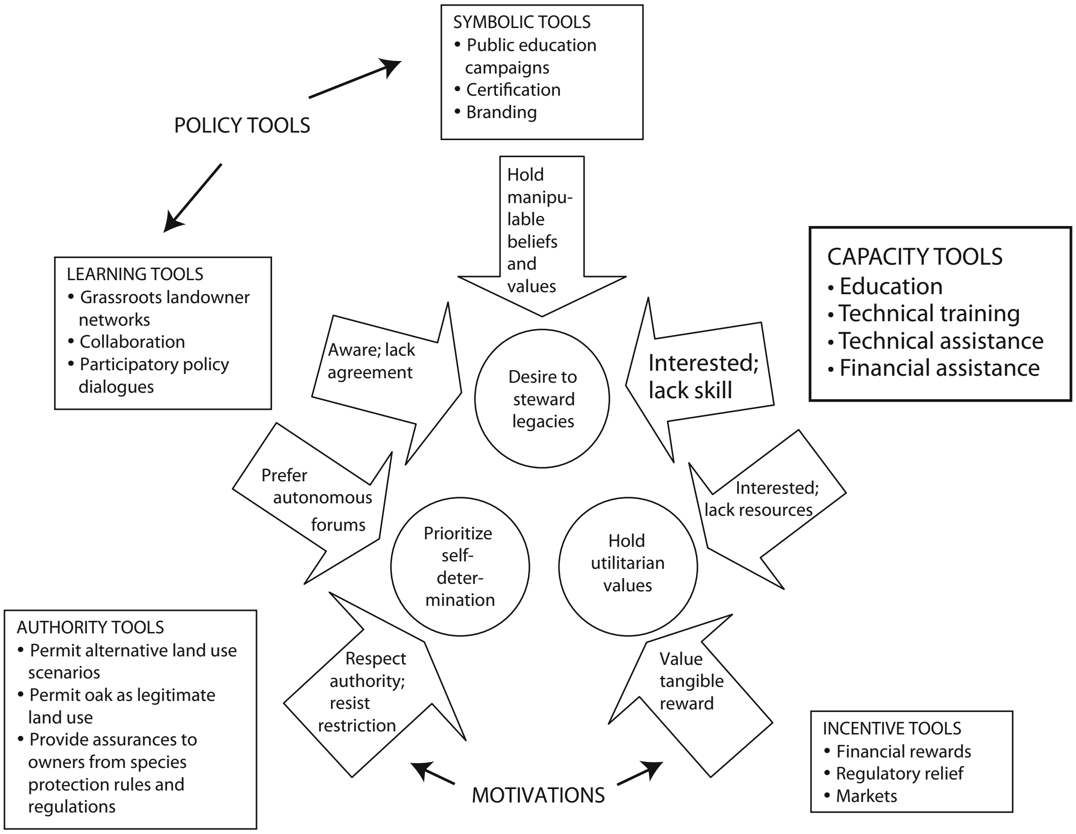


Figure 1. *Roles of five policy tools in supporting motivations for oak habitat conservation. Emphasis is on capacity tools. Modified from Fischer and Bliss (2008).*

According to this framework, the process of facilitating restoration on private land is a multi-pronged approach. Multiple agencies and organizations are seeking to work with landowners using the tools outlined above. Defenders of Wildlife and the U.S. Bureau of Land Management have started the process by producing introductory guides to oak savanna restoration (Campbell 2004, Vesely and Tucker 2004). The focus of these guides is on explaining the importance of oak habitats; therefore, they are initial capacity building tools. Further development of capacity tools is still necessary to communicate a technical understanding of how to set and achieve restoration goals in a way that allows landowners to retain their desire for autonomy.

Project development and process

Fischer and Bliss identified a broad need for capacity building tools. Discussions with land-use decision makers indicate a specific need for detailed information about the costs, timelines, and outcomes that are associated with restoring or converting land to different oak habitat types. Information about outcomes related to multiple restoration variables can help landowners and managers to navigate the tradeoffs they face or perceive between the benefits and risks of restoration. Such information has the potential to help landowners better meet their individual restoration goals, and in doing so, build the capacity of greater numbers of landowners to engage in restoration.

To meet the need for a multi-variable tradeoff analysis, this project models 25 alternative oak habitat restoration scenarios and compares the outcomes that result from each scenario. The 25 alternative scenarios result from conversions of five different existing land condition classes to each of five specific oak habitat restoration goals using the costs and capabilities associated with state-of-the-art restoration methods. Each scenario is simulated seven times using vegetation data collected from seven sites with remnant oak habitats as the starting point. The modeling process provides simulated restoration results related to economic, fire-hazard, wildlife habitat, time to maturity, and scenic beauty goals. These outcomes have the potential to help readers build a better understanding of the time and effort required to achieve their restoration goals, and develop insight into tradeoffs associated with working toward specific goals. Figure 2 is a process diagram that shows the inputs, component parts, and outputs of the project. Components 1, 2, 3,and 4 are discussed further in Chapters II and III, and the project results, component 5, are discussed in Chapter IV.

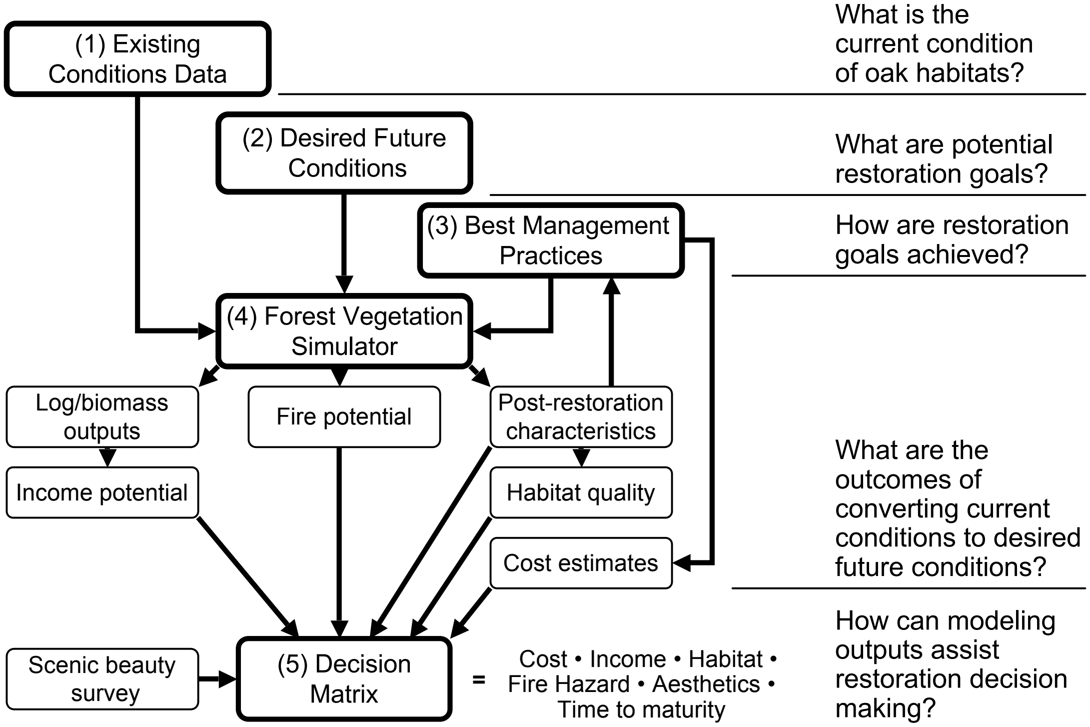


Figure 2. *Project diagram linking 1) existing conditions, to 2) desired future conditions, and 3) best management practices. These three elements are modeled together in step 4) and provide outputs for step 5) a decision matrix.*

Using Fisher and Bliss's definitions, this project is a capacity building tool, but one that connects education and technical assistance to develop a decision tool. It links an understanding of restoration processes and tools with the ability to make informed decisions about their implementation. It ties land conditions and restoration targets to the potential to achieve specific goals. As a decision tool, it is intended to complement existing information about the need to restore oak habitats, with an understanding of the tradeoffs associated with engaging in the complex, non-linear, and site-specific details of oak restoration. Landowners and managers can use the professional opinions and model results to navigate away from risks associated with restoration and toward the benefits they seek.

This project is an outgrowth of the 2007 University of Oregon Environmental Studies master's thesis of Jennifer Garmon. From a series of collaborative meetings with oak habitat restoration professionals and landowners, Garmon's project defined five alternative oak savanna restoration scenarios for Oregon's Willamette Valley. Also described as desired future conditions (DFCs), the scenarios outlined specific goals and objectives for restoration that were intended to meet the habitat quality and economic needs of different landowners. This study takes Garmon's work one-step further by linking the restoration goals with specific vegetation conditions to explore the outcomes that would result from implementing the DFCs on actual sites.

The remainder of this project is organized as follows: Chapter II describes the methods and procedures used to model oak restoration scenarios. Chapter III describes in detail the best management practices used for modeling landscape conversions from existing conditions to desired future conditions. Chapter IV reports modeling results related to six restoration values and includes brief discussions of key implications for each. It concludes with comparative analysis of the restoration scenarios using a decision matrix. Chapter V highlights the implications of this research for restoration prioritization at the scale of the entire southern Willamette Valley.

In the words of one professional, estimating the time and effort that a restoration project will require and the outcomes that might result is a matter of evaluating a site and estimating the degree to which it "looks kind of like a job we did last year." By incorporating the knowledge and insights of professionals, by using data collected from actual oak habitats on multiple sites, and by working toward restoration targets developed by landowners, professionals, and academics, this analysis can provide landowners and managers with the ability to estimate outcomes for their own projects and improve their decision-making capacity.

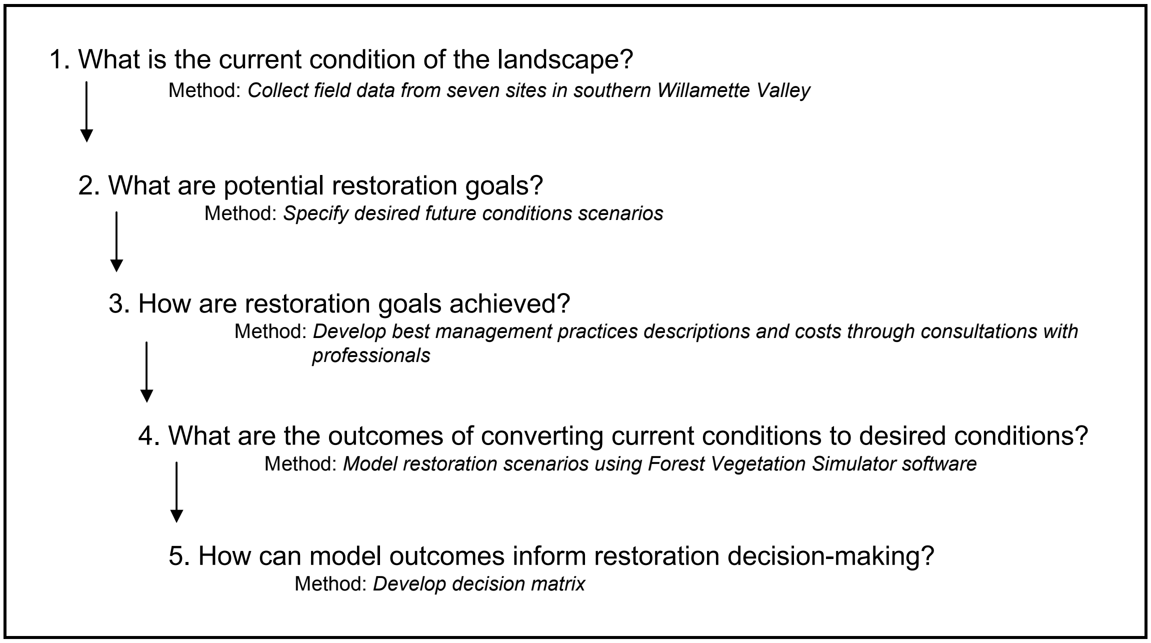
CHAPTER II

MODELING METHODS

Introduction

Building from he analytical goals outlined in Chapter I, I now describe the processes used to build and run digital models of the 25 alternative oak habitat restoration scenarios analyzed in this project. The modeling process requires translating broad qualitative descriptions of habitat types (e.g. oak savanna or oak woodland) into precise quantitative characterizations of those idealized habitats. Specifically, three components are necessary for each modeled scenario: 1) a quantitative description of former oak habitats as they exist today (existing conditions); 2) a quantitative description of generic restoration goals (desired future conditions); and 3) and average cost estimates for the field methods used to convert existing conditions to desired future conditions (best management practices).

I used a five step question-based framework to organize and describe the components of this modeling process (Figure 3). The framework was adapted from Carl Steinitz's work on linking models to questions that guide decisions about altering the landscape (Steinitz 1990). The response to each question I posed is a critical modeling process. Solutions to the first three questions lead to model components. The solution to the fourth question is the primary modeling mechanism. The solution to the fifth question organizes the model results. This chapter is organized using the framework. The first section defines terms associated with vegetation classification that are needed to understand the rest of the modeling components. The second section lays out the methods used to acquire field data and classify existing vegetation conditions into community types (solution to question 1). The third section defines each desired future condition (DFC), and explains how they were developed (solution to question 2). The fourth section describes the modeling software used to execute the scenarios, and outlines the logic behind the modeling process (solution to question 4). The fifth section introduces the structure of the decision matrix used to organize the model results and communicate the tradeoffs among scenarios, including costs, income potential, habitat quality, scenic beauty, fire hazard reduction potential, and time to habitat maturity (solution to question 5). The best management practices (BMPs) (solution to question 3) are described as a stand-alone process in Chapter III.



1. What is the current condition of the landscape?
Method: *Collect field data from seven sites in southern Willamette Valley*

2. What are potential restoration goals?
Method: *Specify desired future conditions scenarios*

3. How are restoration goals achieved?
Method: *Develop best management practices descriptions and costs through consultations with professionals*

4. What are the outcomes of converting current conditions to desired conditions?
Method: *Model restoration scenarios using Forest Vegetation Simulator software*

5. How can model outcomes inform restoration decision-making?
Method: *Develop decision matrix*

Figure 3. *A question-based framework for organizing model processes.*

Definition of terms

To understand the processes used to define existing conditions and DFCs, it is helpful to be familiar with ecological classification vocabulary. In the following pages I define concepts and terms relevant to vegetation classification as I have used them for this project. Reading all definitions may not be necessary for all readers.

Oak habitats

This paper uses oak habitats as a broadly inclusive term to refer to vegetation communities in which Oregon white oak is the dominant tree species. Habitat is a term used by wildlife professionals to describe the area or environment that provides the minimum conditions for plant or animal species to carry out the basic functions of their life cycle (Daubenmire 1968). It can be used at many scales (e.g., a person's habitat may be his or her house, or the planet Earth). I use the term oak habitats to collectively refer to the oak-dominated communities targeted for restoration in this paper. The term emphasizes the importance of oak communities to the many species, including humans, that depend on them. Over 95 vertebrate species use these habitats for nesting, feeding, and/or rearing young, including 20 species with state or federal conservation status (Vesely and Rosenburg 2010). A further 714 native plant species are found in oak habitats, including 391 species that grow primarily or solely in the more open grasslands of oak savannas (Ed Alverson, The Nature Conservancy, unpublished data). These plant species in turn host hundreds of invertebrate species, which are important and often highly specialized pollinators, as well as a food source for many vertebrate species. Wilson (1998) estimated that over 1100 species of arthropods were historically present in the grasslands associated with upland savannas. As many as 80% may now be extirpated or extremely rare (Andy Moldenke, Oregon State University, unpublished data).

Community types

Community types are plant associations with similar structure and composition that recur across a landscape. I used five community types to classify existing conditions, and two of the five to classify DFCs. The community types are divided into three structural classes along a spectrum from open to closed canopies: *upland oak savanna*, *open oak woodland*, and *forest*. Upland oak savanna and oak woodland are used to described both existing conditions and DFCs. Forest structure is further classified by composition into three additional types arranged along a successional gradient from early to late seral stage: *broadleaf forest*, *mixed conifer and broadleaf forest*, and *conifer forest*. I used estimates of canopy cover and species dominance to classify communities.

Figure 4. *Five existing conditions community types. (Clockwise from upper right) Oak savanna, oak woodland, broadleaf forest, mixed broadleaf and conifer forest, conifer forest. Photos: broadleaf forest, Rich Owen. All others, Bart Johnson.*

The three structural classes have distinct characteristics in addition to different canopy cover ranges. Upland savannas are composed of a continuous ground layer of sun-loving forbs, grasses, and shrubs with small numbers of widely spaced trees. Historically shrubs were a minor component of upland savanna communities due to the relatively high-frequency of fire. Today shrubs are more common, and in the Willamette Valley, those found on savannas are often invasive species. Woodlands have greater numbers of trees, resulting in semi-closed tree canopies. Less light is able to penetrate to the ground compared to savannas so that the ground layer plants are typically less numerous and they cover less of the ground surface. Shrubs were historically more common because woodlands experienced less frequent fires and burned with less intensity than savannas due to higher moisture in the ground layer and different types of fuels. Forests have enough trees to create a closed canopy, which means that the crowns of most canopy layer trees are touching or overlapping. As a result, forest understories are characterized by increased numbers of shade-tolerant tree, shrub and ground layer species. Like woodlands, there are typically sparser grasses and forbs. Fires were historically less frequent but tended to burn more intensely in forests when they occurred.

Structural layers

Each community type is composed of three structural layers: the *canopy layer*, the *shrub layer*, and the *ground layer*. The site-specific structure and composition of each layer and their consequent ecological functions are important, because the process of habitat restoration involves accomplishing specific objectives within each layer. Table 1 highlights the qualities of each structural layer by community type.

The *canopy layer* consists of the largest and tallest trees in a given stand. It projects considerable influence over the shrub and ground layers beneath it through competition for light, water, and nutrients. The most common species in Willamette Valley oak habitats are Oregon white oak (*Quercus garryana*) and Douglas-fir (*Pseudotsuga menziesii*). Canopy structure can be characterized along a gradient from open to closed.

The *shrub layer* consists of woody shrubs and small trees below the canopy layer. The small trees are generally less than 2” in diameter at breast height (DBH)—approximately 4.5 feet above the ground. Shrub layer species composition often correlates with the amount of light that penetrates through the canopy layer. Common species in Willamette Valley oak habitats include native snowberry (*Symphoricarpos albus*), western hazelnut (*Corylus cornuta californica*) and poison-oak (*Toxicodendron diversilobum*) as well as non-native Armenian blackberry (*Rubus armeniacus*) and Scotch broom (*Cytisus scoparius*).

The *ground layer* is composed of perennial and annual grasses and forbs that grow below, or alongside, the shrub layer. Ground layer species composition is heavily influenced by soil chemistry and hydrology, as well as canopy layer and shrub layer structure. Common species in Willamette Valley oak habitats include Roemer’s fescue (*Festuca idahoensis ssp. roemeri*) and tarweed (*Madia spp.*) as well as non-native shiny geranium (*Geranium lucidum*) and creeping bentgrass (*Agrostis spp.*).

Table 1. *Structural layer descriptions of each community type.*

	Savanna	**Open Woodland**	**Broadleaf Forest**	**Mixed Forest**	**Conifer Forest**
Canopy Layer	Open	Semi-closed	Closed	Closed	Closed
Shrub Layer	Discontinuous/ Sun-loving	Discontinuous	Discontinuous/ Shade-tolerant	Discontinuous/ Shade-tolerant	Discontinuous/ Shade-tolerant
Ground Layer	Continuous/ Sun-loving	Discontinuous	Discontinuous/ Shade-tolerant	Discontinuous/ Shade-tolerant	Discontinuous/ Shade-tolerant

What is the current condition of the landscape?

To determine whether, or how, to alter a landscape, it is important to define the current conditions of the landscape. Existing conditions are the starting point for each alternative restoration scenario; they define the structure and composition of the vegetation on a site as it exists before restoration work begins. Developing an understanding of existing vegetation is important because it influences the post-restoration potential of a site for many years and, therefore, is useful for choosing DFCs. The process of defining existing conditions requires classifying field data into discrete community types that can be modeled. Throughout this paper I will refer to the different existing conditions classes at each site as “stands” because this is the term used by the modeling software to refer to modeled communities. This section begins with a description of our research team’s data collection methods then transitions into a description of our classification methods.

Research team

Field data was collected by a team of researchers from the University of Oregon’s Department of Landscape Architecture and the Center for Ecology and Evolutionary Biology. The team was composed of faculty members Bart Johnson and Scott Bridgham along with graduate and undergraduate students. The data classification described in this section was completed by Nathan Ulrich and Dr. Bart Johnson of the Department of Landscape Architecture.

Existing conditions study sites[1]

The field data used to define community types and model existing conditions were collected during the summer months of 2003-2005 at seven sites within the southern Willamette Valley, Oregon. Supplementary data were collected in 2009 and 2010. Sites were selected to encompass the range of historic variability within oak ecosystems, and the current state of succession among the systems that persist today. As a result, the existing conditions data reflects a wide range of current conditions and successional trajectories. Sites were located on both private and public lands and have been affected by multiple land use activities including logging, grazing, and recreation. Three sites are located on buttes near the edge of the valley floor: Chip Ross (CR), Mount Pisgah (MP), and South Eugene (SE). Three are located in the western foothills of the Cascade Mountains and contain rolling to steeply sloped topography: Lowell (LW), Brownsville (BR), and Jim's Creek (JC). The last, Finley National Wildlife Refuge (FN), is located on the valley floor near the Coast Range foothills, although some of the FN plots are on a small butte within the wildlife refuge.

Plots were located every 30 meters along stratified random belt transects oriented up and down slopes to cross key environmental gradients. The study utilized nested 200m^2 circular plots within 900m^2 square plots (30m x 30m) to capture the abundance, species, live/dead status, and diameter at breast height (DBH) of small and large trees respectively. All trees less than 50 cm DBH were grouped in size classes of seedling, 0-12 cm DBH, 12-25 cm DBH, and 25-50 cm DBH and counted on the 200m^2 plots. Oaks greater than 50 cm DBH and non-oak tree species greater than 80 cm DBH were recorded on the 900m^2 plots. The 900m^2 plots were necessary to determine the frequency of less common but functionally important large trees. To classify each plot according to community type, four measurements of canopy cover were taken using a spherical densiometer (Lemmon 1956) at the center of each plot during the summer months of June-September when canopy foliage is at its peak. Data was collected from 536 total plots.

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[1] This section is drawn from Murphy (2008), Sonnenblick (2006), and Yospin et al. (in review).

Existing conditions classification process

Rather than model restoration on a plot-by-plot basis, we chose to combine plots into community types by site. This approach provided composite descriptions of existing conditions that were more representative of the community types at each site than individual plots. It also yielded a smaller and more manageable number of stands to model. Although the composite descriptions reduce the variability in structure and composition of community types at individual sites, the project as a whole maintains variability by modeling at seven sites. The classification process yielded 34 existing conditions composite stands—one for each of the five community types at each site (one site, Jim's Creek, only had four community types). Table 2 indicates the number of plots assigned to each community type by site[2,3].

Table 2. *Total number of plots in each community type by site.*

Community Type	**BR**	**CR**	**FN**	**JC**	**LW**	**MP**	**SE**	**Totals**
Savanna/Prairie	18	11	23	21	19	28	9	**129**
Open Woodland	7	7	5	9	9	8	6	**51**
Broadleaf Forest	2	8	36	N/A	10	10	14	**80**
Mixed Forest	16	16	42	2	10	8	14	**108**
Conifer Forest	5	3	25	109	10	4	12	**168**
Total Plots	**48**	**45**	**131**	**141**	**58**	**58**	**55**	**536**

The assignment of plots to community types required two steps: a classification of community type based on canopy cover and a classification of tree species dominance

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[2] Spatially, more than half of open oak woodland plots were edge plots at the transition of savanna to forest. There were few discrete patches or continuous sequences of plots in the woodland classification. In other words, it was rarely a stand-alone cover type. Despite its rarity, we chose to retain open oak woodland as a community type because is a clear point on the continuum between savanna and forest. Although it was less common at our study sites, this type may be more representative of some landowners' property, and it remains a conceptually realistic starting point for restoration.

[3] Eleven plots that were classified as 1851 woodland or forest on a map of 1851 vegetation (Pacific Northwest Ecosystem Consortium, http://www.fsl.orst.edu/pnwerc/wrb/access.html) were were removed from the data set so as to retain only areas of historic savanna and prairie. Six plots from the SE site, however, that were characterized in the 1851 vegetation map as woodland were retained because of the presence of large, formerly open grown, presettlement Ponderosa Pine, Douglas-fir and Oregon white oak scattered among younger Douglas-fir that indicated it had historically been savanna. In addition, seven plots that were initially classified as broadleaf forest but were comprised of maples and conifers and were surrounded by mixed conifer-broadleaf forest were reclassified as mixed forest since they were components of that community and did not represent the oak-dominated broadleaf forest characteristic of the sites.

based on basal area. We initially used the National Vegetation Classification System (NVCS) (Grossman et al. 1998) to assign a community type to each plot based on canopy cover. As used by the NVCS, canopy cover is a measure of the area on the ground covered by the crowns of trees in the canopy layer. It is expressed as a percentage, where a stand with 100% canopy cover has no gaps between crowns and the ground layer is completely shaded. The NVCS defines stands with <25% canopy cover as herbaceous. It defines woodlands as stands with 25-60% canopy cover, and forests as stands with >60% canopy cover. This system created difficulties for our analysis because our data suggested that 60% canopy cover did not distinguish semi-closed canopy woodland stands from fully closed canopy forest stands. We found that there was not a compelling difference in the average basal area, trees per acre, or quadratic mean diameter (an indicator of the average diameter at breast height) between the upper range of the woodland class (40-60% canopy cover) and the forest class (>60% canopy cover). This inconsistency between our data and the NVCS presented a challenge not only for accurate classification, but also for accurate modeling, because the modeling software I used assumes higher canopy cover percentages than our data suggested for plots with equivalent numbers and sizes of trees.

To resolve the canopy cover conflict I searched peer-reviewed literature and found a conflict between our canopy cover observation methods and community type classification methods. Jennings et al. (1999) highlight a long-standing disconnect between the methods foresters and ecologists use to record canopy cover. They point out a qualitative difference in the way ecologists measure canopy cover using densiometers, which collect light at non-vertical angles to the ground from a single point, and the way foresters measure canopy cover with sighting tubes, which collect light perpendicular to the ground from multiple points. The authors suggest that densiometers usually record more light (resulting in lower canopy cover percentages) than sighting tubes, because densiometers measure light that reaches the ground at non-vertical angles through gaps between strata in the tree canopy, as well as light that penetrates vertically down through the canopy. They concluded that densiometers are useful for measuring the amount of light that is available to understory vegetation at a single point on the ground, but that sighting tubes are more accurate for measuring canopy cover as used for vegetation classification.

With evidence that our canopy cover observation methods indicated lower canopy cover percentages than the NVCS assumes for like stands, and because analysis of our data suggested that plots with 40-60% canopy cover were structurally similar to plots with >60% canopy cover, we concluded that 40% canopy cover better represented the cutoff between woodland and forest cover types. We tested this conclusion by modeling canopy cover outputs for all our plots using Forest Vegetation Simulator (FVS) (www.fs.fed.us/fmsc/fvs) software. Results indicated that modeled canopy cover was 1.5x higher on average than our field observations, on plots with canopy cover greater than 25%. A stand with 40% canopy cover measured using a densiometer, equated to 60% canopy cover in FVS—the initial NVCS cutoff. With these outcomes, we elected to shift our cutoff for forested stands from 60% to 40% canopy cover[4]. This shift resulted in a woodland classification of 26-40% canopy cover—a significantly narrower range than the NVCS standard.

Because we adjusted the high end of the NVCS woodland definition downward, we also needed to ensure that the low end cut-of between savanna and woodland, 25%, was appropriate. Measurements in low-density stands tend to be bimodal because readings in plots with no trees, yet spatially located within a savanna, will indicate no canopy cover. At the same time, readings in plots that are directly underneath a single savanna tree will indicate a high canopy cover, which would suggest the plot should be assigned to a woodland or forest community. We analyzed the appropriateness of the savanna class by determining whether the number of trees in savanna stands fit the desired future conditions (DFC) for the class (for definitions of DFCs see the following section: What are appropriate restoration goals?). Too many trees in the stands would suggest that the canopy cover cut-off was too high. Too few trees would suggest that it was too low. Our analysis indicated that the number of trees in the class overall was lower than the DFC definition, but the number of trees in plots with high canopy cover

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[4] 14 oak dominated plots located at the edge of forested communities were assigned a higher canopy cover threshold of 45% to include them in the open oak woodland class because both their tree canopy shapes and ground layer species composition were more characteristic of woodland than forest.

may be too high for the class. As a result, we determined that the 25% cutoff was appropriate for determining the open character of savanna stands and their associated grasslands. Although some plots in this community type have no trees and could be classified as prairie, there were no prairies on our reference sites so all plots with less than 25% canopy cover were classified as upland savanna.

Finally, using percentages of total tree basal area (a measure of the cross-sectional area occupied by tree trunks at the height used to measure DBH), we subdivided forest cover by broadleaf species dominance, conifer species dominance, and mixed broadleaf-conifer dominance. Subdivision cutoffs were determined using the NVCS standard for proportion of canopy cover: greater than 75% of canopy cover in conifer composition indicated conifer dominance, greater than 75% broadleaf canopy cover composition indicated broadleaf dominance, and all stands between 25-75% indicated mixed broadleaf-conifer composition. We used basal area rather than relative proportion of canopy cover to determine species dominance because there was no reliable method to determine the relative canopy covers of individual species using our field data.

What are potential restoration goals?

With this understanding of the current condition of former oak habitats in the Willamette Valley, the next question pertains to how the landscape might be restored. What would restored landscapes look like? What are the desired future conditions (DFCs) for restoration? DFCs describe the structural and compositional qualities of idealized restoration targets. The work of developing the DFCs used in this project was initiated by Jennifer Garmon in her 2006 thesis *Restoring Oak Savanna to Oregon's Willamette Valley: Using Alternative Futures to Guide Land Management Decisions* (Garmon 2006). Each goal was developed through a Delphi decision-making process in meetings with numerous oak restoration stakeholders, including ecologists, land managers, landowners, and restoration professionals. The stakeholders delineated five alternative oak habitat restoration DFCs. Each DFC was intended to meet a range of different restoration priorities, and measured by specific qualitative descriptions and quantitative targets. The descriptions were intended to help landowners align the restoration qualities they desire with the quantitative structure and composition necessary to accomplish their goals. The quantitative targets provide a starting point for developing on-the-ground prescriptions for restoration, and they translate the qualities of each scenario into numbers that can be used as restoration targets on the ground or for modeling. I refined and added to Garmon's oak savanna DFCs for this analysis. This section briefly summarizes Garmon's original oak savanna scenarios and then describes the additional oak woodland scenarios that I included for this project.

Desired future conditions development process

Garmon's thesis (2006) outlined four alternative DFCs for oak savanna and one for achieving fire-hazard reduction goals. The DFCs were designed to achieve multiple land use goals including vegetation and wildlife habitat conservation, ecosystem function, landowner income, and fire-hazard reduction. Because landowners have different priorities, however, her project specified two tiers of ground layer quality for the savanna DFCs: full savanna, which set high standards for ground layer native species composition, and savanna structure, which focused on invasive species control and managing for ground layer species that host native wildlife. Both these DFCs were then paired with functionally appropriate income-generating strategies to develop the third and fourth alternatives. The fire hazard reduction DFC was not concerned with oak savanna restoration. It was intended solely to reduce fire hazard potential, and was included as a contrasting alternative to test against the fire hazard reduction value of oak habitat DFCs.

My analysis used three of Garmon's five DFCs and added two more. Because the historic range of oak associated habitats in the Willamette Valley was greater than just savanna (Hulse et al. 2002), and because landowners have a wide diversity of restoration goals and motivations for restoration (Fischer 2006), I included an oak woodland DFC that was developed later by Garmon's stakeholder group but never published. The prescription for full oak woodland restoration set high quality standards for the ground layer, making it similar to the full savanna restoration DFC. To provide different levels of woodland restoration quality, similar to the two savanna options, I developed a woodland structure DFC that combined the structural standards developed for full woodland restoration with the species composition standards of savanna structure. The five restoration DFCs that I modeled thus included Garmon's prescriptions for full savanna restoration, savanna structure, and fire hazard reduction, as well as prescriptions for full woodland restoration and woodland structure. Table 3 describes the habitat structural and compositional targets of each DFC.

I did not include Garmon's income generating scenarios because they were essentially the two previously outlined restoration goals coupled with income generating strategies. The first strategy was to develop income by using savanna structure sites for grazing. The second strategy developed income by setting aside land on restoration sites and using it for timber production. Neither scenario included new or different oak habitat restoration guidelines. Although the income potential from the mixed-income scenarios was not a component of this analysis, landowners who wish to pursue the scenarios can add their own income projections to the appropriate restoration goal to develop cost estimates for each.

Five desired future conditions

Listed below are the five DFCs modeled in this analysis.

Full Savanna Restoration: This DFC emphasizes "high quality" restoration of oak savanna by working toward high percentages of native species in all three structural layers. It includes some conifer species in the canopy layer to represent historical savanna tree composition, as well as snags for wildlife habitat. It is the most costly and protracted to implement, but represents the highest standard for biodiversity conservation, ecosystem function, and habitat quality.

Savanna Structure and Wildlife: This DFC emphasizes savanna structure in all three layers but does not emphasize native ground and shrub layer composition except to develop specialized habitat for selected wildlife species. A primary concern in the shrub and ground layers is controlling the most aggressive invasive exotic species. Its advantage is that it is significantly less costly to implement than full savanna restoration. The cost savings come at the price of lower habitat quality and reduced overall ecological function.

Full Woodland Restoration: This DFC prioritizes the same high habitat quality and species diversity targets as the full savanna restoration scenario but includes greater numbers of trees and snags for higher total tree canopy cover. Shrub layer targets include greater numbers of species and increased cover compared to savanna. Ground layer cover targets include a greater ratio of forb species to graminoid species, and lower cover relative to savanna.

Woodland Structure and Wildlife: As with savanna structure, this DFC focuses on oak woodland structure at all three layers but does not emphasize native species composition in the shrub and ground layers. The focus is on retaining woodland structure for wildlife habitat but reducing restoration costs for landowners.

Fire Hazard Reduction: This DFC is based solely on reducing fire hazard by developing a canopy layer with non-overlapping tree crowns. This goal can be met through tree and shrub layer thinning alone. Goals focus on maintaining prescribed distances between the crowns of canopy layer trees and minimizing the continuity and height of shrub layer and ground layer vegetation. There is no preference for retaining oak over other canopy layer species, only tree density and structure standards.

Table 3. *Canopy layer, shrub layer, and ground layer attributes of desired future conditions. Modified from Garmon (2006)**

	Full Savanna Restoration	**Savanna Structure**	**Full Oak Woodland**	**Oak Woodland Structure**	**Fire Hazard Reduction**
Canopy layer					
percent canopy cover	5%-25%	5%-25%	25%-40%	25%-40%	50%
relative percent native	100%	100%	100%	100%	100%
spatial distribution	tree crowns generally not touching	tree crowns generally not touching	tree crowns generally not touching	tree crowns generally not touching	10' spacing between tree crowns
large trees/acre	5–10 large trees/ac (12-25 trees/ha)	5–10 large trees/ac (12-25 trees/ha)	15-50 trees/ac (37-123 trees/ha)	15-50 trees/ac (37-123 trees/ha)	same as oak woodland
younger tree cohorts	5 saplings / 5 mid-age	5 saplings / 5 mid-age	10 saplings / 10 mid-age	10 saplings / 10 mid-age	no constraints
species composition	70%-90% oak; 10%-30% conifer: Ponderosa pine, Douglas-fir	70%-90% oak; 10%-30% conifer: Ponderosa pine, Douglas-fir	70%-90% oak; 10%-30% conifer: Ponderosa pine, Douglas-fir	70%-90% oak; 10%-30% conifer: Ponderosa pine, Douglas-fir	no constraints
snags	2 snags/ac--18" dbh or larger	2 snags/ac--18" dbh or larger	4 snags/ac--18" dbh or larger	4 snags/ac--18" dbh or larger	limit if fire hazard
Shrub layer					
total percent cover	2-10%, not to exceed tree canopy cover	2-10%, not to exceed tree canopy cover	10%-40%	10%-40%	constraints only for fuels
maximum percent cover invasive exotic[5]	Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤5% = target, >10% = intervention trigger	Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤50% = target, >50% = intervention trigger	Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤5% = target, >10% = intervention trigger	Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤50% = target, >50% = intervention trigger	constraints only for fuels (e.g. height, volatile compounds)
spatial distribution/structure	dispersed individuals and widely scattered groups	dispersed individuals and widely scattered groups	dispersed individuals and widely scattered groups	dispersed individuals and widely scattered groups	fuel breaks and no ladder fuels
species composition	site specific	site specific	site specific	site specific	site specific
Ground layer					
vascular percent cover	continuous: 50-100% cover (varies by site condition and canopy cover)	continuous: 50-100% cover (varies by site condition and canopy cover)	semi-continuous: 25-100% cover (varies by site condition and canopy cover)	semi-continuous: 25-100% cover (varies by site condition and canopy cover)	no constraints
spatial distribution	continuous	continuous	mostly continuous	mostly continuous	no constraints
functional group composition	50-70% cover graminoids; 30-50% cover forbs	minimum 10% grass; minimum 10% forbs	ratio of forbs to grasses higher than full savanna	minimum 10% grass; minimum 10% forbs	no constraints
native species richness (#/m^2)	minimum 15 species/m^2 and 50-75 total species	minimum 2 species/m2 and 10-20 total species	minimum = less than full savanna	minimum 2 species/m2 and 10-20 total species	no constraints
relative percent native cover[5]	minimum 50% for enhancement; minimum 70% for new seeding. Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤5% = target, >10% = intervention trigger	minimum 5%. Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤20% = target, >20% = intervention trigger	minimum 50% for enhancement; minimum 70% for new seeding. : <1% = target, ≥1% = intervention trigger; Tier 2: ≤5% = target, >10% = intervention trigger	minimum 50% for enhancement; minimum 70% for new seeding. Tier 1: <1% = target, ≥1% = intervention trigger; Tier 2: ≤5% = target, >50% = intervention trigger	constraints only for fuels (e.g. height, volatile compounds)

* Tier 1: "0-tolerance" invasive species. Highly invasive due to life history characteristics. Relatively amenable to control if applied early, otherwise can become virtually unmanageable. Tier 2: "low-tolerance" invasive species. Slower to spread, but difficult to eradicate completely

What are the outcomes of converting current conditions to desired conditions?

With data describing the current condition of historic oak habitats in the Willamette Valley, and clear goals for their restoration, the next step was to develop an understanding of the outcomes that result from converting landscapes from their existing conditions to desired future conditions. Restoration outcomes, including the number, size, and species of trees that are cut as well as those that are retained, provide a basis for identifying and understanding which restoration methods (BMPs) may be most appropriate for a given stand. They can also help indicate whether trees harvested from a site can be sold for income and, if so, how much income. They can highlight which scenarios achieve DFCs most quickly, and which provide the highest quality habitat.

To develop estimates of restoration cost, income potential, habitat quality, fire hazard reduction potential, and time requirement, I modeled each of the 25 alternative restoration scenarios using FVS software. FVS can simulate a wide range of stand management scenarios and provides detailed outputs related to each scenario. The following section describes the software in greater detail, and then explains the logic of the programs I wrote to run the restoration models.

About the Forest Vegetation Simulator (FVS)

FVS is a distance independent (non-spatial) individual tree growth model (Dixon 2002). It was designed for use at the stand scale, but can simulate growth, mortality, and management on multiple stands simultaneously to evaluate landscape scale management policies or actions. FVS is widely used by federal agencies and private consulting firms for project planning and alternative scenario analysis (Chad Keyser, FVS training, personal communication). Simulation statistics and model functionality are customized to local conditions via geographic variants. In addition, FVS includes extensions for analysis of stand characteristics related to disease, economics, carbon sequestration, and fire. I used FVS to model oak restoration because it has the ability to simulate complex thinning procedures and provide a wide range of quantitative outputs for comparing scenarios. Key outputs for this project included pre-restoration and post-restoration stand structure characteristics, fire behavior projections, and tree harvest estimates. I used either the Pacific Northwest Coast (PN) or the Westside Cascades (WC) variant depending on the location of the existing conditions study site being modeled.

FVS is most commonly used to model the growth of forested stands. In western Oregon, it is well suited to the interactions of common and commercially valuable conifer species in the Coast and Cascade mountain ranges. Until recently, FVS' Oregon white oak growth and mortality simulations were unreliable. In May 2010 growth and mortality statistics were updated for oak (Peter Gould and Constance Harrington, USFS Pacific Northwest Research Station, Olympia, Washington), but fire modeling metrics and volume statistics remain less accurate for this species. As a result, I exercised caution in interpreting outputs.

Using the software to model oak habitat restoration scenarios requires writing code to thin trees so as to retain desired numbers of trees in specific species and size classes. I used the DFC definitions to program numeric retention targets for medium and large oaks, as well as for a young regeneration cohort and a small number of large conifers. The software functions used to execute the thinnings and achieve these targets is specified in the following pages.

In my analysis, FVS modeling pertains only to canopy layer restoration. Although FVS has the capacity to model changes in shrub layer composition and structure, I did not use this capacity due to time constraints for data preparation. As a result, I assumed achievement of shrub layer DFCs as defined in Table 2.3 for all model scenarios. Shrub layer composition and structure can have significant impacts on fire behavior and fire modeling, so I simulated these impacts using fire models that assumed shrub layers that fit each DFC. For more information on this subject, refer to the *Wildfire hazard modeling* subsection below.

Forest Vegetation Simulator thinning prescription logic

Stakeholders defined DFC targets using both canopy cover percentages and residual trees per acre. I evaluated the outcomes of thinning to each target in FVS to determine which to use for modeling. Although the targets were intended to produce the same restoration result, each led to different stand canopy cover percentages and tree densities as a result of the initial number and size of trees in the stand. Because the canopy cover target defined by stakeholders assumed the presence of large, full-canopied oaks, when FVS thinned to a canopy cover target it only retained the desired number of trees for each DFC if large oaks were present in a stand. If large trees were not present, then post-restoration conditions would include unrealistically high numbers of small trees—an outcome that did not match the trees per acre target, and that would require additional thinnings as the small trees grew larger.

As a result, I modeled savanna and woodland DFCs using the residual trees per acre target. The tradeoff to using the trees per acre target is that some restored stands may be composed of oaks with narrow crowns that will not initially achieve canopy cover targets. Such stands would likely require more time to achieve canopy cover targets and habitat goals because residual trees would need to grow wider, or younger trees would need to fill in the gaps. While less precise in achieving canopy cover targets, thinning to a residual number of trees per acre better represents the method used to thin restoration sites in the field. A significant advantage to using this measure is that land managers and consultants typically discuss restoration targets in terms of trees per acre because it is easier to conceptualize, prescribe, and measure than canopy cover. This ease of use makes it a more realistic thinning target than canopy cover.

Because stakeholders did not specify a trees per acre target for the fire hazard reduction DFC, I modeled these scenarios using the canopy cover target. This thinning procedure best achieves the goal of breaking up a dense tree canopy to reduce the potential spread of fire from one tree to another and still retain the desired canopy cover. Because FVS is not a spatial modeling program, there is no accurate way to specify distance between crowns of residual trees. However, by removing the smallest trees in the stand to achieve the desired canopy cover, this target makes an accurate estimate of the number of full-canopied trees that would be retained after thinning.

Savanna Density Thinning Prescription: I modeled savanna DFCs using a residual trees per acre target of a maximum 22 total trees. This prescription cut the smallest trees in each stand first, so that the residual trees were always the largest trees in their size class. The first size class to be thinned was 0-10 inches. The five largest oaks, and five largest ponderosa pines in this class were retained, then all other trees in the class were cut. This procedure was intended to help ensure age diversity within the stand in accordance with the DFC. The next class consisted of all oaks greater than 10 inches. The 10 largest oaks in the class were retained then all others were cut. If a stand had fewer than 10 oaks per acre over 10 inches DBH, then all oaks in the class were retained. The final class consisted of all other trees over 10 inches DBH. The prescription preserved the two largest conifers per acre then removed all other trees in the stand. Ponderosa pine had a lower cutting priority than Douglas-fir, so if ponderosa pine was present in a stand, it was preserved and Douglas-fir was cut.

To ensure that restored stands were composed of large and healthy oaks, one additional oak was retained per acre for each unhealthy oak that was retained[5]. The goal was to ensure that large but dying trees did not dominate restored stands. Such an outcome could lead to less than the desired number of trees in a stand as unhealthy trees decline and die. Only oaks greater than 19.8 inches DBH had health codes and were subject to the health evaluation.

Woodland Density Thinning Prescription: The woodland density thinning prescription performed the same functions in the same sequence as the savanna density thinning prescription, but it preserved a greater number of trees—a maximum of 49 per acre—in accordance with woodland DFCs. The prescription retained a young cohort of up to ten oaks and ten ponderosa pines per acre instead of five each, a mature cohort of up to 25 oaks per acre instead of ten, and up to four ponderosa pines or Douglas-firs per acre

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[5] Tree health was derived using three variables: crown ratio, crown loss, and a subjective measure of health taken in the field. Crown ratio is the ratio of live crown height to tree height. Crown loss is a measure of mortality for four branch structural classes. The subjective measure of health was a number, 1-3, indicating visibly healthy, intact trees; visibly healthy but slightly or moderately damaged or compromised trees; and visibly unhealthy, dying, or significantly diseased trees. Each variable was converted to a 100-point scale so that all three scores could be averaged. Crown ratio scores were converted to 1 - CR so that a lower score was better. Combined scores of 0-50 were assigned a tree health status of one; 50-75 were assigned a two; and 75-100 were assigned a three. One was considered healthy, two was considered physically compromised but healthy, three was unhealthy—physically compromised and dying under existing conditions.

instead of two.

Fire Hazard Reduction Thinning Prescription: Stakeholders used two measures to define the fire hazard reduction DFC: 1) a canopy cover target of 50%, and 2) a minimum spacing of 10 feet between tree crowns. There were no species preferences defined for this DFC—trees were thinned proportionally according to existing species composition. I initially simulated thinnings that developed 10 feet between tree crowns, using the mean crown area for trees greater than 10 inches DBH, but found that this spacing produced stand canopy cover percentages within a range of 15-30%. This range is well below the 50% target and similar to the oak savanna target range. Because of the discrepancy between the 50% canopy cover target and the 15-30% canopy cover that resulted from thinning to a 10 foot spacing, we chose to use a 40% canopy cover target for fire hazard reduction scenario modeling. The 40% target allows canopy cover to increase as trees grow after thinning, but remains within the bounds of the original 50% target. 40% is also the upper threshold for woodland DFCs, so this percentage provides a way to compare the effects of oak and conifer species composition on fire effects. Comparison of fire effects from thinning to 40% canopy cover versus 50% canopy cover revealed a marginal and not unexpected decrease in overall fire effects, so I concluded that 40% canopy cover was a reasonable target for this scenario.

Wildfire hazard modeling

I modeled wildfire hazard reduction potential using FVS Fire and Fuels Extension (FVS-FFE) and based estimates on three key fire behavior indicators: flame length, fire type, and crown fire index. Definitions of these variables and an explanation of their significance to landowners can be found at the end of this section. FVS-FFE is a fire model built into FVS that is based largely on other pre-existing fire models (Rebain 2009). Its advantage is that it can track changes in fuels over time since it is linked to FVS's vegetation simulation outputs. For this project, that capability means that FVS-FFE can report pre-restoration and post-restoration fire hazard potential, allowing readers to evaluate the likely advantages and disadvantages of different management actions relative to existing conditions.

To accurately model fire behavior at a site scale, FVS-FFE requires a plant association code that describe understory fuel characteristics. FVS does not have a plant association code for oak habitats, so I used the nearest plant associations to these habitat types in the Pacific Northwest Coast and Westside Cascades variants: the Douglas-fir/ocean spray—baldhip rose (PSME/HODI-ROGY) and Douglas-fir/ocean spray/grass (PSME/HODI/GRASS) associations respectively (Keyser 2008). These associations describe dry sites with moderate temperatures and shallow soils in which Douglas-fir is the primary canopy species. The understory of PSME/HODI-ROGY is dominated by shrubby species such as ocean spray and bald hip rose but includes some native fescue bunchgrass. The understory of PSME/HODI/GRASS is dominated by ocean spray and native fescue. FVS-FFE also uses the dominant tree species, as determined by basal area, to assign ground layer fuels. Generic model outputs, therefore, assume the presence of tall, dry, shrubby understory fuels for existing condition and DFC stands. Except for the fire hazard reduction scenario, however, the DFCs we intended to model have grass and forb dominated understories with few shrubs.

To effectively simulate fire behavior in each of the existing conditions and DFC classes used in this project it was necessary to alter some of FVS-FFE’s assumptions about the structure and composition of fuels in our stands. FVS-FFE uses fuel models—a “mathematical representation of the amount and kind of fuels present” in a stand—to simulate fire behavior and fire effects (NWCG 2001, p. 16). Typically, the software assigns up to four fuel models to a stand based on the plant association code. But as stated above, there are no codes that accurately describe the existing conditions used for this study. In addition, once stands have been converted to a DFC they will be managed into the future to maintain early successional characteristics, so ground layer fuels will be even less accurately linked to the plant association. To simulate fire behavior, therefore, it was necessary to override the fuel models assigned by FVS-FFE and use fuel models that were tailored to our existing conditions and DFC prescriptions.

I assigned five of Rothermel's (1972) 13 widely used fuel models to simulate fires in existing conditions, and then used five of Scott and Burgan's (2005) 40 finely tuned fuel models to simulate fire in DFCs. Models for existing conditions classes were based on the research team's descriptions of average fuel conditions for each existing condition class: tall grass (model 3) for savanna, brush (model 5) for open woodland, hardwood litter (model 9) for broadleaf forest, compact timber litter (model 8) for mixed forest, and timber understory for conifer forest (model 10). Scott and Burgan provide assumptions about fuel composition and structure for each of their 40 models and a crosswalk which describes how the behavior of their models vary from Rothermel's 13 models. I used their descriptions and the crosswalk to select fuel models that decrease fire effects in the restored stands in a manner that would be consistent with the lower fuel loads in post-restoration stands.

Note that fire hazard as discussed in this study is calibrated to wildfire hazard. Wildfires are qualitatively different than prescribed fires, which are intentionally ignited under prescribed conditions and controlled to produce ecological or fire hazard reduction outcomes. Wildfires are generally the result of unintended ignitions and spread in an uncontrolled manner. Weather conditions must be severely dry and windy to sustain wildfires. Prescribed fires are ignited only under milder weather conditions and with adequate tools to protect adjacent natural resources and physical infrastructure.

Definitions of fire behavior indicators

The following section defines and describes the fire characteristics and indices used to evaluate wildfire hazard potential in this study. Indices were chosen based on the recommendations of fire professionals.

Surface Flame Length Under Severe Fire Conditions: Surface flame length is the distance from the tip of the flame to the midpoint of the bottom of the flame. Flame length is different than flame height, which is the vertical height of the flame from the ground. A useful illustration of the difference is to think about a flame in windy conditions: the flame will lean forward with the wind reducing its height but not necessarily its length. A flame that is seven feet in length may be less than six feet in height measured vertically from the ground.

Flame length is important because it is related to tree crown scorch height, tree mortality, and total heat pulse to the site—heat per unit area (NWCG, 2001). Higher flame lengths release more heat for a given area and have greater potential to cause the death of trees and tree foliage than lower flame lengths.

Fire Type: In FVS-FFE fires are characterized as surface fires, passive crown fires, or active crown fires. Passive crown fires will occasionally move from the ground surface into tree crowns but will not pass from tree crown to tree crown independent of the surface fire. Active crown fires will pass from crown to crown independent of the surface fire.

Fire type is important because surface fires do not transfer into tree canopies and are, therefore, less likely to kill trees or cross traditional fire barriers such as roads or bulldozer lines. Passive and active crown fires represent respectively higher risk to trees and property because they burn more fuels and have greater potential to travel further.

Crowning index: The wind speed, in miles per hour, at 20 feet above the ground necessary to cause an active crown fire under severe fire conditions (note that a higher number represents a lower risk of crowning) (Rebain 2009). An active crown fire burns and carries through the canopy layer of a stand or landscape; it may or may not be connected to ground fuels. These fires move rapidly across the landscape and have high potential to spread across long distances.

Crown fires represent the greatest threat to property and human safety. Active crown fires are extremely difficult to impossible to control.

How can model outcomes inform restoration decision-making?

I initially encountered skepticism from some professionals about the ability to model oak habitat restoration and produce outputs that would be useful for evaluating other projects.

This skepticism was rooted in the site-specific nature of on-the-ground oak habitat restoration. We chose to address this challenge by modeling seven sites representing a broad cross section of oak habitats across the southern Willamette Valley. While this large number of sites increases the applicability and general validity of the model results, it also complicates interpretation by generating a large quantity of information. Modeling restoration of 34 pseudo-stands to five different DFCs for each pseudo-stand produced 175 discrete restoration scenarios. Each restoration scenario, in turn, produced outputs related to restoration costs, income potential, habitat quality, and fire hazard reduction potential. The scenarios also returned outputs that provided a foundation for evaluating other restoration outcomes such as scenic beauty at maturity and estimates of the time required to achieve DFCs. This final section outlines the organizational structure used to communicate modeling results and suggests how the reader might use it most effectively.

Data reporting hierarchies

To begin the modeling process, it was necessary to convert qualitative characterizations of oak habitats and restoration goals into precise quantitative descriptions of restoration sites and DFCs. To explain the modeling results, the opposite process was necessary; large amounts of quantitative data needed to be translated back into more qualitative characterizations of site conditions that could be useful for decision-making.

I report outcomes at three levels to reduce the complexity resulting from large quantities of information. The first is a high-level overview that characterizes model outputs in relative terms for comparison among restoration scenarios. The high level overview is formatted as a decision matrix that reports characterizations of all six restoration priorities from each of the 25 alternative restoration scenarios. The matrix is intended to provide a quick reference for landowners to consider tradeoffs between different restoration priorities. The second level is a quantitative reporting of the average results for each of the six restoration priority types all seven study sites. Along with the averages, I report the highest and lowest results for each scenario to frame the range of variability within scenarios. Using averages, rather than reporting outputs for all 175 scenarios, was intended to simplify the complexity of reporting too many outputs. The third level of reporting, however, is complete site-by-site results from each scenario for readers who want a more detailed look at the data relevant to a particular scenario. The site-specific results are reported in Appendix B.

Six restoration priorities

This subsection includes descriptions of each of the six restoration priorities used to evaluate the alternative restoration scenarios, and outlines the methods used to develop results for each priority. The restoration priorities are cost, income potential, habitat quality, time required to achieve DFC, wildfire hazard reduction potential, and scenic beauty at maturity. Results for some of the restoration priorities are impacted by existing conditions and DFCs; results for others are only impacted by DFCs. Those that are impacted by DFCs alone are reported last in the decision matrix because results do not change with existing conditions.

Restoration costs: Costs for restoration are composed of initial costs and ongoing maintenance costs. Initial costs are those incurred during the first three labor-intensive years of restoration. Ongoing maintenance costs are those incurred after initial restoration to maintain the desired composition and structure of the DFC. The costs for initial restoration and ongoing maintenance are reported separately. In addition initial restoration costs are combined with income potential in the decision matrix to provide a *net total initial cost* to the landowner.

Estimates for initial costs were developed by summing the costs for the individual BMPs necessary to achieve the DFC within an existing condition classification. FVS outputs of the numbers, types, and size classes of trees within each existing condition class were used to determine the most appropriate BMP for achieving canopy layer targets. For example, large tree BMP costs were used to estimate logging costs on stands with more than 15 trees larger than 12 inches DBH. Because costs for the controlled burn BMP were reported on a site basis rather than per acre, I assumed a 10-acre site and divided the BMP average by ten to estimate per acre costs in this section. DFC targets for restoration in the ground layer and professional guidance were used to determine appropriate ground layer BMPs for each alternative restoration scenario. Readers may choose to increase or decrease BMP cost estimates for their site based on these descriptions because costs and methods on individual sites vary. All restoration procedures required during the first three years of restoration are included in the initial estimate.

I used an “all else being equal” method to calculate costs: except for the unique canopy layer conditions of each existing condition type, and the affects of the canopy layer on ground layer quality, I assumed the same qualities and site conditions (such as low slopes and ability to burn) for each modeled restoration scenario. This approach may cause outcomes to appear more uniform than they would be in reality. There are several exceptions to its application. First, for the savanna existing condition class, I assumed a relatively degraded ground layer that required significant herbicide application and reseeding to achieve full restoration DFCs. Second, for full savanna and woodland restoration scenarios I used the average cost estimate for ground layer seeding, but for structural scenarios I used the low cost estimate. Third, for the open oak woodland class I assumed a slightly lower herbicide requirement but an equally high seeding requirement. Fourth, for all three forested existing conditions classes I assumed that greater canopy cover reduced the presence of aggressive and persistent weeds to the point that less herbicide was necessary. Fourth, I assumed the low end of the average cost estimate for the logging BMP in conifer existing conditions, the mid-point of the average for logging in mixed forests, and the high end for logging in broadleaf forest existing conditions. These differences are based on the greater amount of time required to log oaks.

Estimates for ongoing costs are the sum of the average costs for the BMPs necessary to maintain a DFC multiplied by the number of times each BMP is applied. Estimates for ongoing costs are made on a ten-year basis. Because some BMPs are reapplied multiple times within a maintenance decade, the years in which the BMP is applied are reported along with the BMP in the results section (Chapter IV). The methods and application frequency required for maintain each DFC were outlined by professional advisors.

Income potential: As modeled in this analysis, income stems from selling woody material thinned during habitat restoration. There are two common markets for this wood. The first is for saw-grade conifers that can be milled into lumber. The second is for wood chips generated from trees that do not meet saw-grade standards. Trees suitable for lumber are typically Douglas-firs or ponderosa pines greater than 12 inches DBH (this DBH cutoff is not a fixed number, it is a general number that assumes the top diameter of such a tree is greater than 5 inches, the minimum for most mills). Saw logs provide the most income potential in oak restoration work. Conifers less than 12" DBH and most thinned hardwoods are classified for the wood chip market. Wood chips, sometimes referred to as woody biomass, may be sold to heat-generating facilities; "value-added" production facilities such as wood pellet, compost and mulch producers; and more recently, electric power generating facilities. Chips are rarely sold for paper pulp because of the extra time required to separate pulp-quality logs from other cut trees.

Saw-log value is derived from the quality, length, and diameter at the top end (narrow end) of the log. Logs have greatest value if they can be peeled into sheets for plywood, or cut into high-quality dimensional lumber. Large numbers of branches, a hallmark of open grown trees cut from former oak habitat sites, however, limit a log's value for peeling and lumber. As a result, I estimated costs for conifers sold as saw logs using ODF's lowest value class for saw grade lumber, 3S (12"+). As of fall 2010 the delivered mill-value for 1000 board feet of 3S (12"+) Douglas-fir logs was $160. One board foot is one foot by one foot by one inch (1'x1'x1"), and one log truck can haul roughly 3500 board feet. Transportation cost estimates of $125 were subtracted from income estimates to arrive at a final estimate for the value of logs but not chips.

I generated estimates of the amount of saw-grade wood in each stand by outputting total board feet per acre for Douglas-fir and ponderosa pine trees greater than 12" DBH in FVS (Appendix B). I then multiplied ODF's most current 3S(12"+) log value by the number of board feet removed in each alternative restoration scenario. In some cases the value of these logs may be less than the cost of transporting them to a mill. Conifers less than 12" DBH have little potential to be sold as saw-logs. These smaller conifers, and all other trees in the stand, therefore, are valued as wood chips. I developed estimates of the total weight of these trees in FVS in order to determine their value as chips.

Chip values are more difficult to estimate than timber values because of the variety of uses for which they can be sold. Unlike the saw log market, the chip market consists of diverse buyers who use chips for multiple reasons. The low value and de-centralized nature of the chip market is the primary reason ODF employees cite for a lack of publicly available cost estimates or tracking figures.

Wood chips are generally purchased by weight, but depending on the purchaser's intended use, they may be purchased by volume. There are two standards for weight values: dry weight (measured as a "bone dry" ton) and green weight. As the names imply, a bone dry ton has less water per ton than a green ton and represents more woody material by weight. Dry tons, therefore, have greater value. Because of this variation in pricing and the lack of centralized estimates, I used income estimates reported by restoration contractors. Restoration contractors are in the business of finding buyers for biomass material removed from oak restoration sites, and are likely to have the most accurate view of who is buying and how much buyers are willing to pay. As of summer 2010, I used a value of $20 per dry ton. Implicit in this estimate is an assumption that the marketed material will be relatively dry, as most restoration work takes place in the drier summer and early fall months. This estimate represents the lower range of multiple estimates that varied between $15-$35 per ton delivered.

Wildfire hazard reduction potential: A description of methods for the wildfire hazard reduction evaluation was included previously in the *Wildfire hazard modeling* subsection on Chapter II. The wildfire hazard potential of each alternative scenario and each existing condition class was ranked to provide landowners with an understanding of the impacts of restoration compared to no action for this restoration priority. I used a multi-variable ranking of wildfire hazard potential that considered FVS-FFE outputs of surface flame length, crown fire index, and fire type, all under severe weather conditions.

Habitat quality: This restoration priority is divided into two categories: habitat quality immediately post-restoration, and habitat quality at maturity. To evaluate habitat quality at maturity I used expert evaluations of the habitat provided by each community type defined in the DFCs: oak savanna, oak woodland, and fire hazard reduction thinning. The experts did not evaluate the difference between full restoration scenarios and structure restoration scenarios. The stakeholders who developed the DFCs intended, however, that the full savanna and full woodland DFCs would provide higher overall habitat quality for both native plants and wildlife (Garmon 2006). The savanna and woodland structure DFCs were also intended to provide wildlife habitat, but it was assumed that they would do so on a site-specific basis by targeting restoration to meet the needs of specific wildlife species. For rankings, therefore, I used the expert evaluations of habitat quality for the three DFC structural classes and then ranked the full restoration scenarios based on the original stakeholders' intentions.

Habitat quality post–treatment is a measure of the degree to which a site achieves a DFC immediately after restoration. To evaluate this restoration priority, I used FVS outputs of post-thin stand conditions to determine how close stands were to DFC targets. Rankings were based on the ratio of large oaks (>20 inches) that were present to large oaks that were desired. All post-restoration habitat quality rankings are, therefore, based on the composition and structure of canopy layer trees alone. A high-quality native ground layer adds significantly to the overall habitat quality of a site, but was not modeled in this analysis.

<u>*Time required to achieve DFC:*</u> Time required to achieve DFCs is the time it takes after initial restoration for a stand to achieve the DFC targets. FVS simulations of stand development were used to estimate time to achieve canopy layer maturity. Growth potential for each stand was calibrated using site index data provided by research foresters at the U.S. Forest Service's Pacific Northwest Research Station in Olympia, Washington (Peter Gould and Connie Harrington, unpublished data). Site index is a species-specific measure of the productivity of a given site. It is indicated by the average height attained by trees at a particular age. For example, Douglas-firs that reach 75 feet tall in 50 years on a given site have a site index of 75 and a base 50. Site index is entered

into FVS for Douglas-fir, and the software translates that site growth potential to other species' growth characteristics. FVS Growth simulations began immediately after thinning simulations. Stands that did not have sufficient numbers of trees to achieve DFCs after restoration were "replanted" with seedlings before the simulations began. FVS reported stand characteristics at ten-year intervals, so the time to achieve DFCs is estimated on a ten-year basis. Ground layer timelines were assigned by DFC rather than by restoration scenario because ground layer conditions were not a component of study models. I used professional estimates of the average time required to achieve full savanna and woodland ground layer targets as well as savanna and woodland structure targets.

Scenic beauty at maturity: In 2009, researchers at the University of Oregon's Institute for a Sustainable (ISE) Environment conducted a survey of landowners in the southern Willamette Valley to understand visual preferences for a range of different habitat types (Robert Ribe and Max Nielsen-Pincus, University of Oregon, Institute for a Sustainable Environment, unpublished data). Survey respondents were shown four diverse images of seven different habitat types. These types were arranged along a gradient of increasing canopy cover and conifer composition. Oak savanna landscapes represented the open and oak end of the spectrum and unthinned conifer forests represented the closed and conifer end of the spectrum. Respondents were asked to rate the scenic quality of each habitat type using an eleven-point bipolar scale where -5 indicated "very ugly," 0 indicated neutral, and 5 indicated "very high scenic beauty." Results are based on the 363 responses to the survey.

Conclusions

This chapter described the methods used to build models of oak habitat restoration using a question-based framework to clarify the modeling process and communicate why each model component was important to the whole. It began by explaining the process of classifying existing conditions; continued on to describe the desired future conditions for restoration; explained the tools used to build the simulation models; and described the decision matrix used communicate model results to landowners. The following chapter communicates answers to the question—*How are restoration goals achieved?*—by describing generic best management practices for achieving DFCs.

CHAPTER III

BEST MANAGEMENT PRACTICES RECOMMENDATIONS

Introduction

Best Management Practices (BMPs) were originally developed as a regulatory device for achieving different kinds of policy objectives. Policy makers have used BMPs to define uniform requirements for meeting specific goals; for example, to achieve clean water standards by reducing non-point source pollution flows. BMPs are intended to be adaptable to change and insure a minimum standard for achieving policy goals Muthukrishnan, et. al. (2004).

The BMP approach has since been adopted by other professions and used to outline quality standards for a host of goals. For this project, I use the term BMP to describe a suite of currently state-of-the-art restoration field methods used to convert former oak habitats from existing conditions to desired future conditions. I outline the costs and application parameters of nine BMPs in order to apply them to assessments of alternative restoration scenarios.

This chapter summarizes BMPs for the three structural layers of an oak habitat: the canopy layer, shrub layer, and ground layer. BMPs were selected because of their 1) effectiveness under a wide range of site conditions, 2) ability to meet multiple objectives, 3) cost-effectiveness, 4) limited impact on soils, and 5) availability for use. In some cases there were tradeoffs that had to be made between one or more of the above qualities to select BMPs. In such cases the former qualities were ranked higher than the latter.

BMPs are informed by professional opinion

The BMPs used in this assessment were derived from 2-3 consultations with each of 15 restoration professionals and land managers. These professionals provided a field-based understanding of the best methods for accomplishing specific restoration goals. They also provided informed cost estimates for using each method for oak habitat restoration—

which can be different than using the same method in another habitat type. Most professionals were eager to share their approaches to restoration, and also to learn about the techniques that other professionals are using. This desire to learn from other practitioners hints at one of the challenges to designating BMPs: there are many ways to approach restoration, and depending on budget and philosophy, many ways to define BMPs.

The professionals who advised this project share many common goals but were not unanimous in the restoration priorities and methods they recommended. For example, one government employee prioritized protecting soils above all other concerns when choosing restoration methods. He found that limiting erosion and soil disturbance saves money and produces better restoration results because it reduces weed infestations. As a result, he recommended more time-consuming and costly shrub layer treatments. Another was less concerned about soils and recommended methods that reduced up-front costs. As a result, he recommended whatever method is cheapest at a given point in time. Because of the tradeoffs inherent to selecting BMPs, and the sometimes-conflicting priorities of professionals, I used the qualities that the greatest number of advisors recommended to define the BMPs for this analysis, which are the five criteria described above.

Why use BMPs for modeling?

By using a single set of BMPs as the method for modeling many scenarios, my analysis focuses on assessing the effects that existing conditions and desired future conditions have on restoration costs and tradeoffs, and not effects from the restoration tools themselves. For example, if multiple professionals provided cost and tradeoff estimates for a given restoration scenario, their estimates would likely assume the use of different field methods. Because each method would have different costs and application parameters, each estimate would reflect assumptions about relationships between the existing condition, *the method*, and the future condition. While there is variability in the costs and functionality of individual BMPs that is associated with applying them in different existing conditions, that variability lies reliably along a spectrum that can be correlated with ground conditions, so it is possible to identify the factors that influence the range in costs.

The BMPs used for modeling have the potential to clarify land managers' understanding of the work required to achieve restoration goals. They are often—though not always—the most commonly used methods in the field. With an understanding of why, how, and when they are used, readers will have a solid introduction to the technical work of restoration—even if other tools are better suited to the specific physical conditions and restoration goals on specific sites. A better understanding of the strengths and weaknesses of the BMPs used here may enable readers to make more-informed decisions about the best methods for sites with which they are concerned.

Developing BMP cost estimates

Professionals figure "back of the envelope" cost estimates by adding: *(labor hours x labor cost/hour) + (equipment hours x equipment cost/hour) + (materials cost x amount of materials) + (transportation costs to and from site x number of trips) – (income from natural resources)*. The challenge to developing accurate estimates is correctly figuring the amount of time and materials it will take to complete a project. Hourly costs for people and equipment, and income potential can be more easily quantified. The time and materials required for a job depends on the interactions of multiple variables such as species composition and structure at all landscape layers, the equipment being used, DFC quality standards, distance to chip and log markets, and site topography.

Generally costs for restoration rise with the amount of labor required to meet project objectives. Thus, higher quality results generate higher costs, as do densely vegetated or difficult-to-access steeply sloped sites. Overall project costs decrease when quality standards fall or when income potential from woody material rises. The higher the proportion of saw grade conifers and/or brushy material for biomass markets, the greater potential there is for the restoration work to pay for itself.

The costs for BMPs cannot easily be disentangled from the unique qualities of individual sites, such as slope, species composition, plant density, distance to chip and log markets, and soil erodibility. As a result, I developed three cost estimates for each

BMP—the highest plausible cost, the average cost, and the lowest plausible cost—which are reported along with the descriptions of each method in this chapter. Note that "average cost" does not indicate the midpoint between the highest and the lowest costs but rather the average cost for the average site as estimated by the experts. Thus the "average cost" may be closer to one extreme than the other. This approach provides information about the range of variability associated with each BMP. The range in variability is useful as an indication of the reliability of the average when it is applied to a specific site—the wider the cost range, the less certainty that the average will be an accurate description of a particular site[6].

Limits to BMPs

The BMPs are not intended to be prescriptive for on-the-ground restoration for specific sites. For actual restoration projects, methods must be tailored to accomplish site-specific goals and meet site-specific conditions. Professional contractors, consultants, extension personnel, and agency employees are the best sources for information about tailoring methods to restoration work on specific sites.

Moreover, oak habitat restoration is still in an early stage of development. There are relatively few projects that can serve as precedents for each restoration scenario. This means that the restorationists I spoke with based their opinions and cost estimates on a limited number of projects. While their experiences are useful for anticipating outcomes and costs for the purpose of modeling, those experiences cannot precisely predict outcomes on different sites. In the future, a Delphi method approach to developing cost estimates may produce more uniform estimates than the methods used here.

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[6] Professional advisors estimated the range of costs for each method using their experience and best judgment. For each estimate they also described the ground conditions that increase or decrease costs. In some cases they quantified costs by referencing specific projects (e.g., citing the highest cost and lowest cost projects they had worked on). Where there was variability in the reported costs for a method, I interpolated to determine an average. Interpolation is the process of arranging all costs for a method along a spectrum from the most expensive to the least, associating those costs with the landscape qualities that influence them, then assigning an average cost for the average complexity site. The high cost for each method was determined by the highest estimate from all professionals. The low cost estimate for each method was determined by the lowest estimate. Where information about methods or costs was not available from professionals, I used publicly available retail cost information to fill in the gaps. All final estimates were made on a per acre basis.

BMPs for modeling oak habitat restoration

In this section I provide an overview of the work required to restore each of the three oak habitat structural layers as well as to maintain desired habitat structure over time. Creating desired conditions sometimes requires implementing multiple BMPs within each habitat layer. As a result, there is more than one BMP recommendation for each layer. The BMP recommendations are organized according to the most likely sequence of treatment. For this reason, I describe logging methods in the canopy layer first, and maintenance methods in the ground layer last. For many restoration objectives there are alternative BMPs that were not selected for modeling in this analysis. The alternative BMPs may be better suited to the restoration priorities of some landowners, but were not selected for modeling based on the five criteria noted above. The alternative methods are listed in Appendix A: Alternative Best Management Practices.

After the overview of each structural layer, I describe the BMP recommendations for that layer. Each recommendation follows the same format: 1) the name of the BMP; 2) assumptions about site characteristics and landowner priorities that are relevant to selecting the BMP; 3) a discussion of how it is used to accomplish restoration goals; 4) a list of factors that constrain its use; and 5) a range of cost estimates, with a description of the site conditions that increase or decrease costs.

It may not be necessary for some individuals to read completely through this chapter. For those only seeking information relevant to their own sites, I suggest reading the overview for each structural layer. Next, review the BMP summary table for each structural layer, which highlights key procedural and cost information. Finally, selectively read through the BMPs that are pertinent to individual restoration goals. I also suggest paying particular attention to the assumptions about site characteristics and landowner priorities listed for each BMP. These assumptions may preclude the use of the BMP on some sites. The alternative BMPs may be better suited to sites on which the selected BMP is not feasible.

Canopy layer BMP recommendations

Canopy layer restoration is generally the first process of oak habitat restoration. Canopy restoration involves reducing the total number of trees to restore health to individual oaks, remove undesirable species, or develop savanna or woodland densities. Common tree species in former oak habitats include native Oregon white oak, bigleaf maple, Douglas-fir, ponderosa pine, and incense cedar. In some areas, non-native cherries and hawthorns are prevalent as well. After restoration of the desired canopy structure and species composition is complete, planting native oaks is sometimes required to ensure development of desired future conditions. Because planting takes place after ground layer restoration, the BMPs for this procedure are located in the Ground Layer BMP Recommendation section at the end of this chapter.

There are four restoration objectives within the canopy restoration: 1) large tree thinning, 2) small tree thinning, 3) slash removal, and 4) stump removal. I have selected one BMP to model for each objective, so there are four BMPs in this section. Not all will be necessary for every alternative restoration scenario. In addition to the selected BMPs, there are two alternative BMPs for large tree thinning, two for small tree thinning, and one for slash removal that are listed in Appendix A. Table 4 lists each of the objectives, the BMPs for accomplishing them, and cost estimates for the BMPs. On some sites, one BMP may be sufficient to accomplish objectives one and two (large tree thinning *and* small tree thinning), but slash removal is a necessary component of all projects, and stump cutting is necessary where mowing will be used for maintenance.

Table 4. *Canopy layer BMP summary.*

Restoration Objective	BMP	Cost
1. Large Tree Thinning	Harvester/Forwarder Logging	High: $1850/acre Average: $800-1200/acre Low: $450/acre One Time Setup Fee: $500
1. Large Tree Thinning	1st Alternative: Manual Felling with Mechanical Yarding	High: $5000/acre Average: $1400/acre Low: $500/acre
1. Large Tree Thinning	2nd Alternative: Manual Girdling with Chainsaws	High: $30/tree Average: $10-17/tree
2. Small Tree Thinning	Rubber-Tracked Skid-Steer Tractor Shearing	High: $2400/acre Average: $700/acre Low: $100/acre
2. Small Tree Thinning	1st Alternative: Tree Masticator	High: $800/acre Average: $375/acre Low: $150/acre
2. Small Tree Thinning	2nd Alternative: Manual Felling, Yarding, & Herbicide Application	High: $2800/acre Average: $1400/acre Low: $300/acre
3. Slash Removal	Rubber-Tracked Skid-Steer Tractor Pile & Burn	High: $200/acre Average: $0/acre Low: $0/acre
3. Slash Removal	1st Alternative: Chip and Remove	High: $2800/acre Average: $1400/acre Low: $300/acre
4. Stump Removal	Manual Stump Cutting	High: $350/acre Average: $210/acre Low: $140/acre

Description of canopy layer restoration objectives

Tree thinning is a complex process that often involves coordinating two or more contractors to accomplish several steps: 1) developing efficient roads to get logging equipment to the site and logs off the site with minimal damage to soils, 2) cutting trees, 3) transferring trees to a central processing location on site (often referred to as yarding), 4) cutting trees into merchantable logs, or chip for use as paper pulp or biomass, 5) hauling logs or chips to a mill or processing station, 6) removing logging debris (slash) from the site, and lastly, (7) removing tree stumps to create access for maintenance equipment. If trees are bound for a market they will need to be de-limbed (processed) or chipped on site. While loggers have their own equipment for processing trees, a third-party chipping contractor generally manages chipping. Depending on the size of the project, logs may be hauled by the logger, by trucking contractors, or by both. Coordinating this work and finding the best market to sell the cut trees is typically the logging contractor or logging consultant's responsibility and is included in the overall costs for the BMP. Markets may include sawmills for high quality logs, paper mills for low quality pulp logs, or biomass plants for chips. The size, species, and quality of the trees have a significant impact on their income generating potential. Generally larger, higher quality conifers produce the most income.

Restoration practitioners cite several critical concerns for restoration thinning and canopy layer BMP selection. These include protecting soils by limiting compaction and erosion, and protecting native ground layer vegetation by logging in late summer or early fall when soils are dry and many plants are dormant. Because this timing imperative creates a seasonal bottleneck for logging contractors, work must be scheduled well in advance. Other concerns include removing woody debris (slash) from the ground to avoid smothering ground layer species and altering the soil's chemical and structural qualities, cutting tree stumps flush with the ground to improve mower access during maintenance, and completing work as quickly but safely as possible to reduce costs.

The average diameter of trees in the canopy layer strongly influences canopy layer BMPs, and generally only one thinning method is necessary. If trees are consistently greater than 12" DBH, the BMP for large tree thinning is likely sufficient, because small trees can be efficiently removed with shrub layer restoration techniques. Where less than five trees per acre are greater than 12" DBH, the BMP for small trees is generally sufficient for thinning the canopy layer, because the large trees can be efficiently removed manually. In rare circumstances, small trees and large trees will be present in sufficient numbers that BMPs for both may be necessary to achieve desired future conditions.

A third party consultant or project manager will sometimes manage restoration operations. Consultants plan logging activity, coordinate contractors, identify wood markets, and act as the landowner's agent. Project management fees average $75-$100 per hour. A minimum total project cost estimate is $1500. Because many restoration contractors provide these services, I have not included consultant or project management costs in my modeling. Federal and state agency personnel may also provide some project management services for free if a project is enrolled in a program supported by the agency.

Merchantability of wood products

Net logging costs to the landowner are determined by two factors, 1) the labor fees billed by the logging contractor, and 2) the income earned from extracted wood. One of the working assumptions in this analysis is that logs and chipped debris thinned from restoration sites can be sold to offset the cost of logging, and ideally, subsidize restoration processes in other structural layers as well. There is agreement among most restoration professionals, however, that timber harvest on many remnant oak habitat sites yields little income relative to commercial logging. Those sites that have not yet succeeded to forest cover, and have not been exposed to ecological disturbance or human management, are likely the result of unproductive or excessively droughty soils that reduce the vigor and quality of merchantable trees. Even on productive soils, the older mature trees, which are typically more valuable, will likely have been open-grown, increasing their branching and devaluing their wood. Loggers rely on large trees for income because large trees yield more wood and more money for the same amount of work as required to cut small trees. The income potential from canopy layer restoration, and the ability to offset logging fees, therefore, depends significantly on the existing quality and quantity of trees on a site.

Hardwood species—and all species on sites that produce low-quality timber—are generally chipped and sold by weight for less money than conifers sold as timber. On sites that cannot produce enough chip material to cover the cost of removing it, material may be cut and sold as firewood (although most efforts to sell firewood are not productive). If no market is available, it may be given away free or left to decompose on site. In a worst-case scenario, fees for removing this material may add to the total project cost. Finding the right market, and the right price, at the right time for the wood products harvested from individual sites, however, is a complex business. Landowners should seek professional help to achieve maximum potential benefits.

On the fee side of the net cost equation, it is important to note that loggers bill by the hour, so the faster they work, the lower the per acre cost of canopy layer treatment. Factors that slow work, such as high numbers of small trees, steep slopes, and erodible soils, therefore, increase costs. There is also a difference in the time it takes to log different species. The loggers I spoke with generally agree that oak takes longer to log than fir because oak wood is harder to cut, oak boles (trunks) are often not as straight as fir and take longer to process (de-limb and buck), and because it takes more time to carefully extract oaks that are to be thinned from the canopies oaks that are to be retained. They disagree, however, about how much longer it takes: some figure 5-10% longer while others have found up to 100% longer. The average is likely somewhere closer to 25-50%. Taken together, these existing conditions factors can have a significant impact on logging fees and overall canopy layer restoration costs. Landowners with steep slopes and erodible soils should assume higher than average cost estimates for canopy layer BMPs on their sites.

<u>1. Large Tree Thinning</u>

Large tree thinning procedures are necessary when restoring within forest or woodland existing conditions, to safely remove the large diameter trees in these classes.

BMP: Mechanical logging using harvester/forwarder combination.

Assumptions

- *Minimum site size: 5-10 acres*
- *Restoration goals prioritize protecting the ground layer*
- *Slopes are less than 35%*
- *Harvested tree DBH averages 10-25 inches*
- *Trees greater than 25” DBH are cut manually*

Discussion

Many mechanical logging methods are comparable in terms of cost and speed, but the majority of restorationists interviewed recommend harvester/forwarder logging. Also known as cut-to-length logging, the single greatest advantage to this method is its light impact on soils. Harvesters and forwarders are both equipped with large rubber tires, and turn by articulating rather than skidding on tracks like most other logging machines. As a result they do not tear the ground when they turn. In addition, the forwarder carries logs from a site rather than dragging them like most other yarding vehicles. These two characteristics combine to create significantly less impact on the ground when compared with other logging methods. Skilled operators using other methods, however, can be just as effective at protecting the ground layer as unskilled operators using harvesters. Hiring skilled operators is essential to maximizing the advantages of this BMP.

Harvesters are equipped with an articulated boom that can reach to cut and extract trees from entangled or difficult to access locations. This is a critical capability in restoration logging where some trees may be retained and need to be protected when nearby trees are removed. Harvesters operate by grasping an individual tree with hydraulic arms attached to a cutting head at the end of the boom. Inside the cutting head, a chain saw on a swivel arm cuts the tree while force from the boom ensures that it falls in a desired direction. Unlike most other mechanical logging tools, harvesters can quickly de-limb trees and cut logs to a specified length in the field. Using two feed rollers, the cutting head de-limbs the tree by forcing the trunk through limbing knives, then cuts the log to a specified length (Figure 5). The cutting head can cut and process trees between 2” and 25” DBH. After the harvester cuts and processes a tree, it places the log on the ground where it can be collected and transported to a loading site by a forwarder. The forwarder is a short vehicle that pulls a trailer equipped with a boom that can lift logs onto the trailer (Figure 6). More traditional logging methods require dragging whole trees to a staging site, called a landing, where they can be de-limbed using a separate processor. This process has greater potential to damage soils because it requires more trips and each trip causes increased erosion. Processing in the field makes it cost-effective for the forwarder to remove many logs in a single trip without dragging trees and damaging the ground layer. Some professionals find that dragging oak limbs to a landing site can be particularly damaging to the ground layer because oaks have many rigid branches. After filling the trailer, the forwarder carries its load to a staging area for transfer to hauling trucks. The forwarder also removes logging slash to the staging area as the final stage of operations.

Figure 5. Harvester. *(Left) cutting-head elements: (A). de-limbing knives (B). feed rollers (C). grappling arms with chainsaw. (Cutting-head is oriented horizontal to the ground here.) (Right) Harvester de-limbing logs in the field. Photo: www.wikimedia.org*

Figure 6. *Forwarder unloading processed logs at landing. Photo: www.wikimedia.org*

Constraining Factors

1. To minimize soil damage from repetitive motion, loggers must develop roads across restoration sites. Although the roads minimize soil disturbance, they still result in erosion and intensify damage to understory species within the road path.
2. Set-up fees, equipment scarcity, and equipment size all limit harvester/forwarder cost-effectiveness on sites less than 10 acres or without significant income potential.
3. Harvesters and forwarders are relatively uncommon and less available compared to other equipment.
4. Although uncommon in oak restoration, cutting trees larger than 20-25" may require traditional hand felling and increased cost.
5. Harvesters leave stumps at least 4" above grade (like other large mechanical logging methods). High stumps impede mower access and must be cut to grade at extra cost.
6. There may be more time and cost associated with collecting slash when compared with whole tree logging methods because harvesters leave slash in the field rather than at a central location.

Harvester/Forwarder Cost Estimate

High: $1850/acre | Average cost $800-$1200/acre | Low: $450/acre

One time initial setup fee: $500/site

Harvester/forwarder services are billed by the hour. Current rates are $150 per hour for the harvester and $125 per hour for the forwarder. Project costs rise as tree density and site topography increase. These estimates do not include income returned from selling logs or biomass. Actual charges to landowners vary according to the income earned from selling trees.

Harvester/forwarders require an additional $100/hour setup fee to pay for transportation and initialization of the equipment on each site. This fee averages $500/hour on most oak restoration sites. If the site is large enough to sustain work for several weeks, the setup fee may be waived. Typical oak restoration sites are 10-20 acres and not large enough to qualify for the waiver.

2. Small Tree Thinning

Small tree thinning procedures are a component of restoring within woodland or savanna existing conditions to efficiently remove the high numbers of small trees in these classes.

BMP: Rubber-tracked skid-steer tractor equipped with shearing attachment and herbicide applicator.

Assumptions

- *Restoration goals prioritize protecting the ground layer*
- *Slopes are less than 40%*
- *Harvested tree DBH averages 2-12 inches*
- *Most harvested trees are hardwood species that resprout after being cut*

Discussion

On many sites, the canopy layer consists of small diameter trees that blur the line between the canopy layer and shrub layer. These trees are typically hardwoods and/or young conifers that are too small for sale as saw logs (under 9" DBH). Because most such trees will not be sold for income, the highest priority for restoration is to efficiently cut and yard them. Small multipurpose rubber-tracked skid-steer tractors typically are the best tools for this job. The tractors have a low impact on the ground at only 3.1 pounds per square inch; they cut trees at grade—which is important for maintenance access; they are capable of performing multiple additional jobs, such as mowing and removing slash; they can apply herbicide to stumps at the same time they cut stems; and they bill at 2/3 the rate of harvesters and shovel loggers.

Like the cutting head on the harvester, the shearing attachment on the skid-steer tractor quickly grasps and cuts trees, but instead of cutting with a chain saw it utilizes hydraulic shears (Figure 7). Many of the hardwoods found on restoration sites will resprout after being cut. A properly outfitted skid-steer tractor has the ability to apply herbicide to the stump of resprouting species as it cuts. This capacity saves time and money relative to other methods in which crews cut the tree then return to apply herbicide in a separate process. After cutting a tree, the tractor transports it to a staging area. There the trees are manually processed if sold for firewood, mechanically loaded into a chipper if sold as biomass, or manually cut into smaller pieces if piled or burned. Like the harvester, the skid-steer tractor has the advantage of being able to safely extract trees targeted for removal from leave trees. Its primary advantages over other methods are its great versatility, its low cost, and its low pressure on the ground.

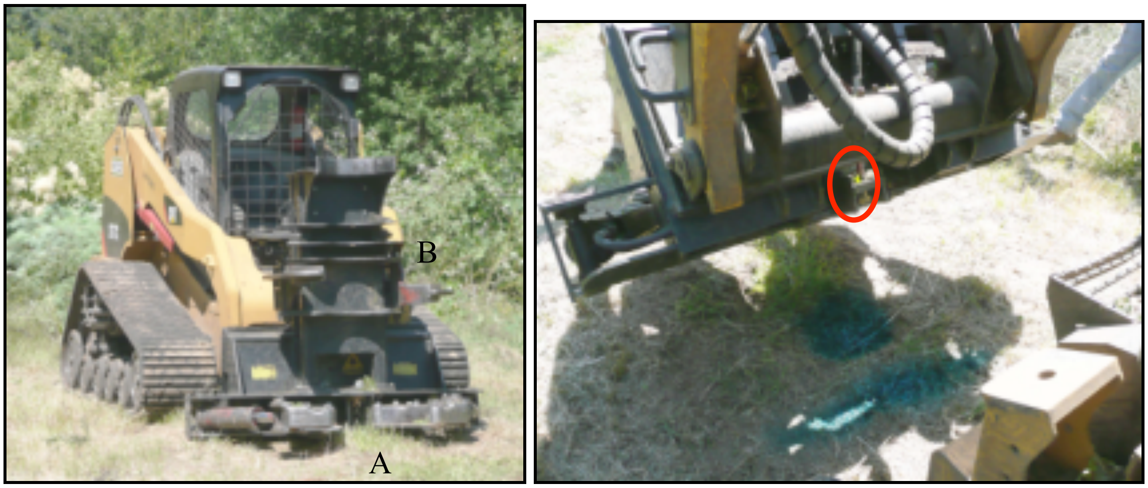


Figure 7. *(Left) Rubber-tracked skid-steer tractor with tree shearing attachment. (A). hydraulic shears (B). grappling arm. (Right) Herbicide applicator nozzle with application on the ground.*

Constraining Factors

1. Skid steering causes significant disturbance to the ground layer. Most professionals indicated this method has a greater impact on the ground layer than manual crews. Good operators can reduce this damage by generally minimizing turns and turning in long arcs where necessary.
2. Densely vegetated sites may need to be mowed first to create access before shearing because skid-steer tractors have limited ground clearance. As a result,

shearing is often used in concert with mowing in the shrub layer. Harvesters and other logging machines are large enough that they can drive over dense shrubs.

Skid-Steer Shearing Cost Estimate

High: $2400/acre | Average cost: $700/acre | Low: $200

The cost of running one skid-steer tractor with a shearing attachment, including herbicide application, is just over $100 per hour. Total per acre costs include mowing access, shearing, piling, and burning slash. Average costs represent cutting 150-200 trees per acre. The high cost was based on clearing an extremely dense 60-acre site (900 trees per acre).

3. Slash Removal

Slash (logging debris) removal is required after all oak habitat canopy layer thinning procedures to avoid smothering ground layer species, altering soil chemistry, and creating a fire hazard.

BMP: Pile slash with multipurpose rubber-tracked skid-steer tractor. Sell as chips on large sites, burn in piles on small sites.

Assumptions

- *Removing slash will make future maintenance easier, preserve soil composition and structure, and improve ground layer quality*

Discussion

Logging slash is the woody by-product of canopy layer restoration—tree limbs, irregularly shaped logs, and small trees. Downed woody debris was not historically an abundant component of oak habitats because of frequent fires. As a result, restorationists prefer to remove slash from the ground layer. Material can be piled and left to decompose onsite; piled and burned; piled and removed from the site; chipped and spread onsite; or chipped and removed off site. Because chipping is an added cost on top of piling, it is only cost-effective if a site yields enough chips to sell as biomass. In addition to its costs, onsite chipping requires adequate space for the chipper truck, hauling trucks, and transfer tractors to maneuver without damaging soils. Only two advisors had worked on projects that generated enough income to offset chipping costs, and both were larger than 50 acres.

For this analysis, piling and burning is the recommended BMP. Two factors justify this conclusion. First, logging or shrub clearing projects utilize mechanical tools that can collect and pile slash relatively quickly, so the tools are often already on site—the cost of logging with harvesters and forwarders even includes the cost of piling, and the cost of shearing with skid-steer tractors includes the cost of piling and burning. Second, selling chips almost never returns a profit; at best it only pays for the cost of chipping and removing material. For modeling, therefore, the difference between chipping and removing slash, or burning slash on site was insignificant. The real cost is in collecting and piling material.

On large sites, slash is generally collected and transported to a loading site or burning pile with a skid-steer tractor equipped with grapple forks (Figure 8). If harvester/forwarder logging is utilized onsite, the forwarder can also collect and transport slash. On smaller sites (<5 acres) that have not already employed mechanical cutting methods, crews collect and transport material manually. Where there is no room to burn onsite without damaging soils, offsite removal may be necessary. Removal is expensive due to the costs of loading, hauling, and paying for disposal. Exposed soils must be sown with native seed immediately after burning to increase competition for weedy species that take advantage of altered soil conditions.

Figure 8. *(Left) Skid-steer tractor with grapple fork attachment. Photo: ekf-industries.com. (Right) Grapple fork attachment for fine material.*

Constraining Factors

1. Heat from pile burning can sterilize soil and alter soil chemistry by volatilizing nutrients. To reduce heat loads, advisors recommend burning slash in small piles or outside of the restoration area.
2. Burning is legally and logistically challenging in areas near urban centers. Smoke and the risk of fire can be threats to the health and safety of neighbors.

Skid-Steer Grapple Cost Estimate

High: $500/acre | Average cost: $100/acre | Low: $0

Stand along costs for piling with a skid-steer tractor are $85/hour, approximately the same rate as hiring three manual laborers ($30/hour per person). The high cost includes piling and removal offsite. The low cost assumes slash removal fees are included in logging costs. Pile burning may or may not be factored into slash removal costs. Pile burning can cost up to $500/day for a two-person crew. The slash from most restoration sites can be burned in a single day. Costs for slash collection and piling are most often factored into canopy and shrub layer thinning methods, so they will not be added to total project cost estimates.

4. Stump Removal

Stump removal is necessary after most oak habitat canopy layer thinning procedures when mowing will be a component of DFC maintenance.

BMP: Cut stumps flush to ground using manually operated chainsaws.

Assumptions

- *Removing logging stumps creates access for mowing equipment during the maintenance phase of DFC development, and reduces fire effects during burns*

Discussion

Stump removal is the process of cutting tree stumps flush to the ground. It is generally necessary after large tree logging because harvesters, like other large mechanical logging methods, generally leave stumps from four inches to 24 inches above grade. Stumps remain after logging because the saw inside the harvester's cutting head sits four inches above the base, so even if the head is placed directly on the ground when cutting, stumps remain. Residual stumps need to be removed because they can impede mower access during the maintenance phase of oak habitat restoration. In addition, stumps may burn longer and hotter than other ground fuels after a prescribed fire, heating soils and nearby plants and causing increased damage to both. They may also potentially reignite a fire after crews have left a site.

Contractors cut stumps flush to the ground using chain saws. Stump cutting is carried out by teams of at least two workers for safety and efficiency. Herbicide treatment of broadleaf stumps may be necessary immediately after flush cutting stumps. After removal, stumps need to be carried to a road or landing for removal.

Manual Stump Cutting Cost Estimate

High: $800/acre | Average cost: $280/acre | Low: $140/acre

Costs for manual stump cutting are billed by the hour. Hourly rates are estimated at $35 per hour, which includes equipment costs. The high estimate was based on costs for an extremely dense site with 900 stumps per acre. The average estimate assumes eight labor hours per acre. The low estimate assumes four hours per acre.

Shrub layer BMP Recommendations

Shrub layer restoration is generally, but not always, the second phase of restoration. If the shrub layer impedes access to logging equipment or crews, however, it will likely be cleared prior to canopy layer restoration. In most cases, the compaction that results from canopy layer thinning will reduce the volume of the shrub layer to the point that physical cutting is unnecessary, and restoration only requires herbicide application or manual methods to remove non-native species or reduce the growth of aggressive natives. For modeling purposes, therefore, full mechanical shrub layer restoration will only be applied to scenarios in which large tree thinning in the canopy layer is not required—for example, in savanna to savanna scenarios. Shrub layer herbicide application will always be considered a component of ground layer preparation (objective 6 in the Ground Layer BMP Recommendation section) because shrubs and ground layer species are sprayed at the same time, not in separate processes.

The shrub layer consists of woody shrubs and small trees less than 2” in diameter. This cutoff represents the lower limit for cutting woody material with canopy layer BMPs, and the upper limit for thinning with shrub layer BMPs. Shrub layer species composition varies, but total species diversity and total shrub cover generally increase as canopy closure increases. As a result, native shrubs have historically been common in oak woodlands, but they represent a minor component of oak savannas. Existing conditions data for this study did not include information about the shrub layer, so shrub layer modeling and BMP recommendations assume generic prescriptions for different transition scenarios.

The primary challenge to shrub layer restoration is removing non-native species. Scotch broom (*Cytisus scoparius*) and Armenian blackberry (*Rubus armeniacus*), for example, proliferate quickly on open, sunny sites. Their fast growth makes it difficult for native species to compete for key resources such as water, nutrients, and light. By forming dense thickets, they can alter habitat quality for native fauna. They can also change the intensity of ecosystem processes: fires that burn through broom stands burn less intensely than do fires in native grasslands. Restoring the shrub layer may also include thinning aggressive native shrubs such as Nootka rose (*Rosa nutkana*) and poison-oak (*Toxicodendron diversilobum*) where they impede restoration goals for the ground layer. Replanting native shrubs is only occasionally necessary. Because replanting native shrubs always follows ground layer restoration, the costs and BMPs for planting shrubs are included in the ground layer BMP section.

There was only one BMP used to model shrub layer restoration. There is, however, one alternative listed in Appendix A for sites on which the primary BMP is not suited. Table 5 lists both BMPs and their associated cost estimates.

Table 5. *Shrub layer BMP summary.*

Restoration Objective	BMP	Cost
5. Shrub Layer Thinning	Rubber-Tracked Skid-Steer Tractor with Mower Attachment & Spot Herbicide Application	High: $850/acre Average: $470/acre Low: $150/acre
5. Shrub Layer Thinning	1st Alternative: Manual Cutting, Grubbing & Herbicide Application	High: $14,4000/acre Average: $2400/acre Low: $1200/acre

Description of shrub layer restoration objectives

Removing shrubs is a three-to-four step process that requires: 1) cutting or mowing plant stems, 2) removing the roots or applying herbicide to kill problematic species, 3) piling and removing the cut material, and, sometimes, 4) replanting native shrubs. Cutting and mowing is necessary to reduce the density of problematic shrubs and create access through them, but because many shrub layer plants resprout after being cut, they must be manually pulled or sprayed with herbicide to kill them completely. The shrub layer can yield large quantities of woody debris. Like logging slash, this debris generally needs to be removed for effective oak habitat restoration. As with slash removal in the previous section, costs for removing cut material are embedded in the costs for shrub layer BMPs.

5. Shrub Layer Thinning

Shrub layer restoration is required in prairie, savanna, and woodland existing conditions to reduce shrub cover to DFC prescriptions and allow light to the ground layer. It may be a component of restoration in some forested existing conditions.

BMP: Mow and remove shrubs using multipurpose rubber-tracked skid-steer tractor with mower attachment.

Assumptions

- *Restoration goals prioritize protecting the ground layer*
- *Herbicide use is acceptable*
- *Slopes are less than 45%*

Discussion

Mechanical mowing using multipurpose skid-steer tractors is the fastest and cheapest way to clear an overgrown or weed dominated shrub layer. In addition, work is easier to coordinate with one or two tractor operators than with large work crews as is required with manual methods. Some public agency managers can employ in-house manual restoration crews who are paid outside of project budgets. These managers suggest that the cost and quality of manual shrub treatment is comparable to mechanical mowing. Without trained and financially subsidized crews, however, manual removal is prohibitively expensive for most private landowners. Clarifying this issue, one land manager wrote: “There is NO WAY that clearing brush such as hawthorn, blackberry, and poison oak is cheaper by hand than a CAT with a mower deck (unless you have free labor and all the time in the world).”

The greatest challenge to achieving shrub layer objectives is removing resprouting shrubs. Digging and pulling roots is problematic for restoration because it disturbs soils, damages native plants, and creates conditions favorable to the germination and establishment of exotic species. In addition, it has the potential to be dramatically more expensive. Applying herbicide is also problematic because it can be damaging to aquatic resources, hazardous to applicators, and because some land owners are averse to its use. Because of its cost and quality advantages however, herbicide application is a recommended component of shrub layer restoration in this analysis.

The fastest and cheapest application method is an all-terrain vehicle (ATV) mounted system employing three crewmembers. One individual operates the ATV while the other two spot-spray alongside the moving ATV. Two or three, or more, herbicide treatments are commonly necessary to remove undesirable shrubs due to the resilience of established shrubs and the preponderance of viable seeds in the soil. Applying herbicide to kill shrubs and then mowing to remove woody material would be the ideal approach because shrub foliage limits overspray onto the ground layer where potentially desirable plants may be negatively affected. The problem with this sequence is that workers generally cannot access a site to apply herbicide without mowing first. As a result, the most common treatment sequence is to mow in late summer when ground layer forbs and grasses are dormant, and then target resprouting shrubs for herbicide treatment the following year. Spraying after mowing also allows managers to survey for remnant natives beneath the shrubs and adapt application methods to protect them if necessary. A final advantage is that mower operators are better insulated from contact with poison-oak (*Toxicodendron diversiloba*) than manual crews. Avoiding or pre-treating this species for the protection of manual work crews can be slow and costly.

Constraining Factors

1. Skid steering causes significant disturbance to the ground layer. Good operators can reduce this damage by generally minimizing turns and turning in long arcs where necessary.
2. Mowers cast small woody chips and plant material across a wide area. The chips are generally not thick enough to suppress native plants in the ground layer but they may alter soil chemistry as they break down or alter fire characteristics.

Skid-Steer Mowing Cost Estimate

High: $700/acre | Average cost: $400/acre | Low: $150/acre

Mowers bill at $91/hour. On a flat site with few trees to work around, one mower can cover 2/3 of an acre in an hour. The average rate covers relatively dense sites and includes time removing small trees. The high cost represents working on extremely dense sites or steep sites, or on projects that require working around retained trees. Low costs are for mowing only. If significant shearing work is a component of the mowing (due to trees larger than 2" DBH), then the pricing for the Small Tree Thinning BMP is a more accurate estimate. For herbicide costs, see the *Ground layer BMPs* subsection below.

Ground layer BMP recommendations

Ground layer restoration is often, but not always, the most complex and costly phase of restoration. It includes methods for removing non-native grass and forb species and replanting with native species. Ground layer species composition historically included a wide diversity of plant assemblages, and restoration entails rebuilding some degree of that diversity. Less is known about the historic structure and composition of the ground layer than the previous two layers because of the early introduction of non-native species for pasturing and agriculture.

Native species composition in the ground layer is dynamic and can change abruptly in time and space. Shifts over time result from disturbance regimes or their absence, and shifts in space result from variability in soil hydrology, chemistry, slope, and aspect. For example, a project manager I spoke with recently planted a carefully composed native seed mixture on one of her sites. The following winter an historic hydrologic flow was restored to part of the area. As a result of that inundation, a host of native wetland species—which were different from those that she planted—sprouted and established on the site, thwarting her seeding efforts. The lesson is that ground layer species composition is often so finely tuned to site conditions that one plant assemblage may exist within feet of a very different assemblage.

On some sites ground layer restoration is not necessary or requires only minimal effort. Multiple restorationists had worked on projects on which the ground layer had not been exposed to weedy species and a high quality, sun-loving native ground layer developed from an existing seed bank after logging. Sites on which this occurred were categorized in one of the three forest existing conditions classes, had never been managed for agriculture, and had not been grazed or logged for many years. In other cases only minimal ground layer restoration work is necessary because of the DFC of a stand. Savanna and woodland structure DFCs only prescribe containment of difficult-to-control invasive species and minimum percentages of grass and forb species. This prescription can generally be met with periodic spot herbicide application and limited broadcast seeding. To simplify modeling to the most common situation, however, full savanna restoration and full woodland restoration scenarios assume low initial native species composition, and that restoration requires removing the existing ground layer and reseeding with native species.

There are six objectives and BMPs for ground layer restoration—three for full ground layer restoration DFCs and three for structural ground layer restoration DFCs. The site preparation and grass and forb seeding objectives are necessary on almost all sites, although high-quality existing conditions will limit the intensity required to implement them. The oak and shrub establishment objectives are generally only necessary for woodland DFCs or on sites deficient in young oaks.

Table 6. *Ground layer BMP summary.*

Restoration Objective	BMP	Cost
6. Full Restoration: Site Preparation	Mechanical Herbicide Application	High: $450/acre Average: $250/acre Low: $200/acre
7. Full Restoration: Grass & Forb Seeding	No-till Seed Drill	High: $1500/acre Average: $500/acre Low: $300/acre Drill cost: $0-50/acre
8. Full Restoration: Oak & Shrub Establishment	Manually Plant	High: $150/acre Average: $75/acre Low: $25/acre
9. Structural Restoration: Site Preparation	Spot Herbicide with ATV	High: $480/acre Average: $150/acre Low: $100/acre
10. Structural Restoration: Grass & Forb Seeding	Broadcast Seed with Centrifugal Spreader	High: $2800/acre Average: $750/acre Low: $225/acre Spreader: $25-60/acre
11. Structural Restoration: Oak Establishment	Retain Stump Sprouts After Cutting Oaks	High: $70/acre Average: $0/acre Low: $0/acre

Description of ground layer restoration objectives

High-quality ground layer restoration typically involves the following four processes in this order: 1) removing non-native species to improve the competitive environment for natives, 2) depleting the non-native seed bank, 3) reestablishing native forbs and grasses, and 4) reestablishing native shrubs and oaks. Removing non-native species is the primary challenge to high quality restoration. However, ground layer management priorities also include increasing and maintaining native species diversity, re-establishing historic ecological processes, providing habitat for vertebrate and invertebrate species, and reducing fire hazard by decreasing fuel continuity.

Ground layer restoration also generally incurs greater costs in terms of time and money than either canopy or shrub layer restoration. For this reason, many restoration projects focus primarily on canopy and shrub layer restoration (savanna or woodland structure DFCs), while ground layer restoration is targeted on sites that host rare or diverse native species (full restoration DFCs). The following examples illustrate the complexity and site-specific nature of ground layer restoration:

1. On sites with native forbs and non-native grasses, high quality restoration requires application of grass-specific herbicide and native grass seed. *This is a high-cost site preparation method, but a low-cost seeding method.*
2. On sites with native grasses and non-native forbs, high quality restoration requires spot application of broad-spectrum herbicide and native forb seed. *This is an average-cost site preparation method, and an average-cost seeding method.*
3. On sites with limited native composition, high quality restoration requires broadcast application of broad-spectrum herbicide followed by multiple applications of native grass and forb seed. *This is a low-cost site preparation method, but a high-cost seeding method.*

Where exotic species are especially problematic or quality goals are high, site preparation and seeding may require two to four years of treatments. For instance, two years of broad spectrum herbicide application may be followed by seeding native forbs and grass-specific herbicide application. Once native forbs are well established, native bunch grasses may be seeded in, thus avoiding reestablishment of exotic grasses and dominance of native grasses.

Although not described in this section, controlled burns are an important component of high quality ground layer restoration. Burning prepares a site for planting by removing thatch and exposing mineral soils for seeds to germinate. When used as an initial restoration method, it is applied after soil preparation and immediately before seeding. Because it is a key habitat maintenance regime, however, this method is described in the DFC maintenance section. Burning will be used as a component of initial restoration for modeling full savanna and full woodland restoration scenarios in the following chapter.

Ground layer BMP subsection organization

Because of the different management requirements for full restoration scenarios and structure restoration scenarios, this section is organized using two alternative restoration sequences. The first sequence is for full ground layer restoration, and the second is for structural ground layer restoration. Readers should reference both sequences to develop an understanding of all ground layer restoration objectives and BMPs, but may want to focus attention on the path that is relevant to their site or sites.

Full restoration ground layer BMPs

Objective 6: Full Restoration Site Preparation

Site preparation is almost always a component of the full savanna restoration scenario DFC to reduce weedy ground layer species composition. It may be a component of savanna structure and woodland DFCs.

BMP: Mechanical broadcast herbicide application using an all-terrain vehicle (ATV) or tractor mounted applicator boom, *or*, spot treat problematic non-native species on sites with existing high quality native composition.

Assumptions

- *DFCs prioritize high-quality native ground layer composition*
- *Site has existing non-native forb and grass species that need to be removed prior to seeding.*
- *There are not enough desirable natives to justify the time and money required to save them.*

Discussion

Site preparation is the process of controlling non-native plants that will inhibit the productivity of natives, and depleting the non-native seed bank. Control may be complete (kill all ground layer species), selective (spot treat only certain species), or, rarely, unnecessary. Ideally, site preparation techniques will preserve existing native species on a site to maintain local genetic diversity. For modeling purposes, however, this project assumes that removing all ground layer species on sites with low native species richness is required. Site-specific decisions about how to prepare the ground layer should be made in consultation with restoration professionals.

Herbicide application requires use of an ATV or tractor. For broadcast application, the tractor is fitted with an aft mounted applicator boom. On oak habitat sites with existing trees, an ATV mounted 20-foot boom can spray approximately two acres an hour. On flat sites with no trees, an agricultural-scale tractor and boom can work even faster. A wicker tool that wipes herbicide on tall species may be more useful when lower native ground layer plants are targeted for retention. A wicker is essentially a spinning towel soaked with herbicide that can be draped over the foliage of taller plants. On high quality sites where only a few exotic species are targeted, professionals advise spot treatment (see the following section for spot treatment recommendations).

Herbicide treatment requires multiple applications over a number of years. At a minimum, herbicide should be applied once a year for two years, but depending on the site and the restoration goal, treatment could increase to six or more applications over three years. Land managers risk failing to achieve restoration goals, increasing cost, and increasing project timelines by replanting before the ground layer has been adequately cleared of weeds and weed seeds.

Herbicide treatment is a relatively low-cost method, but it can be contentious, particularly around aquatic resources or with chemical-averse landowners. Water has the potential to transport herbicide away from its intended area of application. On upland oak habitats with existing trees, however, soil preparation techniques that do not use herbicide are impractical or impossible. Weeding by hand, even if physically possible, is generally prohibitively costly. Solarization, a method that kills weeds and seedlings by heating them under a plastic cover is not cost-effective when working around trees or on slopes. Plowing or tilling, the process of repeatedly turning soil to increase weed seed germination and burying seedlings, is not possible within the root zones of oaks. These financial and practical challenges lead most advisors to the conclusion that herbicide use is an undesirable but necessary method for most ground layer restoration projects.

Constraining Factors

1. Herbicide use may be contentious for some landowners.
2. Most herbicides must not be used near aquatic resources such as streams and wetlands.

Herbicide Treatment Cost Estimate

High: $480/acre | Average cost: $250/acre | Low: $200/acre

Costs for herbicide application using an ATV and spray rig with glyphosate (generic version of Roundup® weed killer) range from $50 to $80 per acre. The high end represents work on sites with steep slopes and greater topographic variability; increased numbers of trees that limit maneuverability; and species composition that requires more time manually spot spraying. Total costs per acre include applying herbicide four to six times. *See BMP 6-A for spot treatment costs.*

7: Full Restoration Grass and Forb Seeding

Seeding is a necessary component of almost all oak habitat restoration DFCs to increase native species diversity and reduce available soil space for non-native species.

BMP: Apply grass and forb seeds using a no-till seed drill.

Assumptions

- *Slopes are less than 35%*
- *Restoration goals prioritize high quality ground layer composition*
- *Site has few existing trees (savanna density) or shallow tree roots*
- *Site size is greater than 5 acres*

Discussion

The greatest cost associated with high quality ground layer restoration is the cost of seed. To reduce costs and increase seed germination, use no-till seed drills to plant on sites where tree roots are not prevalent (often lowland sites that have a history of agricultural use or few remnant trees). A no-till seed drill is pulled behind a tractor and plants seeds directly into the soil. It operates by cutting a narrow furrow in the ground, planting seeds at a specified rate and depth, then covering the seeds back over. No-till drills provide a significant advantage over traditional seed drills because they can be used on packed soils without plowing. They provide an advantage over broadcast applicators because they use half the amount of seed required to plant the same area. As a result, no-till drills reduce cost, simplify operations, reduce soil disturbance, and reduce the potential to expose buried weed seeds relative to traditional seed drills (Fitzpatrick 2004).

No-till drills can also plant seeds over light existing vegetation cover, so they could be used to plant out a seed mix one year then plant over that mix with additional seed the next year. They increase seed germination rates because they apply seeds directly into the soil. They also minimize seed loss to predation. Like other large tools, however, no-till drills are more cost effective on large sites and may not be worth the time and effort required to drill small sites less than 5 acres. If it is not possible to use a no-till drill, the cost-effectiveness of high-quality ground layer restoration decreases dramatically, and lower quality restoration goals become more likely.

Sequencing is very important when planting seed. Forb seeds are generally planted in the first year after soil preparation is complete. Grasses are generally seeded the following year because they grow vigorously and have the potential to smother slower growing forbs. Planting them later gives the less aggressive forbs time to get established. Even after the initial seeding is complete, some professionals encourage “tipping the balance” of the seed bank toward native dominance by seeding so frequently that non-native species have less opportunity to compete. Such a seeding regimen would entail reseeding after every disturbance. This frequency may be cost prohibitive on all but the highest quality sites.

Constraining Factors

1. No-till drills are difficult to use on upland sites with slopes greater than 35%, significant topographic variability, or where existing tree densities impede access. The drill seeds an area 8 feet across but requires almost 12 feet of space between trees because of the width of the wheels.
2. Tree roots can damage the drill, and the drill can also damage roots, negatively impacting the health of desirable trees. It is best used on savanna tree density sites.
3. Drills do not work over tall or thick grasses, on rocky sites, or on sites with low hanging tree branches (which impede tractor access).

No-Till Drill Cost Estimate, Seed Application

High: $50/acre | Average cost: $50/acre or $0/acre | Low: $0/acre

The USFWS operates seed drills on private lands through the Partners for Fish and Wildlife program. The most common arrangement provides use of the drill at no cost to landowners restoring native grassland and oak habitats through the Partners program. It is estimated to cost $40-50/acre through private contractors.

No-Till Drill Cost Estimate, Seeds

High: $1500/acre | Average cost: $400/acre | Low cost: $120/acre

The cost for seeds using a no-till drill varies depending on seed mix composition. The low end of the range reflects costs for relatively common and easy-to-grow grass species that are not sourced from the restoration site. The upper end reflects a high percentage of forb species which are often more scarce and difficult to grow, and two initial seedings. The number and composition of species in the ground layer has a significant impact on restoration costs. The savings that result from planting fewer seeds by using a drill become increasingly important as site scale, and seed quantity, increase.

Objective 8: Full Restoration Oak and Shrub Establishment

Tree and shrub planting is a component of restoration on sites with physically compromised oaks or few seedling oaks to develop a regeneration cohort of young oaks or increase oak composition.

BMP: Manually plant oaks and most shrub species at 50-100 trees per acre.

Assumptions

- *Restoration site does not have enough existing oaks to reach desired future conditions*
- *or, Restoration site does not have oaks with full-canopied form or the potential to achieve it*

Discussion

Planting new shrubs and oaks is the final step in the restoration process. Planting young oaks on open sites is the best way to develop trees with the open grown form that is critical for high quality habitat. Without new plantings, open-form oaks will become increasingly scarce in the future. Planting shrubs is only a component of woodland DFCs. The techniques for planting shrubs are the same as those described for oaks, although planting densities may be higher.

Managers approach planting in different ways. Using shovels and augers they advise manually planting potted or bare root seedlings in the fall, so that seedlings can take advantage of wet winter soils as soon as they are able to grow in the spring. Seedlings may be planted in randomly spaced clusters of roughly five oaks to account for potential mortality. They may also be planted on a loose grid then thinned later to create a naturalistic appearance. Professionals consistently advocate planting more oaks (up to 10 times more) than required to achieve final restoration densities. This approach is used to account for inevitable mortality during the first few years after planting and the slow growth rate of oaks. Devine et al. (2007) found that plastic mulching and solid-walled tree shelters increased seedling growth compared with no treatment, because they protect young seedlings from browse damage and increase moisture availability by removing competing vegetation. Young oaks are also vulnerable to being overrun by machinery or out-competed by shrub layer species. Planting them before removing invasives or seeding the ground layer can slow the work of achieving restoration goals and increase restoration costs. Once the young trees have become established, managers begin the process of selectively removing trees to align the site with DFC densities.

Constraining Factors

1. Oregon white oak is a slow-growing species. Achieving open-grown form and consistent acorn production can take many years to decades, although their deep taproots allow them to establish in grass (www.fs.fed.us/database/feis).
2. Seedlings are extremely vulnerable to animal browsing, fire, and drought in their first years of establishment.

Manual Planting Cost Estimate

High: $150/acre | Average cost: $100/acre | Low: $25/acre

Seedlings are planted individually by hand at a rate of $.50-1.50 each. The low-end estimate is for planted trees and shrubs at savanna densities; the high end is the U.S. Fish and Wildlife Natural Resources Conservation Service reimbursement rate for trees planted with plastic protection sleeves at woodland densities. Costs could rise with the addition of plastic mulch, watering during the first year of growth, and vegetation removal around young seedlings (plastic mulch would obviate the need for vegetation removal).

Structural restoration ground layer BMPs

Objective 9: Structural Restoration Site Preparation

BMP: Spot treat herbicide with ATV-mounted applicators.

Assumptions:

- *DFCs prioritize removing aggressive non-native species prior to seeding*
- *This method may also be used as the high-quality restoration BMP on sites with low incidence of aggressive non-native species, and high native species richness*

Discussion

Spot herbicide application involves selectively targeting species for herbicide treatment, as opposed to broadcast application, which affects all ground layer species equally. The fastest and cheapest spot application method is an ATV mounted system employing three crewmembers. One individual operates the ATV, which carries a small chemical tank; the other two apply the herbicide while walking along both sides of the moving vehicle. Backpack mounted applicators are also effective, but slower. Depending on the species targeted for removal, two or more applications will likely be necessary.

Spot application is not used for oak habitat structure DFCs alone. It is the only herbicide treatment necessary on sites working toward full restoration DFCs with an existing high quality ground layer. In addition, spot treatment is also a common component of maintenance regimes. While prescribed fires and mowing maintain desired ground layer structure, spot treatment is commonly required to selectively remove problematic species once a healthy native ground layer has been established.

Constraining Factors

1. Herbicide use may be contentious for some landowners.
2. Most herbicides must not be used near aquatic resources such as streams and wetlands.

Spot Herbicide Application Cost Estimate

High: $480/acre | Average cost: $150/acre | Low: $100/acre

Costs for spot herbicide application using an ATV and a three-person crew applying glyphosate (generic version of Roundup® weed killer) range from $50 to $80 per acre—the same cost as broadcast application. The high end represents work on sites with steep slopes, and that require more time to protect desirable species or retreat aggressive and persistent species. Total costs per acre include applying herbicide two times at the low cost end of the range, three times for the average, and six times at the high cost end of the range.

Objective 10: Structural Restoration Grass and Forb Seeding

BMP: Broadcast seed with centrifugal spreader.

Assumptions

- *Slopes are greater than 35%*
- *or, Site has a high density of existing trees (woodland existing conditions) with low branches and/or shallow roots*

Discussion

Broadcast seeding is a more traditional approach to seeding and has the advantage of working effectively over uneven terrain, rocky soil, and between obstacles such as trees. The spreader is generally attached to the back of a tractor or towed behind an ATV. It works using the same mechanism that manually operated lawn spreaders use: a spinning disk that casts seed out along a defined trajectory at a user specified rate. For spot application, manual application using a belly spreader is most common. Belly spreaders use the same centrifugal force but the spreader is held on the front of the restorationist's body and spun by hand. They have the advantage of being functional on any terrain, requiring little set up time, and being easy to use.

Constraining Factors

1. Broadcast seeding requires up to twice as much seed as drilling due to seed losses from lack of ground contact and predation. Seed coverage is also less precise than no-till drill application.

2. Manual seeding can be significantly more expensive than drilling because it takes significantly longer.

Seed Spreader Cost Estimate, Seed Application

High: $60/acre | Average cost: $25/acre | Low: $25/acre

High cost is for manual application with a belly spreader at one acre per hour. Low cost is broadcast seeding using an ATV pulled centrifugal spreader.

Seed Spreader Cost Estimate, Seeds

High: $2800/acre | Average cost: $750/acre | Low: $225/acre

Broadcast seeding costs vary widely depending on species composition. See notes about the effects of seed composition on cost in the previous section.

Objective 11: Structural Restoration Oak Establishment

BMP: Retain stump sprouts after cutting.

Assumptions

- *Young or unhealthy oaks exist in sufficient quantity that some can be cut without affecting the potential to achieve DFCs*

Discussion

Where existing oaks remain in the landscape, cutting, fire, or scarification can stimulate epicormic sprouting from the base or roots of the tree. Epicormic sprouts are shoots that develop from latent buds. Young trees that initiate as sprouts from established trees have the advantage of being connected to an existing root system. As a result, they initially tend to grow more vigorously than seedling oaks because they have better access to energy reserves and water. Where it is possible to stimulate this sprouting, it may lead to faster stronger growing oaks with earlier development of open grown form and acorn production. This method also has the advantage of very low costs. A recruitment class can develop from the stumps of oaks thinned in the canopy or shrub layer restoration processes as long as herbicide is not applied to trees targeted for regeneration.

Constraining Factors

1. Method is only effective on sites with existing young oaks
2. New sprouts are susceptible to browsing and may need to be protected

Stump Sprouting Cost Estimate

High: $70/acre | Average cost: $0/acre | Low: $0/acre

There is generally no cost for this procedure because oaks naturally resprout after cutting, and cutting costs are paid during canopy or shrub layer thinning. The high estimate is for regeneration cutting that is not initiated as part of a larger thinning project and assumes two workers completing one acre in one hour.

Habitat maintenance BMP recommendations

Successful development of a high quality native ground layer is a beginning point, not an end point. After achieving the initial desired future conditions for a site, the project enters into a long-term maintenance phase that involves reestablishing ecological disturbances to preserve the DFCs at all structural layers. Without ecological disturbance, a restored oak habitat typically will succeed to the community type that dominated before restoration work began (Apostol and Sinclair 2006). At a minimum, maintenance through ecological disturbance entails strategically introducing a mowing, burning, or grazing regime—or a combination of the three—along with selective herbicide application in order to favor native species and maintain early successional habitat structure.

Willamette Valley oak habitat restorationists generally refer to three primary maintenance methods: burning, mowing, and animal grazing. Mowing is the cheapest and most accessible technique for most landowners but requires site topography that is free of significant rocks or steep topography. Grazing is less common and generally is used as an auxiliary disturbance. It has the potential advantage of providing income, but traditional grazing practices are not as effective as mowing or burning because most ungulates browse selectively and can shift species composition toward unpalatable, weedy species. As noted below, however, rotational grazing has the potential for combining income with conserving grassland diversity.

Timing ecological disturbances according to plant life cycles is critical to maximizing desired benefits to natives and disadvantage to non-natives, perhaps more so than choosing the best methods. Depending on the species that the maintenance procedure is intended to assist and to hinder, maintenance may be performed in the spring, summer, or fall. Maintenance may be timed to occur before species set seed to reduce seed production, during species growth phase to reduce their vigor, or after seeding to expose soil and promote seed germination. It may also be timed to allow ground-nesting birds to fledge their young. Planning appropriate sequencing for individual sites requires professional help.

Habitat maintenance BMP subsection organization

There are two objectives and two BMPs in this section. The objectives, reestablishing ecological disturbances, are necessary for all oak habitat restoration DFCs. As with the ground layer recommendations, this subsection is divided into two paths: one for full restoration scenarios, and one for structural restoration scenarios. The first BMP is required to maintain high-quality, or full restoration, DFCs. The second BMP is sufficient to maintain oak habitat structure DFCs.

Table 7. *Habitat maintenance BMP summary.*

Restoration Objective	BMP	Cost
12. Full Restoration Ecological Disturbance	Prescription Burning with Mowing and Herbicide	High: $11,000/acre Average: $3500/acre Low: $480/acre
12. Structural Restoration Ecological Disturbance	Mowing and Grazing	High: $200/acre Average: $100/acre Low: $0/acre

Full savanna and woodland restoration maintenance BMPs

Objective 12: Full Restoration Ecological Disturbance

Ecological disturbance is a necessary component of all oak habitat restoration DFCs to maintain low tree and shrub cover and develop the open conditions required by ground layer species.

BMP: Prescription burning in combination with mowing and selective herbicide application.

Assumptions

- *Full savanna of woodland restoration is the DFC for the site*
- *Without regular disturbance most oak habitats will succeed to greater densities and altered composition from those outlined desired conditions*

Discussion

Fire is the original tool used to maintain the structure and diversity of many oak habitats in the Willamette Valley. For restoration, it has the particular advantage of removing vegetative debris and exposing mineral soil in preparation for seeding. After establishment of the ground layer, fire can keep aggressive plants in check (generally perennial grasses, shrubs, or seedling trees), giving forbs and annual grasses the space they need to germinate and thrive. It also returns nutrients to the soil in the form of ash, and stimulates growth in some species. Most professionals indicated that without the potential to periodically burn a restored site, it is difficult to impossible to maintain a high-quality ground layer.

However, prescribed fire has highly individualistic effects on native and introduced species in upland prairies and savannas that may vary even for individual species by such factors as burn intensity and frequency (Johnson et al. in prep). In general it appears that fire in Willamette Valley prairies benefits more native than introduced species and detriments fewer native than introduced species in terms of species cover, richness and frequency (Jancaitis 2000, Johnson et al. in prep). When combined with the value of fire for reducing the invasion of woody species, fire appears to be a useful and effective maintenance tool.

Two to three years after establishing the ground layer, restoration professionals recommend an initial burn and then burning again on a three to five year return schedule. If fire return intervals are too short, it may favor introduced species. On the other hand, if too many years pass between fires, it may allow establishment of trees and shrubs beyond the point where they can be controlled by fire. Furthermore, the effects of prescribed burns in Willamette Valley prairie species appear to be short-lived: most species that respond to fire show effects only the first year after a burn. By the second year most effects have vanished or are strongly diminished, suggesting that fire "resets" the clock for succession only briefly, and that its effects for maintaining species diversity may be short-lived (Jancaitis 2000, Johnson et al. in prep).

After a ground layer disturbance of any kind, professionals consistently emphasize the importance of applying native seed. Without seeding burned areas, weeds are likely to quickly dominate the disturbed site. With or without fire, some introduced species may require regular herbicide treatments to keep their spread in check. Prescribed fire is unlikely to kill some problematic species, and was even used by Natives to reinvigorate some species of native *Rubus* (blackberries) and *Vaccinium* (huckleberries) (Boyd 1999).

As a management tool burning is fast, efficient and, if safely executed, affordable. Depending on site location and local laws, land managers may be able to initiate a prescribed fire without professional help at little cost. If not, prescribed fires often require multiple person crews with technical equipment including fire suppression trucks. For modeling, it is assumed that a professional three-person crew equipped with a suppression engine is a necessary minimum. The crew is hired on a full day basis and is responsible for burn planning, ignition, and post-fire mop up. Because of the logistical challenge and potential high cost of burning, it is assumed that mowing will be used to maintain savanna structure every other year between burns. Landowners who work in conjunction with the U.S. Fish and Wildlife Service (USFWS) or Oregon Department of

Forestry (ODF) may be able to arrange for agency personnel to coordinate and implement burns at little to no cost.

Managers repeatedly emphasized that fire is not an initial restoration tool. It is instead a *maintenance* tool. It does not supersede the need to thin trees, clear brush, and remove exotic species. Burning before completing these initial treatments may increase the likelihood of an escaped fire, kill desirable flora, or negatively alter soil chemistry or structure. Because fire benefits some non-native species and is not always effective at killing unwanted species, it should not be introduced prior to thorough seed bank preparation (Maret and Wilson 2000, Clark and Wilson 2001, McDougall 2004). Fire is a highly effective ecological disturbance tool for those with a well-developed understanding of fire effects. It can be dangerous and counter-productive without that understanding and careful application.

Constraining Factors

1. Restoration burning is becoming an increasing challenge in the Willamette Valley due to concerns about smoke pollution, safety, and cost.

Prescription Burning Cost Estimate

High: $11,000/burn cycle | Average cost: $3500/burn cycle | Low: $480/ burn cycle

Burning costs vary significantly by location (county, surrounding land use, topography) and by the number of personnel required to safely accomplish the work. The minimum cost is based on work on a rural site with uniform fuels and safe boundaries (roads, plow lines). Two workers can burn such a site for less than $500 a day. On a site with heterogeneous topography and fuels, and no hard lines between adjacent high-value buildings and natural resources, costs rose dramatically due to the need for multiple personnel, engines and tanker trucks. The average cost represents sites at, or under, 50 acres, with a three-person fire suppression crew, a burn boss to develop a fire prescription and supervise the burn, and a basic engine to safely execute the burn.

Savanna and woodland structure maintenance BMPs

Objective 13: Structural Restoration Ecological Disturbance

BMP: Mowing or grazing

Assumptions

- *Low native ground layer species composition*
- *DFCs prioritize oak habitat structure*
- *or, site constraints or landowner priorities exclude the possibility of initiating prescribed burns*
- *or, landowner prioritizes the income potential from grazing or haying*

Discussion

On some sites, fire can be problematic due to safety and health concerns or high costs. In these locations mechanically mowing then haying or raking the cut material may be the best option. This process limits thatch and litter buildup and more closely resembles the structure of the ground layer after fire consumes the litter and dead vegetation. Without raking or haying the cuttings, mowing has the potential to smother native plants and be counterproductive. Where haying is not an option, mowing alone is sufficient to maintain the ground layer structure required for oak habitats; this method is also the least expensive. Mowing is generally implemented on a one to five year recurrence schedule. Modeling for this project assumed a biennial mowing regime.

Livestock grazing is also an option and some restorationists have experimented with introducing goats to keep shrubby plants at bay. Others have allowed limited access for cattle to reduce grass cover. Animals have the advantage of being mobile and working on steep slopes. They can also provide income if land is leased to ranchers. A primary disadvantage is that grazers may preferentially browse some desirable species, concentrate soil nutrients through waste production, and can damage soils if introduced at inappropriately high densities or the wrong time of the year. Intensive rapid-rotation grazing is a promising approach for using livestock to maintain both habitat structure and native species diversity. By moving livestock in high numbers for short periods of time through a series of temporary pens made with portable solar electric fences, the animals have less tendency to selectively graze on the most palatable species. They are also less likely to concentrate in one location for long periods of time (for instance in riparian areas or under large trees), where trampling and concentrated fertilization from feces and urine can become a problem.

For this project I assumed that grazing would only be introduced if it could be done at no cost to the landowner, so there is no cost estimate for grazing.

Mowing Cost Estimate

High: $120/acre | Average cost: $45/acre | Low: $0/acre

Industrial mowers bill at $60-90 an hour and can cut 1.5 to 2 acres an hour for an average cost of $45 an acre (not including potential transport and setup fees). Given open landscape conditions, and the ability to use readily available farming equipment, costs for raking and baling run approximately $70 per acre. Combined costs are approximately $120 per acre. Selling the hay may offset costs, assuming that there are no weedy or unpalatable plants in the balse. Low costs reflect the potential to earn income by leasing land for grazing—the fees from which can offset mowing or baling costs. Average costs or for mowing alone. High costs are for mowing and baling.

Conclusions

In the process of talking with professionals and selecting the best management practices described in this chapter, it became clear that there are many different restoration tools for achieving oak habitat restoration goals. Each comes with its own set of costs and tradeoffs. I have highlighted those methods that professionals consistently pointed to as the most effective, versatile, efficient, and non-disruptive to the sites they were intended to restore and widely available. The methods are useful across a wide range of landscape conditions and for achieving multiple landowner priorities.

As the tools that enable restoration from existing conditions to desired future conditions, these best management practices provide the foundation for the restoration scenario models in Chapter IV Results and Discussion. Most significantly they provide the cost estimates for each scenario. With an understanding of how site conditions influence the costs for each method, readers can assess how the costs on their own sites might vary from the scenario estimates in the next chapter. But beyond dollars and cents, these methods contextualize restoration field processes, and highlight the technical challenges to achieving restoration goals. By understanding how the methods work, readers gain an understanding of the complexities of working within different existing conditions classes and how those conditions shape restoration goals. The BMPs provide the foundation for scenario modeling, but they also help shape a clear understanding of the real work required for oak habitat restoration.

Knowledge, tools and techniques for oak habitat restoration are evolving rapidly. Some equipment that has limited use today due to few operators or a short track record may soon lead to new and improved BMPs. Just as equipment like harvester-forwarders or skid-steer tractors have rapidly changed how restoration is achieved, other emerging tools hold the promise for higher quality restoration at lower cost. Furthermore, research is rapidly homing in on how to best apply traditional tools such as fire, grazing and mowing to more reliably, effectively and efficiently achieve specific outcomes in different settings.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The process of determining an appropriate desired future condition (DFC) for a given site requires balancing the different restoration priorities that a landowner has for his or her property with the opportunities and constraints of their existing conditions. Existing site conditions, in most cases, are not a matter of choice. Rather, they determine the set of landscape qualities and potentials that a landowner has to work with in choosing DFCs. Pertinent site conditions include current vegetation community type, property size, property location, topography, soils, hydrology, historic land cover, historic land uses, adjacent land uses, and legal mandates and restrictions. DFCs by contrast, are selected at the discretion of the landowner. Each existing condition has the potential to be converted into any one of the DFCs over time. All conversions, however, involve tradeoffs for achieving different priorities. Priorities such as reducing fire hazard, increasing habitat quality, developing scenic quality, and reducing maintenance costs are primarily functions of DFCs. The degree to which these priorities can be achieved immediately after restoration is tied to existing conditions qualities, but the rankings for each achieved DFC were made independent of existing conditions. On the other hand, priorities such as maximizing income potential, reducing time to completion, and reducing initial costs are functions of the interactions between DFCs and existing conditions.

This study highlights patterns related to different alternative restoration scenario outcomes and provides insight about tradeoffs to restoration priorities; however, as statistician George E.P. Box noted, “all models are wrong, but some are useful.” While the results discussed in this chapter are grounded in expert opinions and actual remnant oak habitats, they are not intended as prescriptions for restoration on individual sites. On-the-ground restoration will always be site specific in nature. It requires informed assessments of the most appropriate restoration goals and tools based on the specific qualities of individual sites.

Building on the research and methods described in the previous two chapters, Chapter IV reports the results of this study in a format that can be quickly accessed by landowners and other restoration decision-makers. Results are organized according to the six restoration priorities included in the decision matrix at the end of this chapter, with each priority comprising a separate section of the chapter: 1) initial and ongoing restoration costs, 2) income potential, 3) wildfire hazard potential, 4) habitat quality at DFC maturity and post-treatment, 5) time to achieve DFC, and 6) scenic beauty at maturity. Following these sections is a brief examination of the opportunities and constraints for restoration within each of the six existing condition classifications. The chapter concludes with the restoration decision matrix, which includes summary results for all restoration priorities within each existing condition to desired future condition scenario.

In each of the six sections I first report model results and then interpret them in light of the complexities of on-the-ground restoration. Because each section reports results for separate restoration priorities, readers may choose to read only those sections that pertain to their own interests. The one exception to this approach is that readers who are concerned with costs or income potential should read both sections because net restoration costs are a combination of the two, and neither is intended to stand alone. I suggest also reading the summary of model results for existing condition classes at the end of the chapter.

Unless stated otherwise, the results reported in this chapter represent the average values across all seven study sites. There are three main classes of results. Some restoration priorities were impacted by both existing conditions and DFCs. Where this was the case, results were reported for all 25 existing condition to DFC scenarios. Other restoration priorities were only impacted by DFCs, not by the existing condition. For these priorities I only reported results for the DFCs. In other cases, restoration priorities were impacted by canopy layer restoration but not by ground layer restoration. In this case, model results were only reported once for both full restoration DFCs and structural DFCs.

Restoration costs

Restoration costs are divided into two phases. The first phase includes initial restoration costs incurred during the labor-intensive first three years of a restoration project. The second phase includes ongoing maintenance costs incurred after the initial phase. Maintenance costs are those required to preserve or further develop the vegetation structure and composition created during the initial restoration phase over the life of the project.

Initial restoration costs are reported separately from restoration income potential. When work is done in the field, these costs are closely tied to one another, and teasing them apart is often all but impossible. To maintain profitability, contractors need to recoup their costs associated with operating equipment and paying personnel, so they charge hourly fees for their services. On projects with income potential from selling logs or biomass, however, the same contractor who does the thinning work generally will take responsibility for selling the thinned wood. In this case, the contractor's total fees decrease according to how much income he or she can earn from the resources they remove. As income potential rises, therefore, net restoration costs fall. One result of reporting initial restoration costs separately from income potential is that some of the lowest cost restoration scenarios may appear to be the most expensive. When reading cost estimates, therefore, it is important to keep in mind that the total initial cost for each scenario is the initial restoration cost *minus* restoration income potential.

Initial restoration costs

Table 8 summarizes each of the 25 existing-condition-to-DFC alternative restoration scenarios modeled in this analysis. Initial restoration costs are impacted by both existing stand conditions and DFCs. High initial tree density and high oak composition increase costs because of the greater time required to cut more trees and because it is more difficult to cut and process oaks than conifers. In addition, full savanna restoration and full woodland restoration DFCs always incur the greatest cost within each existing condition class because of the need to eradicate greater numbers of non-native species and replant with expensive native forb seed. Because cost estimates were calculated using professional estimates for the costs of BMPs as applied on sites other than those used in this study, and thus were not calibrated tightly to our data, there were only slight differences in the costs of restoring from the woodland existing condition class and the three forested classes. Costs for restoring from savanna existing conditions are lower, however, because logging is not required in this class.

Despite the relative similarities among cost estimates in different existing conditions classes, three important factors stand out: 1) full restoration DFCs incur roughly 1.5 to 2.25 times the cost of structural restoration DFCs, in large part because of the cost of implementing controlled burns; 2) stands with large trees that require logging with harvesters (all existing conditions classes except savanna) incur greater expense because harvester logging is more costly than skid-steer logging and because harvester logging requires the additional step of flush cutting stumps; 3) the ability to seed with a drill saves significant cost relative to broadcast seeding, so savanna existing conditions which have lower abundances of trees and permit drilling reduce costs for full restoration scenarios.

Restoration professionals indicated that some site characteristics reliably put costs higher or lower than the average. Most significant are conditions that increase the time, and therefore the cost, of canopy layer treatment. For example, thinning in oak stands can take anywhere from 5-100% longer than thinning in conifer stands because the wood is harder to cut and logs are not as straight. Professionals also report that trees greater than 24 inches DBH must be thinned manually because 24 inches is the capacity of the cutting head on harvesters. Finally, greater numbers of trees per acre, particularly smaller trees that cannot be sold as saw logs, also increase costs because it takes more time to clear the same amount of land when tree density increases. There is too little quantitative data about these stand conditions and the degree to which they influence costs, however, to reliably modify the cost calculations in this study.

Table 8. *Cost estimates and BMPs for initial restoration. Low cost: ≤$1000 per acre, medium cost: $1001-$1500 per acre, high cost: $1501-2000 per acre, and very high cost: >$2001 per acre.*

Restoration Scenario	**BMP1**	**BMP2**	**BMP3**	**BMP4**	**BMP5**	**Cost Estimate (per acre)**	**Cost Ranking**
Savanna/Prairie Existing Conditions							
to: Full Savanna DFC	shear/mow	broad herbicide	burn	drill seed		$1,600	**HIGH**
to: Savanna Structure DFC	shear/mow	spot herbicide	drill grass			$870	**LOW**
to: Full Woodland DFC	shear/mow	broad herbicide	drill seed			$1,250	**MEDIUM**
to: Woodland Structure DFC	shear/mow	spot herbicide	drill grass			$870	**LOW**
to: Fire Hazard DFC	N/A					N/A	**N/A**
Woodland Existing Conditions							
to: Full Savanna DFC	harvester	cut stumps	broad herbicide	burn	drill seed	$2,280	**VERY HIGH**
to: Savanna Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,680	**HIGH**
to: Full Woodland DFC	harvester	cut stumps	spot herbicide	drill seed		$1,930	**HIGH**
to: Woodland Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,680	**HIGH**
to: Fire Hazard DFC	harvester					$1,000	**LOW**
Broadleaf Forest Existing Conditions							
to: Full Savanna DFC	harvester	cut stumps	spot herbicide	burn	broadcast seed	$2,755	**VERY HIGH**
to: Savanna Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,880	**HIGH**
to: Full Woodland DFC	harvester	cut stumps	spot herbicide	broadcast seed		$2,405	**VERY HIGH**
to: Woodland Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,880	**HIGH**
to: Fire Hazard DFC	harvester					$1,200	**MEDIUM**
Mixed Forest Existing Conditions							
to: Full Savanna DFC	harvester	cut stumps	spot herbicide	burn	broadcast seed	$2,555	**VERY HIGH**
to: Savanna Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,680	**HIGH**
to: Full Woodland DFC	harvester	cut stumps	spot herbicide	broadcast seed		$2,205	**VERY HIGH**
to: Woodland Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,680	**HIGH**
to: Fire Hazard DFC	harvester					$1,000	**LOW**
Conifer Forest Existing Conditions							
to: Full Savanna DFC	harvester	cut stumps	spot herbicide	burn	broadcast seed	$2,355	**VERY HIGH**
to: Savanna Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,480	**MEDIUM**
to: Full Woodland DFC	harvester	cut stumps	spot herbicide	broadcast seed		$2,005	**VERY HIGH**
to: Woodland Structure DFC	harvester	cut stumps	spot herbicide	broadcast grass		$1,330	**MEDIUM**
to: Fire Hazard DFC	harvester					$800	**LOW**

Another factor that could increase costs but was not modeled in this project is the density and composition of the existing ground and shrub layers. Professionals report that greater numbers of aggressive and persistent weeds increase costs because greater time and effort is required to remove them prior to replanting. If herbicide and mowing are selected as BMPs, costs increase due to greater numbers of treatments. If manual weeding is selected as the BMP, costs increase because more time is required to complete the task. Sites with high densities of persistent species will likely incur costs toward the high end of each BMP cost estimate.

Restoration professionals indicated that, perhaps counter-intuitively, higher quality existing conditions often increase initial restoration costs. Professionals noted that the time and effort required to protect desirable native species while working to remove undesirable species had the effect of increasing costs compared to the process of removing all species on a site and replanting with natives. The same idea follows for logging on sites with high quality oaks in the canopy layer. Most professionals stated that it is faster, and therefore cheaper, to remove all trees on a site than to carefully remove selected trees from the canopies of desirable oaks. This concept has important implications for restoration on sites with few native grasses or forbs, and few high-quality oaks to retain. Although such sites are not typically targeted for restoration, they may present low-cost opportunities to managers, particularly if they are positioned in spatially strategic locations for achieving landscape-scale restoration goals over time.

A final important note about initial cost assessments is that ground layer restoration was assumed to require roughly the same processes and costs for all existing condition classes. Restoration professionals noted, however, that well-shaded and historically undisturbed sites might have very low invasive species composition and a high quality native seed bank. Where this is the case, full restoration DFC costs could be significantly lower within forested stands. This assessment assumed slightly lower weed composition in the ground layer of forested existing conditions such that spot herbicide treatment was sufficient and broadcast treatment was not necessary.

Each scenario includes the BMPs necessary for restoration and a general cost range to achieve the DFC that is based on the average cost of each BMP as indicated in Chapter III.

Ongoing maintenance costs

After initial restoration has been completed, habitat maintenance is required to develop mature DFCs. This second phase of restoration generally begins in the fourth year of restoration and continues through the life of a project. Because maintenance requires a sequence of steps taken over multiple years, ongoing maintenance cost estimates were assessed over a 10-year period.

Ongoing maintenance cost estimates are reported in Table 9 for a 10-year period. For the first decade of a project, BMPs implemented in years 1-3 were modeled as components of initial restoration. Estimates were based on the lowest costs for each BMP because it was assumed that maintenance only required minimal effort. For example, mowing and spot herbicide treatment should be fast because most small trees and shrubs would be removed, and weeds would be suppressed, in the initial restoration phase. The presence of invasive species that are difficult to eradicate will drive up costs.

Assuming the same existing conditions, maintenance costs for full restoration DFCs are 2.25 to 3.5 times greater than those for structural restoration DFCs. The greater costs are due primarily to the cost of implementing controlled burns, but also include extra cost for repeated seeding of grasses and forbs to encourage native species dominance. At a minimum, most sites will need to be mowed or burned at least every five years to maintain savanna and woodland structure. Cost calculations assumed reintroduction of one of these two processes every two years. In addition, spot application of herbicide to control exotics that do not respond to mechanical treatments is necessary every three years. To supplement the existing native seed bank in full restoration DFCs, reseeding was prescribed once a decade.

Table 9. *Ongoing maintenance cost estimates on a ten-year schedule. "Year" indicates the years in which the BMP is implemented. Low cost: <u><</u>$1000 per acre, medium cost: $1001-$1500 per acre, high cost: >$1501 per acre.*

DFC	**BMP 1**	**Year**	**BMP 2**	**Year**	**BMP 3**	**Year**	**BMP 4**	**Year**	**Maintenance Cost Estimate (10 years)**	**Maintenance Cost Ranking**
Full Savanna	burn	1,5	mow	3,7,9	spot herbicide	2,5,8	no-till drill	5	$1,590	**HIGH**
Savanna Structure	mow	1,3,5,7,9	spot herbicide	2,5,8					$450	**LOW**
Full Woodland	burn	1	mow	3,5,7,9	spot herbicide	2,5,8	manual plant	5	$1,150	**MEDIUM**
Woodland Structure	mow	1,3,5,7,9	spot herbicide	2,5,8					$450	**LOW**
Fire Hazard	N/A								N/A	**N/A**

The time and money required for habitat maintenance are generally tied to the quality level of the DFC. Full savanna and woodland DFCs require more intensive and costly maintenance procedures to control undesirable non-native species while simultaneously establishing and protecting native species in the ground layer. Savanna and woodland structure DFCs are less focused on the composition of the ground layer and require less intensive, and sometimes less frequent, maintenance. Both quality levels require similar maintenance regimes to control the invasion of trees and shrubs. As a general principle, the most efficient management strategies integrate the control of woody invasion (e.g., burning and mowing) with management of grasses and forbs. For instance, burning and mowing are typically followed by either spot herbicide of exotics or seeding of native grasses and forbs, so that any space opened up by disturbance is filled with desired ground layer species. Maintenance requirements will vary according to the individual site and its vegetation.

Influences on maintenance costs are not limited to maintenance frequency; they also apply to the BMPs required to do the maintenance work. Controlled burns are widely considered the best tool for maintaining savannas because of their effectiveness at removing thatch, exposing mineral soils, developing ground layer heterogeneity, checking aggressive weeds, and restricting forest succession. The ability to implement a burn, however, may be constrained by cost, high fuel loads on adjacent land, or restrictive burn policies. Where there are few constraints, burning can be quick and cost-effective, which equates to a low-cost maintenance requirement. Where burning cannot be easily implemented, however, it may be considered a high-maintenance requirement, and mowing on an annual or semi-annual basis may be easier and cheaper.

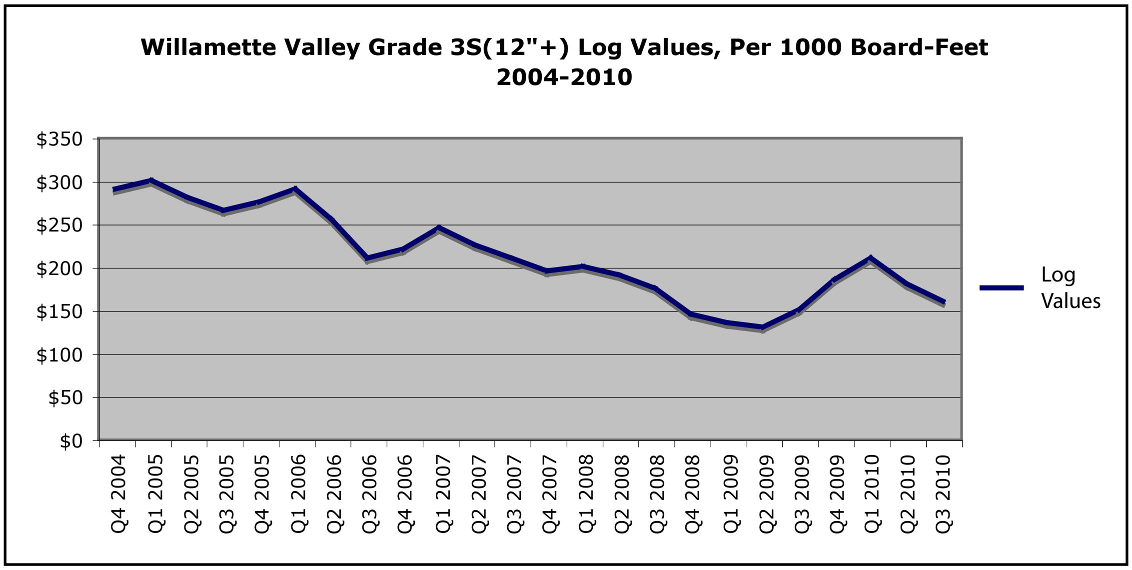
Maintenance costs are easy to overlook at the outset of a project. Professionals indicate that it is often relatively easy to secure funding for initial restoration work, but more difficult to secure the lower sums necessary to maintain habitat structure over time. Cost modeling suggests that ongoing maintenance costs can be significant, and DFCs have a large impact on maintenance totals. Long-term cost planning should be a component of initial oak habitat restoration planning. Thorough planning should consider maintenance funding sources and the BMPs required to maintain DFCs.

Restoration income potential

Oak habitat restoration has the potential to generate income that can offset initial restoration costs. Income is developed from selling the logs and/or wood chips from trees removed during canopy layer restoration. Finding the most appropriate and profitable market for thinned material can be challenging and generally requires the assistance of contractors or consultants. Wood prices vary dramatically with time of year, distance to buyer, fluctuations in commodity prices, and fluctuations in fuel costs. Generally, the income that a landowner receives from logs and chips is the price the material earns at the mill *minus* the costs of cutting, sorting, processing, loading and transporting it (the contractor's fees). The Oregon Department of Forestry (ODF) estimates that costs for cutting and transporting logs (not chips) to market range from $125 to $225 per 1000 board feet of wood. The value of the wood delivered to a buyer must meet this minimum to return income to the landowner.

Professionals emphasize that the cost of hauling wood to a willing buyer is the largest unknown variable in cost estimating. The distance from the restoration site to the buyer, the hauler's ability to offset costs on the return trip back to the site, and the price of fuel are all difficult to predict. Transportation costs are particularly volatile due to the paucity of both chip buyers and saw mills that can handle the low-quality wood thinned from oak restoration sites.

Mill payments too are subject to wide variation over time (Graph 1). For example, the value of 3S(12"+) saw logs in the Willamette Valley (the lowest value class tracked by ODF, and likely the most appropriate for logs thinned from oak habitat restoration sites) fell over $150 per 1000 board feet, nearly 50%, from 2005 to early 2009. From 2009 to the end of 2010 alone it had gained and lost approximately $75 in value per 1000 board feet. Although low-grade saw log prices were falling as of the third quarter of 2010, future trends are impossible to predict.



Graph 1. *Oregon Department of Forestry grade 3S(12"+) log values by quarter, 2004-2010. (www.oregon.gov/ODF/STATE_FORESTS/TIMBER_SALES/logpage.shtml)*

Income estimates are reported in Table 10. Conifers greater than 12 inches DBH are valued as saw logs, and all other trees are valued as woodchips. On actual sites saw log quality trees may sometimes be sold as chips. Where this is the case the log value for a scenario would decrease and the chip value increase. At third-quarter 2010 log and chip prices, a "low" estimate *may* provide enough income to pay for the cost of chipping and removing logs, without offsetting any logging costs. A "medium" estimate was likely to pay for the cost of chipping and removing logs and *may* return some income to the landowner to offset logging costs. A "high" estimate was likely to pay for the cost of canopy layer restoration and hauling wood to a mill and *may* return income to the landowner to offset restoration in other structural layers. At a present value of $160 per 1000 board feet, thinned logs may cost more to remove than they can generate in income after subtracting logging and transportation costs. In early 2010 the same logs had a value of $210 per 1000 board feet, making income potential significantly greater. Higher quality logs than those assumed for estimates in this analysis will raise the income potential of a site.

Table 10. *Income potential estimates from logs and wood chips. Estimates have subtracted transportation costs and include both 2005 and 2010 log prices for comparative purposes*. Low: <$550 per acre; medium: $550-$900 per acre; high: $900-1250 per acre, very high: >$1250 per acre.*

Restoration Scenario	**Average Income Potential Estimate From Logs--Fall 2010 Log Values (Range)**	**Average Income Potential Estimate From Chips --Fall 2010 Chip Values (Range)**	**Total Income Potential Estimate--2010 Values**	**Average Income Potential Estimate From Logs--Winter 2005 Log Values (Range)**	**Generic Ranking Total Income Potential 2010**
Savanna Existing Conditions					
Savanna DFCs	$0 ($0-50)	$0 ($0-50)	**$0**	$50 ($0-250)	**NO INCOME**
Woodland DFCs	$0 ($0-0)	$0 ($0-50)	**$0**	$0 ($0-50)	**NO INCOME**
Fire Hazard Reduction DFC	$0 ($0-50)	$0 ($0-0)	**$0**	$0 ($0-0)	**NO INCOME**
Woodland Existing Conditions					
Savanna DFCs	$100 ($0-350)	$400 ($50-750)	**$500**	$550 ($0-1,800)	**LOW**
Woodland DFCs	$100 ($0-300)	$250 ($50-550)	**$350**	$450 ($0-1,500)	**LOW**
Fire Hazard Reduction DFC	$50 ($0-100)	$250 ($0-450)	**$300**	$200 ($0-650)	**LOW**
Broadleaf Forest Existing Conditions					
Savanna DFCs	$50 ($0-150)	$900 ($750-1,100)	**$950**	$250 ($0-700)	**HIGH**
Woodland DFCs	$50 ($0-100)	$750 ($550-950)	**$800**	$150 ($0-500)	**MEDIUM**
Fire Hazard Reduction DFC	$50 ($0-100)	$650 ($400-850)	**$700**	$250 ($100-600)	**MEDIUM**
Mixed Forest Existing Conditions					
Savanna DFCs	$600 ($300-800)	$700 ($500-850)	**$1,300**	$3,000 ($1,550-4,050)	**VERY HIGH**
Woodland DFCs	$500 ($300-650)	$600 ($350-800)	**$1,000**	$2,400 ($1,450-3,250)	**HIGH**
Fire Hazard Reduction DFC	$250 ($150-400)	$450 ($50-650)	**$700**	$1,350 ($700-2,100)	**MEDIUM**
Conifer Forest Existing Conditions					
Savanna DFCs	$1,500 ($700-2,200)	$300 ($100-500)	**$1,850**	$7,600 ($3,550-11,000)	**VERY HIGH**
Woodland DFCs	$1,400 ($650-2,200)	$250 ($100-500)	**$1,700**	$7,100 ($3,350-10,900)	**VERY HIGH**
Fire Hazard Reduction DFC	$600 ($150-1,150)	$250 ($100-400)	**$850**	$3,000 ($800-5,700)	**MEDIUM**

* Readers accessing this document after 2010 can obtain regionally specific, current income estimates of log values online from the Oregon Department of Forestry (www.oregon.gov/ODF/STATE_FORESTS/TIMBER_SALES/logpage.shtml).

Existing conditions are the most important factor for a site’s income potential. Only mixed and conifer forests have the potential to generate income from selling saw logs, and only the forested and woodland classes have the potential to cover the cost of slash removal through broadleaf tree chipping. The savanna class has no income potential and open woodland is little different because although they contain many trees, the trees are small and provide little wood volume. Without a significant number of trees in general and conifers in particular, a stand has low income potential despite the DFC.

DFCs also play a significant role in developing income. In stands with large numbers of conifers, savanna and woodland DFCs produced high income estimates, but fire hazard reduction produced relatively low estimates. In stands with large numbers of oaks but low numbers of conifers, savanna DFCs still produced the highest income estimates, but both woodland and fire hazard reduction DFCs produced relatively low estimates. Fire hazard reduction had lower income potential for two reasons. First, it removes less total wood than oak restoration scenarios because it leaves large conifers, which yield the most wood per tree. Second, it leaves the highest value trees in the stand. Saw-grade conifers develop much greater income for the same amount of wood as chips. Savanna and woodland DFCs generate more income because they remove the majority of conifers, and savanna earns the most income because it removes the most trees. In addition, there were so few large oaks in all the existing conditions classes that almost all large oaks were retained under savanna DFCs; the vast majority of additional oaks retained for woodland DFCs were, therefore, relatively small and had less effect on income (Table 13).

Unlike restoration logging in conifer-dominated habitat types, with oak habitat restoration many of the largest and most valuable conifer trees will be removed and sold as saw logs. As a result, the greater the proportion of large conifers in a stand, the greater the income potential from restoration. Conifer forest existing conditions, therefore, have the greatest income potential, followed by mixed broadleaf-conifer forest stands.

The income potential from wood chips, the other source of income, depends on stand density rather than species. The more trees in a stand, the greater the potential that they can be sold for income. Modeling results indicate that broadleaf forests generally produce the greatest amount of wood chips, followed by mixed broadleaf-conifer forests. One professional contractor I spoke with removed 80+ green tons of biomass per acre from a broadleaf forest site that was restored to savanna. Model projections estimate an average of 40+ *dry* tons of biomass per acre from broadleaf forest stands, with some reaching upwards of 60 tons per acre (for the difference between green tons and dry tons refer to Chapter II).

While income earned from wood chips alone will rarely, if ever, cover total restoration costs, it does have the potential to offset canopy layer restoration costs. In some cases, it may be more cost-effective to remove chips than to leave thinned debris on site. For example, if a contractor is willing to collect, chip, and haul the material at no cost or at very low cost to the landowner, this may represent a lower cost alternative to paying a different contractor to collect, pile and burn or chip the material on site. Removing logging debris without income may also be preferential if it provides better restoration results than leaving it on site.

For restoration, however, there is a substantial and consistent tradeoff between income and the habitat quality achieved immediately post-restoration. The tradeoff to high income potential in forested stands is that stands with the most conifers are also the furthest along on the successional trajectory toward conifer dominance. Conifer-dominated stands generally do not include enough large, healthy oaks per acre to achieve savanna or woodland densities immediately after thinning. Remnant oaks in stands with a significant conifer component tend to be in poor health and physically compromised. Professionals suggest that although compromised oak limbs will resprout after being released from conifer encroachment, the trees are unlikely to regain an open grown “mushroom” crown structure. By contrast, stands with larger and healthy oaks, generally savannas and woodlands, have the lowest income potential but the greatest restoration potential.

Because mill prices for wood are volatile, income potential can change dramatically. The relative comparisons of income potential by restoration scenario made in this study, however, remain valid no matter the mill price because they are based on the quality and quantity of wood generated. Estimates using present prices provide a relative scale of how much income each scenario could generate, and demonstrate what other restoration procedures that income could offset under current prices. By comparing current prices with historic prices landowners can make better-informed decisions about the minimum price they would require to initiate restoration work. For example, prices for 3S(12"+) were approximately twice as high in 2004 as they are today. Because the price is so low at present, landowners may choose to defer maintenance until a potential future time when prices may be higher. This strategy has tradeoffs in that some oaks may continue to decline in health if they are not released from competition, and there is no certainty that prices will rise again anytime soon. Having a good sense of how much income is required to meet project objectives can allow landowners to move quickly when the window of opportunity opens.

Comparing the higher 2005 log values to 2010 values indicates that once transportation and initial logging costs have been met, oak habitat restoration has significant potential to pay for itself, but before that point restoration can be costly. At 2010 prices, $160 per 1000 board feet, restoring in conifer forests will realistically only pay for structural restoration DFCs. At 2005 prices, $300 per 1000 board feet, restoring in conifer and mixed conifer forests has the potential to pay for full restoration DFCs *and* provide income to pay for ongoing maintenance for up to 30 years in a best case scenario. Based on these numbers, a reasonable break even log value for restoring to full restoration DFC standards in conifer forests is approximately $200 per 1000 board feet, and $275 per 1000 board feet for restoring in mixed forests. Above these values, all extra income can be used to offset future maintenance costs.

Higher prices can also stem from high quality logs. The prices used for analysis above assume ODF's lowest quality log value class; this is a likely but conservative measure. Slightly higher quality logs can increase income potential to the point that restoration could break even at 2010 prices.

Wildfire hazard potential

Across the country there is increasing recognition that the loss of historic fire regimes in fire-dependent plant communities has led to increased fuels and increased fire risk. Oak restoration may be able to serve the dual purposes of restoring valuable habitat and providing the service of reducing fire hazard. If so, fire hazard reduction goals may be able to justify the cost of restoration. Oak habitat restoration can reduce wildfire potential and wildfire behavior at both site and landscape scales by reducing fuel height and continuity, changing fuel composition, and decreasing total fuel loads at all three structural layers. Canopy layer restoration creates stand structures in which tree crowns do not overlap and are physically separated from shrub and ground layer fuels. This discontinuity makes it difficult for fire to pass directly from one tree to the next, or from lower structural layers into the canopy layer. Restoration alters species composition by favoring oaks over conifers, and in some cases native bunchgrasses and forbs over dense, tall exotic grasses. Oak restoration reduces overall fuel loads, because all the modeled DFCs require either removing thinned debris offsite or burning it onsite, eliminating its potential as a wildfire fuel source. Additionally, restoration maintains these structural and compositional fuel reductions through the requisite ongoing processes of mowing and burning.

In three of five cases the full restoration DFCs decreased flame lengths, but in only one out of five cases did the structure restoration DFCs decrease flame length over initial condition (Table 11). The most noticeable results were that flame lengths for the mixed and conifer forests, which had extremely low initial flame lengths, increased under all scenarios because of the opening of the canopy. The implications of these results are that high quality ground layer restoration has an important dampening effect on surface flame lengths, and that oak habitat restoration in general reduces crown fire risk. The physical alterations associated with restoration have important suppressive effects on wildfire behavior and, therefore, fire impacts.

Table 11. *Model projections for three wildfire hazard indicators and total fire hazard estimate post-treatment. Indicators assume severe wildfire conditions: temperatures of 70° F and wind speeds of 20 mph at 20' above the canopy. Total hazard potential rankings average all three indicators but greater weight was placed on indicators that represent extreme hazard (passive crowning fires, high flame lengths, low crown index). Fire type—high: passive, medium: surface/passive, low: surface. Flame length—very high: >14 feet, high: 11-14 feet, medium: 8-11 feet, low 5-8 feet, very low: 0-5 feet. Crown fire index—very high: 0-50 mph, high: 50-100 mph, low: >100 mph (a high crown fire index score was given little weight relative to the other two indicators because it indicated impossibly high wind speeds).*

Restoration Scenario	**Fire Type**	**Surface Flame Length (feet)**	**Crown Fire Index* (mph)**	**Wildfire Hazard Potential**
Savanna/Prairie Existing Conditions	Passive Crown	15.9	270.5	**HIGH**
to: Full Savanna Restoration DFC	Surface	6.7	305.9	**LOW**
to: Savanna Stucture DFC	Surface/Passive	12.4	305.9	**HIGH**
to: Full Woodland DFC	Surface	6.4	214.2	**LOW**
to: Woodland Structure DFC	Surface	11.1	214.2	**MEDIUM**
to: Fire Hazard Reduction DFC	Surface	10.1	270.5	**MEDIUM**
Woodland Existing Conditions	Surface	5.2	128.9	**LOW**
to: Full Savanna Restoration DFC	Surface	4.7	350.2	**VERY LOW**
to: Savanna Stucture DFC	Surface/Passive	8.8	350.2	**MEDIUM**
to: Full Woodland DFC	Surface	4.1	251.9	**VERY LOW**
to: Woodland Structure DFC	Surface	7.1	251.9	**LOW**
to: Fire Hazard Reduction DFC	Surface	6.7	134.8	**LOW**
Broadleaf Forest Existing Conditions	Surface	5.1	111.6	**LOW**
to: Full Savanna Restoration DFC	Surface	4.6	364.8	**VERY LOW**
to: Savanna Stucture DFC	Surface	8.5	364.8	**MEDIUM**
to: Full Woodland DFC	Surface	3.9	255.5	**VERY LOW**
to: Woodland Structure DFC	Surface	6.7	255.5	**LOW**
to: Fire Hazard Reduction DFC	Surface	6.6	310.2	**LOW**
Mixed Forest Existing Conditions	Passive Crown	0.9	37.7	**VERY HIGH**
to: Full Savanna Restoration DFC	Surface	5.1	309.6	**LOW**
to: Savanna Stucture DFC	Surface	9.6	309.6	**MEDIUM**
to: Full Woodland DFC	Surface	4.3	186.1	**VERY LOW**
to: Woodland Structure DFC	Surface	7.5	186.1	**LOW**
to: Fire Hazard Reduction DFC	Surface	6.7	90.5	**MEDIUM**
Conifer Forest Existing Conditions	Surface	0.9	26.1	**VERY HIGH**
to: Full Savanna Restoration DFC	Surface	6.1	336.0	**LOW**
to: Savanna Stucture DFC	Surface	11.3	336.0	**MEDIUM**
to: Full Woodland DFC	Surface	5.3	190.7	**LOW**
to: Woodland Structure DFC	Surface	9.3	190.7	**MEDIUM**
to: Fire Hazard Reduction DFC	Surface	6.7	54.8	**HIGH**

*High crown fire index indicates *lower* crowning potential.

Overall, fire modeling results point to three components of restoration that have large impacts on fire hazard potential. The first and most significant is ground layer fuel composition. Tall, continuous, grassy fuels produce much higher flame lengths than shorter, discontinuous fuels. The discontinuous bunchgrass and forb ground layer composition of full savanna and woodland restoration DFCs, therefore, are projected to produce lower flame lengths than their structural DFC counterparts. As noted in the methods section, higher flame lengths are related to increased mortality and faster rates of spread. Faster moving fires are more difficult to control (NWCG 2001). Many common non-native grasses such as tall oat grass (*Arrhenatherum elatius*), grow in dense patches and can reach upwards of 3 feet tall. Under dry and windy conditions, fuels at that height can produce extreme flame lengths approaching 20 feet. These results are almost completely dependent on the modeling assumption I made to choose fuel models that assume taller, denser fuels for cool season exotic grasses, and shorter, sparser fuels for a native ground layer with discontinuous native bunch grasses and greater percentages of forbs.

The second important component is canopy cover. With oak habitat restoration there is an almost inherent tradeoff between opening the canopy to allow light for ground layer species and increasing flame lengths—unless one goes the extra step to increase native grasses and forbs. The increase is due to a combination of two factors: 1) greater light in the ground layer promotes high plant cover and density (total fuels and fuel continuity), and 2) the lower fuel moistures of an open ground layer increases both the potential for fire to develop in the ground layer and the intensity of fires that do develop. Because of their open canopies and dense grassy fuels, savanna structure DFCs and savanna existing conditions consistently produced the highest flame lengths, whereas the forested existing conditions classes all produced the lowest flame lengths. Greater canopy cover and lower flame lengths, however, do not reduce crown fire potential. Crown fire potential increases with fuel continuity and conifer composition, so it can rise even with low ground fire flame lengths. Openness is relevant not only to the DFC, but also to the relationship between a DFC and stand existing conditions. For example, all restoration scenarios implemented within conifer forests and savannas produce open conditions and high flame lengths because there are not enough oaks in these stands to achieve DFC targets.

The third important component is canopy layer fuel composition. Conifers increase crown fire potential. Even when assuming the same fuel types in the ground layer, stands with greater conifer composition modeled lower crown fire indices (higher hazard) for both existing and post-treatment conditions. Only mixed forest existing conditions, conifer forest existing conditions, and fire hazard reduction scenarios converted from those two existing conditions classes produced crown fire indices low enough that they could realistically develop a crown fire; however, none of these modeled stands was projected to develop an active crown fire. Indices for oak-dominated stands were so high that it is unlikely they could ever be achieved. The big implication of this outcome is that although the fire hazard reduction DFC lowers flame lengths somewhat compared to the woodland structure DFCs, it is the most likely to carry a crown fire under extreme fire conditions. In other words, oak woodlands may be better at reducing fire hazard than the fire hazard reduction DFC.

Landowners concerned about the potential for wildfire to carry onto their property from adjacent lands, or risks associated with severe fires developing on their land may realize greater overall fire hazard reduction benefits from restoring oak woodland than implementing a traditional fire hazard reduction thinning. The benefits of oak woodland restoration result from this DFC's high resistance to crown fire and low ground-fire flame lengths. While savanna restoration was better at reducing crown fires, those reductions came at the cost of higher flame lengths, and woodlands still produced such high average crown fire indices that crown fire seems all but impossible. Similarly, the traditional fire hazard reduction DFC was slightly more effective than oak woodland structure restoration at reducing flame lengths, but less effective at reducing crown fire indices. Because of its discontinuous, low-fuel ground layer, however, full woodland restoration produced the lowest average flame lengths of the five DFCs. These combined qualities make it an extremely effective choice for wildfire hazard reduction.

In addition to their ability to reduce wildfire effects, oak habitats are also resilient to wildfire damage. Oaks have physical adaptations that can help them survive or quickly recover from wildfire. They can resprout from latent buds if branches are killed, and they have relatively thick bark that protects them from moderate intensity fires. If a fire generates enough heat to kill the main stem of a tree, oaks can also resprout from latent buds in the roots and utilize the trees' stored energy for new growth, unlike most conifers native to the Willamette Valley.

Despite the relatively high flame lengths that resulted from savanna and woodland structure DFCs, all savanna and woodland stands produced higher crown fire indices (lower hazard) than the fire hazard reduction DFC because of their greater oak composition. These lower crown fire risks may offset the hazards related to higher ground-fire flame lengths for the structural restoration DFCs. One significant tradeoff to higher flame lengths and lower crown fire risk is that higher flame lengths are associated with increased mortality. So while open stands may not develop active crown fires, they may be more likely to suffer losses that setback other oak habitat restoration goals—such as scenic beauty or habitat quality. By converting to full savanna or woodland restoration DFCs, however, it is possible to reduce both flame lengths and crown indices below those produced by the fire hazard reduction DFC. The overall outcomes of the fire modeling suggest that oak habitat restoration can have significant fire hazard reduction benefits over both existing conditions and traditional conifer fire hazard reduction thinning treatments.

Habitat quality

Each of the existing conditions classes and DFCs analyzed in this paper provides important habitat for native species. Individual wildlife species are better adapted, however, to the structural characteristics and species associations of certain habitat types. While conifer forests provide habitat for many forest species, these habitats are abundant in the southern Willamette Valley. Oak savanna and associated grasslands provide habitat for the 97 native vertebrate species, 48 native bird species, and 391 native plant species noted in Chapter II, and oak habitats in general are necessary for 20 conservation status species (Vesely and Rosenburg 2010). Open oak woodlands provide habitat that many savanna and prairie adapted species use as well as species that require greater tree cover. Because less than 12% of historic oak habitats remain in the Willamette Valley, conserving this habitat type is extremely important for the species dependent on it. It is these species that the following habitat quality evaluation is targeted toward. Because landowners may prioritize the rapid realization of high-quality habitat, habitat quality is ranked at two time steps in this section: immediately after restoration, and at maturity—when the DFC has been reached. Rankings are based on the vegetation achieved at both time steps.

Habitat quality at maturity

Expert rankings based on canopy and ground layer habitat values were used to create an overall habitat ranking for each DFC (Table 12). Experts ranked the habitat provided by oak savanna as the highest of the five DFCs. While they noted that other habitat types also provide important habitat, savanna was ranked highest largely because of its greater rarity. Many experts noted that a high quality savanna ground layer is particularly important for hosting native insects, including specialized pollinators that are critical to oak savanna habitat function. Open grown oaks are also a significant component of savanna habitats because of the large numbers of cavities they provide for cavity dwelling species (Gumtow-Farrier 1991).

Woodland was ranked slightly lower than savanna, not because it plays a less important role but because these habitats are more common in the Willamette Valley, and they host fewer grassland species required by native arthropods due to increased shade in the ground layer. The fire hazard reduction DFC was ranked lowest, because of its expected lower composition of oaks and non-native ground layer species composition.

The rankings in Table 12 highlight the two-tiered nature of oak habitats. The canopy layer provides important habitat for specific faunal species, and the ground layer provides habitat for floral and faunal species. The combined habitat provided by these two layers is greater than the sum of their parts, however. Interactions between arthropod and vertebrate species that use one or the other or both of these layers are important to developing the habitat function that restorationists value.

Table 12. *Habitat quality rankings. Final values assume achievement of final DFCs.*

DFC	**Canopy Layer Habitat Quality Ranking**	**Ground Layer Habitat Quality Ranking**	**Overall Habitat Quality Ranking**
Full Savanna DFC	High	High	**VERY HIGH**
Savanna Structure DFC	High	Medium	**HIGH**
Full Woodland DFC	Medium	High	**HIGH**
Woodland Structure DFC	Medium	Medium	**MEDIUM**
Fire Hazard DFC	Low	Low	**LOW**

Habitat quality post-restoration

Habitat quality post-restoration results are reported in Table 13. Rankings were only developed for the canopy layer because ground layer data was not incorporated in this analysis. Results, therefore, are reported only for savanna and woodland structure and fire hazard reduction scenarios.

Modeling indicated that three out of five of the existing conditions classifications included enough large oaks (greater than 20” DBH) to meet savanna DFCs immediately after restoration, but only one included enough to meet woodland DFCs. Oak woodland, broadleaf forest, or mixed forest existing conditions were required to achieve savanna DFC targets, while broadleaf forest existing conditions were required to approach oak woodland DFCs. These oak woodland and broadleaf forest classes provided considerably more habitat potential than the others. In terms of oak health, it is notable that the broadleaf forests were similar to woodlands, but oak health in the mixed and conifer forest classes declined dramatically, as did the number of large oaks. Notably, the savanna existing condition class did not meet savanna DFCs for large oaks due to the low numbers of existing oaks. Evaluations for the fire hazard reduction scenario were considered “not applicable” because there was no minimum specified for large oaks in the DFC targets.

Table 13. *Post-restoration habitat quality rankings, and projections of time required to achieve habitat maturity for three DFC structure categories. Post-restoration habitat quality rankings—low: <50% DFC minimum, medium: 50-100% DFC minimum, and high: >100% DFC minimum. Time to habitat maturity rankings—low: 0-50 years, medium: 50-100 years, and high >100 years. Note: stands that exceeded the DFC maximum number of large oaks did so because of unhealthy trees, which were retained but not counted toward the DFC, target.*

Restoration Scenario	**Post-Restoration Mid-Size Oaks Per Acre (10-20")**	**Post-Restoration Large Oaks Per Acre (>20")**	**DFC Large Oaks Per Acre (>20")**	**Post-Restoration Large Oaks/ DFC Minimum**	**Proportion of Large Oaks in High Health**	**Proportion of Large Oaks in Poor Health**	**Post-Restoration Habitat Quality**	**Years to Achieve DFC Minimum Large Oaks**	**Time To Achieve DFC**
Savanna/Prairie Existing Conditions	3	1.4							
to: Savanna DFCs	3	1.4	5-10	28%	64%	21%	**LOW**	100+	**HIGH**
to: Woodland DFCs	3	1.4	15-50	9%	64%	21%	**LOW**	100+	**HIGH**
to: Fire Hazard Reduction DFC	3	1.4	None	N/A	64%	21%	**N/A**	N/A	**N/A**
Woodland Existing Conditions	32.3	11.9							
to: Savanna DFCs	1.9	10.7	5-10	214%	46%	23%	**HIGH**	0	**LOW**
to: Woodland DFCs	13.6	11.9	15-50	79%	41%	31%	**MEDIUM**	60	**MEDIUM**
to: Fire Hazard Reduction DFC	15	11.9	None	N/A	41%	31%	**N/A**	N/A	**N/A**
Broadleaf Forest Existing Conditions	55.2	15.1							
to: Savanna DFCs	1.7	13.5	5-10	270%	40%	26%	**HIGH**	0	**LOW**
to: Woodland DFCs	15.1	15.1	15-50	101%	36%	34%	**HIGH**	0	**LOW**
to: Fire Hazard Reduction DFC	17.2	15.1	None	N/A	36%	34%	**N/A**	N/A	**N/A**
Mixed Forest Existing Conditions	24	6.2							
to: Savanna DFCs	7.8	6.2	5-10	124%	16%	65%	**HIGH**	0	**LOW**
to: Woodland DFCs	18.2	6.2	15-50	41%	16%	65%	**LOW**	70	**MEDIUM**
to: Fire Hazard Reduction DFC	4.8	6.2	None	N/A	16%	65%	**N/A**	N/A	**N/A**
Conifer Forest Existing Conditions	3.5	1.7							
to: Savanna DFCs	3.5	1.7	5-10	34%	31%	47%	**LOW**	100+	**HIGH**
to: Woodland DFCs	3.5	1.7	15-50	11%	31%	47%	**LOW**	100+	**HIGH**
to: Fire Hazard Reduction DFC	0.2	1.4	None	N/A	38%	36%	**N/A**	N/A	**N/A**

One outcome of this evaluation is an understanding of the importance of trees in the 10-20 inch size class. Except on savanna and conifer forest stands which had few oaks larger than 10 inches DBH, 10-20 inch trees were much more prevalent in our study. The higher prevalence of smaller trees suggests that savanna existing conditions may not have met DFC targets because remnant oak savanna stands are younger and have developed from prairie stands, and that older former savanna stands with large oaks have converted to later seral stages. It may also indicate that remnant oaks savannas are largely confined to sites with poor soils or harsh growing conditions that constrain the size of mature oaks. Both of these implications can be informative to managers concerned with landscape scale assessments of the current condition of oak habitats in the southern Willamette Valley.

Twenty inches is a high standard for classification of large trees. While it is possible that setting such a high bar is one reason some stands did not achieve DFC targets for large trees, it is worth noting the savannas and conifer forests, the two existing conditions classes with the lowest number of large oaks, did not contain enough smaller oaks to make up for the lack of large oaks over time. These two classes largely contained smaller oaks under 10 inches. So stands that lack large oaks also lack high numbers of oaks. The relative paucity of existing large oaks across all existing conditions types suggests that development of these trees is an important restoration goal within the southern Willamette Valley.

The degree to which the current landscape provides the habitat required by species dependent on savannas and woodlands may also be important to managers. While previous studies have evaluated the present extent of former oak habitats, few have described the quality of those remnants. If current habitats are confined to sites with poor soils or younger trees, it suggests that the habitat type is being maintained by edaphic controls and land use decisions rather than the ecosystem processes that historically developed large oaks.

Time to achieve DFC maturity

Time to achieve DFC maturity is important because DFCs have restoration qualities that landowners prioritize, but it may take many years to achieve those qualities when starting from some existing conditions (Table 13). For example, aesthetics and habitat quality are common and important restoration priorities. If too few large open grown trees are present on a site to achieve DFC targets immediately after initial restoration, it may take 60 or more years to achieve those restoration goals. The time required to achieve targets is dependent primarily on two factors: 1) the number, quality, and structure of existing oaks, and 2) quality targets for the ground layer.

Results indicated two polar extremes in the time it takes achieve DFCs (Table 13). Stands tended to either meet DFC targets immediately after thinning or have so few young oaks and be so slow growing that they take more than 100 years to achieve targets. Only two stands that had not initially achieved DFCs met their targets within 100 years after thinning. Model simulations appeared to project very slow growth for oaks on all sites. They also projected relatively high mortality—large trees died as fast as smaller diameter trees could grow to replace them in some cases, so DFC targets for large trees were never met in those stands.

The implication of these results is that young oak stands may take many years to achieve restoration goals if insufficient trees do not initially exist on site. Initially thinning to higher than DFC targets in all size classes would be a prudent management policy: 1) to account for expected mortality following thinning, and 2) to account for unexpected high mortality events such as a wind, snow or ice storms, given the slow growth rates of Oregon white oak. Leaving high numbers of small oaks in particular may be important to ensuring sufficient numbers of large oaks over time and to providing desired oak cover while trees grow. Projections indicated that smaller trees were so slow to replace larger trees that DFC targets may never be met without the initiation of a recruitment class that contains significantly higher numbers of trees than is ultimately desired (this would allow for mortality within the recruitment class). The time required for such a class to develop into large trees would likely take in excess of 100 years. In addition, it may be prudent for managers to continue to plant or otherwise develop new oaks on a decadal basis to ensure a healthy mature stand over time.

Some authors have found that stands that have already succeeded to conifer dominance frequently grow on more productive soils than stands that are still dominated by hardwoods (Murphy 2008). As a result, once oaks are released from competition or replanted in these stands, they may be able to quickly achieve DFCs. Conversely, prairie and savanna stands that have not been maintained by a disturbance regime such as livestock grazing likely grow on the least productive soils, and these stands may take more time to grow large oaks. The modeling in this study did not bear this idea out. A possible reason for the slow oak growth modeled for both existing savanna and forested sites is that we used projected Douglas-fir site index data (Gould and Harrington, unpublished data) modeled at coarse spatial scales that do not capture the fine scale variation in productivity at our sites rather than actual measurements based on tree growth. No empirical data exist for site index on most of our sites because they are not considered high-quality areas for timber production.

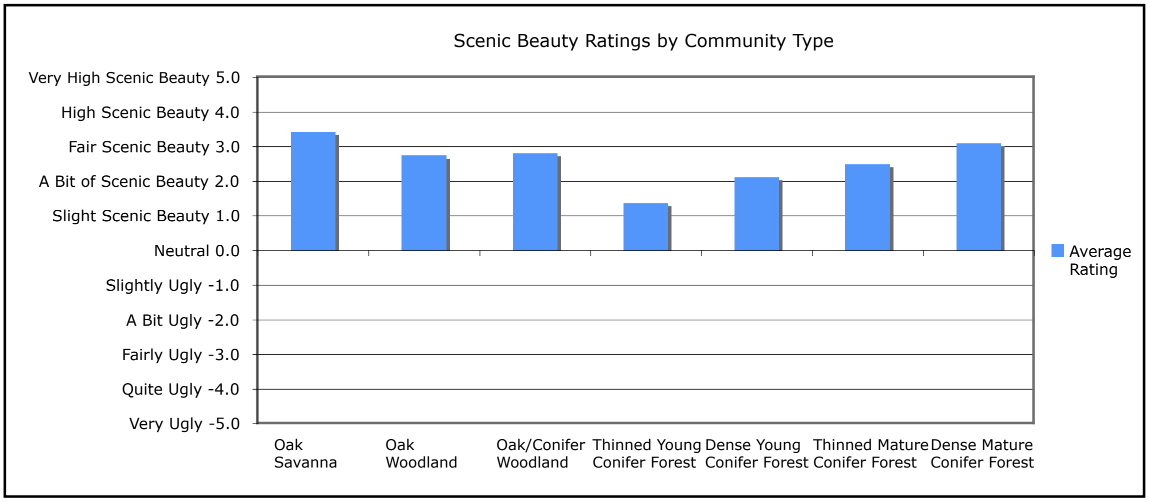
Ground layer quality standards also influence time to achieve DFCs. It takes longer to develop the high quality ground layer of full savanna and woodland restoration DFCs. Initially it can take up to three years to remove aggressive and persistent non-native species in the ground layer during the site preparation phase. Once these species have been eradicated and a native ground layer has replanted it may take only a few years to develop a mature composition. Professionals indicated that ten years is the time it takes to establish self-perpetuating populations of native species and recreate the habitat function that hosts desirable native arthropod and vertebrate species. The ten years required to develop the ground layer will generally be much shorter than the decades required to achieve canopy layer restoration targets in stands that do not meet DFC standards immediately after restoration.

One time to maturity factor I was unable to assess is the degree to which cutting decadent trees has the potential to increase the growth of tree sprouts and develop mature trees more quickly than planting (Bart Johnson, unpublished data). This approach may be a useful strategy for developing a younger cohort of oaks to replace large old oaks and ensure the maintenance of DFC targets over time.

Scenic beauty at maturity

Landowners and managers may need to incorporate aesthetic considerations into restoration planning. Sometimes, aesthetics can be a decisive consideration among values about which decision-makers are otherwise ambivalent because scenic quality can provide significant enjoyment to landowners. An understanding of how scenic quality relates to other restoration priorities can also help managers successfully achieve a broader range of restoration goals. Scenic quality is important because it can communicate that a landscape has been, and should be, cared for (Nassauer 1988, 1997), and ongoing care is critical to oak habitats. Incorporating scenic concerns into restoration planning, therefore, may enable land managers to build public support for oak habitat restoration, particularly in highly visible locations, or where land use decisions require a broad support base among community members. In short, high quality aesthetic experiences of oak habitats can be important for building and maintaining support for restoration. Such support may be particularly important for oak habitats, which are dependent on successive generations of landowners investing in their maintenance and long-term existence.

Overall, respondents to the survey by Ribe and Nielsen-Pincus (see Chapter II) indicated that savannas and unthinned mature conifer forests had the highest scenic beauty. Ratings for habitat types with canopy cover percentages between the savanna and mature forest extremes dropped downward, with respondents indicating that thinned (managed) young conifer forests had the lowest scenic beauty among those studied. Preferences for savanna averaged in the range of “high scenic beauty” to “fairly high scenic beauty.” Preferences for oak woodland and mixed oak/conifer woodland were only slightly lower, with averages in the range of “fair scenic beauty” to “a bit of scenic beauty.” All three of the oak classifications averaged higher than conifer-dominated cover types (Graph 2), with the exception of unmanaged mature conifer forests—a condition somewhat similar to old growth forest. Overall all vegetation types averaged positive or beautiful rankings.



Graph 2. *Survey results of average landowners' visual preference ratings for seven Willamette Valley vegetation classes/habitat types.*

The vegetation types in the University of Oregon ISE landowner survey did not precisely match the habitat types used for modeling in this study so I narrowed the results to those vegetation types that are relevant to this study (Table 14). In particular, the survey did not ask specific aesthetic questions about preferences for ground layer quality, and it divided conifer forests into four classes that were not used in this analysis. The survey did specifically question respondents' scenic beauty perceptions about oak savanna and oak woodland, but there was no fire hazard reduction category. Because the fire hazard reduction scenario requires thinning stands without a species preference, I chose to use averages of the two thinned conifer forest classes from the ISE survey to represent the fire hazard reduction DFC. Lastly, based on a general assumption about peoples' preferences for wildflowers, I rated the full savanna and full woodland restoration scenarios higher than the savanna and woodland structure scenarios used in the survey but without supporting data. This decision can also be supported using Nassauer's research (2004), which indicates that people perceive as attractive landscapes that visibly promote greater diversity and abundance of wildlife. As with other restoration priorities, the scenic quality average ratings are unaffected by existing conditions and, therefore, reflect only DFCs. The high, medium, and low rankings in Table 14 are relative rankings, and do not indicate that respondents rated low-ranking DFCs as “ugly.”

Table 14. *Scenic quality rankings.*

DFC	**Canopy Layer Scenic Quality Ranking**	**Ground Layer Scenic Quality Ranking**	**Overall Scenic Quality Ranking**
Full Savanna DFC	High	High	**VERY HIGH**
Savanna Structure DFC	High	Medium	**HIGH**
Full Woodland DFC	Medium	High	**HIGH**
Woodland Structure DFC	Medium	Medium	**MEDIUM**
Fire Hazard DFC	Low	Low	**LOW**

Survey responses indicate a general preference for the more open canopy structure of savannas and woodlands relative to later successional stages. Responses also indicate a preference for oak species composition. The preference for oak composition over thinned/managed conifer forests may be particularly significant for managers concerned with reducing fire hazard, because modeling results suggest that thinning to favor oak is effective for reducing wildfire behavior and oak may also be scenically preferable to thinned conifer forests. It is possible that landowners may thus find restoration of open oak structure a more aesthetically agreeable goal than fire hazard reduction thinnings, particularly in high visibility areas. The results also suggest that landowners and managers may be able to use the aesthetic preferences for savanna and woodland to promote conservation of these habitat types in general.

Decision Matrix

To synthesize the large quantity of information that composes this chapter, I have summarized study results for each of the six restoration value types in a final decision matrix (Table 15). I have included one new category, total scenario cost estimate, which is based on subtracting the income potential from the initial restoration cost, using 2010 estimates. For suggestions on how to maximize the potential utility of the decision matrix, refer to the following sub-section titled *Using the decision matrix*. The remainder

Table 15. *Restoration priority decision matrix. All costs figured using 2010 estimates.*

Conversion Scenario	**COSTS**				**FIRE**	**HABITAT**		**TIME**	**BEAUTY**
	Initial Restoration Cost (three years)	Income Potential	Total Scenario Cost Estimate (Initial Cost - Income)	Ongoing Maintence Cost (ten years)	Wildfire Hazard Potential	Habitat Quality at Maturity	Habitat Quality: Post-treatment	Time to Habitat Maturity	Scenic Beauty at Maturity
Savanna/prairie					HIGH				
to: full savanna	HIGH	NO INCOME	HIGH	HIGH	LOW	VERY HIGH	LOW	HIGH	VERY HIGH
to: savanna structure	LOW	NO INCOME	LOW	LOW	HIGH	HIGH	LOW	HIGH	HIGH
to: full woodland	MEDIUM	NO INCOME	MEDIUM	MEDIUM	LOW	HIGH	LOW	HIGH	HIGH
to: woodland structure	LOW	NO INCOME	LOW	LOW	MEDIUM	MEDIUM	LOW	HIGH	MEDIUM
to: fire hazard reduction	N/A	NO INCOME	N/A	N/A	MEDIUM	LOW	N/A	N/A	LOW
Open oak woodland					LOW				
to: full savanna	VERY HIGH	LOW	HIGH	HIGH	VERY LOW	VERY HIGH	HIGH	LOW	VERY HIGH
to: savanna structure	HIGH	LOW	MEDIUM	LOW	MEDIUM	HIGH	HIGH	LOW	HIGH
to: full woodland	HIGH	LOW	HIGH	MEDIUM	VERY LOW	HIGH	MEDIUM	MEDIUM	HIGH
to: woodland structure	HIGH	LOW	MEDIUM	LOW	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM
to: fire hazard reduction	LOW	LOW	LOW	N/A	LOW	LOW	N/A	N/A	LOW
Broadleaf forest					LOW				
to: full savanna	VERY HIGH	HIGH	HIGH	HIGH	VERY LOW	VERY HIGH	HIGH	LOW	VERY HIGH
to: savanna structure	HIGH	HIGH	LOW	LOW	MEDIUM	HIGH	HIGH	LOW	HIGH
to: full woodland	VERY HIGH	MEDIUM	HIGH	MEDIUM	VERY LOW	HIGH	HIGH	LOW	HIGH
to: woodland structure	HIGH	MEDIUM	MEDIUM	LOW	LOW	MEDIUM	HIGH	LOW	MEDIUM
to: fire hazard reduction	MEDIUM	MEDIUM	LOW	N/A	LOW	LOW	N/A	N/A	LOW
Mixed conifer broadleaf forest					VERY HIGH				
to: full savanna	VERY HIGH	VERY HIGH	MEDIUM	HIGH	LOW	VERY HIGH	HIGH	LOW	VERY HIGH
to: savanna structure	HIGH	VERY HIGH	LOW	LOW	MEDIUM	HIGH	HIGH	LOW	HIGH
to: full woodland	VERY HIGH	HIGH	MEDIUM	MEDIUM	VERY LOW	HIGH	LOW	MEDIUM	HIGH
to: woodland structure	HIGH	HIGH	LOW	LOW	LOW	MEDIUM	LOW	MEDIUM	MEDIUM
to: fire hazard reduction	LOW	MEDIUM	LOW	N/A	MEDIUM	LOW	N/A	N/A	LOW
Conifer forest					VERY HIGH				
to: full savanna	VERY HIGH	VERY HIGH	LOW	HIGH	LOW	VERY HIGH	LOW	HIGH	VERY HIGH
to: savanna structure	MEDIUM	VERY HIGH	NO COST	LOW	MEDIUM	HIGH	LOW	HIGH	HIGH
to: full woodland	VERY HIGH	VERY HIGH	LOW	MEDIUM	LOW	HIGH	LOW	HIGH	HIGH
to: woodland structure	MEDIUM	VERY HIGH	NO COST	LOW	MEDIUM	MEDIUM	LOW	HIGH	MEDIUM
to: fire hazard reduction	LOW	MEDIUM	NO COST	N/A	HIGH	LOW	N/A	N/A	LOW

of this section highlights the opportunities and constraints for restoration in each existing condition class with a particular emphasis on the attributes that are important for decision-making. Summaries are organized by existing condition because these are the starting points for restoration. At the end of the section, I also discuss two site qualities that were commonly referenced by restoration professionals as having significant impacts on the ability to achieve restoration priorities: steep slopes and land use history. These two qualities may affect restoration cost, quality, and feasibility in any of the five existing conditions classes.

Using the decision matrix

The decision matrix is intended to be a starting point for accessing the information provided in this document. Readers can use it to build a broad understanding of oak habitat restoration, find trends related to increases or decreases in costs or quality, or as a launching point to dig deeper into the concerns relevant to specific sites. Before using the matrix, landowners may choose to classify their land into the existing conditions community type classifications used in this analysis to gain a better understanding of the potential outcomes for their land. Landowners who have more than one initial condition class can evaluate the opportunities and constraints on their land in discrete patches or as an average using the different proportions of each class. To illustrate how the matrix can work to organize the modeling results, I use a hypothetical decision-making scenario.

As a reader I would first use the methods section to determine the approximate oak habitat community type (or types) that exists on my land. If I owned 20 acres of primarily oak-dominated broadleaf forest, along with some mixed conifer forest, I would look first to evaluate the broadleaf forest scenarios in the decision matrix. Under the broadleaf forest existing condition heading, each of the five DFCs will be listed along with high, medium, and low characterizations of the six restoration priorities listed above. If I were interested in developing high quality wildlife habitat but I was also cost-conscious, I would look first to the *Habitat Quality at Maturity* and *Cost to Implement* columns to see which DFCs score highest for these priorities. This evaluation would reveal that full savanna restoration offers the highest quality habitat, but is also costly to implement and maintain. Oak woodland structure, on the other hand, is less costly but provides lower habitat quality.

With this understanding I might next look at some of the other priorities listed in the decision matrix. One of the first things I would notice from the *Income Potential* category is that, in general, the broadleaf forest existing condition has low income potential. Also, I would find that converting from the broadleaf forest to any DFC provides higher quality post-treatment habitat than restoring from most other community types—so I know that I have an opportunity to develop high quality oak habitat no matter what goal I chose. From there I might decide to dig deeper to find out specifically how much more high quality restoration would cost than other scenarios, so I would turn back to the outputs listed in the *Initial restoration costs* subsection to develop an understanding of the total costs for restoring savanna from broadleaf forest. This chart indicates that savanna structure, also a high habitat value restoration goal, costs nearly $1000 less per acre to implement.

To review, I now know that the full savanna restoration scenario provides the high quality habitat I desire, but that it is the most expensive goal. I also know that savanna structure provides somewhat lower quality habitat but that is significantly less expensive to implement and maintain. Lastly, I have learned that my land has potential to produce high quality oak habitat because of the large oaks that exist on it. Given this opportunity, I might initially determine that savanna structure restoration on my land is a good choice. This scenario develops the canopy structure that I find beautiful and that my grandparents, who first bought the property, described to me. Savanna structure also fits within the budget that I had initially developed, and with proper planning, it may provide a path to full savanna restoration through ground layer improvements at a later date.

At this point I may elect to talk further with a private consultant, or with agency personnel, to learn more about the restoration potential of the ground layer. I may also choose to look at the site specific modeling results documented in Appendix B to gain a better idea of the range of variability in possible restoration results. To prepare for a meeting, a review of *Chapter III, Best Management Practices for Oak Habit Restoration* would provide information about the processes used to achieve restoration goals within each structural layer. Though not a component of the decision matrix, the BMPs are informative about the way in which site-scale factors influence individual project costs and outcomes.

Summary figures

I have created two figures that condense the information of the decision matrix into a graphic representation that illustrates the primary trends in each habitat restoration priority. These figures highlight the primary tradeoffs among different existing conditions (Figure 9) and desired future conditions (Figure 10).

Figure 9. *Summary of existing conditions impacts on the ability to achieve selected restoration priorities. Bubble locations represent the points of greatest (but not the only) impact.*

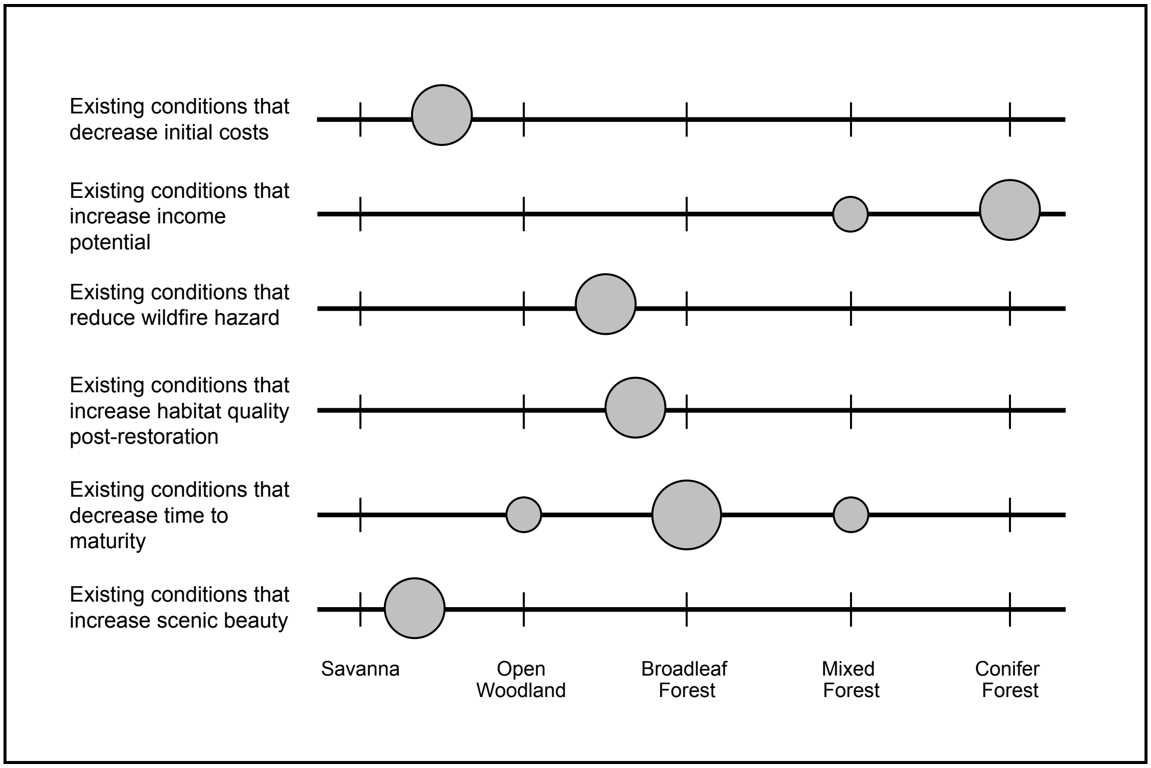
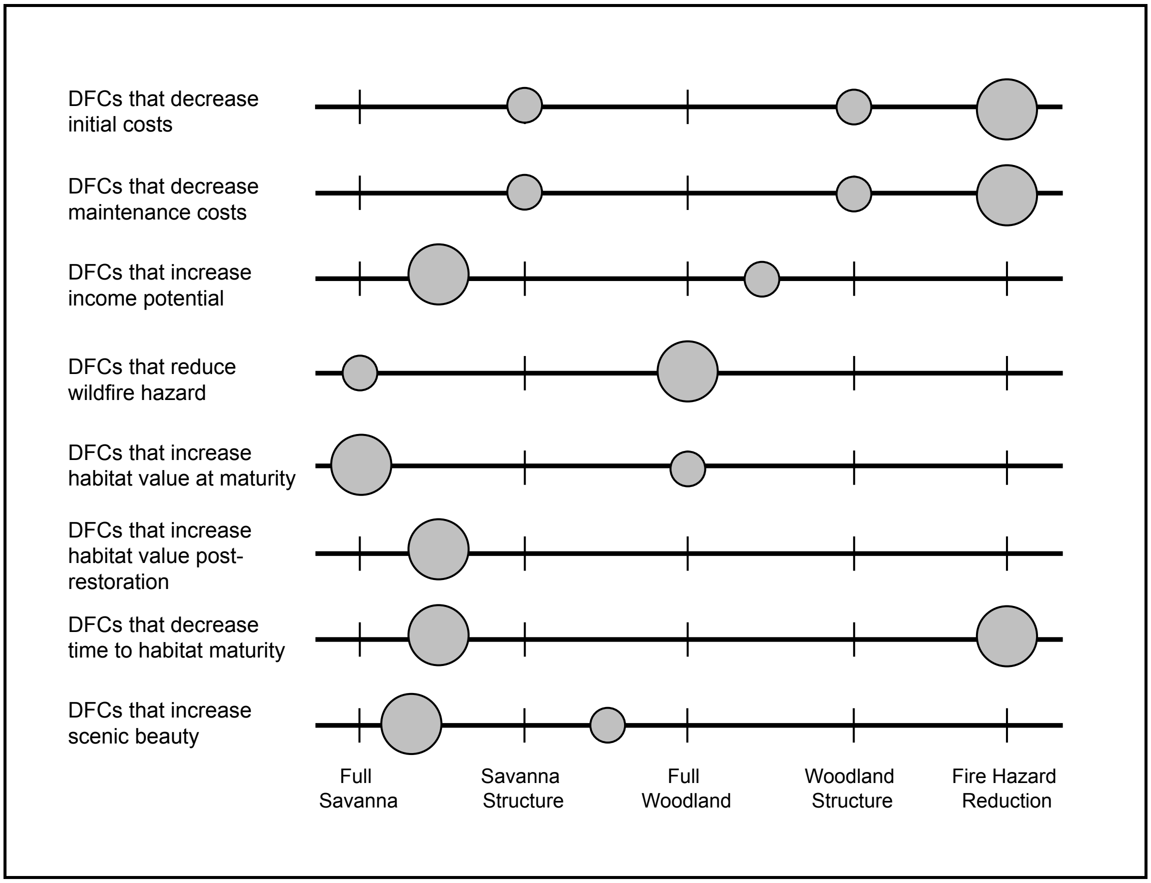


Figure 10. *Summary of desired future condition impacts on selected restoration priorities. Bubble locations represent the points of greatest (but not the only) impact. A larger bubble indicates greater impact.*



Savanna existing conditions

The great advantage to savanna existing conditions is that savannas often host large and high quality existing oaks, which create significant opportunities for high quality habitat and aesthetic outcomes. Savanna existing conditions are rare, and are generally targeted for enhancement rather than conversion to another habitat type for this reason. The tradeoff to the aesthetic and habitat benefits of this existing condition class is that there is little income potential due the paucity of large trees. At the same time, savannas may have income potential from haying, wildlife viewing, hunting, conservation, or as a source of native seed, all of which were beyond the scope of this assessment of restoration income. The costs for restoration vary based on initial ground layer and shrub layer species composition as well as the landowner's selected desired future condition. Ground layer restoration may require significant time to kill weedy species, particularly if the site has a history of intensive human land use from agriculture or grazing. The amount of herbicide required to accomplish this objective is another tradeoff of enhancing an existing savanna. Initial wildfire hazard potential for this class was rated intermediate due to relatively high ground-fire flame lengths resulting from open conditions, but somewhat lower crown fire indices resulting from a lack of trees. The estimated time required to achieve savanna DFCs is low if there are enough large existing oaks to achieve DFCs. Modeling indicates, however, that it may take over 100 years to achieve both savanna and woodland DFCs if insufficient trees are present. Our field observations suggest that these remnant savanna sites have much lower site productivity and oaks grow slowly on unproductive sites.

Oak woodland existing conditions

Open oak woodland is a very versatile existing condition class. The common presence of large and numerous full-canopied oaks creates a significant opportunity to develop both high quality savanna and woodland DFCs. In addition, oak woodlands have high enough tree densities that some thinned material may be chipped and sold to offset slash removal costs. More than any other, this existing condition class highlights the tradeoff between cost and quality: it provides little income but very high oak quality and restoration potential immediately after treatment. Its wildfire hazard potential post-treatment was also rated low because the shaded ground layer in this class maintains low flame lengths, and because widely spaced oaks have little potential to spread crown fires. Post-restoration habitat potential was rated high for both savanna and woodland DFCs because the large oaks that compose this class are likely to already have the structure preferred by cavity dwelling species. Similarly, oak woodlands require very little time to achieve

DFCs because they already host the minimum number of large oaks for savanna DFCs, as well as most of the oaks necessary to achieve woodland DFCs.

Unfortunately, this habitat type was relatively uncommon on our study sites, comprising only 11% of all plots—much less than any other existing condition type (Table 2). Many of these plots were on the edge of forest and meadow conditions, preserving open-grown crown structure on one side of many oaks, and much more constrained crowns on the other. The presence of these edge habitats is thus an important structural element of many sites in its own right, maintaining higher numbers of oaks than a savanna, while retaining higher quality oak crowns than in the adjacent dense forest.

Broadleaf forest existing conditions

Similar to oak woodlands, broadleaf forests have significant potential for both savanna and woodland restoration because they are composed of many large mature oaks. Oaks growing in forest conditions, however, are much more likely to be have narrow crowns. As a result, some of their post-restoration habitat quality and future potential may be reduced relative to woodlands and savannas. Broadleaf forests include extremely high numbers of small trees (Appendix B), so this class has the highest potential for wood chip income to offset thinning costs or pay for chip removal. The tradeoff to high tree densities is that costs for logging increase as stem count increases, and overall restoration costs may be higher in this existing condition class than for any other. Initial wildfire hazard potential was lower in this class than all others due to low ground layer fuel heights and low numbers of conifers. This means that fire hazard reduction goals may not be effective justification for offsetting the costs of restoration. Time to achieve desired future conditions is variable but generally low. Although this existing condition includes substantial numbers of large oaks, these oaks may be physically compromised by competition. As with all forested classes, time to achieve ground layer restoration goals may be low if the site does not have a history of agricultural use; several restoration professionals have noted that upon thinning the canopy layer and allowing light to the ground layer of forests, a high-quality native ground layer may regenerate from the native seed bank. Where existing natives are present as suppressed individuals in the soil seed bank, seed acquisition and sowing costs decrease and overall costs decrease substantially as a result.

Mixed broadleaf & conifer forest existing conditions

Modeling suggests that mixed forests provide a balance between income potential and habitat quality. This class has significant restoration potential due to its large oaks, and significant income potential due to its large conifers. While the oaks are likely to be heavily impacted due to conifer encroachment, research suggests that they can produce healthy acorn crops once released (Devine and Harrington 2004), and they still provide significant habitat potential while young oaks mature. However, note the sharp decline in the percentage of healthy oaks and sharp increase in the number of unhealthy oaks relative to broadleaf forests. Furthermore, there are only half as many large oaks post-restoration. Time may be of the essence for prioritizing restoration within mixed existing conditions, however, because conifers grow fast and oaks senesce quickly within shaded conditions. Overall costs for restoration were among the lowest because mixed forests have the potential to generate income from both large saw-grade conifers and smaller chipped trees. Modeling suggests that this class provides the potential to achieve savanna DFCs immediately post-restoration but may require more time to achieve woodland DFCs. As noted, however, both DFCs are somewhat compromised by the narrow crown shapes and/or loss of crown structure due to forest succession. Initial wildfire hazard potential is greater in mixed forest stands than on broadleaf forest or oak woodland stands because of the increased percentages of conifer fuels. Implementation of any of the five DFCs provides fire hazard reduction benefits. The combined cost-effectiveness of restoration and potential for substantial numbers of large diameter oaks in this existing condition class provides a unique set of tradeoffs to be considered for restoration (Table 15).

Conifer forest existing conditions

Conifer forests have at least one significant advantage for oak habitat restoration: they have the greatest income potential of all existing condition classes. While wood chip outputs for this class are similar to those for oak woodlands, the number of saw logs thinned during restoration has the potential to pay for canopy restoration and offset some ground layer restoration costs. Net restoration costs decrease as the numbers and diameters of conifers increase. If stands are located on steep slopes, however, logging costs may increase. The tradeoff to income potential for this class is that conifer forest stands have few remaining large or healthy oaks. Overall time to completion may take considerably longer because a new cohort of young oaks will need to grow to maturity. Once these oaks reach maturity, however, they will have full, high-quality crowns. Achieving a high-quality savanna or woodland ground layer may be less expensive than in savanna and woodland stands due to decreased presence of aggressive and persistent non-native species. Initial wildfire modeling suggests that conifer forests have considerable wildfire hazard potential, so this class has the most to gain from the fire hazard reduction benefits of any of the five DFCs. Overall then, restoring a conifer forest to an oak habitat, which on the surface may appear to be a low site-scale priority, may in fact have a number of distinct advantages as part of a landscape-level strategy for restoring oak habitat function. This is due to the potential for both lower costs and higher quality, with the tradeoff that it will take a longer time to achieve than restoring a site with extant oaks.

Two high impact site qualities

In light of all the necessary caveats I've had to make in each section of the modeling results, it be clear that the real world of restoration is much more complex than can be straightforwardly assessed through quantitative modeling. There are two further caveats that need to be described. For the purposes of modeling I've modeled results based on vegetation structure and composition with only some attention to physical site conditions. This "all else being equal" approach has had the advantage of supporting comparisons based on vegetation alone. However, there are two further conditions that need to be noted for assessing tradeoffs and making decisions on real sites: slope steepness and site history.

Steep slopes: When working on steep slopes, costs rise rapidly because most mechanical treatment methods cannot operate as safely or efficiently as on lower gradients. In some cases, steep slopes may necessitate a shift from mechanical to manual BMPs to accomplish restoration work. As a result, the potential to achieve high quality restoration results generally decreases because of the high cost of restoration, except on very small sites where work can be accomplished affordably using manual methods, or on sites with existing high quality species composition.

Intensive land use history: When working on formerly managed lands such as agricultural or grazing lands, the likelihood of existing high quality native species composition in the ground layer decreases and the potential for problematic invasive species composition increases. This has the potential to dramatically increase costs for high quality restoration because of the high cost and significant time required to deplete the existing seed bank and establish a new ground layer.

Conclusions

In this chapter I reported oak habitat restoration model results for six different restoration priorities: restoration costs, income potential, habitat quality, scenic beauty, fire hazard reduction potential, and time requirements. The restoration priority decision matrix summarized results for each of the priorities across each of five existing condition classes, and can be used to quickly reference advantages and tradeoffs associated with each of the 25 modeled alternative restoration scenarios. This assessment provided the basis for summarizing the benefits and tradeoffs of restoration alternatives for each existing vegetation type.

The most notable tradeoffs are those between cost, quality and time, and they relates to both existing conditions and DFCs. Full savanna and woodland restoration DFCs incur greater cost than structural DFCs during initial development and during the maintenance phase due to the effort required to establish a compositionally diverse ground layer and control non-native species. Similarly, existing conditions classes that provide high-quality wildlife habitat immediately post-restoration generate less income than those that have little near-term habitat value. Generally, later successional communities provide greater income potential because of increased total numbers of trees and greater numbers of conifers in particular. Modeling also suggests a potential tradeoff between existing quality and the time required to promote greater quality. If sites do not contain enough large oaks to meet restoration targets immediately after restoration, it may take many decades for them to do so.

One implication of these tradeoffs is that existing conditions have a significant influence over landowners' ability to optimize among different restoration priorities. By tailoring restoration priorities to the opportunities within existing conditions classes, however, landowners may be able to maximize the number of restoration values that they can achieve within the constraints they face. Restoration managers making decisions at a landscape scale may be able to use the opportunities within different existing conditions classes to meet greater numbers of objectives. For example, by targeting restoration on conifer-dominated sites adjacent to existing oak reserves, managers may be able to increase total restoration area and habitat quality over a long time scale at relatively little cost. Such a strategy may also take advantage of ground layer connectivity to provide greater habitat potential for oak dependent wildlife species.

CHAPTER V

CONCLUSIONS

To this point I have discussed restoration values within the context of discrete existing conditions classes because this is the level at which most landowners make restoration decisions. For managers who evaluate restoration opportunities at a larger scale than individual sites, it may be important to consider tradeoffs and opportunities among different existing conditions classes. This final chapter summarizes implications from this study for landscape-scale restoration priorities.

Restoration prioritization: cost versus quality

Oak habitat restoration is hard work. It requires focused long-term commitments of time and money. For this reason, most of the restorationists who advised me on this project emphasized the value of targeting high quality sites to achieve high quality results and prioritizing sites with large remnant oaks that are in rapid decline. This prioritization approach is based in part on the difficulty of knowing what to restore on a site that has lost species diversity, in part on the ability to conserve genetic diversity by not having to import seed or starts from an off-site source, and in part on the practical advantage of protecting species that may be difficult to establish once diminished. Finally, protecting large, old oaks preserves structurally high-quality trees that cannot be quickly replaced. Regardless of the approach, the increased ability to achieve high quality restoration outcomes by working with initially high-quality sites is great enough that many professionals prioritize these sites first.

Perhaps counter-intuitively, however, professionals stated that working on initially high quality sites is also the most expensive approach to restoration. Taking the time to protect desired remnant species, treating problematic species within narrow windows of opportunity determined by the life cycles of desired species on the site, and manually removing or spraying undesired species is more costly than utilizing the efficient techniques available for removing all species from a site and seeding or replanting. This tradeoff between cost and quality may be important to recognize when prioritizing restoration sites, particularly at landscape scales and over long-term horizons.

Rethinking restoration targets based on existing conditions

In 1987 Reed and Sugihara suggested that some of California's northern *Quercus garryana* oak savannas and woodlands would succumb to conifer encroachment in 20-30 years due to cessation of fire. Agee (1993) reported the same time frame for Pacific Northwest oak habitats. Roughly 25 years later, their predictions have proven accurate in some locations within the southern Willamette Valley. In many parts of the landscape, oaks have been lost in large numbers, and where they remain they are often in poor health as a result of shading and habitat succession. One conclusion from this study is that there may be opportunity in the loss of oaks. Restoration of mixed and coniferous forests has, by far, the greatest potential to offset restoration costs and return income to the landowner. Traditionally this class has been considered a lower restoration priority due to the poor health and low abundance of remnant oaks. For landowners who prioritize oak habitat but do not have the financial resources to pay for the cost of restoration, however, these forested existing conditions classes provide a significant opportunity to more affordably achieve their goals. In addition, professionals have indicated that these forested classes often have the potential to shelter high quality remnant seed banks, and often host fewer aggressive exotic species. Where this is the case, canopy clearing may stimulate germination of native prairie species seeds or the growth of suppressed plants. The reduced removal and containment costs for weed species in combination with the release of a relatively high quality native ground layer may significantly lower total restoration costs in these existing conditions classes and improve restoration results. While canopy layer restoration goals may take up to 100 years to achieve as a result of starting with fewer large, healthy oaks per acre, this timeline is no different than for existing savannas as both stand types contain very similar numbers of oaks after restoration (Table 13).

Rethinking traditional restoration thinning strategies

When cutting in the canopy layer, it can be cheaper to work in an area that has low tree density or to completely clearcut a site than to work around oaks and other species targeted for retention. Given this higher cost and the decreased habitat quality of heavily shaded oaks, it may also make sense both economically and ecologically to cut all trees on restoration sites with few oaks or unhealthy oaks and then replant to develop savanna. In addition, it may be possible to achieve faster development of open-canopied trees by cutting oaks with compromised crowns and allowing them to resprout from their existing root system.

Completely clearing a landscape of trees to recreate an oak savanna or woodland requires the patience of working over landscape time—it can take 100 years for seedling oaks to develop high habitat value, rounded-form structure. One way to frame such an approach, though, is to consider agricultural lands that are restored to prairie as an example. Removing all species on a site and replanting for oak habitat is similar to the established prairie restoration practice of clearing former agricultural fields and replanting native grasses and forbs. One key difference, however, is that the ground layer is less likely to be heavily disturbed in a conifer forest so ground layer restoration may be less complex and costly. If a high quality ground layer does remain on an oak restoration site, full ground layer restoration scenarios will cost closer to structural ground layer restoration scenarios—a potential savings of nearly $900 per acre, with the added advantages of retaining local genetic diversity and the possibility of paying for the work through logging income. If initial restoration costs can be reduced in this manner, then the savings could possibly fund future maintenance, something not possible when restoring agricultural lands.

Suggestions for further research

One of the challenges to modeling was developing sound estimates of initial costs without using quantitative ground layer data. Ground layer restoration can be a relatively expensive component of total costs, particularly in existing conditions classes that require less logging—savanna and woodland. The different species targeted for conservation or suppression in the ground layer often require site-specific ground layer treatments. Given the diversity of existing ground layer conditions, this layer is also difficult to average for modeling. A quantitative understanding of present ground layer conditions on remnant oak habitats would provide a foundation for a quantitative ground layer assessment similar to the one made in this study for oaks in the canopy layer.

Projections of the time required to achieve habitat maturity are sensitive to site index. The site index data I used for simulations did not translate into appreciable differences in time to maturity for different stands. This could be because the site index data were not accurate at the fine spatial scales of our vegetation data, or because we did not separate out managed sites from those where succession was edaphically controlled. Better evaluations of the effects of site index on tree growth could lead to useful insights about potential opportunities for targeting restoration on productive sites. More site-specific site index data could also be used to develop tools that assist individual landowners with oak habitat restoration decisions in the same way that such data is already used to help landowners make better decisions about timber production.

Lastly, the information in this thesis is extensive and sometimes complex. More concise or narrative interpretations of the methods and results developed here could perhaps be more useful to landowners who want to get straight to the implications of the research. Future work could include developing narratives that interpret the potential outcomes of restoring on different land types, with different histories, and working toward a range of landowner priorities. Narratives could include information relevant to how different landowners approached the restoration process, the decisions they made and why they made them, the different costs they incurred, and the types of benefits they received. Alternatively, a web-based decision tool that uses the data and results of this research could provide an easily understandable, interactive tool for landowners who want to consider the opportunities and constraints their site offers, and the likely tradeoffs essential to different choices.

Final thoughts

Fischer (2006) emphasizes “the importance of considering the human dimensions of conservation efforts, especially the cultural circumstances behind the role that every stakeholder plays in conservation. It is [the] complex set of values, beliefs, motivations and socio-economic contexts that ultimately determines the success or failure of conservation strategies” (Fischer 2006, 8-9). Conservation and restoration of Oregon white oak habitats requires facilitating restoration solutions that meet the priorities of those doing the work and paying the bills. In large part, oak habitats flourished in Oregon because of the benefits they provided to humans, notably Native Americans, who helped to maintain them over time. Helping landowners to achieve the benefits they need or desire from oak habitats today is equally critical to their long-term persistence.

Landscape architecture as a discipline is interested in the influence of human ideas and actions on the land. With this project I was interested in developing insight about the overlap between human and non-human systems related to oak habitats with this project. Where do (or where can) human priorities and the requirements of non-human ecosystems meet? How can decision-makers prioritize and pursue courses of action that benefit both? In a future where an increasing number of land use priorities will increase development pressure on a fixed supply of land, the integration of human needs with the conservation and restoration priorities of oak habitats in the Willamette Valley will only grow more complex.

Oak habitats in the Willamette Valley have a significant cultural legacy because they are ecological communities that have developed with humans. They reveal a balance—and tradeoffs—in the merger of human and non-human systems; they tell a story about the beneficial role that humans can play in the “natural” landscape. Most authors who write about oak and prairie communities in the Pacific Northwest discuss the important role that Native people had in maintaining these community types. Understanding why the first human residents preserved them and how they used them is not just interesting background, it informs us about *why* oaks habitats in this area have the structure and composition they do. Why community types are *where* they are. Speaking about the work of maintaining oak habitats a Native Californian noted "…they do not set fire for nothing, it is for something that they set fire for" (Harrington 1932). Oak habitats were shaped for specific reasons and in understanding those reasons, as well as the ecological processes that shaped them, restorationists can gain a better understanding of how and why they need to be preserved in all their diversity of form and location within the contemporary cultural context.

In recognition of the important role that humans have in maintaining the diversity of Oregon white oak habitats and the failure to do that work over the past 150 years, restoration may best be considered catch-up for years of deferred maintenance. Wilcove and Chen (1998) talk about restoration economics as having two components: "an accrued debt reflecting a deferred maintenance problem that has resulted from inadequate funding in the past and an annual payment reflecting the necessary upkeep of properly managed habitats." This framework puts the high upfront costs of oak habitat restoration into perspective and also emphasizes the importance of future maintenance investments. While there is resilience and dynamism in restored Willamette Valley oak habitats, these community types have and will require the engagement of people who care about them. There will always be a need for humans to play a role in their perpetuation. My goal has been to facilitate these caretakers' ability to engage in this important work by shedding light on the tradeoffs that are likely when restoring to specific desired future conditions from different starting points. In doing so, I have aimed to promote informed decision-making for both site scale and landscape scale restoration so as to provide benefits for oak habitat health and human priorities.

APPENDIX A

ALTERNATIVE BEST MANAGEMENT PRACTICES

Objective 1: Large Tree Thinning

1st Alternative BMP: Manual felling with mechanical yarding.

Assumptions

- *Restoration goals prioritize protecting the ground layer*
- *or, Site size is less than 10 acres*
- *or, Soils are highly erodible or susceptible to compaction*
- *or, Slopes are greater than 35%*

Discussion

On sites that are too steep, too small, or where soils are too fragile to employ a harvester/forwarder combination, manual felling is the best option. Manual crews can work on small sites where setting-up large mechanical tools is difficult and expensive, they can more easily navigate extensive steep slopes, and they are better able to cut large trees (>25" DBH). Cost-effective felling requires good coordination among multiple workers and limiting damage to the log, the site, and leave trees. Manual felling means trees are cut, de-limbed, and trimmed to a desired length (bucked) using manually operated chain saws. Logs are yarded to a landing or road using a winch or tractor.

Procedures for yarding on steep slopes vary with site conditions. Where possible, most professionals prefer to drag logs upslope using a winch system to a landing site. If access is limited by distance or obstructions, logs may need to be dragged out using a tractor. Professionals note that most slopes in the Willamette Valley are short enough that tractors equipped with booms can reach to extract trees from below (most logging vehicles can operate on 45% slopes for short periods of time). Felling trees where they can be easily yarded without increasing ground layer damage requires a high degree of experience and skill. Simply girdling a tree and letting it decay on site is an option if a tree is in a position where it cannot be safely removed.

Constraining Factors

1. Workers are vulnerable to falling and splitting logs, limbs, and debris. Also with greater numbers of ground-based workers, there is a greater risk of miscommunication leading to accidents.
2. It is difficult to meet restoration-logging requirements for protecting the ground layer using manual methods. Manually felled logs will generally have a greater fall impact on the ground. Mechanical methods pick-up the butt end of the log as it falls so that the primary impact is on the branched upper end of the tree where its weight is dispersed.
3. Transporting logs to a landing site requires the use of heavy equipment and dragging, which can damage soils. Cable yarding, which lifts most of the log off the ground, and yarding on downed limbs can limit damage but also increase costs because of extra setup time and equipment needs.

Manual Felling Cost Estimate

High: $5000/acre | Average cost: $1400/acre | Low: $500/acre

Loggers bill by the hour, and their rates vary with skill and ability. Technical climbers, who can bring down large trees and remove timber out of oak, bill $75-100/hour. Cutters who thin and process trees without the need to preserve the timber or protect leave trees bill closer to $35/hour. Loggers always work in teams of at least two. Total per acre cost estimates include yarding. The high estimate was for a steep site with large trees and a sensitive shrub layer inside the Eugene, Oregon urban area. The low estimate represents a low density thinning with no large timber trees. According to several project advisors, the costs of manual and mechanical harvesting are not significantly different on sites less than 10 acres, but as project size increases manual methods lose their competitiveness.

Objective 1: Large Tree Thinning

2nd Alternative BMP: Manual girdling with chainsaws.

Assumptions:

- *Removing encroaching trees from the crowns of oaks targeted for restoration may cause damage to target tree*
- *Standing dead trees (snags) are acceptable*

Discussion

Girdling is an alternative thinning option where removing trees may be dangerous, difficult, too expensive, or damaging to retained trees. Managers cite girdling as a useful method for killing trees on steep slopes where it may be difficult to get crews or machinery in to effectively cut and remove the wood, and where removing them may damage trees targeted for retention. Girdled trees have the management benefit of decaying over time. This slow decomposition reduces the amount of woody material that needs to be removed from a site at one time. Girdling also has benefits for wildlife. Girdled trees become snags, which create habitat for invertebrates; invertabrates are in turn are food sources for vertebrates (Apostol and Sinclair 2006). Snag development is a significant component of several restoration DFCs. Girdling is not a stopgap measure for budget strained managers. It should only be used as a part of a well-considered and complete management plan with full awareness of the long term impacts of standing dead trees.

Girdling is always completed manually. Workers use a chainsaw with an attached stop to make two 2” deep cuts around the circumference a trunk. The cuts are spaced 15 centimeters apart, and after cutting they peel the bark off the trunk between the cuts. This process ensures that the upward flow of water and nutrients and the downward flow of sugars is cut-off. Most trees will defoliate and die within a year.

Constraining Factors

1. Standing dead trees are a significant fire hazard, and their presence may preclude ground layer maintenance with prescribed fire.
2. Girdling too many trees at one time can increase the build up of fuels on a site and dramatically increase the risk of wildfire. Wildfire has the potential to kill desirable trees and spread in an uncontrollable manner.
3. The defoliation of girdled trees may open up light to the understory and promote the growth of species that require more expensive methods to control—such as Armenian blackberry or false brome (*Brachypodium sylvaticum*).
4. Decaying wood is not marketable so all income potential is forfeited with this method.

Girdling Cost Estimate

Average: $10-17/tree

Costs for girdling are similar to other manual cutting jobs: two employees at $30 per hour each. Equipment costs are $6 per hour for a total of $66/per hour. Depending on the species, crews can girdle 4-6 trees per hour.

Objective 2: Small Tree Thinning

1st Alternative BMP: Tree masticator.

Assumptions

- *Savanna structure is the desired future condition*
- *Landowner prioritizes fast work*
- *Minimum site size: 5-10 acres*
- *Slopes are less than 35%*

Discussion

An alternative to skid-steer tractors for thinning small trees on sites with savanna or woodland structure DFCs that is not used for this analysis is whole tree grinding or masticating. A masticator is a pulverizing tool attached to a boom on a heavy tracked vehicle that can bear down on a tree and chip it in a matter of minutes. Another common design is a horizontally mounted shredder on the front of a wheeled or tracked vehicle (similar to manually powered rotary lawn mower). The advantage to these tools is that they are fast and produce no slash to collect (they chip and scatter the slash up to 300 feet in the process of destroying each tree). Their relative speed means these tools can be less costly than others. On dense sites, masticators may also be the most cost-effective option for cutting trees stumps to grade after logging. The boom-operated masticator can pivot on its base and clear trees within a 50' circle—minimizing its movement and ground disturbance.

Constraining Factors

1. Masticators may leave very large quantities of woody debris on a site. This debris can alter the ground layer's chemical composition and structure—generally favoring non-native species. Hardwood chips are heavy and slow to decompose so they can smother native plants and seeds for a long time, particularly where they are thickest around the stumps of trees. Masticators are better suited to working on relatively open sites with fewer trees (savanna or low woodland tree densities).
2. Burning after masticating can cause prescribed fires to burn hotter and longer than historic grassfires, because of the extra wood on the ground. Such fires could damage soils, dormant plants, and retention trees.
3. Masticators can cause significant soil damage as the grinding head comes into contact with the ground, and as the heavy excavator turns on its tracks. Windell and Bradshaw (2000) and one project advisor cite potential damage to retention trees from flying debris as reason for exercising caution with this method when in sensitive areas.

Discussion

Given the potential for altering or damaging the ground layer if the site will not be raked and burned prior to planting, this method should not be an option for full savanna restoration or on sites with high tree counts. For low quality savanna structure scenarios or for fire-hazard reduction scenarios, it has the potential to reduce costs on some sites by eliminating the slash removal component of small tree logging operations and working fast. Under most restoration scenarios, however, it offers little advantage over skid-steer shearing with off-site removal of woody material.

Masticator Cost Estimate

High: $800/acre | Average cost: $375/acre | Low: $150/acre

Masticators are competitive with harvesters but more expensive than skid-steer tractors at $150 per hour. The low cost represents a Benton County project for which the boom-operated masticator was used to remove trees as large as 16” dbh in savanna and woodland densities. High costs were for the stump removal project cited above. Windell and Bradshaw (2000) found that costs ranged from $75-850 per acre on conifer-dominated U.S. Forest Service lands. Average cost estimates for employing this method on oak habitat restoration sites are incomplete.

Objective 2: Small Tree Thinning

2nd Alternative BMP: Manual felling, yarding, & herbicide application.

Assumptions

- *Restoration goals prioritize protecting the ground layer*
- *or, Site size is less than 10 acres*
- *Harvested tree DBH averages 2-12”*
- *or, Soils are highly erodible or susceptible to compaction*

- *or, Slopes are greater than 40%*

Discussion

Where slopes are too steep for safe operation of skid-steer tractors or soils are susceptible to damage from heavy equipment, most professionals use a “hack and squirt” method of manually cutting trees then applying herbicide to prevent hardwoods from resprouting. The method can be applied using different tools and sequences. Some managers prefer to apply herbicide to wounds inflicted in the bark of trees 6-8 months before thinning. This sequence ensures trees are dead when crews return to thin. If some trees are not dead when they return, they can reapply herbicide at that time. A variation on this method is to inject herbicide into trees using specially designed applicator lance. The lance adds certainty to project planning because it is more likely to kill trees the first time. Other managers prefer to apply herbicide immediately after cutting trees to reduce the number of trips onto a site. Wounds are only susceptible to herbicide for a short time after they are cut, however, so it is important to apply herbicide to fresh cuts. If some trees are not killed by this initial application, they return to reapply herbicide later. The exact sequence does not matter for modeling purposes since the basic costs remain the same two workers using a chain saw and an herbicide applicator.

For oak habitat restoration, which requires future maintenance, tree stumps must be cut at grade so that mowing equipment can access the site. Once trees have been killed and removed, they are manually processed and piled. If piles will be burned or left on site, the trees and brush are generally compacted using chain saws to increase the density of the pile. If debris will be removed from the site, then piles are located where they can be accessed by equipment—either near roads or on less steep terrain.

The work of manually removing small trees is often done in conjunction with clearing the shrub layer. This merger can make modeling difficult because professionals generally do not separate out costs by structural layer. Also, manual and mechanical thinning methods are often employed on the same site but in different locations because of different restoration priorities.

Constraining Factors

1. Manual tree thinning is significantly slower than mechanical thinnings. As a result, it is also significantly more expensive.
2. Manual felling brings greater risk of worker injury. Falling trees, chain saws, and multiple people working together combine to make good communication critical for safe operations. One professional pointed out that the manually removing trees can be slower than removing shrubs because it is not safe to have more than one or two crews felling trees on a site at the same time.

Manual Tree Cutting Cost Estimate

High: $2800 | Average cost: $1400 | Low: $300

For safety and efficiency, manual cutting requires teams of at least two workers. One worker with equipment (chain saw or herbicide applicator pack) bills at an average rate of $35 per hour. A two-person crew generally requires four hours to five days to thin one acre. Costs will increase with greater tree densities and where tree composition tilts toward hardwood dominance because only hardwoods require herbicide treatment. This cost estimate has a lower degree of certainty because it is based on imprecise information.

<u>Objective 3: Slash Removal</u>

1st Alternative BMP: Chip & remove.

Assumptions

- *Sufficient quantities of slash are generated from logging that the income developed from chips will pay for the cost of chipping and removal*
- *Site is large enough to store all slash in a large pile (~1 acre), setup chipping truck, and accommodate transport trucks*

Discussion

Chipping and removing logging slash off-site has the potential to improve restoration results and reduce costs on large sites that generate large volumes of debris. This method improves results because material does not have to be burned, thus minimizing soil damage, and it reduces costs because chip removal pays for itself when sufficient quantities of chips can be sold as biomass.

Chipping still requires that slash be transported and piled using skid-steer tractors or harvesters. All the slash is generally collected at one or two large landings where a chipping truck can set-up and load chips into transport trucks. A separate loader provided by the chipping contractor is required to transfer slash into the chipper. The amount of debris required to financially break-even created a pile 40'x40'x450'—nearly 750,000 cubic feet of slash—at one site.

Constraining Factors

1. Sites must generate extremely large quantities of slash—at least 1250 tons—to develop enough chips to pay for the cost of equipment and transport. Only the largest restoration sites are big enough to meet this minimum. Modeling suggests a minimum of 30 acres on extremely dense sites, but more likely 60 acres for most woodland and forest sites.
2. Onsite chipping requires adequate space for the chipper truck, hauling trucks, and transfer tractors to set-up and maneuver without damaging soils.

Chipping Cost Estimate

High: $400/acre | Average cost: $0/acre | Low: $0/acre

One time initial setup fee: $2500/site

The minimum setup fee for onsite chipping is $2500. This cost does not include operational costs, or hauling costs. To meet this minimum, a project must generate a considerable quantity of chips. Markets vary, but as of spring 2010, green biomass chips could be sold for $10 per ton. Projects that break even and do not incur costs to the landowner require extremely densely stocked sites—one generated 5400 tons of material, or over 100 tons of slash per acre.

Alternative Shrub Layer BMP Recommendations

Objective 5: Shrub Layer Thinning

Ist Alternative BMP: 1. Manual cutting, grubbing, & herbicide application.

Assumptions

- *Restoration goals prioritize protecting the ground layer*
- *or, Canopy layer procedures have already reduced the volume of the shrub layer*
- *or, Site size is less than 10 acres*
- *or, Ground conditions inhibit mower access*
- *or, Landowner prefers manual strategies to herbicide use*
- *or, Slopes are greater than 45%*

Discussion

Where mechanical mowing is not an option, manual control using weed wrenches, loppers, or powered weed trimmers (weed eater) is the next best option. With manual methods, the sequence of work follows the same rational as mechanical methods, but the tools are different. To avoid damage to the ground layer, shrubs are cut or pulled, not dug, then sprayed with herbicide after they resprout. Backpack mounted herbicide applicators are most effective on difficult terrain. If poison-oak is a dominant component of the shrub layer, pre-treatment with herbicide may be necessary to avoid worker exposure to poison-oak burns. On excessively steep slopes, some managers choose to not treat the shrub layer at all because of the physical challenges and financial cost associated with achieving high quality results and the potential to damage erodible soils.

Where herbicide use is not an option, digging shrubs (grubbing) is the method of last resort. While species like Scotch broom (*Cytisus scoparius*) lend themselves well to manual removal because they can be pulled with minimal soil damage, others such as Armenian blackberry (*Rubus armeniacus*) and rose (*Rosa sp.*) do not because their root systems require digging. Seeding immediately after disturbing soil is imperative to reducing weed seed germination. Digging should be limited to the dry season when soils will not be compacted—the same time of year when digging is most difficult because soils are more firmly bound together. Without herbicide, the time and cost required to remove unwanted shrubs increases dramatically.

Constraining Factors

1. Costs for manual work can be highly variable and prohibitively expensive. Except where trained in-house work crews or subsidized labor are available, costs are generally too great to make manual shrub control a common restoration approach.
2. The wear from trampling may cause significant soil damage—particularly on sites with increased soil moisture. Pulling and digging weeds is particularly damaging to soils.

Manual Shrub Removal Cost Estimate

High: $14,400/acre | Average cost: $2400/acre | Low: $1200/acre

Manual shrub removal is time consuming. A crew of 12 individuals can clear 1-12 acres in a week depending on density. Costs per worker average $30 per hour. Some organizations subsidize the hourly cost of workers but these subsidies were not factored into this analysis. The maximum reflects costs on an extremely dense site with wet soils and no herbicide use.

APPENDIX B

FVS MODEL RESULTS BY SITE

The restoration scenario outputs in Appendix B are comprised of several components:

Stand characteristics relative to DFC application:
BT: Before thinning
AT: After thinning
CT: Cut trees after thinning

Tree species category and diameter class (trees per acre):
ALL: All species trees per acre
WO: Oregon white oak trees per acre
1-10: 1 to 10 inches DBH trees per acre
10-20: 10.01 to 19.8 inches DBH trees per acre
20+: greater than 19.8 inches DBH trees per acre

Other stand characteristics:
CC: Canopy cover percentage
QMD: Quadratic mean diameter
SNAGS: Number of snags greater than 10 inches DBH per acre
TPA: Number of trees per acre (all species)
SEED: Number of seedling trees (less than 1 inch DBH) per acre
VC3: Value class 3 (oaks per acre greater than 19.8 inches DBH in lowest health class)

Economic Estimates:
BIO: Biomass in tons per acre
BIO NO TIMBER: Biomass in tons per acre without conifers greater than 12 inches DBH (used to estimate quantity of chips produced per acre)
BD FT: Board feet of conifer species per acre
Log Value (2010): BD FT * $160
Log Value (2005): BD FT * $300
Transportation Cost: BD FT * $125
Log Income Potential (2010): Log Value (2010) - Transportation Cost
Log Income Potential (2005): Log Value (2005) - Transportation Cost
Chip Value (2010): BIO NO TIMBER * $20

Stand IDs (one for each row) are a combination of site and stand type as follows:
BR(x): Brownsville
CR(x): Chip Ross
FN(x): Finley
JC(x): Jim's Creek
LW(x): Lowell
MP(x): Mount Pisgah
SE(x): Southeast

(x)Fb: Broadleaf fores
(x)Fc: Conifer forest
(x)Fm: Mixed broadleaf-conifer forest
(x)S: Savanna
(x)W: Woodland

Table B.1 *Before restoration stand characteristics.*

Stand ID	BT TPA	BT SEED	BT ALL 1-10	BT ALL 10-20	BT ALL 20+	BT WO 1-10	BT WO 10-20	BT WO 20+	WO VC3
BRFb	818	371	378	61.7	6.9	96.5	51.5	4.7	0.0
CRFb	401	132	172	77.3	20.6	52.3	61.6	17.4	6.6
FNFb	532	210	246	52.6	23.5	59.5	36.2	21.9	9.0
LWFb	644	130	412	94.7	6.5	83.6	68.5	6.1	0.5
MPFb	575	82	408	62.8	22.5	317.3	56.5	22.5	6.6
SEFb	577	57	408	91.7	20.7	263.6	57.0	17.8	8.1
MIN	401	57	172	52.6	6.5	52.3	36.2	4.7	0.0
MAX	818	371	412	94.7	23.5	317.3	68.5	22.5	9.0
AVG	591	164	337	73.5	16.8	145.4	55.2	15.1	5.1
BRFc	264	71	111	62.1	20.1	33.0	0.0	3.6	0.9
CRFc	294	0	153	87.5	54.0	0.0	7.3	3.2	3.2
FNFc	219	27	96	60.1	35.9	18.0	2.6	2.2	1.1
JCFc	523	240	160	85.5	37.7	3.0	0.8	0.2	0.0
LWFc	477	113	286	57.5	19.5	8.4	6.5	0.5	0.0
MPFc	489	256	118	85.3	30.4	27.7	5.5	1.2	0.0
SEFc	272	36	120	75.4	40.2	0.0	1.7	0.8	0.4
MIN	219	0	96	57.5	19.5	0.0	0.0	0.2	0.0
MAX	523	256	286	87.5	54.0	33.0	7.3	3.6	3.2
AVG	363	106	149	73.3	34.0	12.9	3.5	1.7	0.8
BRFm	351	94	150	82.1	26.0	34.9	23.1	1.1	0.3
CRFm	447	124	193	108.0	21.6	31.1	36.1	11.5	3.7
FNFm	546	112	345	71.7	17.4	99.0	30.0	6.0	1.7
JCFm	630	356	205	62.5	6.8	2.3	11.4	2.3	2.3
LWFm	628	180	327	86.1	33.8	30.1	19.3	14.0	12.1
MPFm	333	11	220	75.1	27.5	0.0	10.7	0.6	0.0
SEFm	336	34	179	102.7	20.1	62.9	37.5	7.6	7.6
MIN	333	11	150	62.5	6.8	0.0	10.7	0.6	0.0
MAX	630	356	345	108.0	33.8	99.0	37.5	14.0	12.1
AVG	467	130	231	84.0	21.9	37.2	24.0	6.2	3.9

Table B.1 continued. *Before restoration stand characteristics.*

Stand ID	BT TPA	BT SEED	BT ALL 1-10	BT ALL 10-20	BT ALL 20+	BT WO 1-10	BT WO 10-20	BT WO 20+	WO VC3
BRS	7	0	5	2.3	0.3	0.0	2.3	0.3	0.0
CRS	52	43	4	1.9	3.2	3.9	1.9	3.2	0.0
FNS	56	41	12	1.8	2.0	11.6	1.8	2.0	0.0
JCS	198	163	27	4.7	2.6	3.3	0.7	0.4	0.2
LWS	189	105	74	8.4	1.4	36.0	8.4	1.4	1.2
MPS	184	79	101	3.1	1.5	82.8	3.1	1.5	0.5
SES	246	150	93	2.4	1.0	84.1	2.4	1.0	0.0
MIN	7	0	4	1.8	0.3	0.0	0.7	0.3	0.0
MAX	246	163	101	8.4	3.2	84.1	8.4	3.2	1.2
AVG	133	83	45	3.5	1.7	31.7	2.9	1.4	0.3
BRW	176	6	92	70.5	8.0	48.4	32.6	8.0	2.6
CRW	299	113	132	36.1	18.1	79.8	30.0	18.1	4.8
FNW	588	461	71	37.3	18.4	16.6	33.1	18.4	3.7
JCW	246	178	41	16.4	10.3	7.0	2.1	0.5	0.0
LWW	422	216	153	31.6	21.1	72.7	26.3	20.1	10.7
MPW	825	407	340	64.0	13.0	329.7	61.4	13.0	3.8
SEW	457	160	231	57.7	8.3	98.6	40.7	4.9	0.0
MIN	176	6	41	16.4	8.0	7.0	2.1	0.5	0.0
MAX	825	461	340	70.5	21.1	329.7	61.4	20.1	10.7
AVG	430	220	152	44.8	13.9	93.3	32.3	11.9	3.7

Table B.2. *Savanna restoration scenario outputs: after thin stand characteristics.*

Stand ID	AT CC	AT TPA	AT WO 1-10	AT WO 10-20	AT WO 20+	CT WO 10-20	CT WO 20+	AT WO QMD	CT ALL 1-12	CT ALL 12+	AT SNAGS
BRFb	16.8	17.0	5.0	5.3	4.7	46.2	0.0	20.8	373.0	56.6	10.2
CRFb	32.4	23.6	5.0	0.0	16.6	61.6	0.8	29.0	166.7	79.2	0.0
FNFb	35.0	26.0	5.0	0.0	19.0	36.2	2.9	27.0	242.6	53.5	4.1
LWFb	18.7	17.5	5.0	4.4	6.1	64.1	0.0	22.2	407.1	88.8	8.9
MPFb	30.5	23.6	5.0	0.0	16.6	56.5	6.0	25.9	403.1	66.7	4.2
SEFb	30.4	30.1	5.0	0.3	17.8	56.7	0.0	23.6	407.0	83.6	0.0
MIN	16.8	17.0	5.0	0.0	4.7	36.2	0.0	20.8	166.7	53.5	0.0
MAX	35.0	30.1	5.0	5.3	19.0	64.1	6.0	29.0	407.1	88.8	10.2
AVG	27.3	23.0	5.0	1.7	13.5	53.5	1.6	24.8	333.2	71.4	4.6
BRFc	10.6	10.6	5.0	0.0	3.6	0.0	0.0	21.4	106.0	76.6	0.0
CRFc	20.1	15.2	0.0	7.3	3.2	0.0	0.0	19.0	152.5	126.3	0.0
FNFc	13.5	11.8	5.0	2.6	2.2	0.0	0.0	21.5	91.0	89.2	2.4
JCFc	5.8	13.0	3.0	0.8	0.2	0.0	0.0	17.1	151.8	120.2	0.5
LWFc	11.5	19.0	5.0	6.5	0.5	0.0	0.0	14.9	276.5	68.0	0.0
MPFc	14.4	13.8	5.0	5.5	1.2	0.0	0.0	16.0	112.8	106.9	0.0
SEFc	8.7	14.5	0.0	1.7	0.8	0.0	0.0	19.1	115.4	111.1	0.0
MIN	5.8	10.6	0.0	0.0	0.2	0.0	0.0	14.9	91.0	68.0	0.0
MAX	20.1	19.0	5.0	7.3	3.6	0.0	0.0	21.5	276.5	126.3	2.4
AVG	12.1	14.0	3.3	3.5	1.7	0.0	0.0	18.4	143.7	99.8	0.4
BRFm	16.4	17.3	5.0	9.1	1.1	14.0	0.0	16.4	149.0	91.4	0.0
CRFm	26.5	20.7	5.0	2.2	11.5	33.9	0.0	24.3	187.5	113.9	3.0
FNFm	22.4	18.7	5.0	5.7	6.0	24.3	0.0	23.7	340.3	74.9	0.9
JCFm	16.1	16.5	2.3	10.0	2.3	1.4	0.0	22.2	203.2	55.1	9.2
LWFm	34.1	31.2	5.0	8.1	14.0	11.3	0.0	22.6	322.6	93.5	4.3
MPFm	13.9	17.0	0.0	9.4	0.6	1.3	0.0	16.0	227.9	82.4	0.0
SEFm	24.2	24.6	5.0	10.0	7.6	27.5	0.0	19.4	181.6	95.2	3.0
MIN	13.9	16.5	0.0	2.2	0.6	1.3	0.0	16.0	149.0	55.1	0.0
MAX	34.1	31.2	5.0	10.0	14.0	33.9	0.0	24.3	340.3	113.9	9.2
AVG	22.0	20.9	3.9	7.8	6.2	16.2	0.0	20.7	230.3	86.6	2.9

Table B.2 continued. *Savanna restoration scenario outputs: after thin stand characteristics.*

Stand ID	AT CC	AT TPA	AT WO 1-10	AT WO 10-20	AT WO 20+	CT WO 10-20	CT WO 20+	AT WO QMD	CT ALL 1-12	CT ALL 12+	AT SNAGS
BRS	2.7	2.5	0.0	2.3	0.3	0.0	0.0	16.1	4.6	0.0	0.0
CRS	8.0	10.2	3.9	1.9	3.2	0.0	0.0	22.2	0.0	0.0	0.0
FNS	7.2	8.8	5.0	1.8	2.0	0.0	0.0	28.6	6.6	0.0	0.0
JCS	4.8	13.1	3.3	0.7	0.4	0.0	0.0	17.2	19.0	4.2	0.0
LWS	11.3	14.8	5.0	8.4	1.4	0.0	0.0	15.8	69.5	0.0	0.0
MPS	7.1	9.6	5.0	3.1	1.5	0.0	0.0	17.7	96.0	0.0	0.0
SES	6.4	8.5	5.0	2.4	1.0	0.0	0.0	19.4	88.2	0.0	0.0
MIN	2.7	2.5	0.0	0.7	0.3	0.0	0.0	15.8	0.0	0.0	0.0
MAX	11.3	14.8	5.0	8.4	3.2	0.0	0.0	28.6	96.0	4.2	0.0
AVG	6.8	9.6	3.9	2.9	1.4	0.0	0.0	19.6	40.6	0.6	0.0
BRW	22.8	19.6	5.0	4.7	8.0	27.9	0.0	25.3	90.0	60.8	0.0
CRW	32.7	21.8	5.0	0.0	14.8	30.0	3.3	32.1	126.6	37.4	0.0
FNW	28.8	18.7	5.0	0.0	13.7	33.1	4.7	38.4	66.4	42.0	4.2
JCW	8.9	14.6	5.0	2.1	0.5	0.0	0.0	16.2	31.7	22.0	1.7
LWW	38.1	32.7	5.0	0.6	20.1	25.7	0.0	26.4	145.5	27.7	0.0
MPW	23.5	18.8	5.0	0.8	13.0	60.6	0.0	24.4	343.1	55.4	0.0
SEW	20.6	22.0	5.0	5.1	4.9	35.6	0.0	23.4	233.0	47.2	0.0
MIN	8.9	14.6	5.0	0.0	0.5	0.0	0.0	16.2	31.7	22.0	0.0
MAX	38.1	32.7	5.0	5.1	20.1	60.6	4.7	38.4	343.1	60.8	4.2
AVG	25.1	21.2	5.0	1.9	10.7	30.4	1.1	26.6	148.0	41.8	0.8

Table B.3. *Savanna restoration scenario outputs: economic estimates.*

Stand ID	CT BIO	BIO NO TIMBER	CT BD FT	Log Value (2010)	Log Value (2005)	Transportation Cost	Log Income Potential 2010	Log Income Potential 2005	Chip Value (2010)
BRFb	51.5	46.7	1,726	$276	$518	$216	$60	$302	$934
CRFb	47.5	36.7	3,935	$630	$1,181	$492	$138	$689	$733
FNFb	37.6	37.0	201	$32	$60	$25	$7	$35	$740
LWFb	54.2	54.1	39	$6	$12	$5	$1	$7	$1,082
MPFb	42.7	40.2	893	$143	$268	$112	$31	$156	$803
SEFb	60.5	55.7	1,719	$275	$516	$215	$60	$301	$1,113
MIN	37.6	36.7	39	$6	$12	$5	$1	$7	$733
MAX	60.5	55.7	3,935	$630	$1,181	$492	$138	$689	$1,113
AVG	49.0	45.0	1,419	$227	$426	$177	$50	$248	$901
BRFc	69.1	4.6	24,976	$3,996	$7,493	$3,122	$874	$4,371	$92
CRFc	163.9	15.4	62,768	$10,043	$18,830	$7,846	$2,197	$10,984	$307
FNFc	105.9	6.5	40,879	$6,541	$12,264	$5,110	$1,431	$7,154	$130
JCFc	162.4	26.1	52,254	$8,361	$15,676	$6,532	$1,829	$9,145	$522
LWFc	75.4	25.7	20,321	$3,251	$6,096	$2,540	$711	$3,556	$514
MPFc	121.6	11.4	44,894	$7,183	$13,468	$5,612	$1,571	$7,856	$228
SEFc	141.2	7.3	57,481	$9,197	$17,244	$7,185	$2,012	$10,059	$145
MIN	69.1	4.6	20,321	$3,251	$6,096	$2,540	$711	$3,556	$92
MAX	163.9	26.1	62,768	$10,043	$18,830	$7,846	$2,197	$10,984	$522
AVG	119.9	13.8	43,368	$6,939	$13,010	$5,421	$1,518	$7,589	$277
BRFm	87.5	43.2	18,016	$2,883	$5,405	$2,252	$631	$3,153	$863
CRFm	81.5	30.1	19,068	$3,051	$5,720	$2,383	$667	$3,337	$602
FNFm	66.0	24.2	16,486	$2,638	$4,946	$2,061	$577	$2,885	$484
JCFm	60.1	34.2	8,956	$1,433	$2,687	$1,120	$313	$1,567	$685
LWFm	80.6	38.6	15,987	$2,558	$4,796	$1,998	$560	$2,798	$772
MPFm	97.2	41.7	23,031	$3,685	$6,909	$2,879	$806	$4,030	$834
SEFm	73.5	25.9	18,278	$2,924	$5,483	$2,285	$640	$3,199	$518
MIN	60.1	24.2	8,956	$1,433	$2,687	$1,120	$313	$1,567	$484
MAX	97.2	43.2	23,031	$3,685	$6,909	$2,879	$806	$4,030	$863
AVG	78.1	34.0	17,117	$2,739	$5,135	$2,140	$599	$2,996	$680

Table B.3 continued. *Savanna restoration scenario outputs: economic estimates.*

Stand ID	CT BIO	BIO NO TIMBER	CT BD FT	Log Value (2010)	Log Value (2005)	Transportation Cost	Log Income Potential 2010	Log Income Potential 2005	Chip Value (2010)
BRS	0.1	0.1	0	$0	$0	$0	$0	$0	$2
CRS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
FNS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
JCS	4.1	0.4	1,317	$211	$395	$165	$46	$230	$9
LWS	2.3	2.3	0	$0	$0	$0	$0	$0	$45
MPS	0.8	0.8	0	$0	$0	$0	$0	$0	$16
SES	0.8	0.8	0	$0	$0	$0	$0	$0	$15
MIN	0.0	0.0	0	$0	$0	$0	$0	$0	$0
MAX	4.1	2.3	1,317	$211	$395	$165	$46	$230	$45
AVG	1.2	0.6	188	$30	$56	$24	$7	$33	$13
BRW	36.3	16.8	6,973	$1,116	$2,092	$872	$244	$1,220	$336
CRW	27.6	26.9	224	$36	$67	$28	$8	$39	$539
FNW	25.8	25.8	0	$0	$0	$0	$0	$0	$517
JCW	30.0	3.5	10,382	$1,661	$3,115	$1,298	$363	$1,817	$70
LWW	16.6	15.8	289	$46	$87	$36	$10	$51	$316
MPW	36.9	36.9	0	$0	$0	$0	$0	$0	$739
SEW	32.2	19.9	4,790	$766	$1,437	$599	$168	$838	$397
MIN	16.6	3.5	0	$0	$0	$0	$0	$0	$70
MAX	36.9	36.9	10,382	$1,661	$3,115	$1,298	$363	$1,817	$739
AVG	29.3	20.8	3,237	$518	$971	$405	$113	$566	$416

Table B.4. *Woodland restoration scenario outputs: after thin stand characteristics.*

Stand ID	AT CC	AT TPA	AT WO 1-10	AT WO 10-20	AT WO 20+	CT WO 10-20	CT WO 20+	AT WO QMD	CT ALL 1-12	CT ALL 12+	AT SNAGS
BRFb	30.6	40.0	10.0	20.3	4.7	31.2	0.0	17.4	368.0	38.6	10.2
CRFb	44.8	46.6	10.0	14.2	17.4	47.4	0.0	23.9	161.7	61.2	0.0
FNFb	46.0	47.0	10.0	12.1	21.9	24.1	0.0	23.1	237.6	37.5	4.1
LWFb	30.7	37.7	10.0	19.4	6.1	49.1	0.0	18.4	402.1	73.6	8.9
MPFb	44.2	46.6	10.0	9.0	22.5	47.5	0.0	22.4	398.1	48.7	4.2
SEFb	42.3	54.0	10.0	15.3	17.8	41.7	0.0	20.4	401.1	65.6	0.0
MIN	30.6	37.7	10.0	9.0	4.7	24.1	0.0	17.4	161.7	37.5	0.0
MAX	46.0	54.0	10.0	20.3	22.5	49.1	0.0	23.9	402.1	73.6	10.2
AVG	39.8	45.3	10.0	15.1	15.1	40.1	0.0	20.9	328.1	54.2	4.6
BRFc	16.6	18.6	10.0	0.0	3.6	0.0	0.0	21.4	101.0	73.6	0.0
CRFc	20.5	15.5	0.0	7.3	3.2	0.0	0.0	19.0	152.5	126.0	0.0
FNFc	19.7	19.8	10.0	2.6	2.2	0.0	0.0	21.5	86.0	86.2	2.4
JCFc	8.8	26.0	3.0	0.8	0.2	0.0	0.0	17.1	150.6	117.2	0.5
LWFc	15.0	32.0	8.4	6.5	0.5	0.0	0.0	14.9	268.1	65.0	0.0
MPFc	20.6	21.8	10.0	5.5	1.2	0.0	0.0	16.0	107.8	103.9	0.0
SEFc	12.8	27.5	0.0	1.7	0.8	0.0	0.0	19.1	107.8	108.1	0.0
MIN	8.8	15.5	0.0	0.0	0.2	0.0	0.0	14.9	86.0	65.0	0.0
MAX	20.6	32.0	10.0	7.3	3.6	0.0	0.0	21.5	268.1	126.0	2.4
AVG	16.3	23.0	5.9	3.5	1.7	0.0	0.0	18.4	139.1	97.2	0.4
BRFm	31.4	39.2	10.0	23.1	1.1	0.0	0.0	15.5	144.0	74.5	0.0
CRFm	39.9	43.7	10.0	17.2	11.5	18.9	0.0	20.1	182.5	95.9	3.0
FNFm	36.8	41.7	10.0	20.7	6.0	9.3	0.0	19.2	335.3	56.9	0.9
JCFm	19.2	21.0	2.3	11.4	2.3	0.0	0.0	21.5	203.2	50.6	9.2
LWFm	47.2	54.2	10.0	19.3	14.0	0.0	0.0	20.3	317.6	75.5	4.3
MPFm	19.6	21.6	0.0	10.7	0.6	0.0	0.0	15.9	227.9	78.1	0.0
SEFm	38.2	47.6	10.0	25.0	7.6	12.5	0.0	17.4	176.6	77.2	3.0
MIN	19.2	21.0	0.0	10.7	0.6	0.0	0.0	15.5	144.0	50.6	0.0
MAX	47.2	54.2	10.0	25.0	14.0	18.9	0.0	21.5	335.3	95.9	9.2
AVG	33.2	38.4	7.5	18.2	6.2	5.8	0.0	18.6	226.7	72.7	2.9

Table B.4 continued. *Woodland restoration scenario outputs: after thin stand characteristics.*

Stand ID	AT CC	AT TPA	AT WO 1-10	AT WO 10-20	AT WO 20+	CT WO 10-20	CT WO 20+	AT WO QMD	CT ALL 1-12	CT ALL 12+	AT SNAGS
BRS	2.7	2.5	0.0	2.3	0.3	0.0	0.0	16.1	4.6	0.0	0.0
CRS	8.0	15.2	3.9	1.9	3.2	0.0	0.0	22.2	0.0	0.0	0.0
FNS	7.4	13.8	10.0	1.8	2.0	0.0	0.0	28.6	1.6	0.0	0.0
JCS	8.1	26.1	3.3	0.7	0.4	0.0	0.0	17.2	17.8	1.2	0.0
LWS	12.8	19.8	10.0	8.4	1.4	0.0	0.0	15.8	64.5	0.0	0.0
MPS	8.6	14.6	10.0	3.1	1.5	0.0	0.0	17.7	91.0	0.0	0.0
SES	7.9	13.5	10.0	2.4	1.0	0.0	0.0	19.4	83.2	0.0	0.0
MIN	2.7	2.5	0.0	0.7	0.3	0.0	0.0	15.8	0.0	0.0	0.0
MAX	12.8	26.1	10.0	8.4	3.2	0.0	0.0	28.6	91.0	1.2	0.0
AVG	7.9	15.1	6.7	2.9	1.4	0.0	0.0	19.6	37.5	0.2	0.0
BRW	35.4	42.6	10.0	19.7	8.0	12.9	0.0	20.3	85.0	42.8	0.0
CRW	46.0	42.9	10.0	11.7	18.1	18.3	0.0	26.4	121.6	21.4	0.0
FNW	40.0	38.7	10.0	10.3	18.4	22.8	0.0	29.3	61.4	27.0	4.2
JCW	12.4	27.6	7.0	2.1	0.5	0.0	0.0	16.2	29.7	19.0	1.7
LWW	48.7	59.1	10.0	15.6	20.1	10.7	0.0	22.5	135.5	11.3	0.0
MPW	36.0	38.8	10.0	15.8	13.0	45.6	0.0	20.7	338.1	40.4	0.0
SEW	35.0	50.0	10.0	20.1	4.9	20.6	0.0	18.9	228.0	29.2	0.0
MIN	12.4	27.6	7.0	2.1	0.5	0.0	0.0	16.2	29.7	11.3	0.0
MAX	48.7	59.1	10.0	20.1	20.1	45.6	0.0	29.3	338.1	42.8	4.2
AVG	36.2	42.8	9.6	13.6	11.9	18.7	0.0	22.1	142.7	27.3	0.8

Table B.5. *Woodland restoration scenario outputs: economic estimates*

Stand ID	CT BIO	BIO NO TIMBER	CT BD FT	Log Value (2010)	Log Value (2005)	Transportation Cost	Log Income Potential 2010	Log Income Potential 2005	Chip Value (2010)
BRFb	42.5	39.5	1,093	$175	$328	$137	$38	$191	$790
CRFb	35.8	27.6	2,922	$467	$876	$365	$102	$511	$552
FNFb	27.4	27.4	0	$0	$0	$0	$0	$0	$549
LWFb	46.6	46.6	0	$0	$0	$0	$0	$0	$931
MPFb	30.3	29.5	260	$42	$78	$32	$9	$45	$590
SEFb	50.4	47.3	1,086	$174	$326	$136	$38	$190	$947
MIN	27.4	27.4	0	$0	$0	$0	$0	$0	$549
MAX	50.4	47.3	2,922	$467	$876	$365	$102	$511	$947
AVG	38.8	36.3	893	$143	$268	$112	$31	$156	$727
BRFc	61.7	4.3	21,865	$3,498	$6,559	$2,733	$765	$3,826	$86
CRFc	162.9	15.4	62,274	$9,964	$18,682	$7,784	$2,180	$10,898	$307
FNFc	94.8	6.2	35,834	$5,733	$10,750	$4,479	$1,254	$6,271	$124
JCFc	157.7	26.1	50,116	$8,019	$15,035	$6,265	$1,754	$8,770	$522
LWFc	72.8	25.4	19,207	$3,073	$5,762	$2,401	$672	$3,361	$509
MPFc	110.4	11.1	39,752	$6,360	$11,926	$4,969	$1,391	$6,957	$223
SEFc	135.7	7.3	54,671	$8,747	$16,401	$6,834	$1,913	$9,567	$145
MIN	61.7	4.3	19,207	$3,073	$5,762	$2,401	$672	$3,361	$86
MAX	162.9	26.1	62,274	$9,964	$18,682	$7,784	$2,180	$10,898	$522
AVG	113.7	13.7	40,531	$6,485	$12,159	$5,066	$1,419	$7,093	$274
BRFm	72.2	36.4	14,078	$2,253	$4,223	$1,760	$493	$2,464	$729
CRFm	68.3	22.3	16,799	$2,688	$5,040	$2,100	$588	$2,940	$445
FNFm	49.9	17.0	12,393	$1,983	$3,718	$1,549	$434	$2,169	$340
JCFm	57.4	33.5	8,263	$1,322	$2,479	$1,033	$289	$1,446	$670
LWFm	61.0	33.1	10,049	$1,608	$3,015	$1,256	$352	$1,759	$663
MPFm	87.3	41.1	18,711	$2,994	$5,613	$2,339	$655	$3,274	$822
SEFm	59.1	18.7	15,069	$2,411	$4,521	$1,884	$527	$2,637	$374
MIN	49.9	17.0	8,263	$1,322	$2,479	$1,033	$289	$1,446	$340
MAX	87.3	41.1	18,711	$2,994	$5,613	$2,339	$655	$3,274	$822
AVG	65.0	28.9	13,623	$2,180	$4,087	$1,703	$477	$2,384	$578

Table B.5 continued. *Woodland restoration scenario outputs: economic estimates.*

Stand ID	CT BIO	BIO NO TIMBER	CT BD FT	Log Value (2010)	Log Value (2005)	Transportation Cost	Log Income Potential 2010	Log Income Potential 2005	Chip Value (2010)
BRS	0.1	0.1	0	$0	$0	$0	$0	$0	$2
CRS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
FNS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
JCS	1.3	0.4	285	$46	$86	$36	$10	$50	$9
LWS	2.0	2.0	0	$0	$0	$0	$0	$0	$39
MPS	0.5	0.5	0	$0	$0	$0	$0	$0	$10
SES	0.5	0.5	0	$0	$0	$0	$0	$0	$9
MIN	0.0	0.0	0	$0	$0	$0	$0	$0	$0
MAX	2.0	2.0	285	$46	$86	$36	$10	$50	$39
AVG	0.6	0.5	41	$7	$12	$5	$1	$7	$10
BRW	27.3	9.6	6,340	$1,014	$1,902	$792	$222	$1,109	$192
CRW	14.7	14.7	0	$0	$0	$0	$0	$0	$294
FNW	16.0	16.0	0	$0	$0	$0	$0	$0	$320
JCW	25.4	3.5	8,448	$1,352	$2,534	$1,056	$296	$1,478	$70
LWW	7.4	7.4	0	$0	$0	$0	$0	$0	$149
MPW	27.7	27.7	0	$0	$0	$0	$0	$0	$554
SEW	21.3	12.2	3,248	$520	$974	$406	$114	$568	$245
MIN	7.4	3.5	0	$0	$0	$0	$0	$0	$70
MAX	27.7	27.7	8,448	$1,352	$2,534	$1,056	$296	$1,478	$554
AVG	20.0	13.0	2,577	$412	$773	$322	$90	$451	$260

Table B.6. *Fire hazard reduction scenario outputs: after thin stand characteristics.*

Stand ID	AT CC	AT TPA	AT WO 1-10	AT WO 10-20	AT WO 20+	CT WO 10-20	CT WO 20+	AT WO QMD	CT ALL 1-12	CT ALL 12+	AT SNAGS
BRFb	40	43.6	0.0	36.7	4.7	14.8	0.0	16.4	378.0	25.0	10.2
CRFb	40	30.7	0.0	10.1	17.4	51.5	0.0	25.0	171.7	67.2	0.0
FNFb	40	27.0	0.0	3.5	21.9	32.7	0.0	25.3	247.6	47.5	4.1
LWFb	40	44.8	0.0	31.5	6.1	37.0	0.0	17.3	412.1	56.5	8.9
MPFb	40	31.6	0.0	9.1	22.5	47.4	0.0	22.4	408.1	53.7	4.2
SEFb	40	37.3	0.0	12.3	17.8	44.7	0.0	20.9	417.0	66.4	0.0
MIN	40	27.0	0.0	3.5	4.7	14.8	0.0	16.4	171.7	25.0	0.0
MAX	40	44.8	0.0	36.7	22.5	51.5	0.0	25.3	417.0	67.2	10.2
AVG	40	35.8	0.0	17.2	15.1	38.0	0.0	21.2	339.1	52.7	4.6
BRFc	40	40.5	0.0	0.0	3.6	0.0	0.0	21.4	111.0	41.7	0.0
CRFc	40	27.5	0.0	0.0	1.6	7.3	1.6	29.5	152.5	114.0	0.0
FNFc	40	29.6	0.0	0.0	2.0	2.6	0.2	27.7	96.0	66.5	2.4
JCFc	40	32.3	0.0	0.0	0.2	0.8	0.0	27.4	160.0	90.6	0.5
LWFc	40	44.7	0.0	1.5	0.5	5.1	0.0	19.0	288.7	30.1	0.0
MPFc	40	28.7	0.0	0.0	1.2	5.5	0.0	20.9	117.8	87.0	0.0
SEFc	40	29.7	0.0	0.0	0.8	1.7	0.0	26.3	120.4	85.9	0.0
MIN	40	27.5	0.0	0.0	0.2	0.0	0.0	19.0	96.0	30.1	0.0
MAX	40	44.7	0.0	1.5	3.6	7.3	1.6	29.5	288.7	114.0	2.4
AVG	40	33.3	0.0	0.2	1.4	3.3	0.3	24.6	149.5	73.7	0.4
BRFm	40	32.4	0.0	2.1	1.1	21.0	0.0	19.6	154.0	71.4	0.0
CRFm	40	35.6	0.0	6.2	11.5	29.9	0.0	22.8	192.5	94.0	3.0
FNFm	40	37.3	0.0	8.6	6.0	21.4	0.0	22.2	345.3	51.3	0.9
JCFm	40	51.6	0.0	11.4	2.3	0.0	0.0	21.5	205.4	17.7	9.2
LWFm	40	28.4	0.0	0.0	14.0	19.3	0.0	25.7	329.7	89.3	4.3
MPFm	40	31.9	0.0	0.0	0.6	10.7	0.0	29.5	227.9	62.5	0.0
SEFm	40	39.0	0.0	5.4	7.6	32.0	0.0	20.8	186.6	75.7	3.0
MIN	40	28.4	0.0	0.0	0.6	0.0	0.0	19.6	154.0	17.7	0.0
MAX	40	51.6	0.0	11.4	14.0	32.0	0.0	29.5	345.3	94.0	9.2
AVG	40	36.6	0.0	4.8	6.2	19.2	0.0	23.2	234.5	66.0	2.9

Table B.6 continued. *Fire hazard reduction scenario outputs: after thin stand characteristics.*

Stand ID	AT CC	AT TPA	AT WO 1-10	AT WO 10-20	AT WO 20+	CT WO 10-20	CT WO 20+	AT WO QMD	CT ALL 1-12	CT ALL 12+	AT SNAGS
BRS	3	7.1	0.0	2.3	0.3	0.0	0.0	16.1	0.0	0.0	0.0
CRS	8	51.7	46.6	1.9	3.2	0.0	0.0	22.2	0.0	0.0	0.0
FNS	8	56.0	52.2	1.8	2.0	0.0	0.0	28.6	0.0	0.0	0.0
JCS	12	197.9	21.3	0.7	0.4	0.0	0.0	17.2	0.0	0.0	0.0
LWS	21	189.4	68.7	8.4	1.4	0.0	0.0	15.8	0.0	0.0	0.0
MPS	14	184.3	150.5	3.1	1.5	0.0	0.0	17.7	0.0	0.0	0.0
SES	14	246.4	93.2	2.4	1.0	0.0	0.0	19.4	0.0	0.0	0.0
MIN	3	7.1	0.0	0.7	0.3	0.0	0.0	15.8	0.0	0.0	0.0
MAX	21	246.4	150.5	8.4	3.2	0.0	0.0	28.6	0.0	0.0	0.0
AVG	11	133.3	61.8	2.9	1.4	0.0	0.0	19.6	0.0	0.0	0.0
BRW	40	44.6	0.0	17.5	8.0	15.0	0.0	20.7	95.0	30.9	0.0
CRW	40	24.9	0.0	6.8	18.1	23.2	0.0	28.0	131.6	29.4	0.0
FNW	40	30.4	0.0	11.9	18.4	21.2	0.0	28.7	71.4	25.4	4.2
JCW	33	245.7	7.0	2.1	0.5	0.0	0.0	16.2	0.0	0.0	1.7
LWW	40	27.8	0.0	6.7	20.1	19.6	0.0	24.6	155.5	22.6	0.0
MPW	40	39.5	0.0	26.5	13.0	35.0	0.0	19.3	348.1	29.7	0.0
SEW	40	41.9	0.0	33.6	4.9	7.2	0.0	17.6	238.0	17.4	0.0
MIN	33	24.9	0.0	2.1	0.5	0.0	0.0	16.2	0.0	0.0	0.0
MAX	40	245.7	7.0	33.6	20.1	35.0	0.0	28.7	348.1	30.9	4.2
AVG	39	64.9	1.0	15.0	11.9	17.3	0.0	22.2	148.5	22.2	0.8

Table B.7. *Fire hazard reduction scenario outputs: economic estimates.*

Stand ID	CT BIO	BIO NO TIMBER	CT BD FT	Log Value (2010)	Log Value (2005)	Transportation Cost	Log Income Potential 2010	Log Income Potential 2005	Chip Value (2010)
BRFb	27.2	21.2	2,148	$344	$644	$268	$75	$376	$424
CRFb	39.4	30.1	3,307	$529	$992	$413	$116	$579	$602
FNFb	29.7	28.0	596	$95	$179	$75	$21	$104	$560
LWFb	37.6	36.3	461	$74	$138	$58	$16	$81	$726
MPFb	33.8	30.1	1,315	$210	$394	$164	$46	$230	$602
SEFb	47.6	43.3	1,530	$245	$459	$191	$54	$268	$866
MIN	27.2	21.2	461	$74	$138	$58	$16	$81	$424
MAX	47.6	43.3	3,307	$529	$992	$413	$116	$579	$866
AVG	35.9	31.5	1,560	$250	$468	$195	$55	$273	$630
BRFc	29.5	4.9	8,792	$1,407	$2,638	$1,099	$308	$1,539	$98
CRFc	103.6	20.5	32,434	$5,189	$9,730	$4,054	$1,135	$5,676	$409
FNFc	47.5	6.1	15,209	$2,433	$4,563	$1,901	$532	$2,661	$122
JCFc	71.0	14.7	19,630	$3,141	$5,889	$2,454	$687	$3,435	$294
LWFc	27.4	15.0	4,449	$712	$1,335	$556	$156	$779	$301
MPFc	59.4	10.0	17,775	$2,844	$5,332	$2,222	$622	$3,111	$200
SEFc	64.9	8.2	20,977	$3,356	$6,293	$2,622	$734	$3,671	$163
MIN	27.4	4.9	4,449	$712	$1,335	$556	$156	$779	$98
MAX	103.6	20.5	32,434	$5,189	$9,730	$4,054	$1,135	$5,676	$409
AVG	57.6	11.3	17,038	$2,726	$5,111	$2,130	$596	$2,982	$227
BRFm	44.5	26.8	6,299	$1,008	$1,890	$787	$220	$1,102	$537
CRFm	61.8	27.9	12,128	$1,940	$3,638	$1,516	$424	$2,122	$558
FNFm	37.9	21.4	5,907	$945	$1,772	$738	$207	$1,034	$427
JCFm	13.5	1.7	4,086	$654	$1,226	$511	$143	$715	$33
LWFm	61.1	33.1	10,099	$1,616	$3,030	$1,262	$353	$1,767	$662
MPFm	47.7	32.0	5,600	$896	$1,680	$700	$196	$980	$641
SEFm	47.6	19.3	10,130	$1,621	$3,039	$1,266	$355	$1,773	$386
MIN	13.5	1.7	4,086	$654	$1,226	$511	$143	$715	$33
MAX	61.8	33.1	12,128	$1,940	$3,638	$1,516	$424	$2,122	$662
AVG	44.9	23.2	7,750	$1,240	$2,325	$969	$271	$1,356	$463

Table B.7 continued. *Fire hazard reduction scenario outputs: economic estimates.*

Stand ID	CT BIO	BIO NO TIMBER	CT BD FT	Log Value (2010)	Log Value (2005)	Transportation Cost	Log Income Potential 2010	Log Income Potential 2005	Chip Value (2010)
BRS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
CRS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
FNS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
JCS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
LWS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
MPS	0.0	0.0	0	$0	$0	$0	$0	$0	$0
SES	0.0	0.0	0	$0	$0	$0	$0	$0	$0
MIN	0.0	0.0	0	$0	$0	$0	$0	$0	$0
MAX	0.0	0.0	0	$0	$0	$0	$0	$0	$0
AVG	0.0	0.0	0	$0	$0	$0	$0	$0	$0
BRW	20.6	11.1	3,373	$540	$1,012	$422	$118	$590	$223
CRW	19.7	17.9	646	$103	$194	$81	$23	$113	$359
FNW	15.5	15.5	0	$0	$0	$0	$0	$0	$310
JCW	0.0	0.0	0	$0	$0	$0	$0	$0	$0
LWW	14.1	12.7	495	$79	$149	$62	$17	$87	$254
MPW	23.6	23.6	0	$0	$0	$0	$0	$0	$472
SEW	16.6	6.6	3,585	$574	$1,076	$448	$125	$627	$132
MIN	0.0	0.0	0	$0	$0	$0	$0	$0	$0
MAX	23.6	23.6	3,585	$574	$1,076	$448	$125	$627	$472
AVG	15.7	12.5	1,157	$185	$347	$145	$40	$202	$250

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