

INVESTIGATION OF ALTERNATIVE FUEL REMOVAL STRATEGIES

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

University of Washington

2003

Program Authorized to Offer Degree: College of Forest Resources

University of Washington

Graduate School

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Acknowledgements

I really enjoyed working with Kevin Ceder, Larry Mason, Dr. James McCarter, Bruce Lippke, Jeff Comnick, Luke Rogers and Matt McLaughlin on this research. I learned a great deal through their patience and support.

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1. Introduction

1.1 Background

Dry, mid to high elevation federal forests in the inland West are overstocked with unhealthy, suppressed, small trees (Cooper 1960, Pyne 1997, Arno 2000). This is a result of decades of grazing, fire suppression, and logging (Pyne 1982, Arno 1996). Historically 10-25 year fire return intervals maintained a healthy ecosystem in these forests (Agee 1993). Many of these forests have grown under suppressed conditions which leave them more susceptible to insect and disease (Stewart 1988, Cochran and Barrett 1998, Pfilf et al. 2002). Due to lengthened fire intervals the dominant species in these forests have transitioned from fire tolerant to fire intolerant species (Pfilf et al. 2002). In forests now dominated by fire intolerant species the fuel load available to burn is more vulnerable to more intense fires (Huggard and Gomez 2001). Due to the high fuel load and altered species composition from tolerant to intolerant tree species, the fires may burn out of control as intense wildfires (USDA Forest Service 2002a). Fire suppression has caused these naturally or mechanically reseeded stands to grow into densely stocked forests (Pyne 1997, Everett et al. 2000, Strohmaier 2001). Removal of surplus fuel is needed to restore frequent low intensity fire regimes (Omi and Martinson 2002).

High fire risk forests in the United States (US) are concentrated on public lands including the national forests (USDA Forest Service U.S. Dept. of Interior and Western Governors' Association 2001). The majority of United States Forest Service (USFS) land is

concentrated in the Western half of the US. Figure 1 shows the distribution of large fires for 2002 alone. There are many overlaps between the USFS land and the 2002 fires as shown by comparison of Figure 1 A and B. Concentrations of high fire risk forests appear in very similar locational distributions as do the large forest fires in 2002 in the Western United States (Powell et al. 2001).

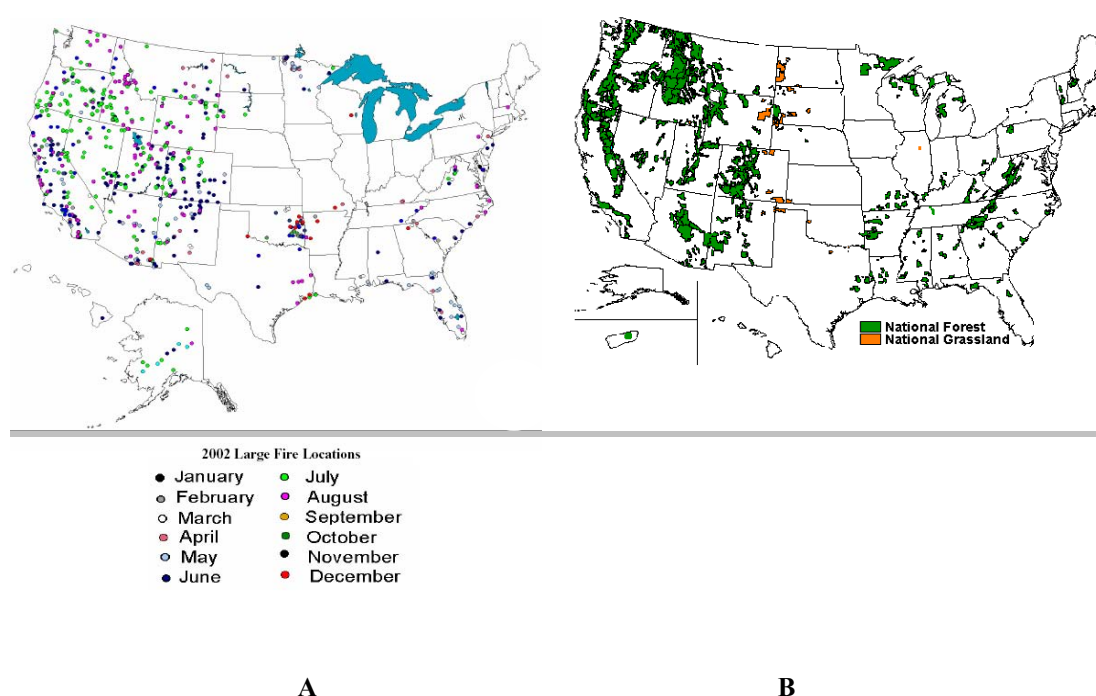


Figure 1 A and B 2002 Large Fire Locations and USFS ownership

The extent of the problem nationally is evidenced by the trend of acres burned over the last 10 years and the number of acres in high fire risk (United States National Interagency Fire Center 2002). Figure 2 shows acres burned in wildland fires 1993-2002. Note particularly the large number of acres burned in 2000 and 2002. The USFS manages 192 million acres of which 56 million acres have been determined to be in high fire risk

conditions (Powell et al. 2001). Roughly half of the high fire risk acres on National Forest lands are located in the Pacific Northwest (Western Governors Association 2001, 2002).

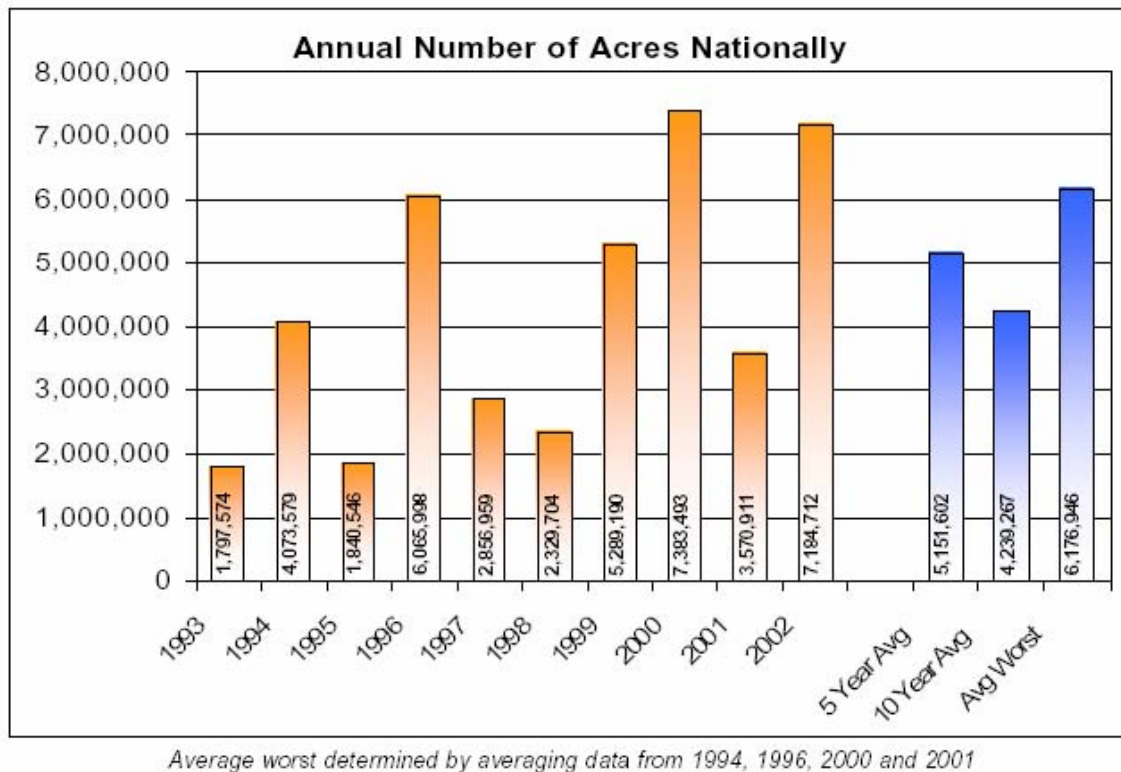


Figure 2 Acres Burned in Wildland Fires Reported 1993-2002 (NICC 2002)

There are many potential impacts from forest fires to rural communities that are located near high fire risk forests. Impacts of wildfire include decreased forest health, air pollution, loss of wildlife habitat, destruction of private property, and decline in the quality of life for people who live near this forestland. The federal government is developing strategies for fuel reduction treatment in at-risk forests through the National Fire Plan (Western Governors Association 2001, 2002, The Office of the President 2002).

Fuel reduction treatments are being tested through innovative contracting mechanisms and research. Fuel removal thinning costs may be considered as an investment in reducing the expense to the government of suppressing fire. Currently, the federal budget spent on fire suppression well exceeds the allocation for fuel reduction activities. In recent years record costs have been incurred by federal agencies to fight forest fires, \$1.4 billion in 2000 and \$2.2 billion in 2002 (The Office of the President 2002). There are also costs to local areas business, and states, counties, and cities when forest fires occur (Babbitt and Glickman 2000).

1.2 Research Objective

The objective of this study is to evaluate the cost and/or revenue associated with fire risk reduction effectiveness for different management alternatives on two National Forests (NF) in order to support more effective hazardous fuels reduction strategies. This assessment analyzes fire risk and net revenue associated with hazardous fuels reduction treatment simulations. The two forests that were chosen both have high fire risk overstocked forest areas dominated by small diameter suppressed trees and, as a result, both forests recognized to be are in need of fuel removal thinning treatments to reduce fire risk (Fremont National Forest 2003, Okanogan National Forest 2003). On the other hand while these forest share a similar risk reduction challenge there are many aspects of these forests that are quite different such as the harvesting and manufacturing infrastructures, the forest types, moisture and weather patterns, etc.

Hypothesis: Positive net revenues from logs sales will result from harvest activities designed to reduce fire risk in most of the moderate to high risk inland west forests.

Null Hypothesis: There is little potential for positive net revenue from logs sales that will result from harvest activities designed to reduce fire risk in moderate to high risk inland west forests.

Also worthy of consideration in the context of fuel removal treatment evaluations is a broader set of costs and benefits expanded to include an assortment of market and non-market values that result from risk reduction investments. Simply put, it may be that, even if fuel removal harvests don't generate positive revenues from log sales, the many other benefits resulting from resource protection and utilization will outweigh any government costs for service contracts to remove surplus fuel loads.

An additional goal of this investigation is present a technical methodology to assist forest managers in quick evaluation of forest fire risk distributions and potential treatment alternatives across broad landscapes. Without technology to assist such analysis, the complexity of forest planning for hundreds of thousands of acres is daunting. It is the intention of this investigation to demonstrate technical modeling capabilities beneficial to foresters that must communicate management choices to involved lay publics so that they might better understand the consequences of treatment alternatives or no action.

2. Methods

This project has been designed as a parametric sensitivity analysis to be used in tandem with existing forestry modeling capabilities to assess the effectiveness of varying degrees of harvest intensities for fire risk reduction against operational costs and revenues associated with alternative fuels reduction strategies. To support this project, information needed to gain better understanding of the opportunities and obstacles associated with fuel removal activities on federal lands has been gathered from the scientific literature, government publications, and personal interviews with forestry professionals and community representatives.

2. Methods

2.1 Literature and Government Report Review

A review of pertinent elements of the scientific literature and various government reports was completed in order to achieve several informational goals identified as important to the results of this project. In addition to general background information on the history and magnitude of wildfire risk associated with overstocked forests, other information including but not limited to logging and hauling costs, forest product types and values, Forest Service administration costs, Forest Service contracting authorities, community demographics and infrastructures, etc. has been assembled to best inform this investigation.

2.2 Local Interviews

There is a wealth of experience and knowledge held by members of local communities (USDA Forest Service USDI and Western Governors' Association 2001). Interviews were conducted with public agency professionals, loggers, foresters, consultants, and economic development organizations. These interviews provided information on local costs, values, and perceived opportunities. Interviews were conducted by telephone and in person. The interviews covered questions regarding quantitative information such as costs of operation and qualitative discussions including experiences of treating overstocked stands. Respondents shared opinions and commentary on how to improve and streamline current fuel removal techniques and contract options. In order to respect

respondent privacy, specific details and data will not be associated with specific contractors or organizations, however, a list of interviewees is presented within the bibliography (local interviews 2002).

Many individuals generously contributed information founded upon their professional judgment and personal experiences. For example, operational cost estimates provided by private contractors served to enrich the quality of cost data from other sources.

Suggestions from local people on how to customize Forest Service contract offerings for increased efficiencies proved essential for better understanding of operational possibilities. The benefits provided to this project from personal interviews served to underscore a recurring theme in this project: successful fuel reduction strategies will likely be based upon integration of anecdotal and institutional knowledge. Through this investigation interview data, research information from the literature, and results of modeling analysis are presented together by topic of interest.

2.3 Technical Tools

Evolving forestry and mapping technologies can help foresters design complex fuel reduction strategies that integrate multiple management goals. This project has developed a parametric sensitivity analysis that utilizes available technologies to analyze a range of conditions that apply to customized local needs. Software capabilities employed for use in this project include the Landscape Management System (LMS), Forest Vegetation Simulator (FVS), Fire and Fuels Extension (FFE), Microsoft Access™, Microsoft

Excel™, and ESRI ArcView™. Customized software functionality created for use in this project included spreadsheets and databases to assess performance metrics.

The Landscape Management System

The effects of forest management alternatives on fire risk reductions, forest product outputs, and economic metrics, were simulated using the Landscape Management System (LMS). LMS is an evolving computer-based, landscape-level forestry analysis software tool developed at the University of Washington College of Forest Resources (McCarter 1997, McCarter et al. 1998, McCarter 2001). LMS offers a software platform for the integration of component software capabilities that include growth and yield models, interactive stand treatment simulation programs, tabular and graphical analytical outputs, and stand and landscape visualization programs. Data sources necessary for LMS include stand inventory information (tree-based measurements), landscape data (slope, aspect, elevation, site quality), and Geographic Information System (GIS) spatial data (stand boundaries, streams, roads, etc.). Using LMS it is possible to simulate stand and landscape inventory growth projections forward in time to create predictions of potential stand and landscape forest conditions. Simulations may be created that include harvesting, regeneration, and wildfire. The graphical user interface (GUI) within LMS is designed to provide a user-friendly “click and go” command format. The intended result is that this powerful forestry software is available for use by individuals with minimum computer skills and limited financial resources. Consequently, LMS has proven to be useful not only as a powerful analysis support tool for forestry professionals but also as a

communication tool for use with stakeholder groups embarked on the often conflict-vulnerable process of consensus building. LMS is available for download and provided at no charge through a forestry research partnership between the University of Washington and Yale University. The web site address is <http://lms.cfr.washington.edu/>.

Forest Vegetation Simulator

The Forest Vegetation Simulator (FVS) is an individual-tree, distance-independent growth and yield model (Crookston 1990, Van Dyck 2000). FVS will simulate growth and yield for most major forest tree species, forest types, and stand conditions. FVS can simulate a wide range of silvicultural treatments. Variants of FVS provide growth and yield models for specific geographic areas of the United States. Prognosis (Stage 1973) is the original model that evolved into the Forest Vegetation Simulator. Stage developed Prognosis for use in the Inland Empire area of Idaho and Montana. In the early 1980s, the National Forest System's Timber Management Staff selected the individual-tree, distance-independent model form as the nationally supported framework for growth and yield modeling. Over the following years, the Forest Management Staff's Growth and Yield Unit incorporated much of the Prognosis modular structure and capabilities into the national model framework. This model framework is the Forest Vegetation Simulator, or FVS (Wykoff et al. 1982).

There are 21 different FVS variants. Each is calibrated to a specific geographic area of the United States. Various extensions are available for some of the variants. These extensions provide the ability to estimate the influence of other agents upon tree growth

(such as insects, disease, and fire), extend FVS modeling capabilities, and permit multiple stand simulation. For the simulations needed for this investigation the East Cascades Variant (EC) of FVS and the South Central Oregon and Northeastern California Variant (SORNEC) of FVS were selected for use within LMS to contribute growth-modeling capabilities for the Okanogan National Forest and the Fremont National Forest respectively. More information and a suite of FVS regional variants are available from the USFS web site at: <http://www.fs.fed.us/fmhc/fvs/>.

Fire and Fuels Extension to the Forest Vegetation Simulator

The Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) links the existing FVS, models that represent fire and fire-effects, with newly developed fuels dynamics and crowning submodels (Beukema et al. 1997, Scott and Reinhardt 2001). The Fire and Fuels Extension (FFE) has been developed to assess, risk, behavior, and impact of fire in forest ecosystems (Beukema et al. 2002). FFE can produce reports of changes in various indices of potential fire severity as a result of alterations to stand characteristics resulting from simulated management alternatives. More information and downloadable FFE for use with selected variants of FVS are available from the USFS web site at: <http://www.fs.fed.us/fmhc/fvs/>.

The 35-year simulations selected for this project were performed using the East Cascades (EC) and Southern Oregon and Northeast California (SORNEC) variants of the Forest Vegetation Simulator (FVS) with the Fires and Fuels Extension (FFE) within the

Landscape Management System (LMS). 35 years was used as a time horizon to consider the durability of post harvest risk reduction for each simulation into the future.

This project uses the capabilities of the Fire and Fuel Extension to the Forest Vegetation Simulator (FVS). The Fire and Fuel Extension (FFE) was developed to integrate the FVS growth model with elements of existing models of fire effects and behavior (Beukema et al. 2002). The FVS growth model was used to simulate tree growth and silvicultural treatments. FFE was used to assess fire risk for all scenarios and fire impacts for the wildfire simulation. Both tool were run from the Landscape Management System to allow additional analytical procedures which addressed other research questions. Inventory information from 1995 was used to simulate stand growth to 2030, with treatments performed in 2000.

2.4 Data and Information

Current Vegetation Survey

Conditions on the Fremont and Okanogan National Forests were represented, simulated, and analyzed using the Current Vegetation Survey (CVS) Occasion 1 data sets. Data for these national forests was collected during the period from 1994 to 1996. Re-measurements of many plots occurred during successive panels of CVS Occasion 2, but full re-measurement data was not available for both forests. As a result, CVS Occasion 1 data, with a base year of 1995, was selected to provide the forest inventory information used to undertake the simulation analysis required for this study. The 1995 data were

“grown” forward within FVS for one growth period to 2000 to bring data close to present time before treatment simulations were conducted.

The Fremont National Forest contains 601 total CVS plots. Plots with dominant species by basal area of lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), or white fir (*Abies concolor*) were used in the analysis. Plots with other dominant species associated with higher-elevation long duration fire cycles or non-forested plots associated with grasslands, rocky outcrops, or water were not considered in this analysis. For the Fremont National Forest 61 plots were dominated by juniper (*Juniperus occidentalis*). While these areas may well benefit from fuel reduction, presently there is no growth model for this species. For this reason the plots dominated by juniper were discarded from the data set as well. It is worthy of mention, however, that juniper harvests could augment feedstock supplies for biomass-to-energy projects and that juniper removals will likely reduce overall forest fire risk (Swan 2002). A total of 502 plots or 84% of the total plots were selected as forested areas to be evaluated for treatment simulations.

A total of 663 CVS plots were available from the Okanogan National Forest. Plots used in the analysis were those in which the dominant species, determined by basal area, was ponderosa pine, lodgepole pine, Douglas fir (*Pseudotsuga menziesii*), or western larch (*Larix occidentalis*). Plots with other dominant species associated with higher elevation long duration fire cycles and non-forested plots were considered not suitable and were removed from the data set used for this analysis. The number of plots used in the

simulations for the Okanogan National Forest was 413 or 62% of the total available CVS plots.

The selected 502 plots (FNF) and the 413 plots (ONF) from the CVS database were used to create two forest inventory datasets representative of the variety and distribution of forest age classes, densities, tree species, tree sizes, and crown characteristics present in the ONF and the FNF that would be subject to consideration for hazardous fuel reduction treatments. For purposes of conducting forest-wide simulations, the data from each plot has been assumed to represent the inventory of a one-acre forest stand. Subsequently, the simulated FNF will have a 502 acre “forest” and the simulated ONF will have a 413 acre “forest”. To expand per acre volumes from CVS data for landscape inventory estimates, one would use 1849.6 as an expansion factor resulting from the 1.7 mile grid used to systematically distribute CVS sampling point locations.

2.5 Growth, Treatment, and Wildfire Simulation

To analyze the relative effectiveness of alternate harvest treatment intensities on fire risk reduction and the subsequent economic results, four silvicultural prescriptions were developed to conduct harvest simulations for each CVS plot for the Fremont and Okanogan National Forests. A NO Action simulation of growth without disturbance and a Wildfire simulation where all acres were ignited were conducted to represent opposite ends of a control spectrum to evaluate do nothing verses the consequences of potential fire disturbances verses effectiveness of the risk reduction treatments. The four harvest

treatments were selected to span a range of removal intensities, removing various categories of trees from the very small to the very large and with both fixed and variable density targets. The treatment alternatives were selected, as well, to be readily comparable to simulation findings emerging from other fire risk reduction research projects. All harvest simulations growth projections were done using variants of FVS within LMS. The East Cascades (EC) Variant of FVS was used for the Okanogan inventories, and the South Central Oregon and Northeastern California (SORNEC) Variant of FVS was used for the Fremont inventories. Simulated treatments were conducted in 2000. Post treatment inventories were grown forward to 2030 using 5-year growth simulation periods. A set of results were developed with and without ingrowth. Alternatives modeled included no action (no treatment or disturbance within the study period), four different harvest treatments, and a wildfire simulation.

The six treatment prescriptions that were developed to investigate the response of different forest types to different treatment strategies include:

- ❖ **No Action (*No action*).** This prescription assumes no harvest activities and no wildfire for the duration of the simulation period. While no wildfire seems an unrealistic expectation, this simulation is valuable to display increases in risk for the forest landscape over time.

- ❖ **Remove 9” and Under, (9 and under)**. This prescription harvests all trees 9” in diameter at breast height (DBH) and smaller. This treatment represents an approach in use by the Forest Service and recommended by Babbitt and Glickman in 2000.

- ❖ **Remove 50% BA, From Below (Half BA)**. This treatment is a removal of half of the total basal area (BA)/acre by removing the smallest trees (thinning from below).

- ❖ **Leave 45 sqft BA, From Below (BA 45)**. This treatment is intended to simulate restoration of savannah-like conditions that are similar to what has been described in literature as the pre-settlement open-stand conditions that resulted from frequent but low wildfires (Agee 1993). In the FNF, all ponderosa pine were left standing, while in the Okanogan both ponderosa pine and western larch were favored as leave trees. In both cases, these species were selected for retention in order to help restoration these forests to what is considered to be an open pre-settlement condition dominated by thick bark fire tolerant species. For an example of what BA 45 means as a management target consider that if trees are approximately 12” DBH then at BA 45 approximately 57 trees per acre (TPA) would be left after harvest.

$$TPA = BA/DBH^2*.005454$$

- ❖ **Remove 12” and Greater, From Above (12 and over)**. This treatment is to simulate harvest designed to maximize profit by taking the largest and most valuable trees that are 12” DBH and larger. This practice was commonly known as high grading in

the first half of the twentieth century. This simulation conservatively estimates the value of stand inventories at risk from wildfire.

- ❖ **Wildfire Simulation (*Wildfire*).** This simulation is undertaken to demonstrate the levels of mortality for different stand inventories that might be associated with wildfire. The wildfire was simulated using the FFE extension within FVS. Burn conditions to be specified in the model were a temperature of 70 degrees Fahrenheit, a wind speed at 20 feet in the stand of 20 miles per hour, and nominal moisture levels of “very dry” (Crookston et al. 2002).

All treatments and the wildfire simulation occurred in year 2000. The four thinning treatments modeled included a removal of all trees with a DBH less than or equal to nine inches (9 and under); a thin from below removing 50% of the original basal area (Half BA); a thin from below with a residual basal area target of 45 square feet favoring ponderosa pine and western larch (BA 45); and a removal of all trees with a DBH greater than or equal to 12 inches (12 and over).

Results were produced for each alternative with and without regeneration to simulate either controlled burn fuel removal or fire risk impacts associated with accumulating fuel loads from ingrowth. Simulations with regeneration were modeled to have a stocking level of 500 trees per acre 4 years after a treatment or wildfire. The distribution of species for the new seedlings was based on the distribution of species by basal area in the residual stand. No action simulations received no regeneration. All simulations including No action utilize FVS

to “grow” existing inventories (including regeneration where applicable) forward through time to the end of the simulations period at 2030.

2.6 Analysis of Fire Risk

Simulations that were treated but not assigned regeneration inventories suggest outcomes in 2030 that might be achieved if controlled burns or other treatments remove additions to fuel loads that might otherwise result from ingrowth. Simulations that were treated and assigned post-treatment regeneration inventories (ingrowth) are conducted to demonstrate that effective long term risk reduction will likely require some type of post treatment fuels control.

Each alternative was analyzed to examine the impact on fire risk and economic net revenue. Initial forest conditions were analyzed for each national forest for fire risk, forest structure, and species composition. Additionally, each CVS plot was analyzed at each projection cycle for fire risk.

Fire Risk Classification

High, moderate, and low fire risk was estimated for each CVS plot in the simulation dataset based on the Severe Crowning Index assessment from the Potential Fire Report produced by FFE. The Crowning Index indicates the estimated wind speed in miles per hour (mph) at 20 feet off the ground that would initiate an active crown fire assuming ignition of a surface fire. Assumptions required by the model include a temperature of 70 degrees Fahrenheit and ‘very dry’ moisture conditions (Crookston et al. 2002). Results from the crowning index estimates

for each stand were sorted into one of three risk classes. Lower wind speeds indicate greater risk. If the crowning index was less than 25 mph, then the plot was considered to be in the high fire risk category. Moderate risk stands were those with a Severe Crowning Index between 25 and 50 mph. Low fire risk stands were those with a crowning index greater than 50 mph. It should be noted here that risk classifications are arbitrary thresholds useful and necessary for comparative analysis but that they may very well understate the risk at the margins. The word moderate properly segments a risk difference between high and low although the risk of a fire from wind speeds only slightly higher than 25 MPH might not be considered a moderate risk by many publics. It is in part for this reason that performance comparisons for treatment alternatives were reported in this investigation for high and moderate as separate risk classes and then combined as the total area to be considered for risk reduction treatments.

The initial 1995 fire risk distribution for the Fremont and Okanogan National Forests was reported as the percentage of CVS plots in each of the fire risk categories prior to any treatment or growth simulation. Fire risk distribution was similarly reported for projected and treated plot inventories at each growth cycle. For purposes of simulations to demonstrate comparisons between treatment alternatives only the plots with high and moderate initial classification were treated. Low risk areas did not receive treatment simulations since treatments of low risk areas would logically be considered unnecessary or of low priority. While some low risk areas may experience increases in risk over time most low risk areas appear to be either very young small diameter forests or

rangeland/forest interface with sparse distributions of forest inventories that are unlikely to require fuels reductions at the time of this study.

Forest Structure

Forest structure was determined using an approach utilized by the Business Bureau of Economic Research in Montana in “A strategic assessment of fire hazard in Montana” (Fiedler et al. 2001). This canopy structure classification system identifies stands as being single-layered, two-layered, multi-layered, or scattered. Five potential layers could be present in a stand, based on a minimum amount of basal area in a diameter size class. The sapling size class required at least 5 square feet of basal area in trees with less than 5” DBH to be present. The pole, medium, large, and very large size classes included trees within a DBH range of 5-9”, 10-15”, 11-20”, and greater than 20”, respectively. These size classes required at least 10 square feet of basal area to be present to be considered as a canopy layer. Stands classified as single- and double-layered had one and two size class layers present, respectively. Multi-layered stands had more than two layers present. Scattered stands had no layers present and at least 25 square feet of basal area in the stand. Using this system, each plot was classified in 1995. The initial stand structure distribution for each landscape was determined as the percentage of plots in each category.

Forest Type

Forest type for the Fremont National Forest was determined based on criteria provided by the Sue Puddy, the Silviculturist at the Fremont National Forest. This classification system identified plots by dominant species and structure. The categories were Ponderosa Pine Closed, Ponderosa Pine Moderate, Ponderosa Pine Open, Ponderosa Pine Very Open, Juniper, Lodgepole Pine, Mixed Closed, and Mixed Open. Plots with at least 12 ponderosa pine tpa with a DBH greater than 14" were classified as one of the Ponderosa Pine types. The canopy closure algorithm by Crookston and Stage (1999) was then used to distinguish Ponderosa Pine Closed (greater than 50% canopy closure), Ponderosa Pine Moderate (35-50%), Ponderosa Pine Open (25-35%), and Ponderosa Pine Very Open (less than 25%). Plots with greater than or equal to 70% of the tpa in juniper were classified as Juniper. The Lodgepole Pine forest type was defined by plots with greater than or equal to 50% of the total tpa in lodgepole pine and less than 15% of the total tpa in ponderosa pine trees with a DBH greater than 10". Plots in the Mixed forest types were classified as not meeting any of the above criteria. Mixed Closed plots had greater than 40% canopy closure. Mixed Open plots had less than or equal to 40% canopy closure. Forest type distribution for both the Fremont and Okanogan National Forests were reported as the percentage of plots in each structure type in 1995.

Forest type was reported for each national forest for conditions in the initial time period. Forest type for the Okanogan National Forest indicated the percentage of plots in Cold Dry, Dry, Mesic, and Moist conditions. Cold dry forests typically have mixed mortality

fires in an elevation range from 6000-7200 ft. Dry forests have 7.5-50 year fire return intervals and are found from 1,200 to 5000 ft. Mesic forests experience weather driven catastrophic fire events every 100 or more years found in a wide elevation range from 1800-6000 ft. Moist forests are 100 to 300 year fire return interval found in mid elevations of 3000-4500 ft (Northeastern Cascades Late-Successional Reserve Assessment Team 1998). The forest type was determined using plot locations, which are UTM coordinates, for each CVS plot which were “joined” in the GIS with a forest type layer provided by John Townsley, the Silviculturalist at the Okanogan National Forest.

2.7 Analysis of Economics

Each of the four harvest alternatives were also analyzed to examine the positive or negative economic net revenue that resulted when estimated harvest and hauling costs were subtracted from the gross revenues from sale of estimated log yields. Interviews provided a range of primary data regarding local logging and hauling costs and log values by grade and species per thousand board feet (MBF). Secondary data was also gathered from available Forest Service documents and market reports that show the current market opportunities and trends of historic of log prices. The collected cost information for operational costs/acre, and average log values/MBF that were incorporated into the economic evaluation of the treatment alternatives examined in this project are described later in the text. Within LMS, a bucking algorithm was used to optimize estimates of log segments that result from trees harvested in simulated silvicultural treatments. Estimated volumes of logs by grade and species from harvest simulations were multiplied by

delivered log prices to estimate gross harvest revenue for each stand (plot). Microsoft Access™ and Excel™ were used to compute the gross and net revenue per acre based upon subtraction of local logging costs, and hauling costs from local market log values by species and grade. In some cases, effective fuel reductions required the removal of non-merchantable small diameter trees. Where this was the case an additional operational cost/acre referred to in this study as pre-commercial thinning (PCT) was charged against gross revenues to complete the economic analysis for each stand. The gross log value/acre minus the logging, hauling, and (PCT) costs equals net economic return per acre. Estimates of preparation, administration and litigation costs to the USFS are not considered in this analysis but have historically been significant as noted in the USFS publication “The Process Predicament” (USDA Forest Service 2002b).

Conversions

To utilize the specific logging costs, hauling costs, and log value estimates that were gathered from interviews and publication, some numbers required conversion from tons to thousand board feet. Forestry professionals from both National Forests were interviewed for the appropriate conversion factor to use. Weight to volume conversion factors are by nature variable due to water content in log, tree species, and time since the log has been felled. A conversion rate of 7 tons/MBF was agreed to be most generally representative and was selected to be used to convert some costs and values based on tonnage into \$/MBF. Table 1 shows the range of conversion factors that resulted from local interviews (local interviews 2002).

Table 1 Tons Per Thousand Board Feet (MBF) for Eastern Washington and Oregon

HIGH	LOW	AVERAGE
5.6	8.6	7

Logging and Hauling Costs

Eighteen logging contractors were interviewed in Oregon and Washington. These loggers were willing to share information on the logging equipment mixes that they have, the costs to log with their equipment, and the cost to haul the wood to the mill. The haul costs were assigned based on the interview results according to the average haul the loggers suggested for each forest. Harvest operations costs estimates collected from these contractors include both cable and ground based logging operations. Table 2 shows the high, low and average logging hauling and PCT costs per acre. These costs were assigned by calculating an average of all the high and low operations costs collected from contractors for each forest. These figures were used for economic valuation of thinning simulations for the FNF and ONF. The PCT costs are included to estimate the range of costs required to thin some of the non-merchantable stems in conjunction with the removal of any merchantable material. A low PCT cost of \$300/acre and a high of \$500/acre were used to simulate treatment of non-merchantable material as part of fuel reductions in any stand with greater than 200 TPA 6" in diameter or smaller. The interviews with contractors and USFS employees suggested 200 TPA, of submerchantable material as the threshold of when PCT costs become a realistic addition

to logging costs. PCT costs include removal of submerchantable material to the road or landing. This material could be used as biomass fuel for energy generation, but has historically not been economically feasible to remove to a conversion site.

Table 2 FNF and ONF Low and High Logging, Hauling/MBF and PCT Costs/Acre

	LOW	HIGH
Fremont Cable	\$160	\$246
Fremont Ground	\$132	\$217
Okanogan Cable	\$210	\$296
Okanogan Ground	\$182	\$267
Pre-Commercial	\$300	\$500

There is a high degree of variability in logging and hauling costs suggested by interview respondents. To demonstrate a representative range of potential operations costs, simulated harvest yields were analyzed for both high and low cost for the four thinning treatments. Interviews with many employees in the Forest Service, Department of Natural Resources, and Oregon Department of Forestry served to confirm contractor cost estimates and validate the range of costs per acre. Several factors including equipment, terrain, contract specifications, and density of stand are known to influence operating cost

variability. In addition, many of those interviewed commented on their experiences logging for the USFS compared to logging on private land. Some contractors reported that higher operations charges were necessary to profitably operate on federal forests as opposed to private or state owned forest lands. Other contractors reported that as a result of unfavorable experiences with USFS contracts that they only work on private land now. Interview comments suggested that the many complicated factors regarding contract requirements for harvest activities on federal lands have made such operations difficult and expensive.

Mill Log Values

Logs that are removed during fuel reduction thinnings, can include a mixture of non-merchantable trees, pulp logs and sawlogs. Interviews with mills around the FNF and ONF were combined with log price market reports to estimate delivered log prices. Prices in this study are current as of August 2002. Table 3 shows the prices collected from nine mills and three regional log value reports.

Table 3 Regional Log Sort Values \$/MBF Used for Economic Valuation

FNF SORTS	PP	DF	LP	RC	WP	ES	WF	GF	AF	WL	WH
Pulp	100	122	122				122				
Hewsaw	452										
Saw 4	400										
Saw 3	530										
Saw 2	575										
Saw 1	625		270				300				
ONF Sorts	PP	DF	LP	RC	WP	ES	WF	GF	AF	WL	WH
Pulp	100	100	100	100	100	100		100	100	100	100
Hewsaw	350	350	322	377	343	350		336	336	350	336
Saw 4	331			462							
Saw 3	487			525							
Saw 2	525	410	289	585	343	300		300	300	410	300
Saw 1	800	479	375	711	628	428		330	330	479	330

Net Revenue Calculation

Volumes of harvest were simulated for alternative thinning treatments and divided to estimate potential yield volumes by species and grade estimated by the bucking algorithm in LMS. Estimates of merchantable volumes of pulp and sawlogs were divided by species and grade. Each species and grade volume was multiplied by the assigned price per MBF. Gross estimated revenues from log sales were determined for each stand and for each treatment alternative by summing species and grade returns for each stand. Treatment costs were subtracted from gross revenue from log sales to determine net revenue. The average net revenues for each treatment type by risk class were calculated for comparison with risk reduction success resulting from each treatment alternative. Risk reduction and the associated economic results when compared for each treatment alternative are presented to offer dual measures of effectiveness. Such comparisons are valuable to foresters planning treatments for maximum risk reduction at least cost. Since harvesting and hauling contractor costs are subtracted from gross revenues, the resultant positive or negative net return from each treatment simulation may be considered indicative of either potential timber sale revenues (theoretical bid maximums in excess of operational costs in the case of a positive returns) or stewardship costs for risk reduction (while logs may not be profitable from a timber sale perspective they do have sufficient value to discount fuel reduction costs when included in a combined goods and services transaction). Neutral returns mean that the value of the logs harvested will cover the risk reduction treatment costs but do not have sufficient value to warrant a timber sale offering. In some cases

foresters may want to combine treatments and stands such that the positive revenues available from one stand fuel reduction harvest can be used to offset the negative revenues associated with another stand fuel reduction harvest. This may be done to create a service contract that is cost neutral or a timber sale where the harvest value of some stands carries the cost of fuel reductions for other stands and still yields positive revenue.

3. Case Study Site Descriptions

The Fremont National Forest (FNF) in Oregon and the Okanogan National Forest (ONF) in Washington were selected as study areas for this project. Both of these National Forests are located within the dry interior portion of the western United States. Both of these forests are thought to have had frequent fire return cycles, prior to European settlement, that created many areas that were dominated by open stands of ponderosa pine (Fremont National Forest 2003, Okanogan National Forest 2003). Both the FNF and the ONF contain substantial acreages of overstocked forests that are considered to be at risk from wildfire Table 4. Both National Forests have experienced destructive wildfires in recent years. The communities surrounding these two forests provide a variety of infrastructure options to remove fuel from overstocked stands. However, the logging, transportation, and processing of low value smaller wood has historically not been profitable. The rural communities surrounding these forests have experienced double-digit unemployment and economic declines due to job losses associated with reductions in federal timber harvest volumes. Individuals, organizations, and businesses from both areas demonstrated interest in this investigation and contributed valuable reference information through personal interviews. The citizens of these local Oregon (OR) and Washington (WA) communities appear eager to meet the challenge to remove the fuel from forests with a high fire danger.

Table 4 Acres in Initial Fire Risk Class for Forests on FNF and ONF

NATIONAL FOREST	HIGH	MODERATE	LOW	TOTAL
Fremont	284,838	436,506	207,155	928,499
Okanogan	216,403	369,920	177,562	763,885

3.1 Fremont National Forest

The FNF is in the south central dry interior of the state of Oregon. There are several rural communities surrounding the FNF boundary. The forest lies roughly between the towns of Lakeview, Klamath Falls and Bend, Oregon just North of the California/Oregon border Figure 3. Also see Appendix D for forest maps.

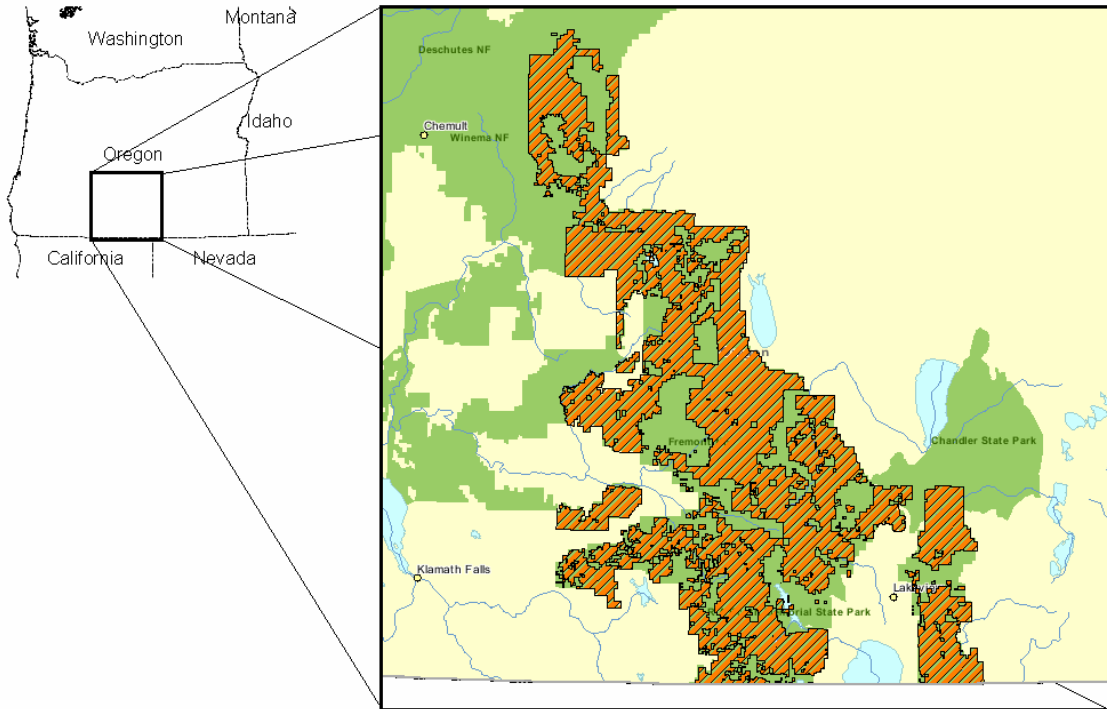


Figure 3 Fremont National Forest Boundary

The majority of the 1,198,301 acres within the boundary of the FNF are in Lake County which is 8,359 square miles. The population of Lake County is 7,470 and neighboring Klamath County is 64,116 (US Census Bureau 2003). The town of Lakeview is at the Southeastern corner of the FNF close to the California border and has a population of 2,800 (Fremont National Forest 2003). Lake County has .9 people per square mile. The unemployment rate for 2002 was 8.7% and it was 10.4% in 2001. The high for the 1990's was an unemployment rate of 12.2% (Lake county 2003). "Lake County was also the only county in the state that experienced a net job loss during the 1990's" (Kauffman 2001).

The forest includes wildlife and tree species adapted to the climate and elevation variation from 5,000 to 7,000 feet with mild terrain on slopes roughly 40% and less. About half the FNF is a mixed open forest type, see Figure 4, with multi-structured canopies.

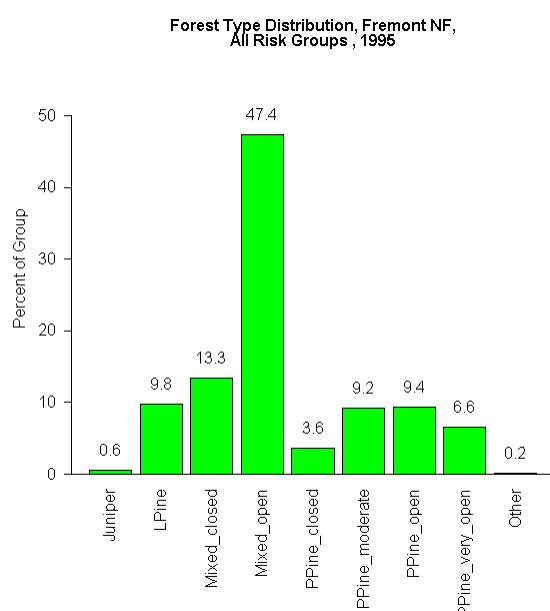


Figure 4 FNF Forest Type Distribution

Half of the forest plots have greater than 500 Trees per acre (TPA) and a Basal Area (BA) ranging from 50-150. The quadratic mean diameter (QMD) is 12" and less for over 90% of the forestland. The major tree species include ponderosa pine (*Pinus ponderosa*), juniper (*Juniperus occidentalis*), lodgepole pine (*Pinus contorta*), and at higher elevations white fir (*Abies concolor*). Most of these trees are adapted to summer drought

and extreme temperature fluctuations due to the nature of the arid region (Fremont National Forest 2003). The 10-20 inches average precipitation occurs from the autumn through the spring and as a result the summers are dry and hot. See the Appendix A for detailed charts of the original forest conditions. Of the 502 plots on the FNF the fire risk distribution is 154 high, 236 moderate, 112 low risk.

Figure 5 shows high moderate and low fire risk by percentage of total forest.

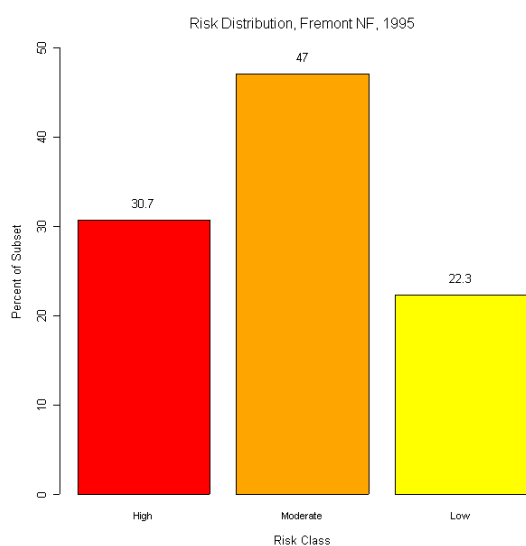


Figure 5 FNF Fire Risk Distribution

Fire risk analysis conducted with FFE indicate that 77.8% of FNF is presently in a moderate to high risk condition with 30.7% of the FNF considered to be high fire risk forests. The FNF has experienced destructive wildfires in recent years. In 2002 over 125,000 acres of the FNF burned due to wildfire (local interviews 2002).

In 2001 22 MMBF were harvested from FNF (local interviews 2002). There is one mill in Lakeview, Oregon. However, as many as 4 mills in the surrounding area receive logs from the FNF. The Fremont National Forest also has a sustained yield unit, and network of local efforts and non-profit organizations working to maintain forestry infrastructure.

3.2 Okanogan National Forest

The Okanogan National Forest (ONF) is located in North central Washington. In 2000, the ONF was merged with the Wenatchee National Forest to become the Okanogan-

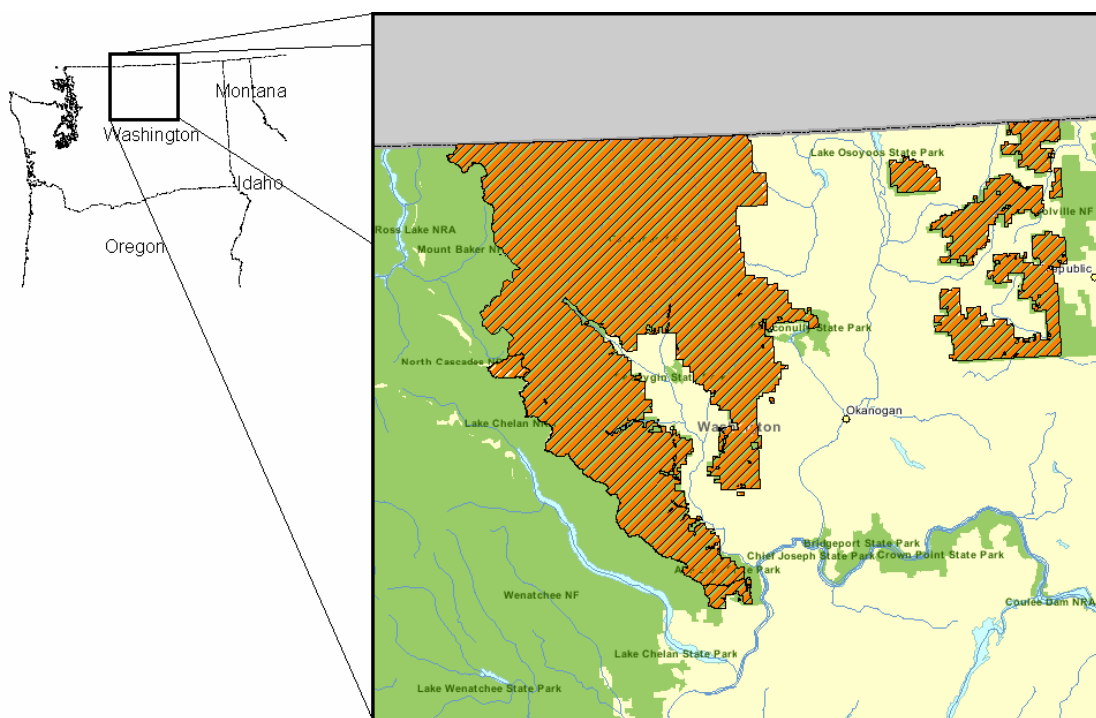


Figure 6 Okanogan National Forest boundary

Wenatchee National Forest (OWNF). Okanogan is the Northern portion of what is now the Okanogan-Wenatchee NF.

Figure 6 shows the original Okanogan National Forest boundary. Also see Appendix B for forest map. The Okanogan National Forest consists of 1,226,550 acres total that are spread across four counties including Skagit, Whatcom, Okanogan, and Chelan counties. The population is most concentrated around the towns of Omak and Okanogan. Several of the other towns close to the forest include Oroville, Tonasket, Twisp, Brewster, Winthrop, Chelan, and Leavenworth. The population in 2001 for Okanogan County was over 20,100 and for Chelan County 67,000 (US Census Bureau 2003). The unemployment rate for the past ten years has been over 10% for Okanogan County. In 2000 it was 11% and 2001 it was 10.8%.

ONF is predominately dry forest type ranging in elevation from 3000 to 6000 feet in elevation

Figure 7. The Okanogan National Forest is dominated by multistructured Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and Western larch (*Larix occidentalis*) with a QMD of less than 12". The BA of the forest plots is concentrated from 50 to 200 sqft. The tree densities for the majority of the forest plots range from 250 to 4000 TPA. Most of these trees in the ONF are adapted to summer drought; high summer temperatures of 90 degrees Fahrenheit are not uncommon (Okanogan National Forest 2003). The 20-40 inches average precipitation occurs from the autumn through the spring and as a result the summers are dry and hot

(local interviews 2002). See Appendix B for detailed charts of the original forest conditions.

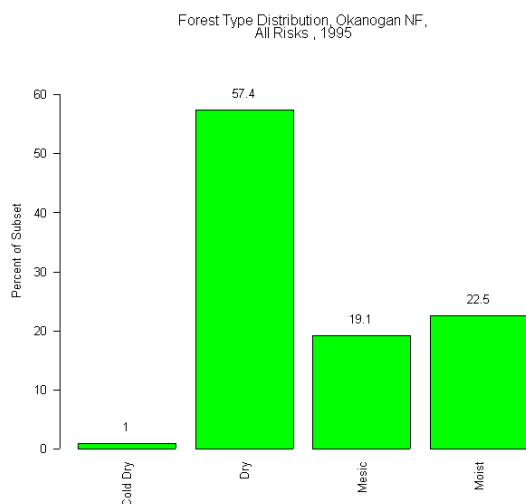


Figure 7 ONF Forest Type Distribution

FFE analysis of the ONF data in Washington indicates that of the 413 stands total, 117 (28.3%) are classified as high risk, 200 stands (48.4%) are moderate risk, and 96 stands (23.2%) are low fire risk Figure 8. There have been large fire years in the past decade in 2000 and 1994 on the ONF.

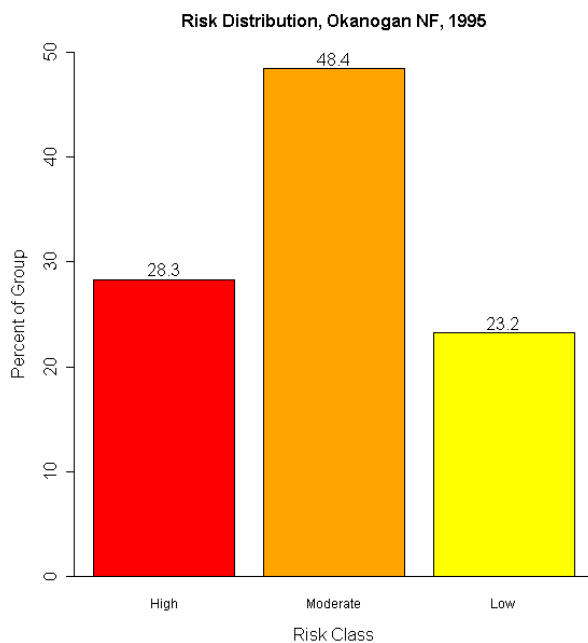


Figure 8 ONF Fire Risk Distribution

The mills and infrastructure surrounding the ONF are further distances away from the forest compared to the mills around the FNF increasing the haul distance and cost required to transport the wood to be processing facilities. There are also a wider variety of species in ONF potentially available for harvest that may require hauling trees to a wider variety of mills. The total harvest at Okanogan for 2001 was .1 MMBF. Whereas in 1989 the 10 year average harvest volume was 71 MMBF for the Okanogan National Forest (Okanogan National Forest 1989).

4. Results

4.1 Fire Risk Results

Fremont National Forest

As shown in

Figure 5, 30.7% of the 502 plots on the FNF are in high fire risk classification. There appear to be some common characteristics of high fire risk stands on the FNF. High risk stands have thin bark species and multi-layered canopies that are indicators of past fire suppression (Agee 1993). Figures 9 and 10 display the occurrence of these common traits of high fire risk stands on FNF. The majority of the stands designated as high fire risk are white fir dominated (53.0%) and have multi-layered canopies (94%). The presence of white fir, a thin barked shade tolerant and fire intolerant species, as well as, multi-layered canopies would indicate that wildfire has been successfully suppressed and that the current condition is not reflective of historic frequent ground fire conditions (Hopkins 1981).

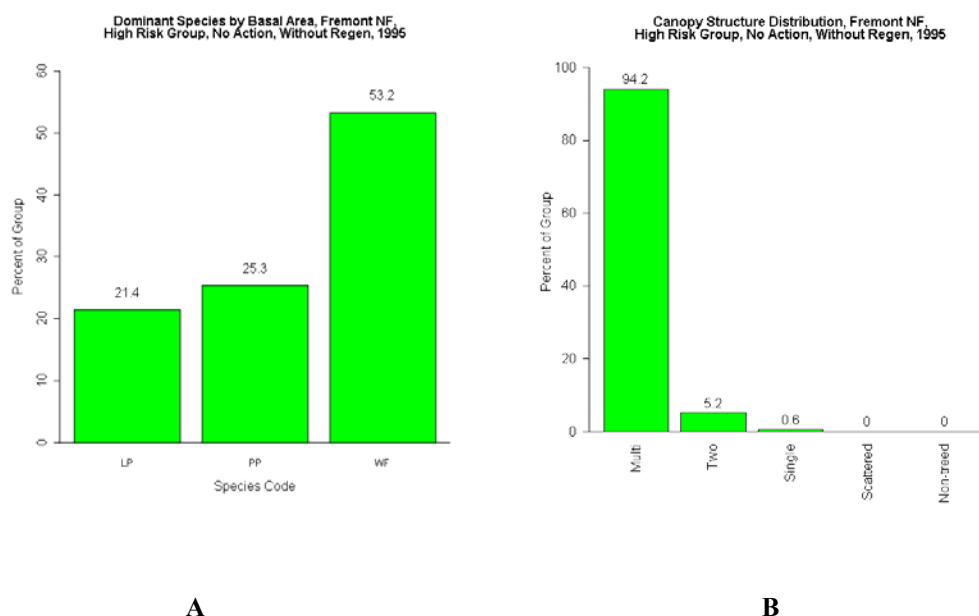


Figure 9 A and B FNF High Fire Risk Species and Structure Distributions

Conversely, the low risk stands are dominated by ponderosa pine and scattered structure canopy. The scattered structure would suggest that many low risk stands could be low density rangeland/forest interface. See the Appendix A for a full set of tables and charts that display initial and post-treatment forest conditions.

The simulations results indicate that the thinning treatments, Half BA and BA 45, may be the most effective in reducing fire risk in high and moderate risk forests. After the Half BA treatment, 55.4% of high and moderate risk forests were transitioned to low risk while after the BA 45 treatment, 63.8% of high and moderate risk forests were

transitioned to low risk. This is compared with the 9 and under treatment which results in only 22.1% of the stands in the low fire risk category after treatment. Somewhat unexpectedly the 12 and over treatment results showed a transition of only 20.5% to low risk from high and moderate risk stands. See Appendix A for detailed tables showing risk transitions from one risk class to the next.

Stands designated as in a high risk forest condition logically represent those forested areas with the most opportunity for fire risk reduction. Figure 10 shows that the greatest reduction of risk resulting from fuel removal treatments occurs with the BA 45. Figure 10 shows the response to treatment with regeneration included in the simulations. This is equivalent to thinning and not planning any follow up fuels reduction treatments such as future thinning or burning to control fuel build up from regeneration ingrowth.

Subsequently, 15 to 20 years after fuel reduction treatments, fire risk begins to increase dramatically with accumulation of new trees in the understory, suggesting that entries for ingrowth removals should commence 10-15 years after treatment to prevent future risk.

Conversely, Figure 11 is intended to display the forest risk through time as it might be with a control burn program to remove risk from ingrowth. Subsequently reductions in risk are maintained into the future by excluding regeneration from the simulations.

Amongst the high risk stands both the BA 45 and the Half BA treatments reduce the risk in most of the stands; 151 or (98.1%) of the BA 45 and 144 or (93.5%) of the Half BA treated stands moved from high risk to either moderate or low risk status. However, the BA 45 treatment resulted in many more stands dropping from high to low risk status than

the Half BA treatment. 110 plots (71.4%) went from high to low risk for the BA 45 treatment while only 42 plots (27.3%) went from high to low risk as a result of the Half BA treatment. The post-treatment growth simulations without regeneration for stands originally at high risk indicate that stands in low risk classification actually increase slightly (average 4-5% depending on treatment) over time for the FNF, see Appendix A. This may be due to reductions to ladder fuels associated with growth of leave trees. See Appendix A for the full set of fire risk response results for FNF and Appendix B for ONF.

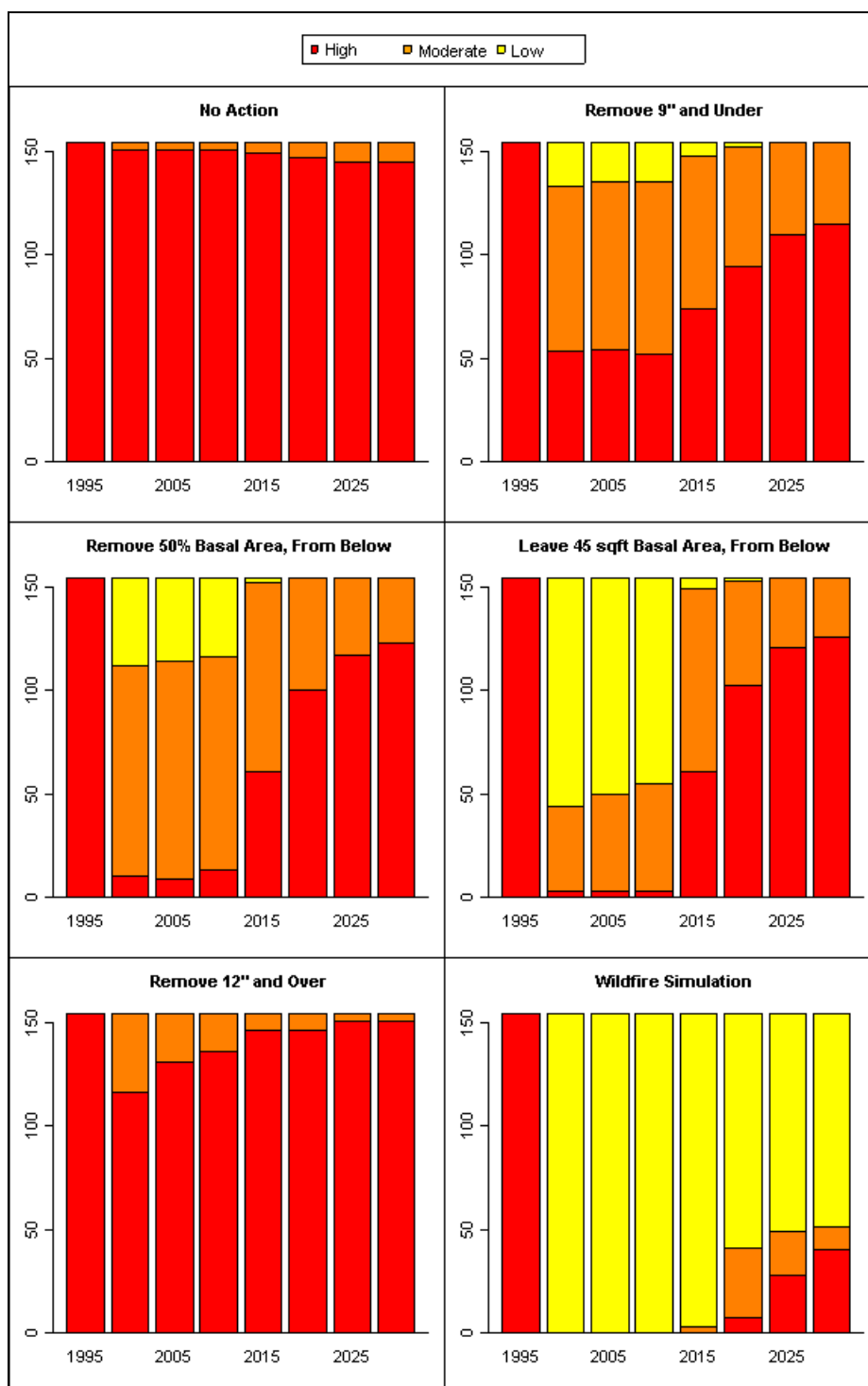


Figure 10 FNF High Fire Risk Response to Six Simulations with Regeneration

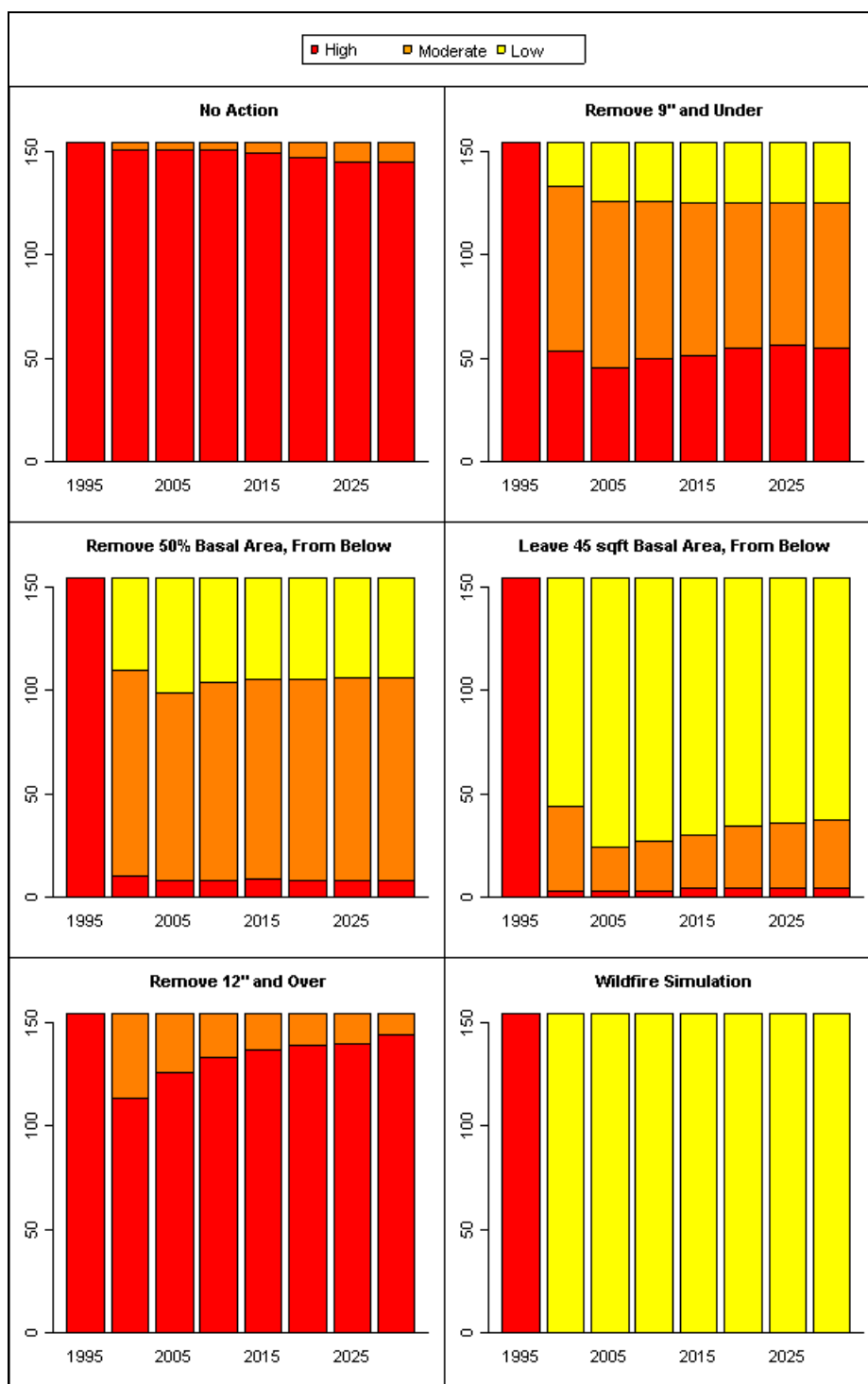


Figure 11 FNF High Fire Risk Response with No Regeneration after Treatment

All three thinning from below treatments result in substantive risk reduction as does the Wildfire simulation Table 5. The 12 and over treatment does result in some risk reduction but most change is within the moderate risk. No action simulations result in net risk increases on high and moderate stands in the FNF. The Wildfire simulations result in near total mortality from crown fires in both high and moderate fire risk stands on FNF.

Table 5 FNF fire risk reduction treatment metrics

fremont 2000 Without Regen High & Moderate Risk Groups

Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	940			6.4			113						
9&Under	66	-874	-93	14.7	8.3	129.5	80	-34	-29.7	-86	53	-118	4
HalfBA	43	-897	-95.5	17.9	11.5	179.4	57	-57	-50	-216	10	-254	17
BA45	63	-877	-93.3	18.3	11.9	186.4	45	-69	-60.6	-249	3	-284	65
12&Over	907	-33	-3.5	4.4	-2	-31.5	53	-60	-52.8	-80	124	-148	-45
WildFire	0	-940	-100	12.9	6.5	101.4	1	-113	-99.5	-390	0	-318	47

fremont 2000 Without Regen High Risk Groups

Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	1220			5.9			151						
9&Under	82	-1138	-93.3	15.3	9.5	160.6	104	-47	-31.3	-21	53	-53	-3
HalfBA	53	-1167	-95.6	18.8	12.9	219.9	76	-76	-50	-42	10	-102	17
BA45	37	-1184	-97	21.8	15.9	270.2	45	-106	-70.2	-110	3	-129	45
12&Over	1180	-40	-3.3	4	-1.9	-32.2	72	-80	-52.6	0	116	-49	-16
WildFire	0	-1220	-100	7.2	1.4	23	0	-151	-99.9	-154	0	-147	7

fremont 2000 Without Regen Moderate Risk Groups

Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	757			6.7			88						
9&Under	56	-701	-92.6	14.2	7.5	111.7	64	-25	-28	-65	0	-65	-3
HalfBA	35	-722	-95.3	17.2	10.5	156.3	44	-44	-50	-174	0	-152	0
BA45	80	-677	-89.4	16	9.3	138.4	44	-44	-49.9	-139	0	-155	20
12&Over	730	-27	-3.6	4.6	-2.1	-31.2	42	-47	-53	-80	6	-99	-29
WildFire	1	-757	-99.9	16.6	9.8	146.2	1	-88	-99	-236	0	-171	48

Okanogan National Forest

High fire risk stands comprise 28.3% of the Okanogan National Forest stand data examined in this investigation. The most prevalent species in ONF stands is Douglas-fir (64.2%). While Douglas-fir is not necessarily a thin barked species in inland west ecosystems it functions as a late seral shade tolerant species in ONF forests that is present when fire return cycles become infrequent (Agee 1993). Within high fire risk stands in the ONF, the dominant forest species is Douglas fir (72.7%) and multistructured canopies (89.7%) are the dominant forest structure. Both FNF and ONF appear to have high risk forest characteristics of multi-storied canopy and late seral dominant species that are likely a result of prolonged fire exclusion. While low risk stands in the ONF are dominated by Douglas-fir they appear to have a higher percentage of ponderosa pine than high and moderate risk areas as well as a scattered canopy structure. See Appendix B for the full set of fire risk response results for ONF.

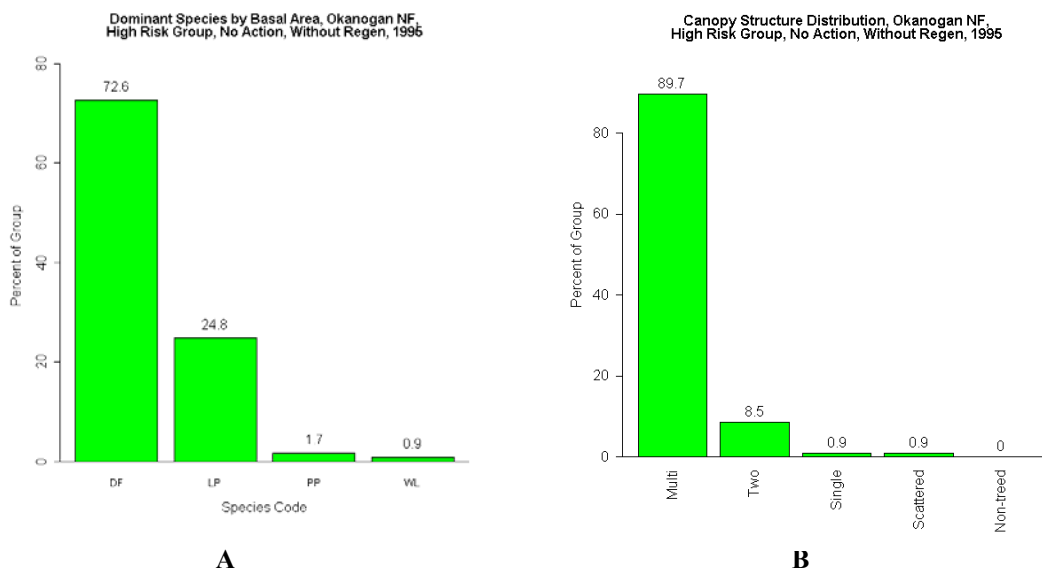


Figure 12 A and B ONF High Fire Risk Species and Structure Distributions.

The response of the high and moderate risk classes to treatment simulations indicates that the treatment, BA 45, was the most effective in reducing the risk. Post-treatment results for BA 45 show 72.5% of high and moderate stands transitioned to low risk status. The Half BA treatment resulted in 56.2% of stands going to low risk after treatment. This is compared with the 9 and under which resulted in 35% of the stands in the low fire risk category. The 12 and over treatment resulted in 17.4% of high and moderate risk stands going to low risk, however, as with the FNF, most of these stands originate as moderate risk. No action resulted in increased numbers of stands in high risk over time. Due to the climate and inventory differences between the ONF and the FNF, the Wildfire simulation on the ONF did not result in near total mortality to all forest inventories as it did in the FNF. High and Moderate risk forests in the ONF retained a mean TPA of 40 after wildfire with 71.3% reduced to low risk.

The high fire risk stands represent the highest level of fuel and the most critical opportunity for fire risk reduction. Simulations indicate that risk reduction under such conditions is maximized with the BA 45 treatment. Figure 13 shows the response to treatment with regeneration included in the simulations. This is equivalent to thinning and not planning any follow up maintenance of fire risk in the form of thinning or burning included in the management plan. Elevated risk levels begin to reappear in treated stands on the ONF after 15-25 years suggesting that future fuel removal entries are necessary to control fire risk.

Figure 14 shows the results when regeneration is excluded from the simulations. Exclusion of regeneration is intended to demonstrate treatment effectiveness when combined with future control of fuel build-up from ingrowth. BA 45 initially reduced high fire risk to low for 62.4% of the stands but, by the end of simulation period in 2030, 46% remained in low risk indicating a 16% increase in risk. Very few stands returned to high risk, however **Error! Reference source not found..** In 2030, only 5.1% of stands initially designated as high risk with BA 45 remained high risk. While there appears to some change over time from low to moderate risk without regeneration for Half BA and 9 and under very few stands regain high fire risk classification during the study period. This trend is different than what was observed on the FNF where slight reductions in risk occurred over time. The exception is the 12 and over stands that began as high risk. By the end of the simulation period 92% remained as high risk. Forests that were not treated,

No action, remained as high risk. See Appendix B for the full set of fire risk response results.

One difference between Okanogan and Fremont is that Okanogan high risk stands that are treated do not return to high risk as soon after treatment as Fremont stands. The wildfire simulation on the ONF does not completely burn up all the high risk stands as does the wildfire simulation for the FNF. Some of the forest stands on ONF are also further west and have a cooler and moister climate. As a result, the fuel moisture content in many high fire risk ONF stands is higher and therefore is less susceptible to complete combustion from wildfire than the stands in the FNF.

Table 6 ONF fire risk reduction treatment metrics

okanogan 2000 Without Regen High & Moderate Risk Groups
Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk chang to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1153			5.3			114							
9&Under	66	-1087	-94.3	13.9	8.7	164.7	71	-43	-37.8	111	26	-139	13	4
HalfBA	61	-1092	-94.7	16.1	10.8	205.3	57	-57	-50	178	13	-218	15	9
BA45	117	-1036	-89.9	15.5	10.2	194.2	45	-70	-60.9	230	3	-231	34	24
12&Over	1122	-31	-2.7	3.8	-1.5	-28	64	-51	-44.3	55	92	-110	-4	-8
WildFire	40	-1113	-96.5	13.1	7.8	148.7	23	-91	-79.8	226	39	-218	26	8

okanogan 2000 Without Regen High Risk Groups
Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk chang to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1346			5			138							
9&Under	74	-1272	-94.5	13.4	8.4	167.7	75	-63	-45.8	37	26	-66	5	1
HalfBA	93	-1254	-93.1	14.2	9.2	183.2	69	-69	-50	21	13	-76	2	2
BA45	94	-1252	-93	15.2	10.2	202.9	45	-93	-67.5	73	2	-94	11	6
12&Over	1315	-31	-2.3	3.9	-1.1	-21.4	88	-50	-36.2	3	86	-27	0	0
WildFire	71	-1275	-94.7	8.9	3.9	78.2	34	-104	-75.3	47	39	-73	3	3

okanogan 2000 Without Regen Moderate Risk Groups
Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk chang to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1040			5.4			100							
9&Under	61	-979	-94.2	14.3	8.8	163.1	69	-32	-31.5	74	0	-73	8	3
HalfBA	43	-997	-95.9	17.2	11.8	217.2	50	-50	-50	157	0	-142	13	4
BA45	130	-910	-87.5	15.7	10.3	189.5	45	-56	-55.7	157	1	-137	23	16
12&Over	1009	-30	-2.9	3.7	-1.7	-31.5	49	-51	-50.8	52	6	-83	-4	-8
WildFire	22	-1018	-97.9	15.5	10.1	186.8	17	-84	-83.5	179	0	-145	23	5

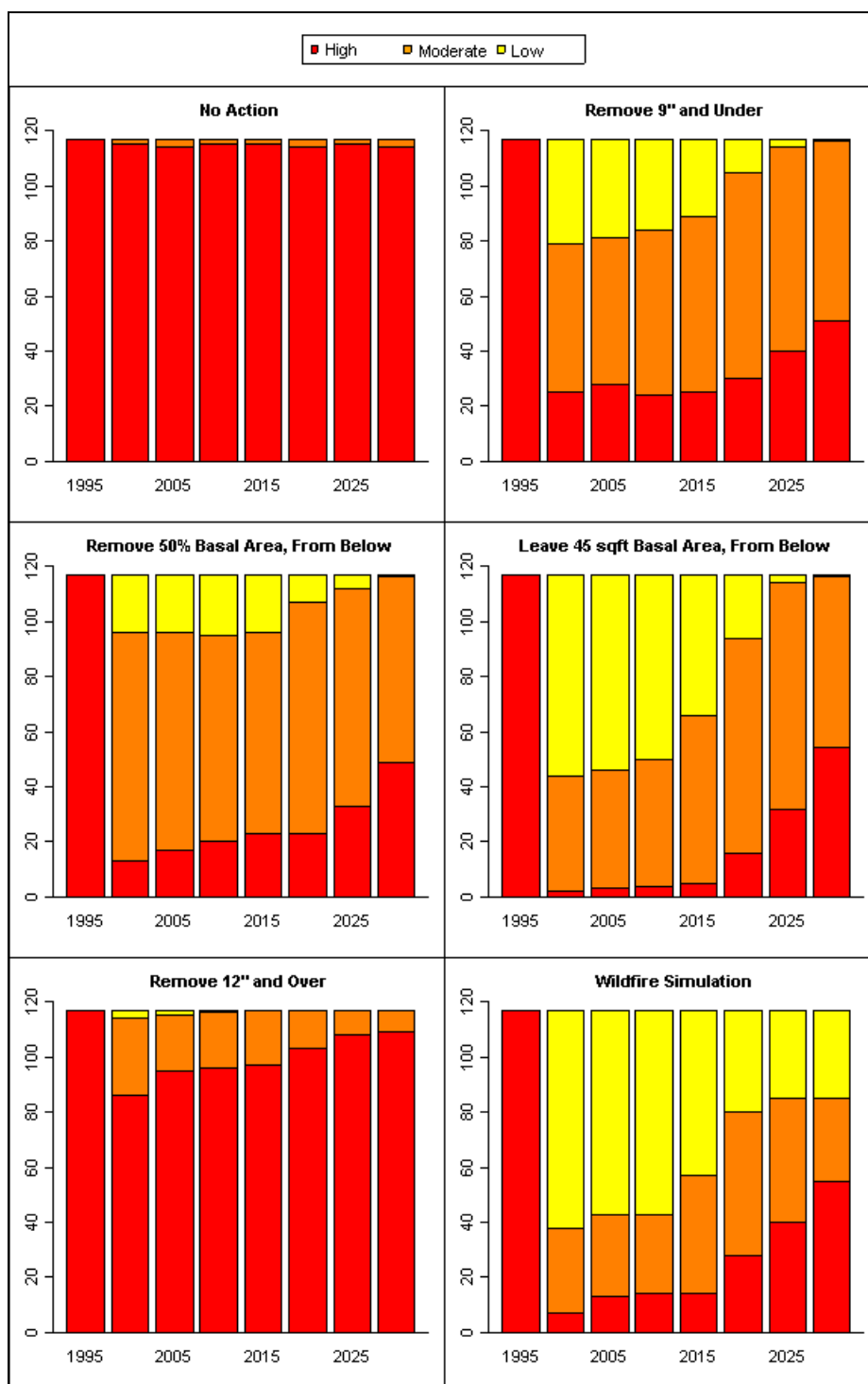


Figure 13 ONF High Fire Risk Response to Six Simulations with Regeneration

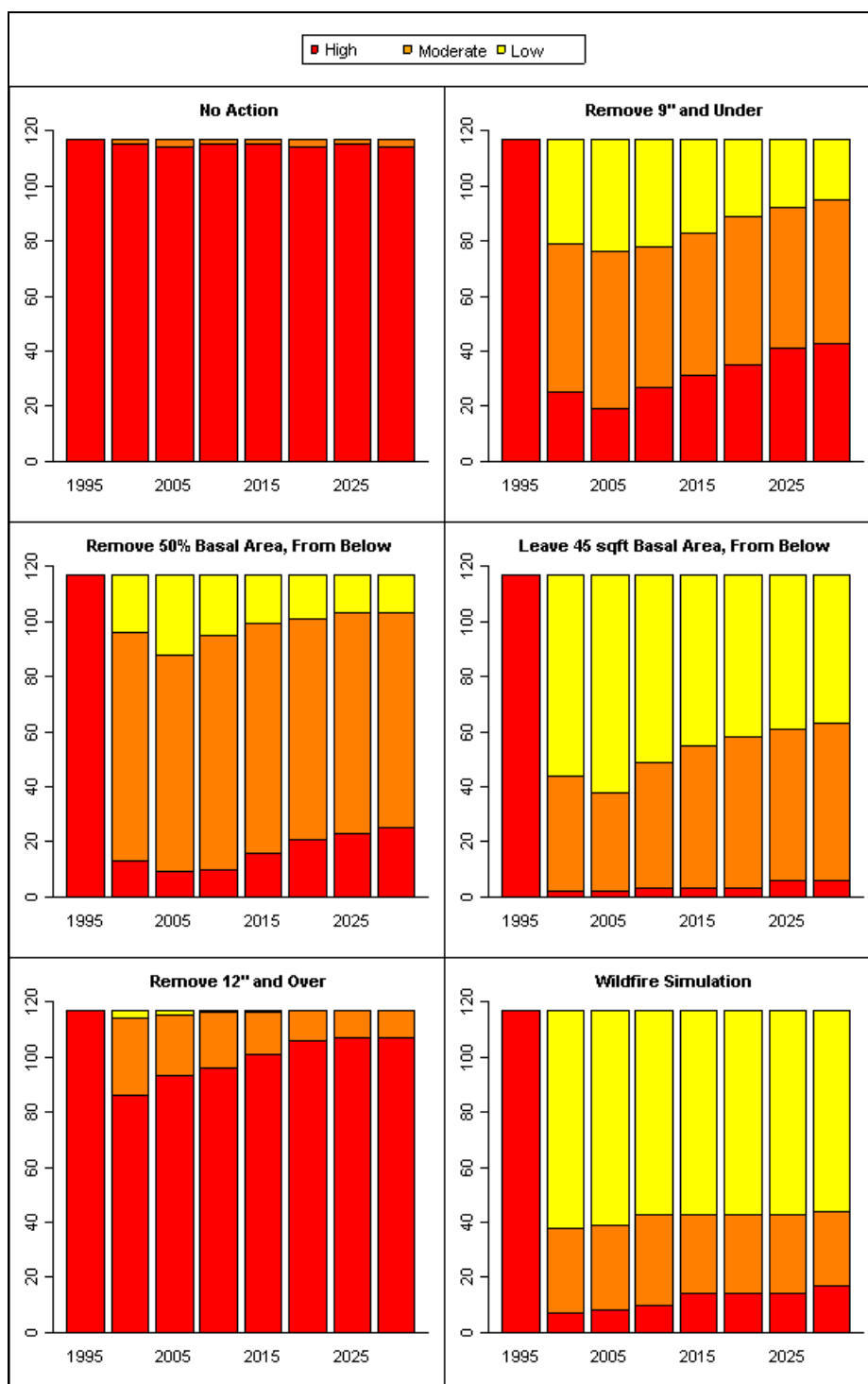


Figure 14 ONF High Fire Risk Response with No Regeneration after Treatment.

4.2 Economic results

FNF Economics results

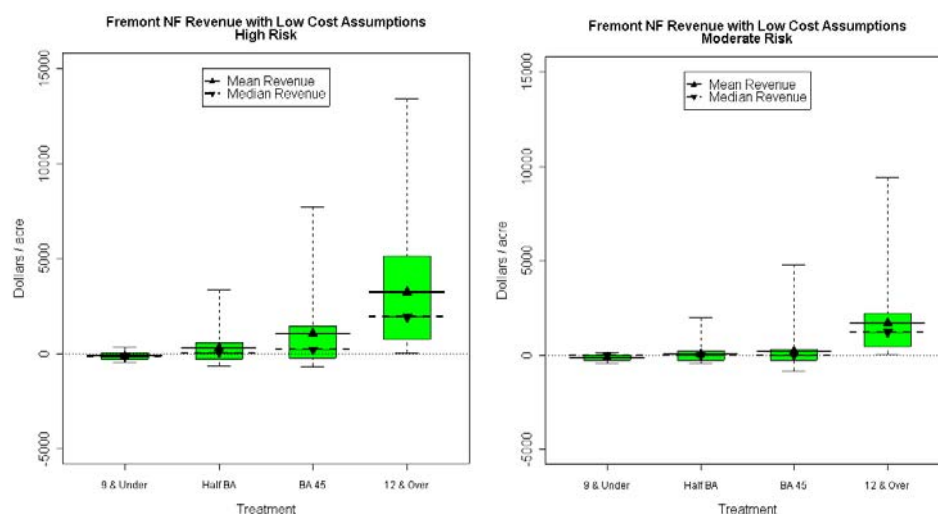
The mean, minimum, and maximum net revenue economic results from harvest simulations are displayed in \$/acre for both high and moderate fire risk stands in FNF in Table 7. The economic results of this analysis show that 9 and under has an average net cost to the USFS with both high and low logging costs scenarios on the FNF. The 12 and over provides significant revenue with both high and low logging costs used in this analysis. The other two thinning treatments, Half BA and BA 45, provide positive revenues with low logging costs on the FNF, but have negative revenues with high logging costs applied to treatment simulations.

Table 7 FNF mean net revenue for high and moderate risk with high and low costs

Treatment	High Cost Mean	High Cost Minimum	High Cost Maximum	Low Cost Mean	Low Cost Minimum	Low Cost Maximum
9 and under	(\$374)	(\$1,132)	\$92	(\$134)	(\$466)	\$240
Half BA	(\$319)	(\$1,309)	\$1,270	\$139	(\$569)	\$2,683
BA 45	(\$168)	(\$2,015)	\$3,885	\$529	(\$770)	\$6,241
12 and over	\$1,244	(\$1,857)	\$8,270	\$2,198	(\$765)	\$11,414

The economic analysis of net revenue for each thinning treatment simulation has a range of results demonstrated in Figure 15 A and B. See Appendix A for the full set of economic results for FNF. The high risk stands treated with BA 45 with high logging costs are very close to neutral revenue which indicates that on many stands the value of the logs removed will cover the costs of the risk reduction. High risk stands treated with

BA 45 and with low logging costs produce positive revenues with very few stands modeling negative net revenue. The Half BA treatment appears to generate modest positive returns with low cost assumptions while the high cost assumptions result in negative net revenues. The 9 and under treatment remains a negative net revenue with both high and low costs for all risk categories. Treating the high risk stands is more likely to result in positive returns than treating the moderate risk stands because generally high risk treatments yield greater saw log volumes than do moderate risk stands.



A

B

Figure 15 A and B FNF Net Revenue High and Moderate Risk Low Costs

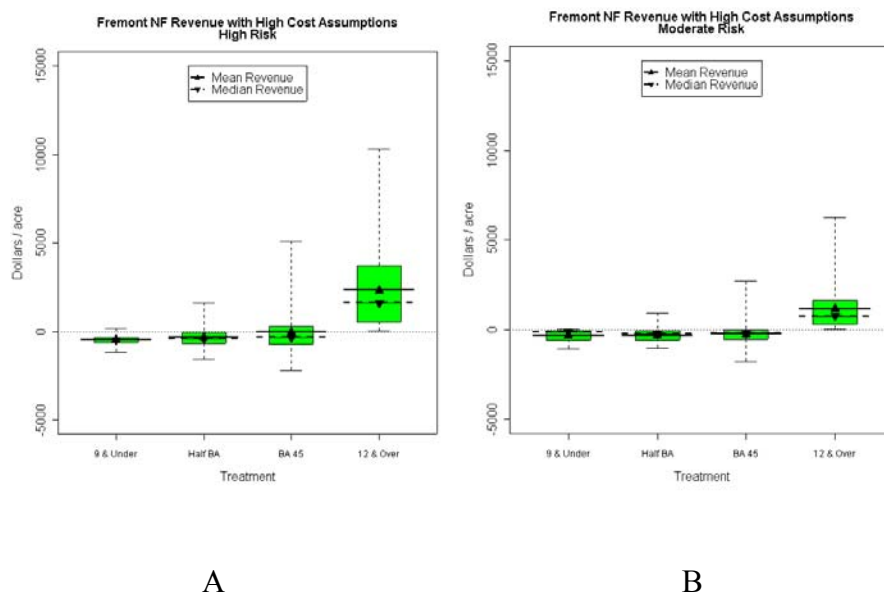


Figure 16 A and B FNF Net Revenue High and Moderate Risk High Costs

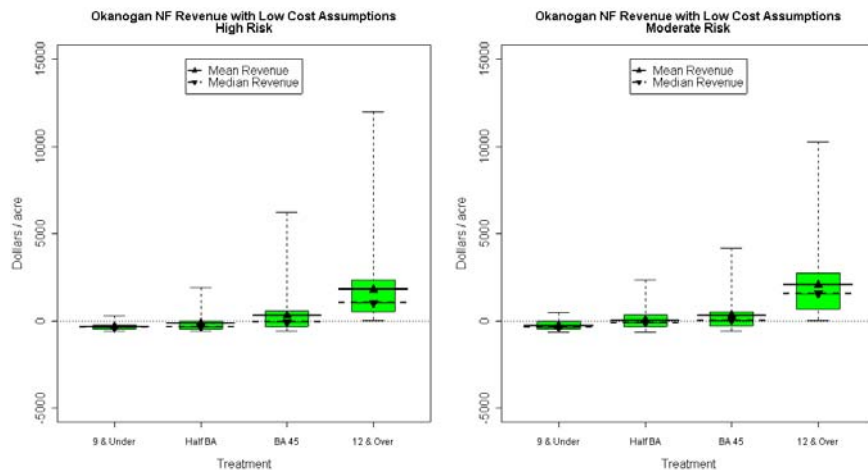
ONF Economics results for the entire forest and each fire risk

The results of average net revenue per acre for high and moderate risk stands in ONF are shown in Table 8. The economic results of this analysis show that for high and moderate risk stands on the ONF, the 9 and under and the Half BA treatments have an average net cost to the USFS under both high and low logging costs scenarios. However, the Half BA treatment is close to breakeven with low logging costs. The 12 and over thinning is the only treatment that provides revenue with both high and low logging costs used in this analysis. But all of the other three thinning treatments have some stands with positive net revenue. The BA 45 average net revenue is positive with low logging costs on the ONF but has an average cost of \$169/acre to thin with high logging costs Table 8.

Table 8 ONF mean net revenue for high and moderate risk with high and low costs

Treatment	High Cost Mean	High Cost Minimum	High Cost Maximum	Low Cost Mean	Low Cost Minimum	Low Cost Maximum
9 and under	(\$345)	(\$892)	\$67	(\$287)	(\$625)	\$270
Half BA	(\$265)	(\$946)	\$953	(\$39)	(\$618)	\$2,110
BA 45	(\$169)	(\$1,160)	\$2,660	\$291	(\$598)	\$5,191
12 and over	\$1,025	(\$331)	\$7,358	\$1,953	\$4	\$11,113

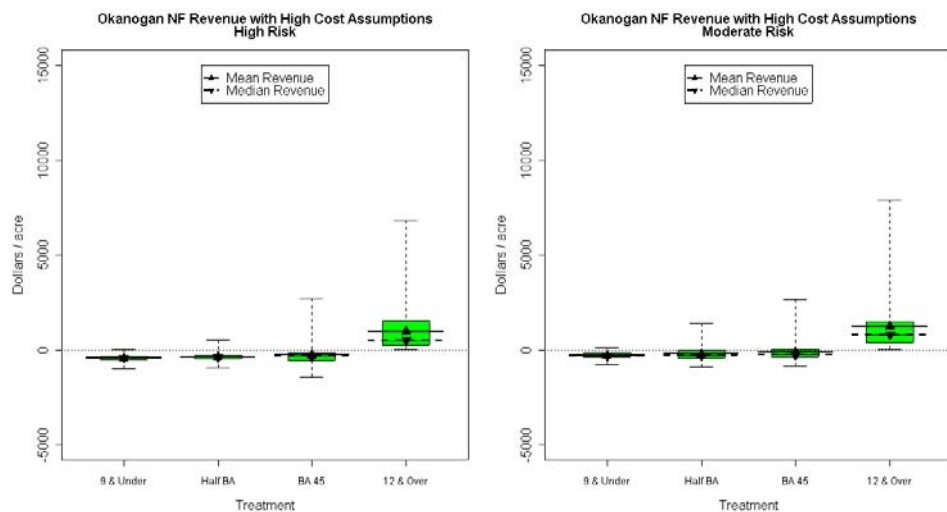
The economic analysis of high fire risk stands revenue by treatment simulation has a range of results displayed in Figure 17 and Figure 18. See Appendix B for the full set of economic results. Only the 12 and over treatment has positive net revenue with both high and low logging costs for both high and moderate risk classes. BA 45 treatment has positive net revenue with low logging costs for both high and moderate risk classes but not for high cost assumptions. The Half BA has marginally negative returns for all cases. The 9 and under treatment generates average negative net revenues with high and low costs for both risk classes.



A

B

Figure 17 A and B ONF High and Moderate Risk Net Revenue with Low Cost



A

B

Figure 18 A and B ONF Net Revenue High and Moderate Risk with High Costs

4.3 Cost to fight fire on the Fremont and Okanogan National Forests

The FNF and ONF have forest fire fighting costs depending upon fire size and conditions that can range from \$300 to almost \$11,000/acre. These figures do not include suppression costs to states, counties, or municipalities nor do they include losses of forest resources and property. The closer to the wildland/urban interface generally the greater the fire fighting cost. Individual large forest fires may cost as much as \$1,000,000/day due to large numbers of ground crews and expensive ground and air equipment (local interviews 2002). Fire fighting cost trends appear to be increasing as fires become more explosive and impossible to control (United States National Interagency Fire Center 2002). In addition to fire fighting costs, once the fire is out, regeneration and restoration projects can be problematic and add more costs. Individuals in the local communities and Forest Service agree that the alternative to thinning overstocked forests will be spending billions of dollars over the next 100 years to fight wildfire (local interviews 2002). In figure 25, fire fighting costs for 1992-2002 are displayed as averages by year/magnitude for the Fremont National Forest. The average cost/acre has been calculated and displayed with the discounted average cost/acre based upon a 30 and 60 year return cycle at a 5.0% discount rate. The discounted costs are presented here to demonstrate that if an equal number of acres burned every year such that all acres were burned by the end of the discount period (in this case either 30 or 60 years) then the net present cost outlay would be \$564/acre or \$271/acre. Since a majority of stands on both forests are in high to

moderate risk classifications and most stands are well outside of historic fire return intervals, it should not be unreasonable to speculate that all or at least most acres might burn within a discrete future period. Such cost estimates can serve as value indicators that are important when forest managers must decide on the level of stewardship investment (negative return fuel reduction treatments) that is appropriate to avoid the estimated cost exposure of high risk forest conditions.

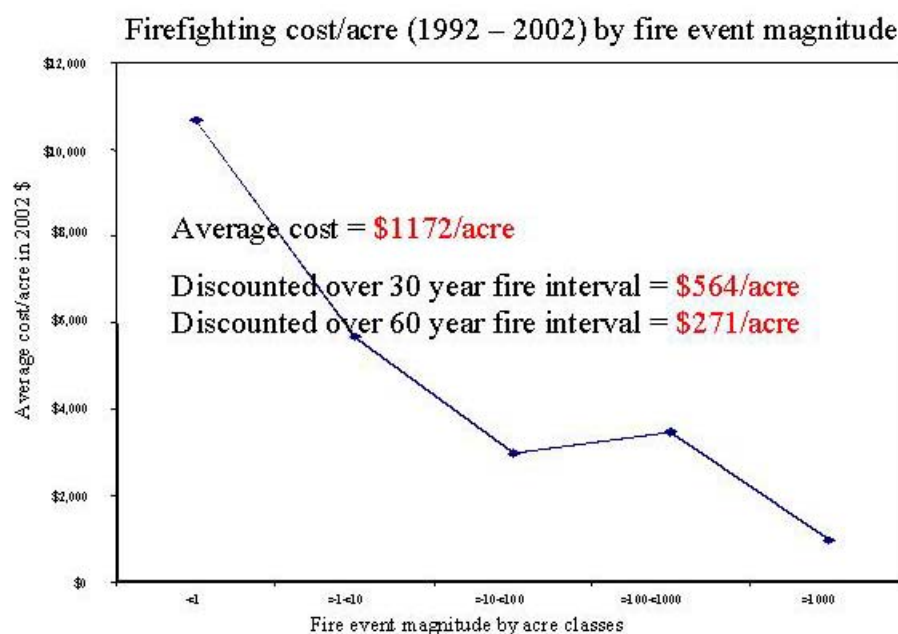


Figure 19 Gross fire fighting costs by magnitude for 1992-2002.

Average fire suppression costs/acre 1992-2002 for the FNF are presented in figure 26. The need for expensive fire suppression efforts has resulted in increases to FS fire suppression budget. Ironically, however, forest management budgets (funding that is

needed to support fire risk reductions through fuels removal treatments) are shrinking (Michaels and Evans 2003). In 2002, 125,000 acres of forest burned on the FNF. Forest silviculturalists and fire scientists report that where prior fuel reduction activities had been undertaken, forest fires dropped to the ground and burned with low intensity (Michaels and Evans 2003). Where fuel loads had not been reduced fires increased intensity and consumed the crowns (local interviews 2002). These anecdotal observations agree with wildfire simulations conducted as part of this investigation. All stands in high and moderate risk classes (78% of the total FNF area studied) would experience near total mortality in the event of a wildfire. The total precommercial thinning budget for the Fremont Winema National Forest combined for thinning non merchantable trees was \$1,020,000 in contrast to much higher fire fighting costs (Michaels and Evans 2003).

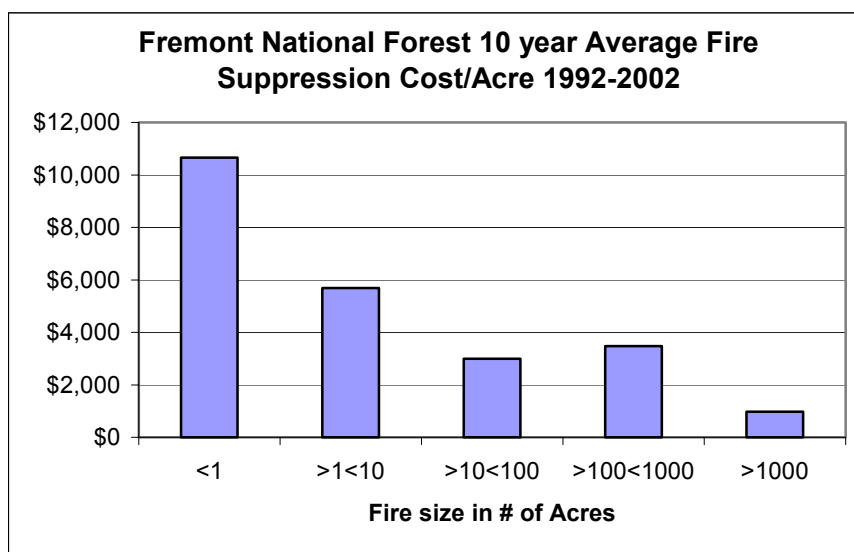


Figure 20 FNF Fire Suppression average costs/acre by magnitude for 1992-2002

Okanogan has experienced similar costs associated with fighting fire as those reported by the FNF. Actual costs by fire size are shown in figure 26 (Burdick 2002). Both forests display the common trend of higher costs/acre for smaller fires, which are often in the wildland/urban interface. However, an increasing number of large forest fires has resulted in suppression costs in the \$ millions/year for both national forests. The total fire suppression costs for the Forest Service for Okanogan-Wenatchee was \$11,024,200 in 2001 and \$12,552,000 in 2002. These figures do not account for the state, county and private fire suppression costs or loss of valuable resources. They do include the funding of the initial attack resources, heat and light, administration costs, fire management personnel, etc.

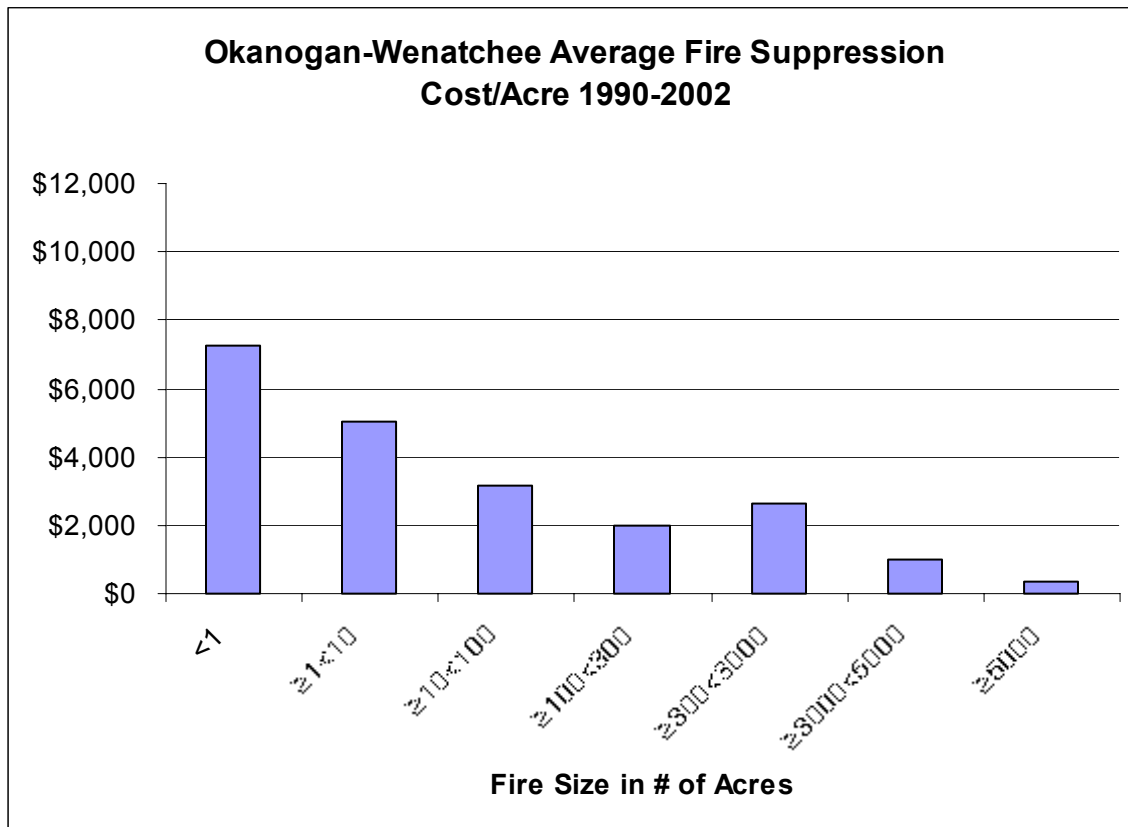


Figure 21 OWN Fire Suppression average costs/acre 1990-2002

5. Discussion

5.1 Fire Risk

Analysis of 1995 CVS data utilizing the USFS models FFE and FVS shows that 30.7% of the FNF and 28.3% of the ONF are in high fire risk classification. These high fire risk stands have the potential of a ground fire moving into the crown at wind speeds less than 25 MPH. In reports issued in 2001 and 2002 the Western Governors Association refers to forests of the intermountain West as urgently in need of treatments to reduce hazardous fuel loads (USDA Forest Service U.S. Dept. of Interior and Western Governors' Association 2001). A Density Management white paper by USFS suggests the backlog of high fire risk forests will increase by 13% on USFS land over the next 5 years (Powell et al. 2001).

The No Action growth simulations for both forests experience gradual increases in fire risk over time. Risk increases appear to be more dramatic for the ONF. No Action assumes no forest fire or treatment in any stand during the simulation period of 1995-2030. While this assumption of no disturbance is historically unrealistic, there is comparative benefit from being able to review No Action outcomes against other treatment alternatives. For this study both No Action and Wildfire simulations act as dual controls to establish a range of consequences that could result if hazardous fuel removals are not undertaken.

The Wildfire simulations assume that everything burns in the same treatment year. As with No Action this assumption is also historically unrealistic. However, modeling the comparative behavior of wildfire in the different risk classes of the two different forests provides valuable insights that substantiate estimates of the severity of fire event consequences. Such estimates could be helpful, for instance, to foresters attempting to balance risk of No Action against the costs and benefits of treatments.

There are four silviculture treatment alternatives that are used in this study. They were chosen to represent varying harvest intensities and to produce simulation outputs that could be readily comparable to those produced by other fuel reduction treatment research projects. Additional treatment alternatives could certainly be developed for more customized approaches to individual stand conditions. The treatment simulations presented in this thesis are used to demonstrate a useful modeling methodology to assist Forest Service silviculturalists and to assist better understanding of the treatment effectiveness sensitivities inherent in fuel reduction activities.

One treatment has a fixed density target of BA 45 that is independent of initial density condition. Another treatment has a variable density target of Half BA. Two other treatments are designed to take either small material from below (9 & under) or large material from above (12 & over). By comparing the outcomes of these treatment alternatives, multiple insights may be gained. It is clear, for example, that for some stands the 9 & under does not reduce risk as effectively as the Half BA or the BA45. This would indicate that on some stands, in order to insure successful fuel reduction

treatment, more trees (some that are larger) than just the 9" and smaller DBH trees will need to be removed. The simulations in this investigation show that in many cases the additional numbers of stems that are removed to meet the Half BA or BA 45 targets are only a few more trees than the lighter touch treatment of 9 and under. Depending upon the initial pretreatment basal area, the Half BA or BA 45 may be more successful at achieving density and risk reductions. For example, when initial basal area is less than 90 sqft./acre, Half BA will result in greater density reductions (lower risk) than the fixed target of 45 sqft./acre. But when initial BA is greater than 90 sqft./acre then the BA 45 will likely result in greater density reductions. In cases where there are few TPA greater than 9" DBH, the 9 and under will result in the greatest density reduction. Conversely the 12 and up would result in greatest density reduction if most trees are over 12" DBH. The inventory data for both of the study forests indicates that the high and moderate risk areas of both forests have a majority of trees/acre with DBH less than or equal to 9". The pretreatment mean QMD for high and moderate risk areas of the FNF is 6.4". The pretreatment mean stems per acre for the high and moderate risk areas of the Fremont equals 940 TPA of which 93% are less than or equal to 9". The pretreatment mean QMD for high and moderate risk areas of the ONF is 5.3'. The pretreatment mean stems per acre for the high and moderate risk areas of the Okanogan equals 1153 TPA of which 94.3% are less than or equal to 9".

In some areas of forest the 9 and under treatment appears to be effective in reducing risk (22.1% of high and moderate stands in the FNF were reduced to low risk with this

treatment and 35.0% of high and moderate stands in the ONF were reduced to low risk with this treatment). For a few stands, 9 and under may even generate positive economic returns although the mean economic returns for both forests with this treatment for either high or low cost assumptions were negative (Low cost FNF -\$134/acre, Low cost ONF -\$287/acre, High cost FNF -\$374/acre, High cost ONF-\$345/acre) . In stands where the 9 and under treatment is effective this treatment could be a desirable alternative to the other options. However, this treatment is costly and does not appear to be as effective for overall risk reduction as either the Half BA or the BA 45 treatment.

Thinning to a variable density target of half the pretreatment basal area (Half BA) proved to be an effective treatment in many of the stands (55.4% of high and moderate stands in the FNF were reduced to low risk with this treatment; 56.2% of high and moderate stands in the ONF were reduced to low risk with this treatment). Economic performance for this treatment differed by forest. The FNF showed a modest positive return (\$139/acre) for low cost assumptions but had a negative return (-\$319/acre) for high cost assumptions. Half BA has negative returns (Low cost -\$39/acre, High cost -\$265/acre) for both cost assumptions on the ONF.

Half BA performed better than the 9 and under treatment for both risk reduction and economic return but did not do as well as BA 45 for either performance metric. Thinning to a target BA 45 appears to be generally the most effective and cost conservative approach to fuel reduction treatments. When treated with the BA 45 alternative the high and moderate risk stands had 63.8% of stands reduced to low risk on the Fremont and

72.6% of total stands reduced to low risk on the Okanogan. With low cost assumptions BA 45 resulted in positive economic returns on both forests (Low cost FNF \$529/acre, Low cost ONF \$291/acre) but with high cost assumptions this treatment had negative returns on both forests (High cost FNF -\$168/acre, High cost ONF -\$169/acre).

The 12 and over treatment was simulated with little expectation that this treatment alternative would be very effective for fire risk reduction. This treatment does not remove any small diameter ladder fuels. In many respects this treatment resembles the historic harvest practices from the late 19th century to mid 20th century that have contributed to the present risk condition. However, the 12 and over simulations are very useful to reveal some interesting characteristics of these forests. While risk reductions successes were few the mean economic returns that resulted from this treatment were considerable (Low cost FNF \$2198/acre, Low cost ONF \$1953/acre, High cost FNF -\$1244/acre, High cost ONF -\$1025/acre). The positive revenues that result from this treatment may be considered as a conservative estimate of the value of forest resources that could be lost to wildfire. By multiplying the number of plots for each forest by the CVS acreage expansion factor of 1849.6, the total acreage represented by the data for each forest can be determined. When this acreage estimate is multiplied by the mean economic returns/acre generated by the 12 and over simulation an estimated range of forest value that is at risk from wildfire can be calculated. Since no value is credited for trees smaller than 12" DBH this methodology should produce a very conservative value estimate. Based upon such calculation, the high and moderate risk areas of the Fremont

National Forest (721,344 acres represented by 390 plots) would have a resource value of between \$900 million and \$1.6 billion while the high and moderate risk areas of the Okanogan National Forest (586,323 acres represented by 317 plots) would have a resource value of between \$600 million and \$1.2 billion.

Also of interest; the additional trees removed in Half BA and BA 45 (both of which are from below with the exception that the BA 45 leaves all ponderosa pine on the FNF and all ponderosa pine and western larch on the ONF) beyond the number of trees removed in the 9 and under treatment, amount to only 23 TPA and 3 TPA respectively for Half BA and BA 45 in the high and moderate risk areas on the FNF. For the mean change represented here, the analysis would indicate that the additional trees are less than 12" DBH for most cases and that the 40-60 largest diameter TPA in each stand remain standing post treatment. The data indicate that the number of leave trees in Half BA and BA 45 treatments is greater than the number of 12' and larger trees indicating that in the average stand all 12' and larger trees are left standing. These few extra harvested trees appear to result in much greater risk reduction and better economics.

On the high and moderate areas of the Okanogan, the mean post treatment TPA for Half BA when compared to 9 and under is reduced by 3 TPA, however, for the BA 45 the mean TPA of leave trees is actually 51 trees more than the 9 and under indicating that in this case less stems may have been taken. Also the median post harvest TPA for BA 45 is 24 trees less than 9 and under, suggesting a skewed distribution has obscured results. It is important to remember as well that the BA 45 treatment requires that all ponderosa

pine and larch be left to develop into a desired future condition. In some cases leaving these species will mean that more and possibly larger overstory trees of other species are taken in order to save the desired leave trees and still meet the BA target. This analysis appears to indicate that on both forests some combination of the three thin from below treatments, customized to individual stand conditions, could remove much of the present forest fire risk at low cost or even positive return. Other studies such as, “A strategic assessment of fire hazard in Montana” (Fiedler et al. 2001) have found similar results.

There is a difference between “with regeneration” and “without regeneration” simulation results. The “without regeneration” simulates the effectiveness of each treatment with an assumed management strategy, such as control burning or follow up thinning treatment, to prevent risk build-up from the development of understory ladder fuels resulting from regeneration. The “with regeneration” simulation is to represent the forest risk response with no follow up treatments to control ingrowth after the initial fuel reduction. The “with regeneration” simulation shows that risk reduction effectiveness lasts for about 10 years before the risk level increases again. Maintenance of forests in lower risk status will require fuel removal treatments or controlled burns as a necessary component of landscape planning. While the specific implications of ingrowth control are beyond the scope of this study, it is important to recognize that continuing and possibly costly management will be required to keep forest fire risk levels under control.

Treatment planning may be assisted by use of these model results to align the risk reduction, the duration of reduction, and the economic results to achieve the most effective combination of treatments across the landscape over time.

5.2 Economics

Thinning to reduce fire risk has been considered to be costly because of the low value of small diameter logs (Wagner et al. 1998). The economic results in this analysis show that thinning treatments such as BA 45 and Half BA that are most effective for risk reduction may also be cost neutral or revenue positive in many situations

Table 7 and Table 8. The fire risk reduction results from the FFE output and economic analysis developed for this investigation show that lighter touch fuel reduction treatments such as 9 and under may be costly and are not as effective at reducing risk as less costly alternatives such as BA 45 and Half BA.

These results also show the Half BA and BA 45 thinning treatments have the potential to effectively reduce fire risk while returning timber revenues to the government. Under present market conditions, completing low intensity treatments such as the 9 and under will likely require some form of compensating contract or service agreement to carry a high cost of treatment.

When some stand treatments prove to be unavoidably costly, stands with negative returns can be paired with other stands that will yield positive returns. The potential package

could be treated as a stewardship contract in which the cost to treat some stands is offset by the returned value of treating other stands.

Another strategic management option for the negative revenue stands could be as a focus for retention areas if such stands provide desirable environmental benefits for wildlife habitat, recreation, or aesthetic values. It will be important to identify those high and moderate risk stands that because of such special circumstances will not be selected for risk reduction treatments. To protect these sensitive areas it may be desirable to prioritize revenue generating fuels removals in adjacent stands to create protective fire breaks.

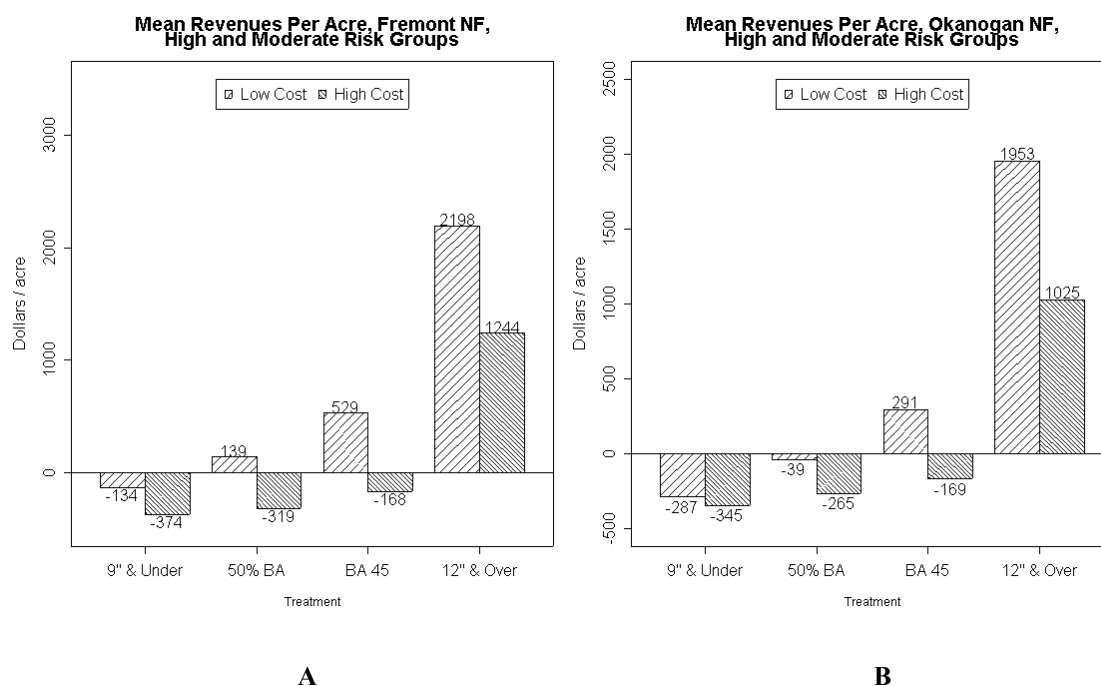


Figure 22 A and B FNF ONF High and Moderate Net Return Low and High costs

Results show BA 45 to generally be the most effective risk reduction treatment at the least cost. On the Fremont National Forest the high and moderate risk stands have a

higher average net return of \$529/acre Table 7. On the Okanogan National Forests the high and moderate fire risk stands average \$291/acre revenue with low logging costs.

Small Diameter Fuel Removal Infrastructure

Sustainability of risk reduction strategies will be dependent upon viable log markets, local harvest contractors and accessible manufacturing infrastructure. In many areas of the inland west these resources may be in decline. For example longer haul distances in the Okanogan area increase operations costs and reduce ability of the Forest Service to treat some areas that are at risk. The development of needed local infrastructure to harvest and utilize logs from fuel reduction activities will require confidence from local investors that raw material supplies and operational opportunities will be available in the future. Assurances from the federal government that fuel reduction activities levels will be sufficient and enduring will be a necessary part of a multiple-year fuel reduction strategy.

Long term stewardship contracts are one vehicle that might be useful. A steady supply of work and contracts will reduce costs of fuel removal and improve local economies. Presently some mills in the Fremont area shut down and send the employees home for part of the year when there is not a consistent supply of raw material to run the mill (local interviews 2002). In the Okanogan area, many mills have closed as harvest activity has slowed.

The infrastructure available to remove wood in these two inland communities is constantly changing. Many small mills, and loggers report that work opportunities are sporadic and shut downs are common. Interview respondents suggest such circumstances are due to several factors including high costs of operation and an inconsistent supply of contract opportunities for operating on Forest Service land. Interviews with USFS personnel and the local workforce suggest that respondents believe there to be untapped opportunities to save costs and perform environmentally sensitive and economically profitable thinning operations for fire risk reduction. Local interviews and government reports agree; harvest operations are needed to reduce fuel loads and treatments will need follow-up ingrowth controls such as controlled burns to reinitiate shorter fire return cycle.

There were a variety of related experiences and opinions collected during the course of interviews for this investigation. One consensus among respondents familiar with the federal timber sale program is that USFS timber sales sometimes receive no bids because of the bidder concerns about cruise volume accuracies and/or high minimum bid requirements. In contrast, the USFS foresters suggested that some timber sales do not receive bids because market conditions are poor. Both groups agree, however, that there are untapped costs savings available with better collaboration on sale design between the Forest Service and harvesting contractors. Interviews results indicate that contractors suggest that operations on other ownerships that are more flexible such are likely to achieve landowner objectives better and at less cost than present Forest Service timber sales or service contracts. However, the Forest Service has recently begun to experiment

with innovative contract designs directed toward greater contract flexibility as part of what is being called End Result Stewardship Contracting.

Prescribed Burning Costs

There are additional costs associated with managing high fire risk forests beyond an initial mechanical fuel removal treatment. The cost of maintaining a reduced fire risk includes prescribed burning costs. For example, assume the Fremont National Forest prescribed fire cycle should be about every 10 years or before risk levels begin to increase. Assuming \$90/acre to treat stands with prescribed fire every 10 years after treatment at a 5% discount rate the net present cost of prescribed burning is \$143/acre for FNF. Perhaps the wetter Okanogan National Forest does not require as frequent of a prescribed fire cycle. Assuming \$100/acre to treat stands every 20 years at a 5% discount rate the net present cost of prescribed burning for ONF would be \$60/acre. These anticipated costs should be important considerations for long-term forest planning such as reforestation has been considered in the past. Since 1930, the Forest Service has maintained the Knutson-Vandenberg Fund (KV Fund) from which funds deposited by timber sale purchasers are used to cover the costs of reforestation, timber stand improvements, and special cultural measures to improve renewable resources. Contributions into an enduring funding mechanism, such as the KV Fund held, within each ranger district for expenditures as necessary to control fuel loads, will be needed from fuel reduction harvest revenues or Congressional appropriations if a stable long-term program to avoid catastrophic forest fires is to be successful.

Small Diameter Timber Products

There are many potential small diameter timber (SDT) uses available to process material from fuel removal thinning treatments. The analysis in this investigation only assesses the product value associated with the merchantable logs removed and sold into existing current markets. The majority of stems removed to reduce fuel loads are from overstocked stands which predominately produce small-diameter timber with low value that may not be greater than costs to harvest, transport and process (Wagner et al. 1998). SDT has variable size limits dependent on the local market. However, there are markets for effective use of small-diameter and underutilized wood, such as traditional sawn lumber, engineered wood products, biomass to energy, local crafts industries, and others. Processing costs can be low for products such as roundwood SDT (Levan-Green and Livingston 2001). There are also evaluations of the value of SDT compared with larger wood to understand the cost or value of thinning an overstocked stand (Chmelik et al. 2003). There are several methods for valuing a log. Three methods of calculating gross product value of logs evaluated in the Pacific Northwest are the direct, intermediate and detailed method (Nagubadi et al. 2003).

It is important to understand the relationship of the wood products that may be available in each overstocked forest, the distance to the market, and silvicultural treatment needed to improve forest health. By assessing these three important variables before thinning each treatment of SDT may be more efficiently and economically distributed. There are

three product categories that use SDT: 1)energy/chemical, 2)fiber/particle, and 3)solid products (Barbour and Fight 2002).

Marketing and standardized processing of SDT may determine the long-term success of utilizing large volumes of this material over the next several decades. Value-added wood products such as doors, windows, molding, and flooring, may provide opportunities to make processing SDT profitable if marketed effectively (Punches 2002). It is important to understand the uses and grading standards of SDT to market the products effectively (Stern 2001). Guidelines need to be developed and agreed upon for use and specifications of SDT for construction (Wolfe 2000). These factors are all practical business issues that influence the value and demand for small-diameter timber.

Biomass to energy facilities are another potential use of small diameter timber. Clean and sustainable sources of energy that are available from utilization of wood biomass as an alternative to fossil fuels are needed in the inland west. There may be opportunities to develop biomass to energy facilities in rural communities if consistent supplies of wood biomass are available. The Collins Pine Company which owns a sawmill in Lakeview, Oregon has expressed interest in building a cogeneration plant to use small diameter wood from the FNF. A \$30 million investment requiring a 20 year return on investment will be needed to build a 30 megawatt plant. Such a facility could create jobs, clean electricity, and create a market for wood biomass from forest fuel reduction treatments. However, investments of this magnitude are unlikely without federal biomass supply assurances. Additional local economic development opportunities are created through

demand for jobs in the woods to remove excessive fuel loads. According to a Fremont National Forest Report issued on 12/19/2002, estimated job multipliers for harvest activities are 8 direct and 16 indirect jobs created per MMBF/year of logs that are harvested (Fremont National Forest 2002). Table 9 shows the opportunities for job creation around FNF based on the amount of merchantable and pulp wood removed from the most conservative thinning, 9 and under, for moderate and high risk stands.

Table 9 FNF MMBF available/year and direct and indirect jobs from fuel reductions

	MMBF AVAILABLE/YEAR	DIRECT JOBS/YEAR	INDIRECT JOBS/YEAR
All volume for 10 years	107	858	1716
All volume for 20 years	54	429	858
Pulp volume only for 10 years	79	630	1260
Pulp volume only for 20 years	39	315	630

Non-Market Benefits of Fuel Removal Thinning

The economic results of this analysis do not include non-market benefits. However, there are several important factors which impact the community and forest when the fire risk is reduced and the negative impacts of wildfire are avoided. The first six benefits should be readily recognized results of reducing high fire risk in western forests through fuel

removal treatments. The additional benefits are variable based on the proximity of the forest to communities, the intensity of the wildfire, and the perceived public value of water, carbon accounting, and green electricity.

- ❖ Additional Jobs provided from fuel removal activities
- ❖ Reduced fire fighting cost
- ❖ Reduced fatalities
- ❖ Reduced facility loss
- ❖ Reduced loss of timber and habitat
- ❖ Regeneration and restoration cost savings
- ❖ Carbon sequestration
- ❖ Green energy credits
- ❖ Electrical transmission cost savings
- ❖ Water saved from reduced density
- ❖ Rural community value of fire risk reduction
- ❖ State tax receipts from economic activity

6. Conclusion

USFS models FFE and FVS were used to assess fire risk and the cost per acre of hazardous fuel reduction treatment alternatives for Fremont and Okanogan National Forests. Results indicate that some fuel removal treatments can produce positive net revenue in many high and moderate fire risk stands. The Null Hypothesis (There is little potential for positive net revenue from logs sales that will result from harvest activities designed to reduce fire risk in moderate to high risk inland west forests), should be rejected based on the results of this study.

- ❖ Fuel removal thinning to reduce fire risk may produce positive net revenue
- ❖ New Stewardship Contracting authorities such as long term contracts and designation by description are two examples of many potential opportunities to reduce fuel removal costs and sustain local infrastructure.
- ❖ Long term supply assurances will encourage investment in infrastructure
- ❖ There are market and non-market benefits from fuel reductions that are not generally considered when assessing federal expenditures for risk reduction.
- ❖ When all costs and benefits are considered what may appear as short term losses actually may be investments in positive long term savings.

The USFS employees and contractors have many of the same insights and suggestions for local solutions to reduce fuel in high fire risk forests. There is general agreement that streamlining the process and the contract requirements could result in improved operations at less cost (Kauffman 2001). For example many contractors are confident that hazardous fuel reductions can be performed with operator selection of take trees to conform to silvicultural descriptions stipulated in a contract description. The Forest Service is experimenting with this approach and others as it develops new strategies for stewardship contracting, recently authorized by congress (The Pinchot Institute for Conservation 2002). Historically, opportunities for innovative approaches to fuel removals have been limited by inflexible contracting constraints for both timber sales and service contracts (local interviews 2002).

Without available raw material supplies, mills close. Manufacturing infrastructure is needed to utilize logs developed by fuel reduction activities. Prices paid by the manufacturing sector for logs are important to cover costs of fuel reduction treatments. An increasing number of mill closures will require transportation of logs greater distances to fewer mills. Greater haul distances mean greater costs for hazardous fuel reductions. Greater costs for hazardous fuel reductions ultimately mean less acres get treated and forest fire risks remain high. Development of new infrastructure such as biomass-to-energy facilities to utilize otherwise non merchantable wood biomass represents an important environmental and economic opportunity. However, there must be confidence that consistent biomass volumes will be available in order to attract new investments in

biomass conversion opportunities. Long term contracts are a possible opportunity to support investment.

Based on the results of the simulations on the Fremont National Forest and Okanogan National Forest the high fire risk stands could be treated at no cost to the government. Break even or positive net revenue treatment results could be further insured with increased investment in local harvest and manufacturing infrastructure.

Present levels of fuel loads are historically unprecedented resulting in increased frequency and intensity of wildfire. Results of this study show that in the FNF 77.8% of forests are at high to moderate risk and that 76.6% of Okanogan forests are at high to moderate risk. However, some hazardous fuels reduction treatments can effectively reduce the risk of wildfires that kill the overstory trees and on many stands can generate positive revenues from timber sales. Appropriate thinning and burning treatments may provide economic opportunities for rural communities, protect habitat for threatened and endangered species of wildlife, reduce carbon emission, improve carbon sequestration, and reduce the threat of wildfire to the forest ecosystem and surrounding communities.

An additional goal of this investigation has been to present a technical methodology to assist forest managers in quick evaluation of forest fire risk distributions and potential treatment alternatives across broad landscapes. Without technology to assist such analysis, the complexity of forest planning for hundreds of thousands of acres is daunting. Technical modeling capabilities provide beneficial assistance to foresters that

must communicate management choices to involved lay publics so that they might better understand the consequences of treatment alternatives or no action.

7. Future work

Future work, outside of the scope of this project, could utilize the technological capabilities showcased in this thesis to develop a process to prioritize stands that need treatment immediately. This prioritization could include a series of queries such as:

- ❖ What are the most strategic configurations of treated stands across the landscape?
- ❖ What spatial intensity and proximity of treatment is required to restore and maintain frequent low intensity understory fire regimes?
- ❖ Could using the FFE fire risk classification results to identify high priority treatment areas help to identify stands most in need of treatment?
- ❖ Will FFE, when combined with economic analysis, assist foresters in crafting innovative approaches to greatest risk reduction at least cost?

Findings from simulations will need to be cross referenced with insights from field foresters familiar with the forest. Additional decision support tools are also needed to assist a fire scientist, forester, or harvest planner to integrate management goals and more effectively interact with interested publics. Such tools might include wildlife, hydrological, soil, weather and carbon models that are linked together for integrated forest management planning. For example, GIS tools that combine the topography and climate data with the inventory information to model the interactions of spatial characteristics such as wind direction, soil conditions, aspect, etc. with crowning index

risk assessments against treatment costs will help to integrate management targets most effectively.

Developments in technology such as the World Wide Web create opportunities for broader and higher quality communication about forest management alternatives with interested publics. An investment in standardized web delivery of information could increase the outreach capabilities of the USDA Forest Service while reducing the costs and time associated with the public review process. A transparent planning process will be needed to restore public confidence in Forest Service management capabilities.

Bibliography

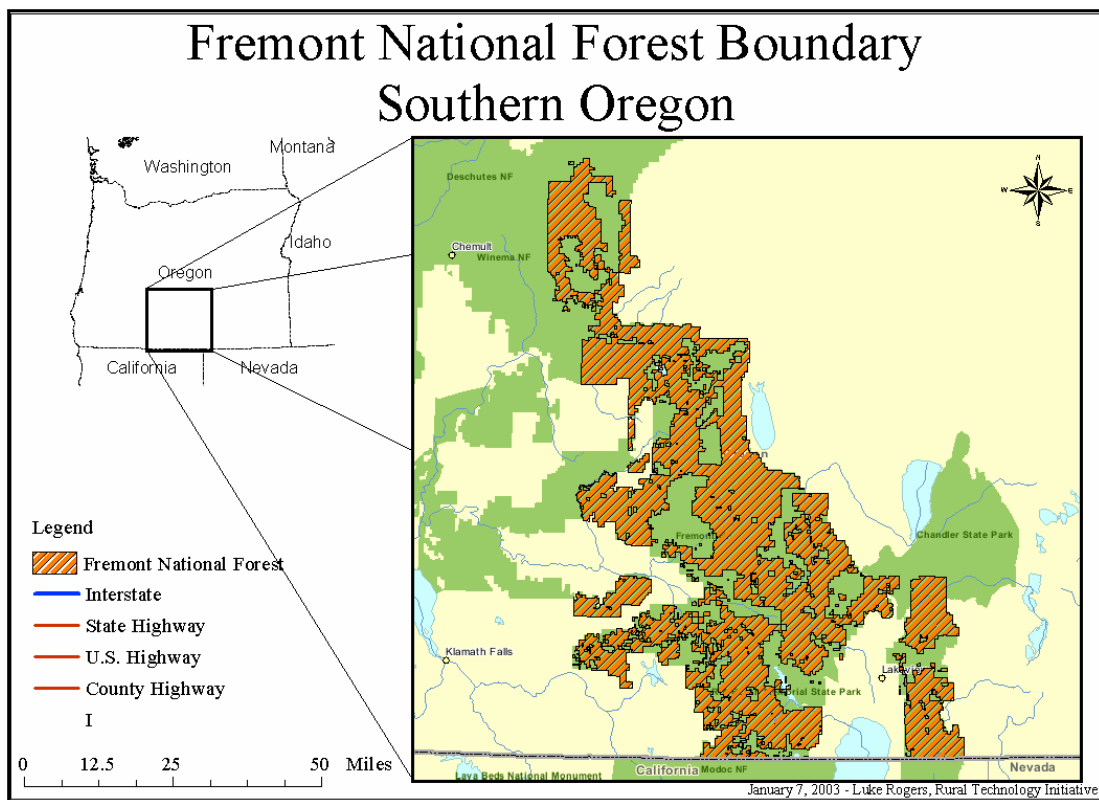
- Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, WA D.C.
- Arno, S. F. 1996. The seminal importance of fire in ecosystem management. In: Hardy, C.C.; Arno, S.F., eds. The use of fire in forest restoration. GTR-INT-341. USDA Forest Service. 3-5., USDA Forest Service.
- Arno, S. F. 2000. Fire in Western Forest Ecosystems: Chapter 5 in: Brown, James K.; Smith, Jane Kapler, eds. 2000. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. . 257p, USDA Forest Service, http://www.fs.fed.us/rm/pubs/rmrs_gtr42_2.html.
- Babbitt, B., and D. Glickman. 2000. Managing the Impacts of Wildfires on Communities and the Environment; A Report to the President. <http://www.fs.fed.us/fire/nfp/president.shtml>.
- Barbour, J. B., and R. D. Fight. 2002. Financial Analysis and Processing Options for Hazardous Fuel Reduction Integrated with Silviculture, Harvesting and Evaluation of Business Opportunities. 02.PNW.B.1, USDA Forest Service PNW research station, Portland, OR.
- Beukema et al. 2002. Fire and Fuels Extension to FVS. *in*, USDA Forest Service, Intermountain Forest Range and Experiment Station.
- Beukema, S. J., D. C. Greenough, C. E. Robinson, W. A. Kurtz, E. D. Reinhart, N. L. Crookston, J. K. Brown, C. C. Hardy, and A. R. Stage. 1997. An introduction to the Fire and Fuels Extension to FVS. Pages 191-195 *in* R. Teck, M. Moeur, and J. Adams, editors. Proceedings of the Forest Vegetation Simulator Conference, 1997 February 3-7. USDA Forest Service, Intermountain Forest Range and Experiment Station, Fort Collins, CO.
- Burdick, J. 2002. email correspondence 2/10/02 with Burdick, Jim. Assistant Fire Staff in Fire Planning for Okanogan & Wenatchee National Forest.
- Chmelik, J. T., R. D. Fight, and J. B. Barbour. 2003. Softwood Lumber Prices for Evaluation of Small-Diameter Timber Stands in the Intermountain West. Research Note FPL-RN-0270, USDA Forest Service Forest Products Laboratory.
- Cochran, P. H., and J. W. Barrett. 1998. Thirty-five-year growth of thinned and unthinned ponderosa pine in the Methow Valley of northern Washington. Res. Pap. PNW-RP-502., USDA Forest Service.
- Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecol. Monogr.:129-164.
- Crookston, N. L. 1990. User's Guide to the Event Monitor: Part of Prognosis Model Version 6. GTR INT-275. GTR INT-275, USDA Forest Service, Intermountain Research Station, Ogden, UT.

- Crookston, N. L., S. J. Beukema, and C. E. Robinson. 2002. Chapter 3 Users's Guide in The Fire and Fuels Extension to Forest Vegetation Simulator. RMRS-GTR-000, USDA Forest Service, Rocky Mountain Research Station, Ogden, UT.
- Everett, R. L., R. Schellhaas, D. Keenum, D. Spurbeck, and P. Ohlson. 2000. Fire history in ponderosa pine/Douglas-fir forests on the east slope of the Washington Cascades. *Forest Ecology and Management*:207-225.
- Fiedler, C., C. Keegan III, C. Woodall, T. Morgan, S. Robertson, and J. Chmelik. 2001. A strategic assessment of fire hazard in Montana. Bureau of Business and Economic Research, Missoula, Montana, <http://www.bber.umt.edu/forestproducts/pdf/MTfirereport.pdf>.
- Fremont National Forest. 2003. Interviews with Norm Michaels and Mike Evans and website research.
- Huggard, C. J., and A. R. Gomez. 2001. *Forests under fire*. University of Arizona Press, Tucson, AZ.
- Kauffman, M. 2001. The USDA Forest Service National Stewardship Pilot Projects in the Pacific Northwest: The FY 2001 Report of the Pacific Northwest Regional Multi-party Monitoring and Evaluation. The Watershed Research and Training Center, Hayfork, CA, http://www.pinshot.org/pic/cbf/PNW_regional_FY01.PDF.
- Lake county. 2003. <http://www.oregonsouthback.com/>.
- Levan-Green, S. L., and J. Livingston. 2001. Exploring the Uses for Small-Diameter Trees. *Forest Products Journal* **51**:10-21.
- local interviews. 2002. **Forest Service**: Woody Woodell, Sue Puddy, Norm Michaels, Richy Harrod, Michael Daugherty, Jody Perose, Frank Puddy, Doug Coon, John Townsley, Tom Ketchum, Arlo VanderWoude, Chris Anderson, Brad Flatten, Jan Flatten, Bob Gibbs, Dave Azuma, Mike Evans, Richard Stubbs, David Eitner, James Burdick, Myrna Duke, John Daily and Sally Estes.
- State land managers**: Washington Department of Natural Resources-John Calhoun, Dave Christenson, George Shelton, John Tweedale, Roy Henderson, Judy Cline, Oregon Department of Forestry-Ed Scheink, John Brown, John Pellissier.
- Private land managers: Whiskey Creek, Collins Pine, Hampton tree farms, Boise Cascade
- Mills**: Fremont Sawmill, Crown Pacific, and 7 mills who wished to remain nameless.
- Contractors**: John Lass Logging, Vargas Timber Cutting, Dave Harmon Logging, M & L enterprises, John Shepard Logging, Yankee Group, Bill Neubert Logging, Holly Mountain Resources, 11 contractors who wished to remain nameless.
- Industry, Environmental and Local Organizations**: Ecosystem Workforce Program-Charles Spencer and Cassandra Moseley, Sustainable Northwest: Marcus Kauffman, Okanogan Communities Development Council-Mike Ferris, Lake County Resources Initiative-Jim Walls and Bill Duke, Defenders of Wildlife-Rick Brown, American Forest Resource Council-Chuck Burley, Oregon Associated Loggers-Jim Giessinger, Washington Contract Loggers Association-Bill Pickell, Chelan County PUD-Brett Bickford. *in*.
- McCarter, J. B. 1997. Integrating forest inventory, growth and yield and computer visualization into a landscape management system. Pages 159-167 *in* R. Teck, M.

- Moeur, and A. J., editors. Forest Vegetation Simulator Conference. USDA Forest Service, Intermountain Research Station, Ogden, Utah.
- McCarter, J. B. 2001. Integrating forest inventory, growth and yield, and computer visualization into a landscape management system. Dissertation University of Washington.
- McCarter, J. B., J. S. Wilson, P. J. Baker, J. L. Moffett, and C. D. Oliver. 1998. Landscape Management through Integration of Existing Tools and Emerging Technologies. *Journal of Forestry* **96**:17-23.
- Michaels, N., and M. Evans. 2003. Fremont National Forest interview 2/25/03. *in*, Lake County, Oregon.
- Nagubadi, R. V., R. D. Fight, and J. B. Barbour. 2003. Valuing a Log: Alternative Approaches. Research Note PNW-RN-541, USDA Forest Service, Portland, OR.
- National Interagency Coordination Center. 2002. National Interagency Coordination Center 2002 Statistics and Summary. *in*. National Interagency Coordination Center, http://www.nifc.gov/news/2002_StatsSum/intro_summary.pdf.
- Northeastern Cascades Late-Successional Reserve Assessment Team. 1998. An Assessment of the Northeastern Cascades Late-Successional Reserves. USDA Forest Service Methow Valley Ranger District, Okanogan, WA.
- Okanogan National Forest. 1989. Final Environmental Impact Statement, Land and Resource Management Plan, Okanogan National Forest. USDA Forest Service, Pacific Northwest Region, Okanogan, WA.
- Okanogan National Forest. 2003. <http://www.fs.fed.us/r6/okanogan/>.
- Omi, P. N., and E. J. Martinson. 2002. Effect of Fuels Treatment on Wildfire Severity. Joint Fire Sciences Program Report, <http://www.cnr.colostate.edu/FS/westfire/FinalReport.pdf>.
- Pfilf, R. J., J. F. Marker, and R. D. Averill. 2002. Forest Health and Fire: An overview and evaluation. National Association of Forest Service Retirees, Chantilly, VA, www.fxs.org/NAFSRforesthealth.pdf.
- Powell, D. C., V. A. Rockwell, J. J. Townsley, J. Booser, S. P. Bulkin, T. H. Martin, B. Obedzinski, and F. Zensen. 2001. Forest Density Management Recent History and trends for the Pacific Northwest Region. R6-NR-TM-TP-05-01, USDA Forest Service.
- Punches, J. 2002. Evaluation of Small-Diameter Timber for Value-Added Manufacturing: AN Integrated Approach. Oregon State University Department of Wood Science and Engineering, Roseburg, OR.
- Pyne, S. J. 1982. *Fire in America: Cultural History of Wildland and Rural Fire*. Princeton University Press.
- Pyne, S. J. 1997. *America's Fires, Management on Wildlands and Forests*. Forest History Society, Durham, NC.

- Scott, J. H., and E. D. Reinhardt. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Research Paper RMRS-RP-29, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.
- Stage, A. R. 1973. Prognosis model for stand development. Research Paper INT-137. Research Paper INT-137, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.
- Stern, G. E. 2001. Construction with Small-Diameter Roundwood. *Forest Products Journal* **51**:71-82.
- Stewart, J. L. 1988. Forest insects and disease research: what is needed. Presentation to Western Forestry and Conservation Association Pest Committee. *in*, Seattle, WA.
- Strohmaier, D. J. 2001. The seasons of fire. University of Nevada Press, Las Vegas, NV.
- Swan, L. 2002. USDA Forest Service. *in*, Medford, OR.
- The Office of the President. 2002. Healthy Forests An Initiative for Wildfire Prevention and Stronger Communities, <http://www.whitehouse.gov/infocus/healthyforests/toc.html>.
- United States National Interagency Fire Center. 2002. Wildland Fire Statistics. *in*. <http://www.nifc.gov/stats/wildlandfirestats.html>.
- US Census Bureau. 2003. Oregon and Washington Statistics. <http://www.census.gov/>.
- USDA Forest Service. 2002a. Fire risk in East-side forests. Pacific Northwest Research Station Science Update:11.
- USDA Forest Service. 2002b. The Process Predicament: How Statutory, Regulatory, and Administrative Factors Affect National Forest Management. USDA Forest Service, Washington, DC.
- USDA Forest Service U.S. Dept. of Interior and Western Governors' Association. 2001. A Collaborative Approach for Reducing Wildfire Risks to Communities and the Environment, Ten Year Comprehensive Strategy. USDA Forest Service, U.S. Dept. of Interior, and Western Governors' Association.
- USDA Forest Service USDI and Western Governors' Association. 2001. A Collaborative Approach for Reducing Wildfire Risks to Communities and the Environment, Ten Year Comprehensive Strategy. USDA Forest Service, U.S. Dept. of Interior, and Western Governors' Association.
- Van Dyck, M. 2000. Keyword Reference Guide for the Forest Vegetation Simulator. USDA Forest Service, WO-TM Service Center, Fort Collins, CO.
- Wagner, F., C. E. Keegan, R. D. Fight, and S. Willits. 1998. Potential for Small-Diameter Sawtimber Utilization by the Current Sawmill Industry in Western North America. *Forest Products Journal* **48**:30-34.
- Western Governors Association. 2001, 2002. Western Governors Association: A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment 10-Year Comprehensive Strategy Implementation Plan.
- Wolfe, R. 2000. Research Challenges for Structural Use of Small-Diameter Round Timbers. *Forest Products Journal* **50**:21-29.
- Wykoff et al. 1982. Forest Vegetation Simulator model. *in*, Fort Collins, Colorado.

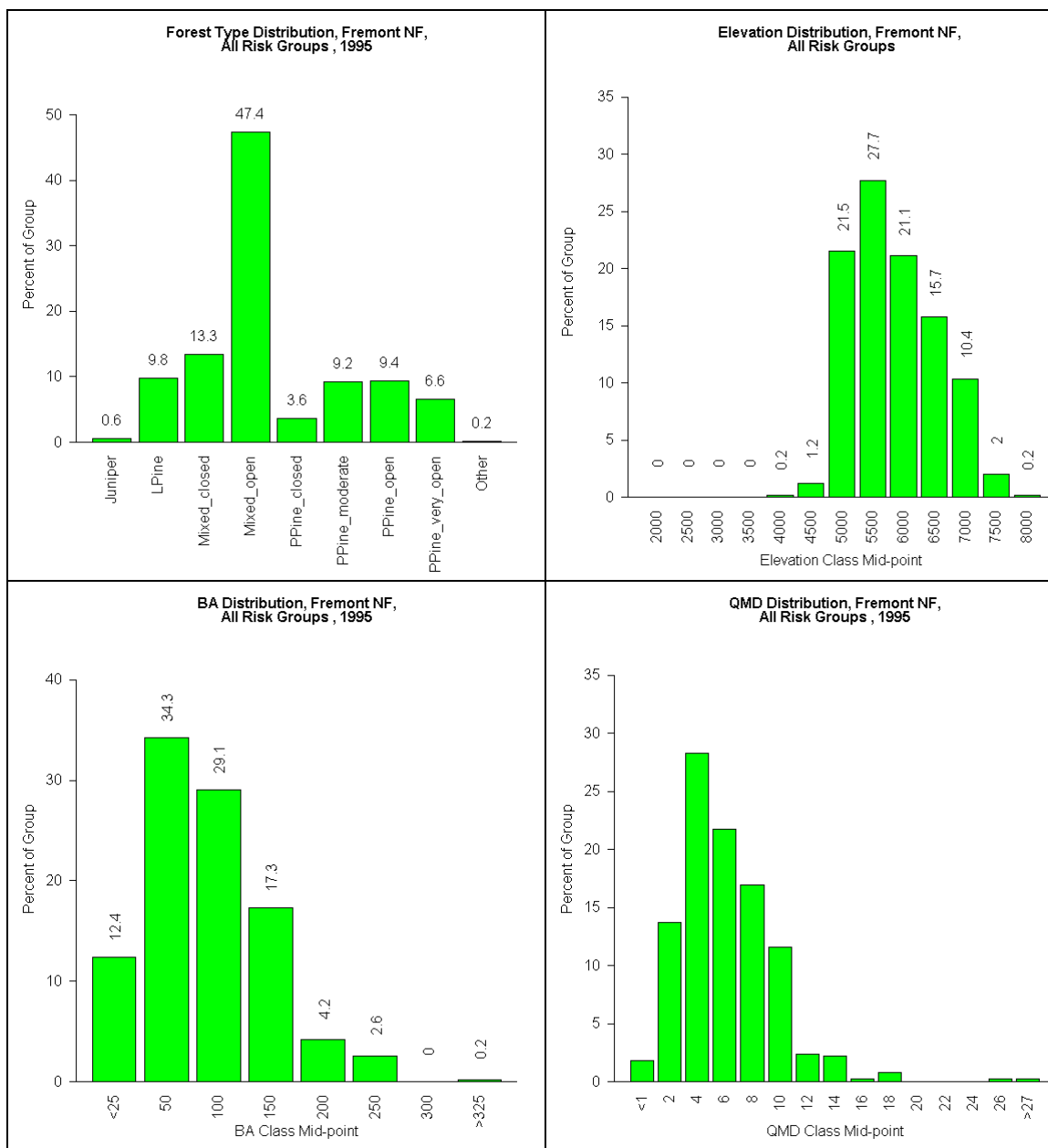
Appendix A Fremont National Forest Map and Results



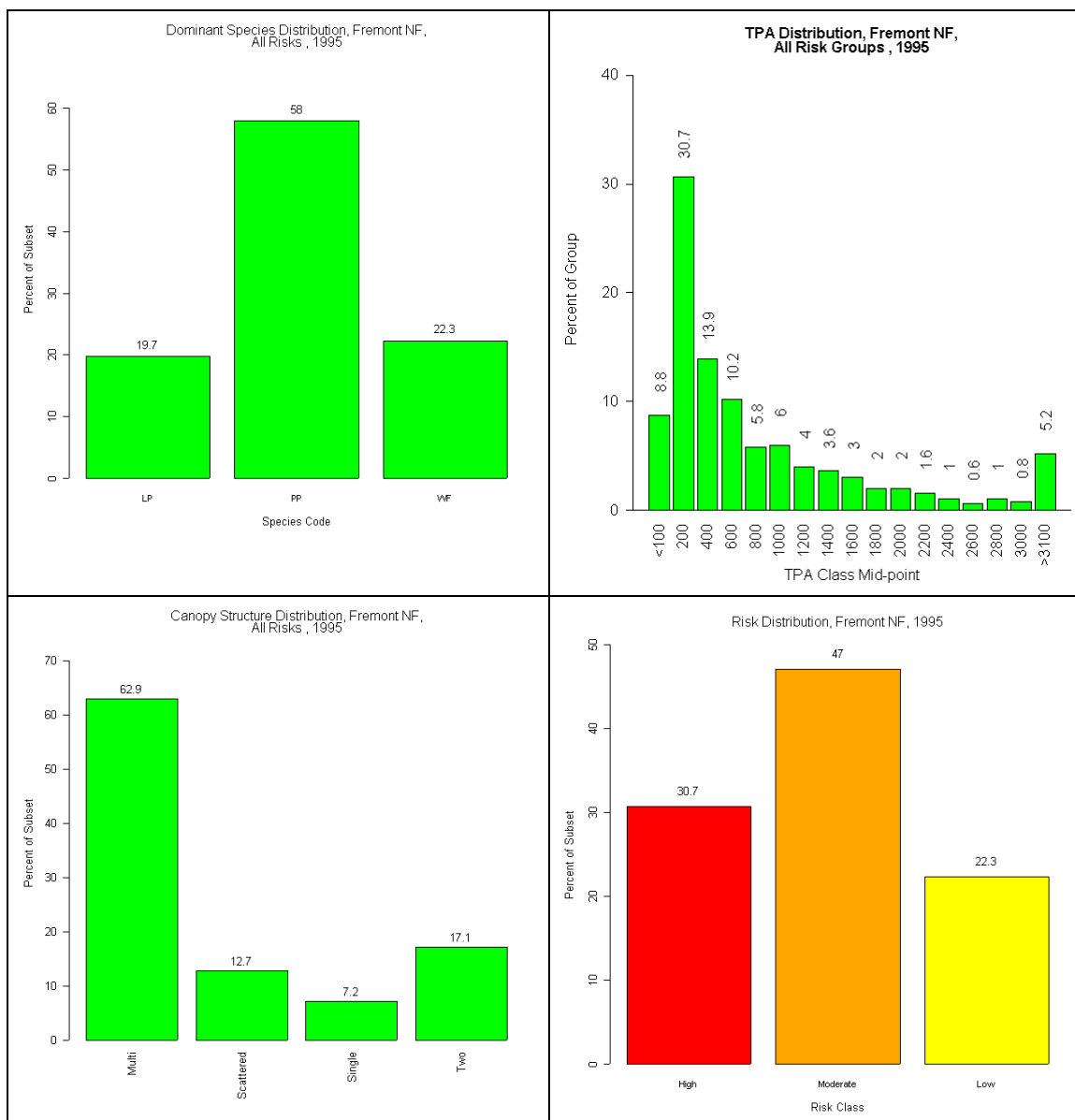
Fremont National Forest Risk Classes

Risk Class	Stands	Percent
High Risk	154	30.68
Moderate Risk	236	47.01
Low Risk	112	22.31
Total	502	

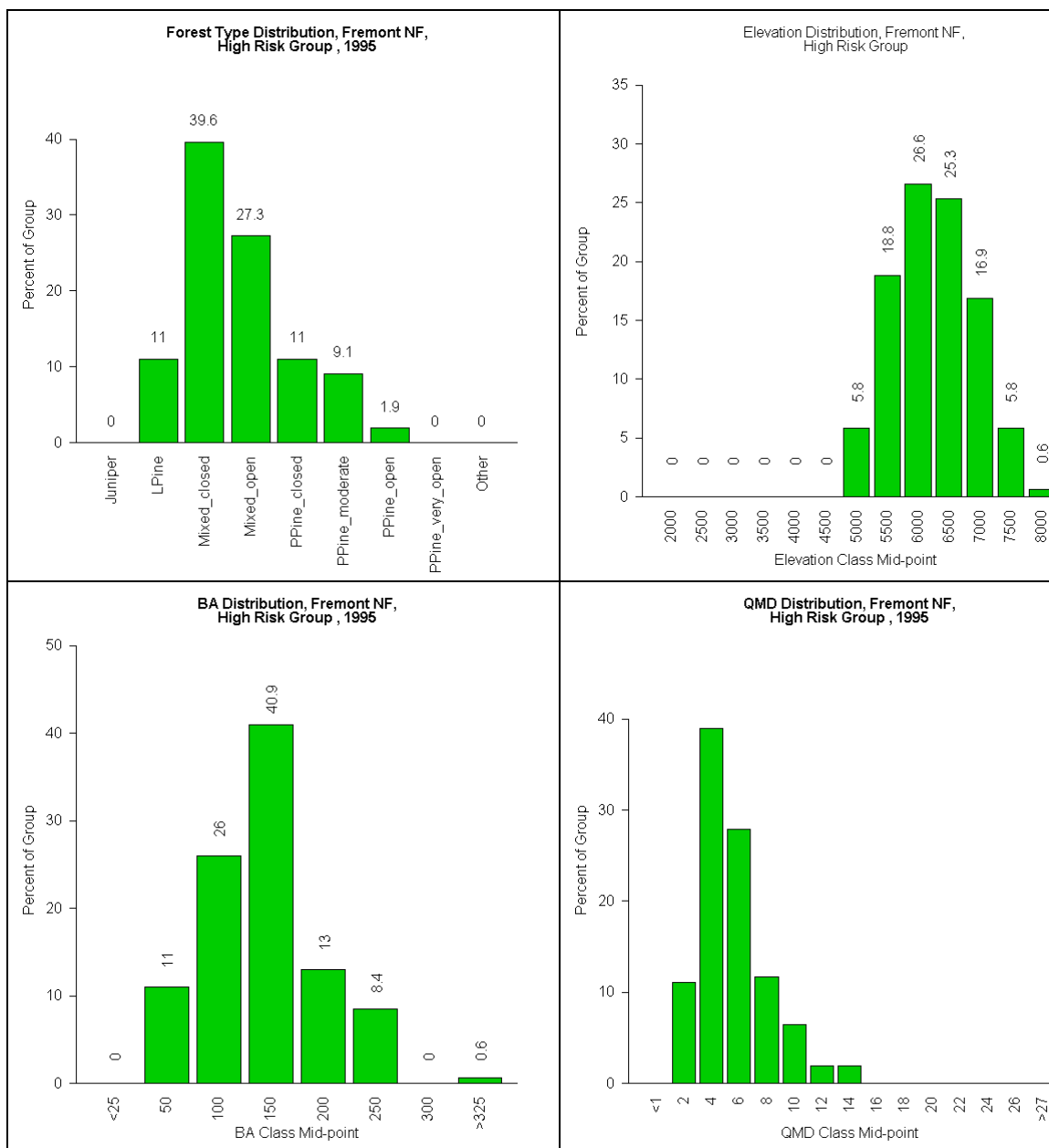
Fremont: Forest type, Elevation, Basal area, QMD



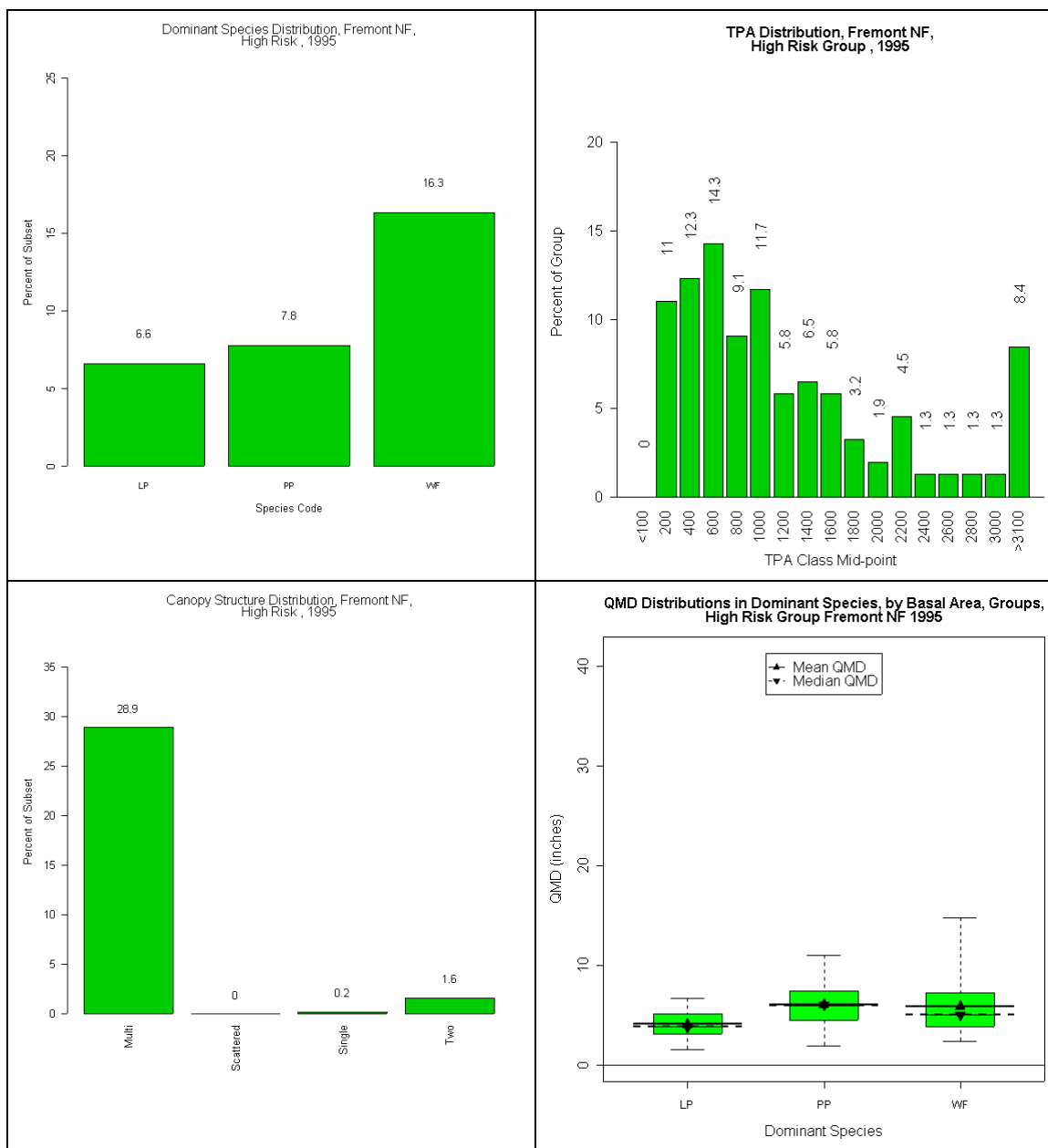
Fremont: Species, TPA, Canopy structure, Fire risk



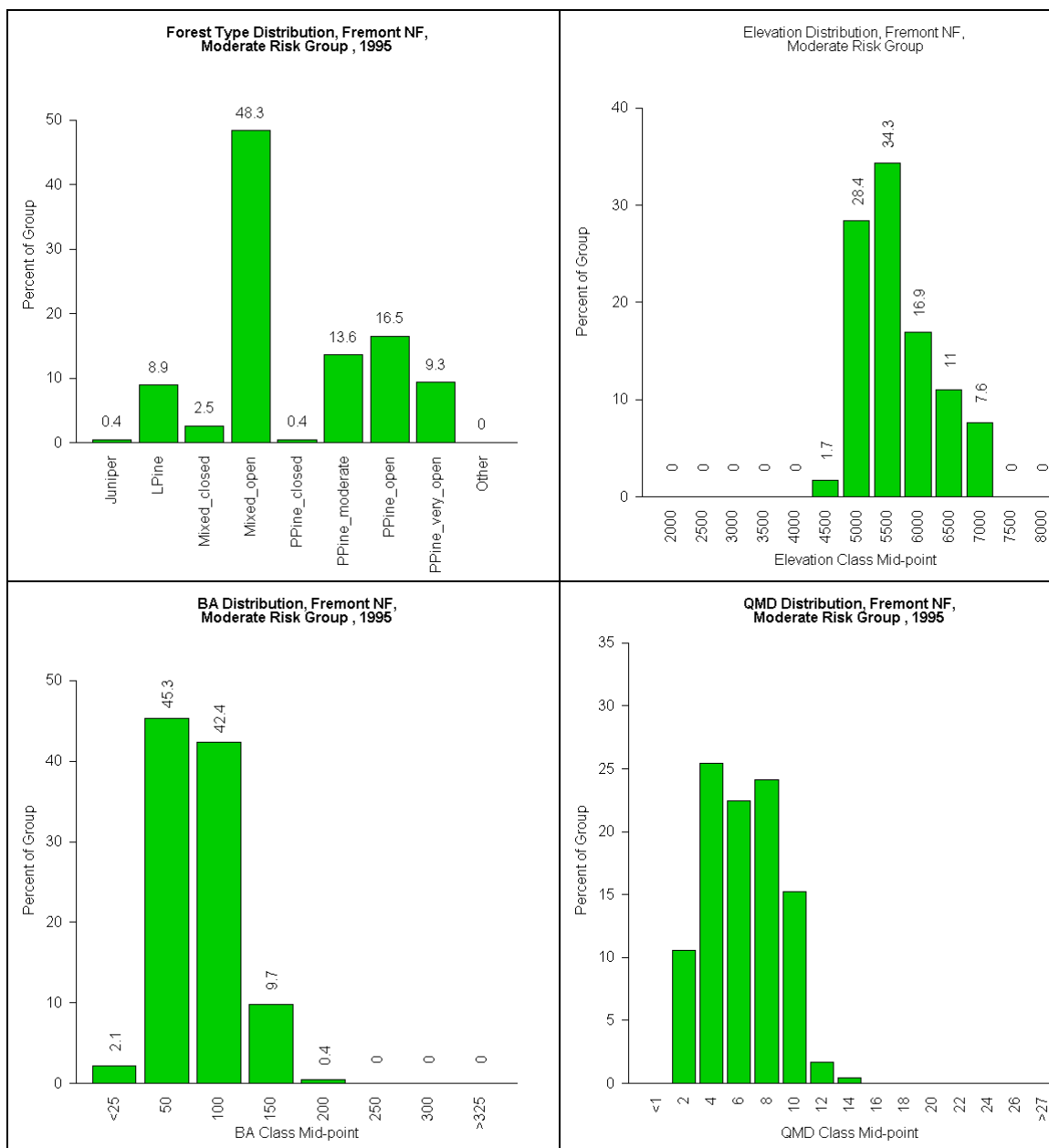
Fremont - High Risk Stands: Forest type, Elevation, Basal area, QMD



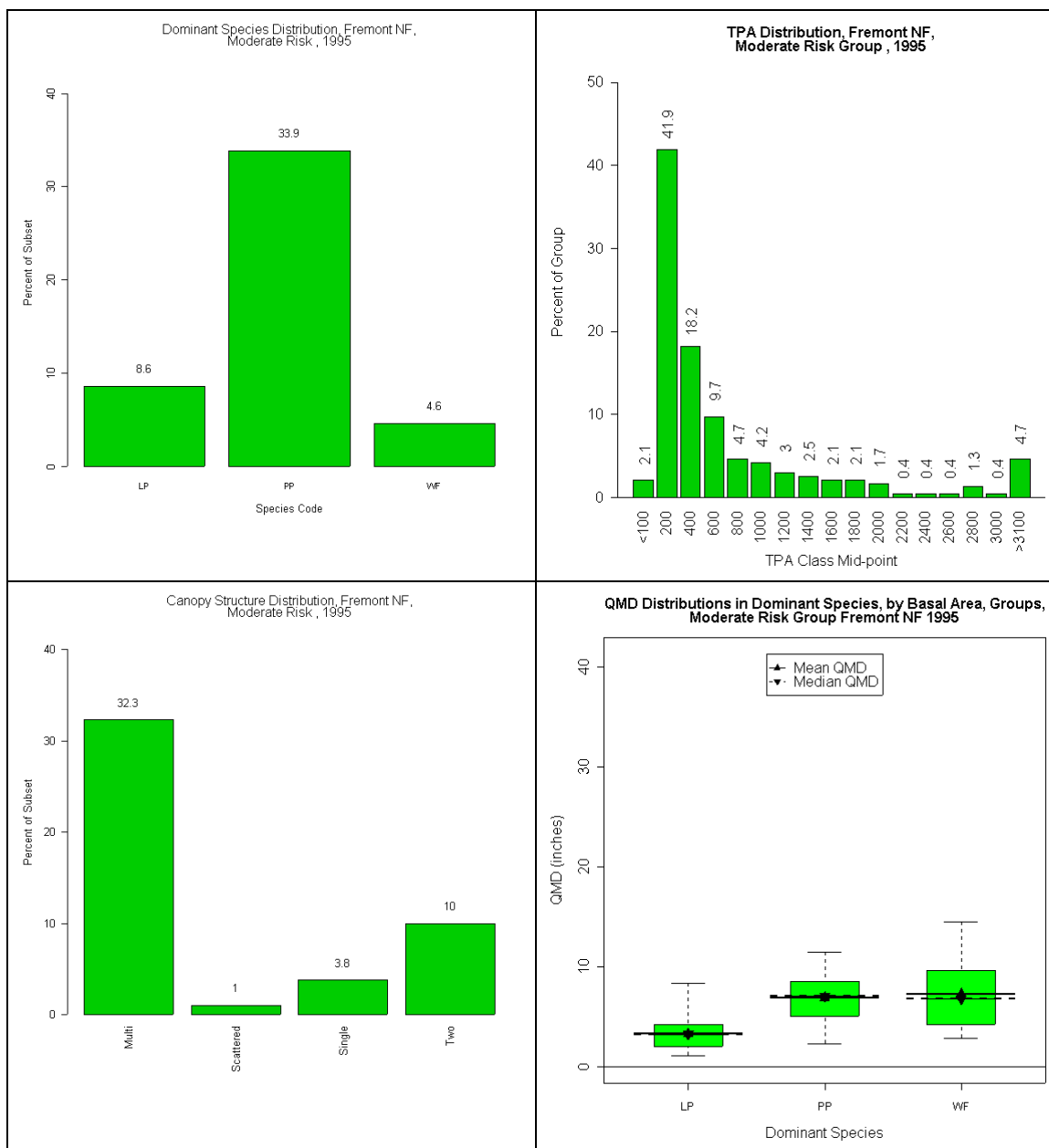
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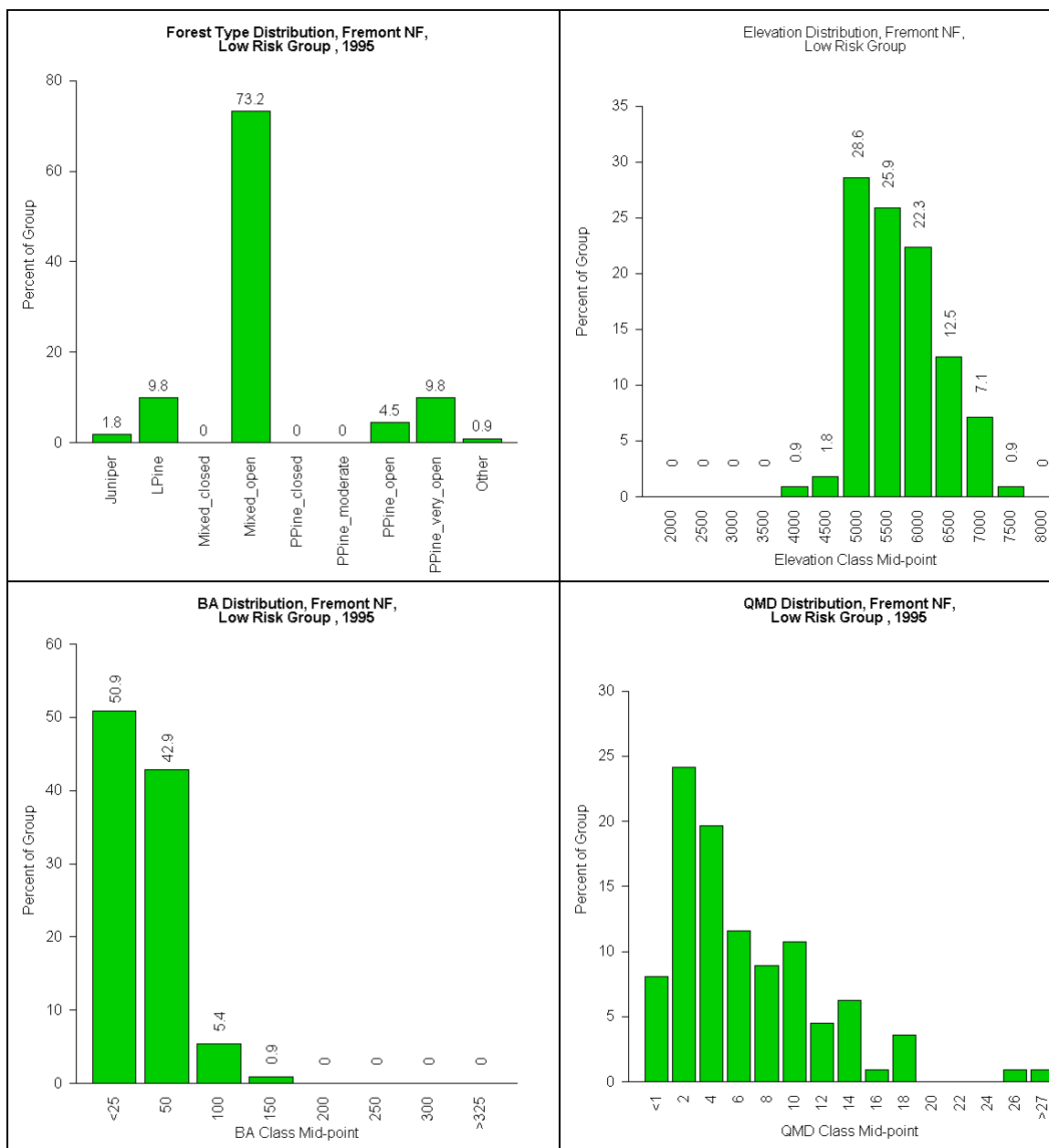
Fremont - Moderate Risk Stands: Forest type, Elevation, Basal area, QMD



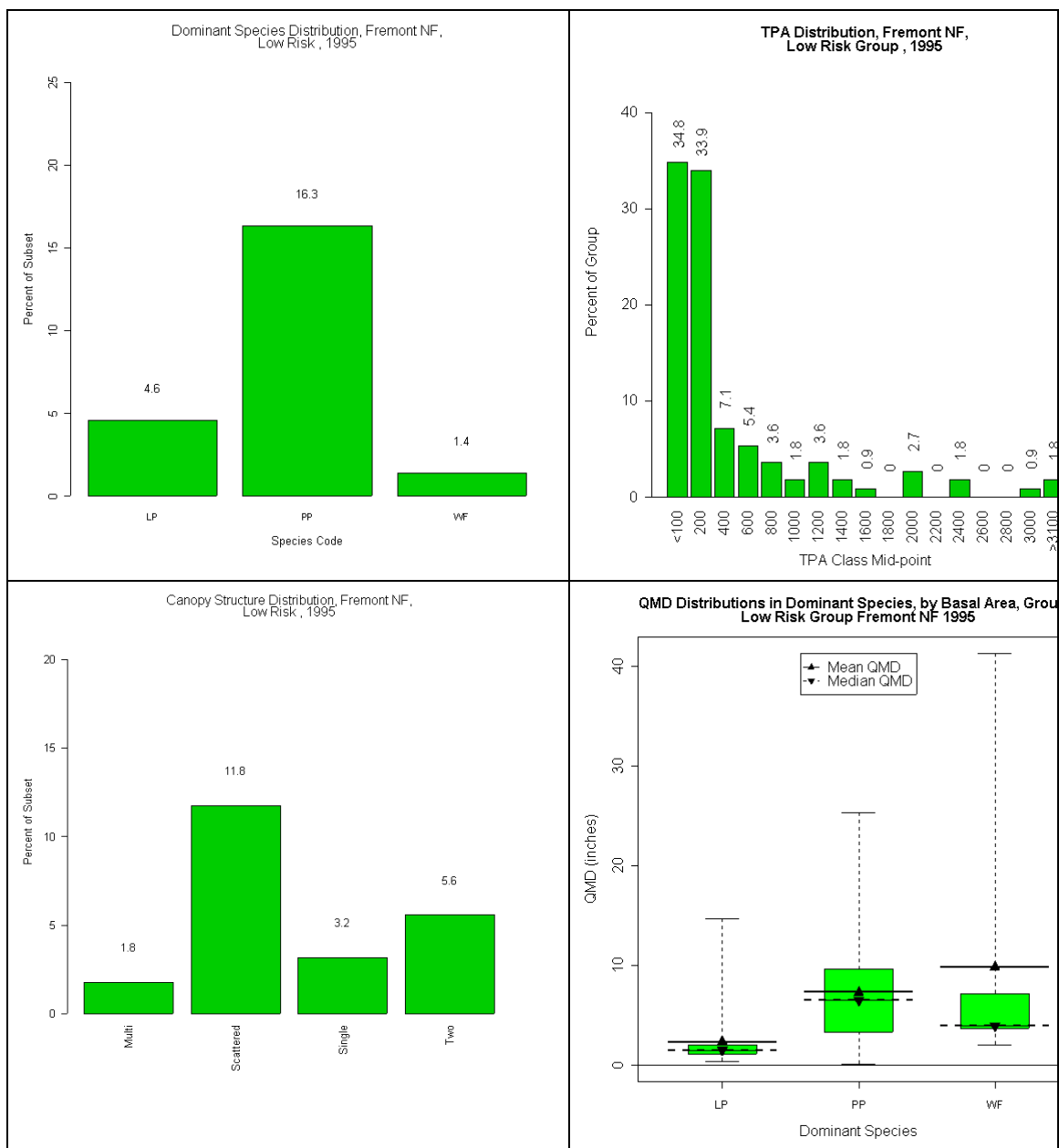
Fremont - Moderate Risk Stands: Species, TPA, Canopy Structure



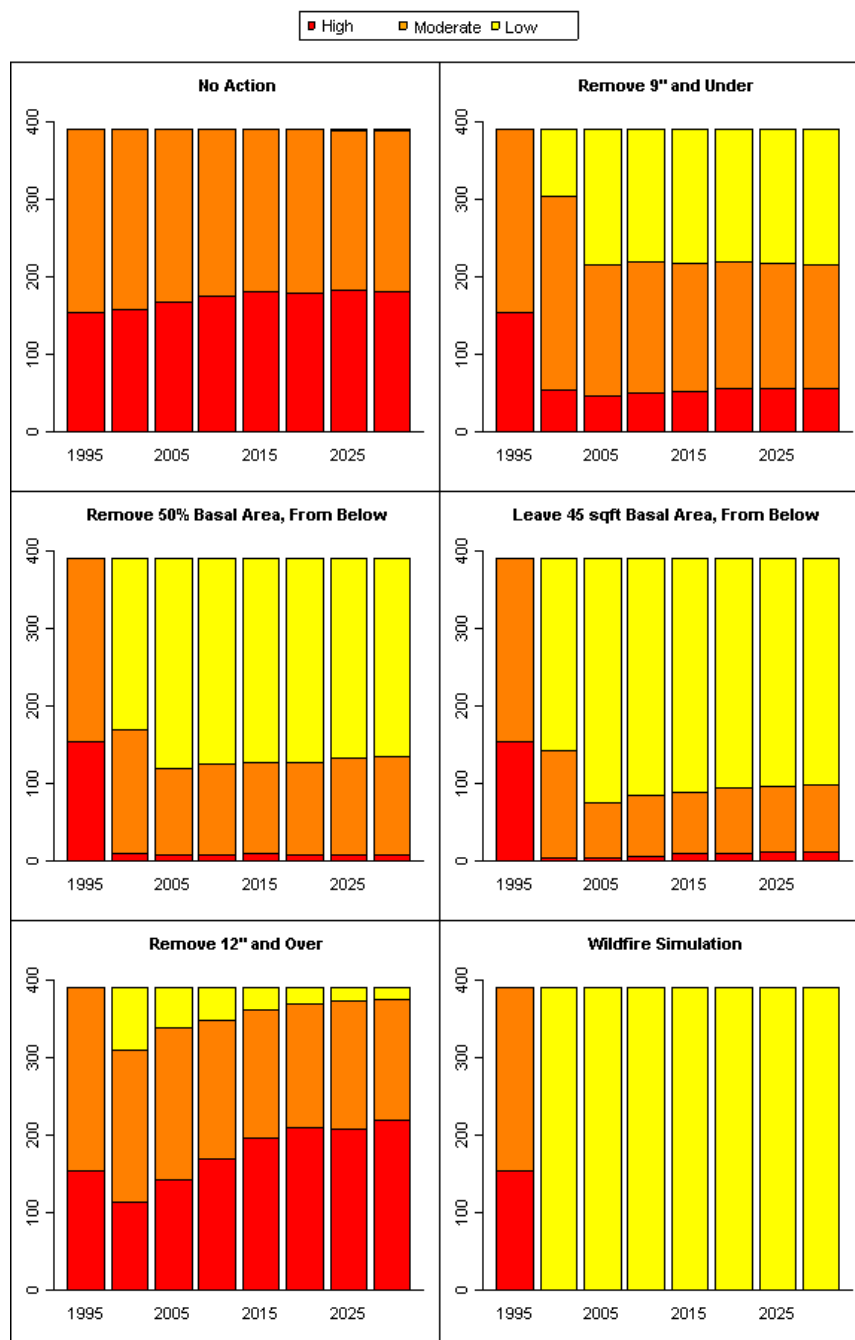
Fremont - Low Risk Stands: Forest type, Elevation, Basal area, QMD



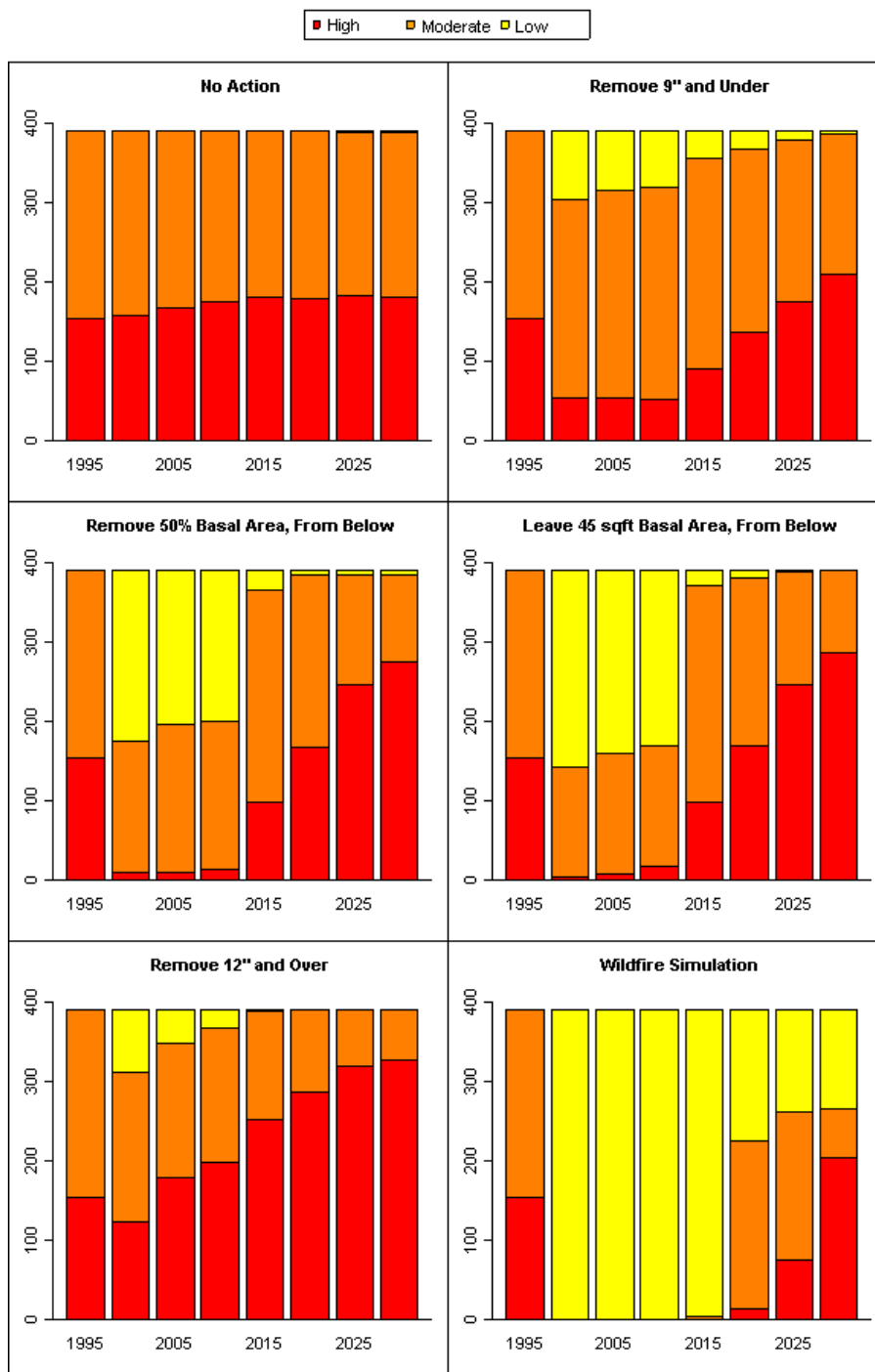
Fremont - Low Risk Stands: Species, TPA, Canopy Structure



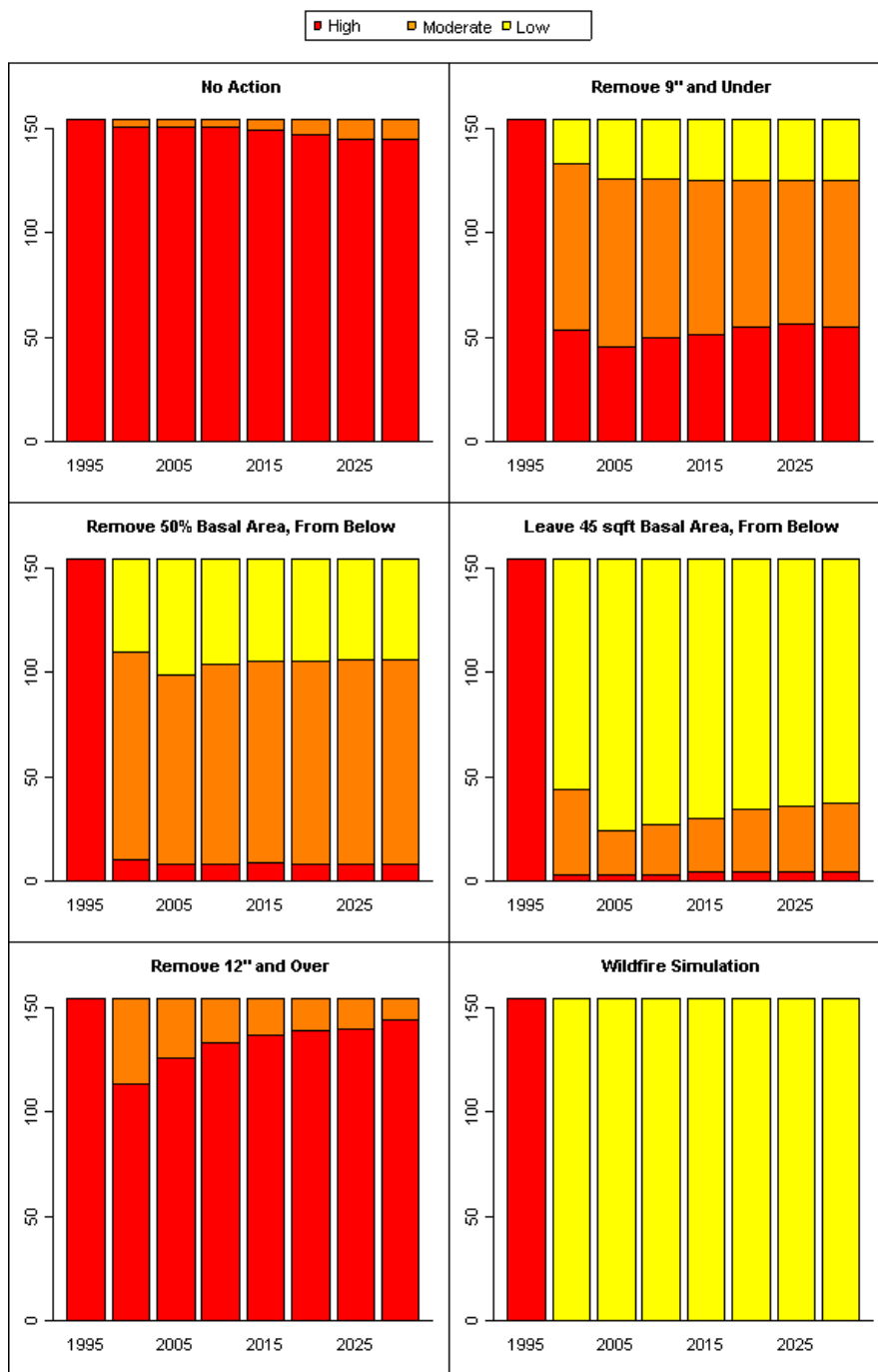
Fremont - High & Moderate Risk Stands: Fire Risk without regeneration



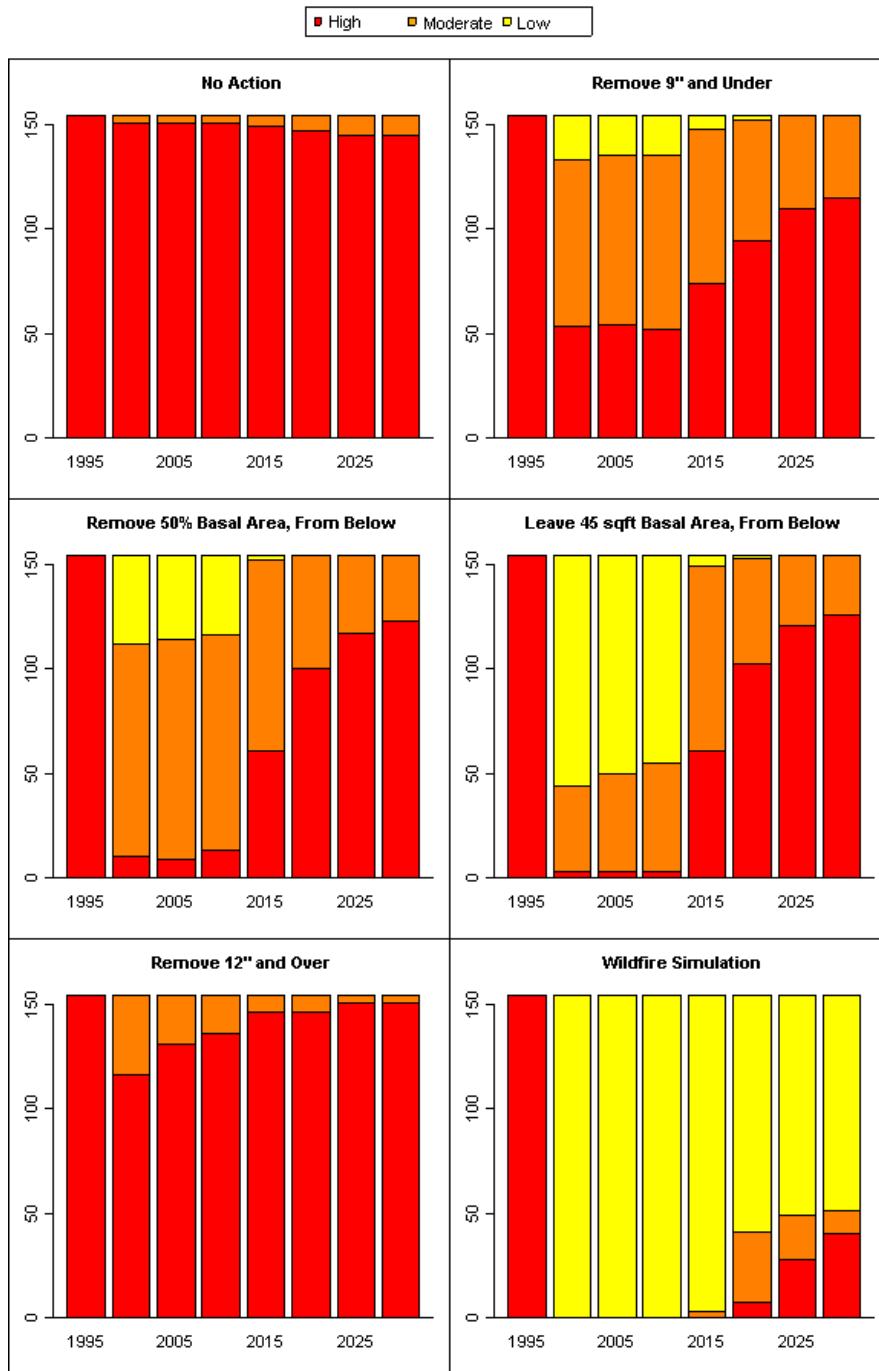
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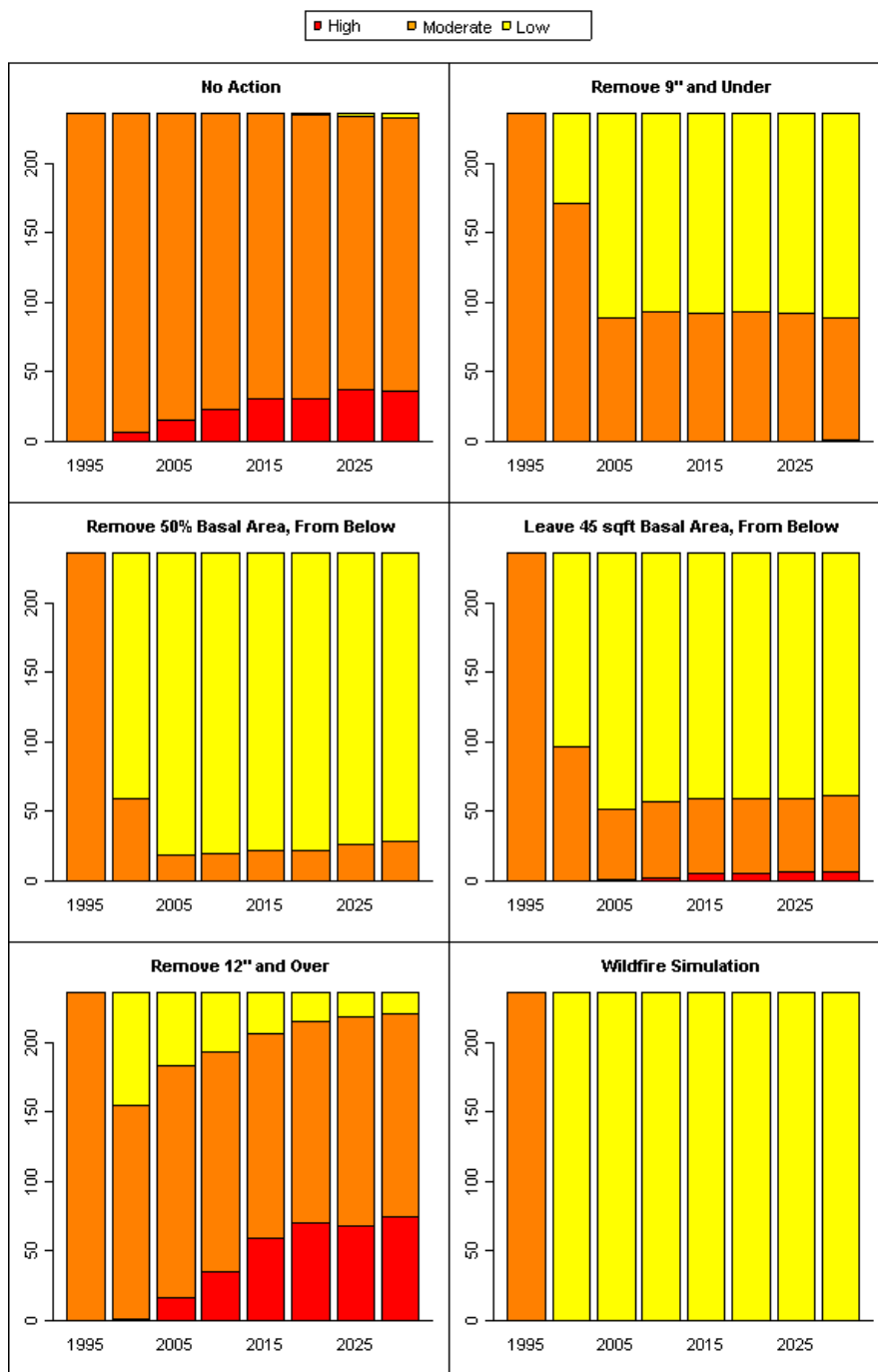
Fremont - High Risk Stands: Fire Risk without regeneration



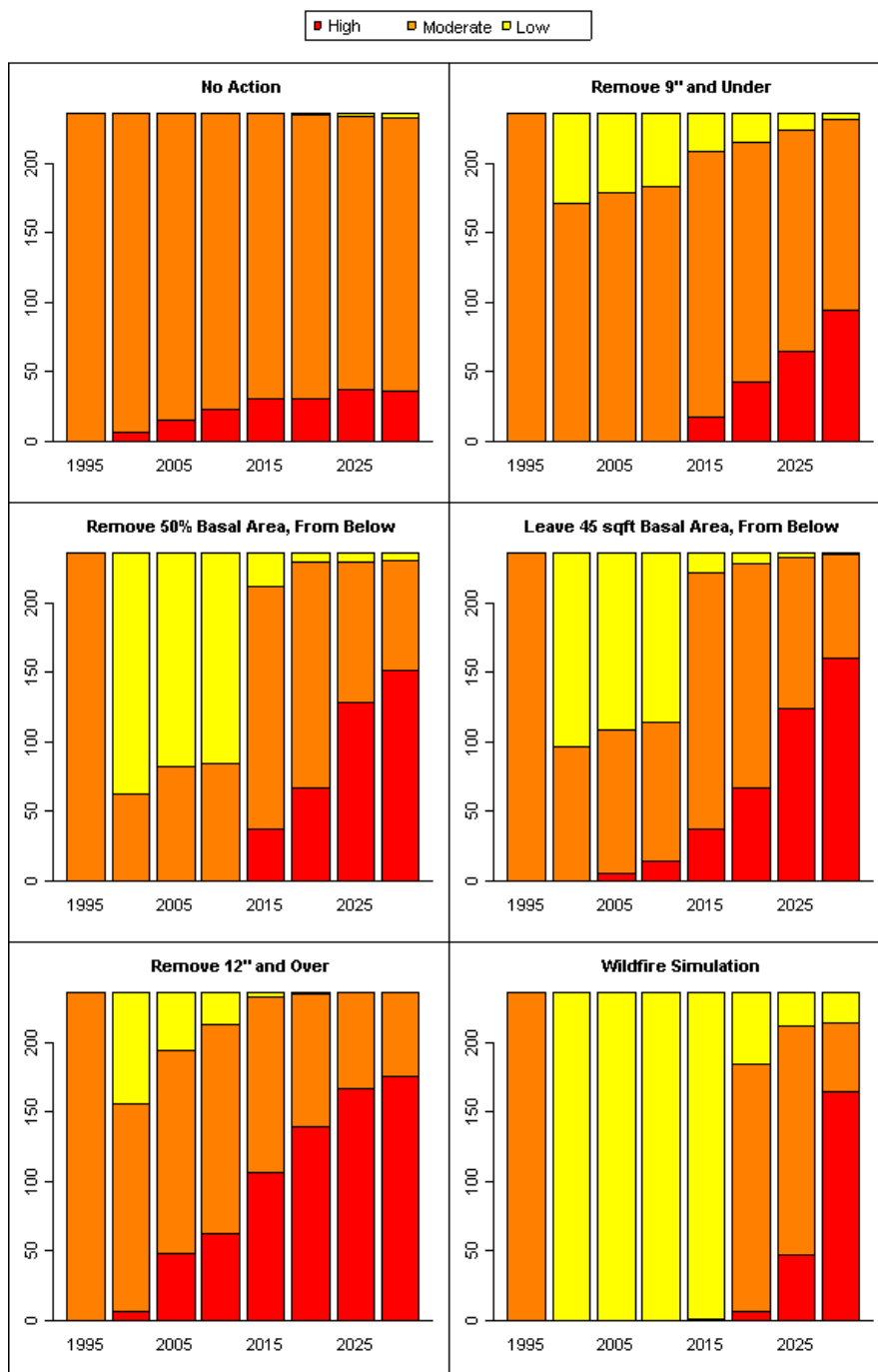
Fremont - High Risk Stands: Fire Risk with regeneration



Fremont - Moderate Risk Stands: Fire Risk without regeneration



Fremont - Moderate Risk Stands: Fire Risk with regeneration



Fremont – Fire Risk Reduction Metrics

fremont 2000 Without Regen High & Moderate Risk Groups
Median Treatment Effects

Treatment	Median TPA			Median QMD			Median BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	548			6.1			105						
9&Under	62	-486	-88.7	14.2	8.1	131.7	73	-32	-30.4	-86	53	-118	4
HalfBA	32	-517	-94.2	17.1	11	178.8	52	-52	-50	-216	10	-254	17
BA45	31	-517	-94.3	16.3	10.1	165.1	45	-60	-57	-249	3	-284	65
12&Over	509	-39	-7.1	4.2	-1.9	-31.6	48	-56	-53.8	-80	124	-148	-45
WildFire	0	-548	-100	14.3	8.1	132.4	0	-104	-99.7	-390	0	-318	47

fremont 2000 Without Regen High & Moderate Risk Groups
Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	940			6.4			113						
9&Under	66	-874	-93	14.7	8.3	129.5	80	-34	-29.7	-86	53	-118	4
HalfBA	43	-897	-95.5	17.9	11.5	179.4	57	-57	-50	-216	10	-254	17
BA45	63	-877	-93.3	18.3	11.9	186.4	45	-69	-60.6	-249	3	-284	65
12&Over	907	-33	-3.5	4.4	-2	-31.5	53	-60	-52.8	-80	124	-148	-45
WildFire	0	-940	-100	12.9	6.5	101.4	1	-113	-99.5	-390	0	-318	47

fremont 2000 Without Regen High Risk Groups
Median Treatment Effects

Treatment	Median TPA			Median QMD			Median BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	922			5.3			150						
9&Under	81	-841	-91.2	14.8	9.5	179.1	94	-56	-37.1	-21	53	-53	-3
HalfBA	40	-882	-95.7	17.6	12.3	232.3	75	-75	-50	-42	10	-102	17
BA45	20	-902	-97.8	20.1	14.8	280.5	45	-105	-70	-110	3	-129	45
12&Over	870	-52	-5.6	3.9	-1.3	-25.5	64	-86	-57.4	0	116	-49	-16
WildFire	0	-922	-100	0	-5.3	-100	0	-150	-100	-154	0	-147	7

fremont 2000 Without Regen High Risk Groups
Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	1220			5.9			151						
9&Under	82	-1138	-93.3	15.3	9.5	160.6	104	-47	-31.3	-21	53	-53	-3
HalfBA	53	-1167	-95.6	18.8	12.9	219.9	76	-76	-50	-42	10	-102	17
BA45	37	-1184	-97	21.8	15.9	270.2	45	-106	-70.2	-110	3	-129	45
12&Over	1180	-40	-3.3	4	-1.9	-32.2	72	-80	-52.6	0	116	-49	-16
WildFire	0	-1220	-100	7.2	1.4	23	0	-151	-99.9	-154	0	-147	7

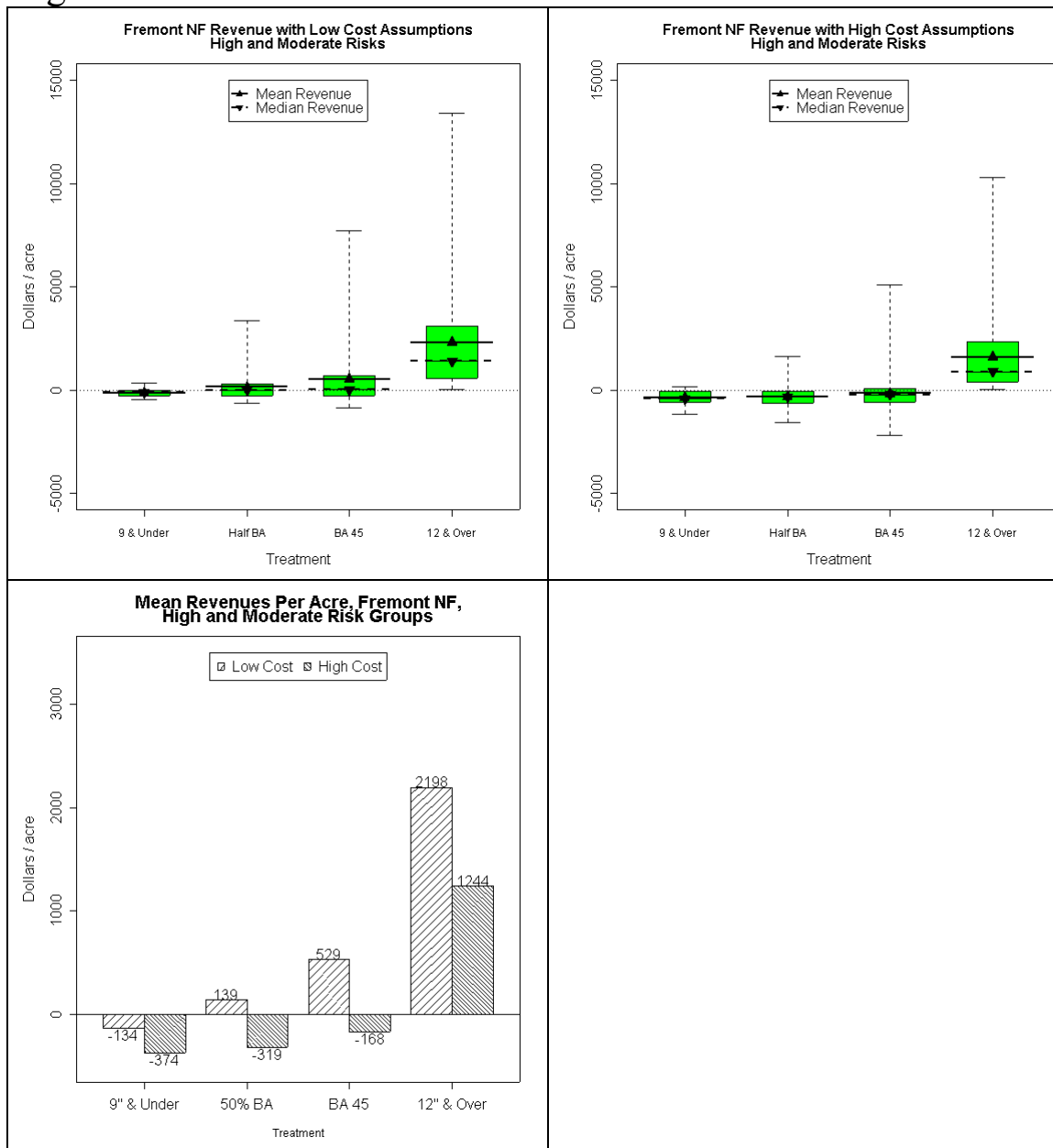
fremont 2000 Without Regen Moderate Risk Groups
Median Treatment Effects

Treatment	Median TPA			Median QMD			Median BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	341			6.9			87						
9&Under	55	-287	-83.9	14	7.1	101.7	63	-24	-28	-65	0	-65	-3
HalfBA	28	-313	-91.8	17	10	144.6	44	-43	-50	-174	0	-152	0
BA45	37	-304	-89.1	14.9	8	115.1	45	-42	-48.3	-139	0	-155	20
12&Over	316	-26	-7.6	4.6	-2.3	-33.7	42	-45	-51.8	-80	6	-99	-29
WildFire	0	-341	-99.9	16.5	9.6	138.5	1	-86	-99.2	-236	0	-171	48

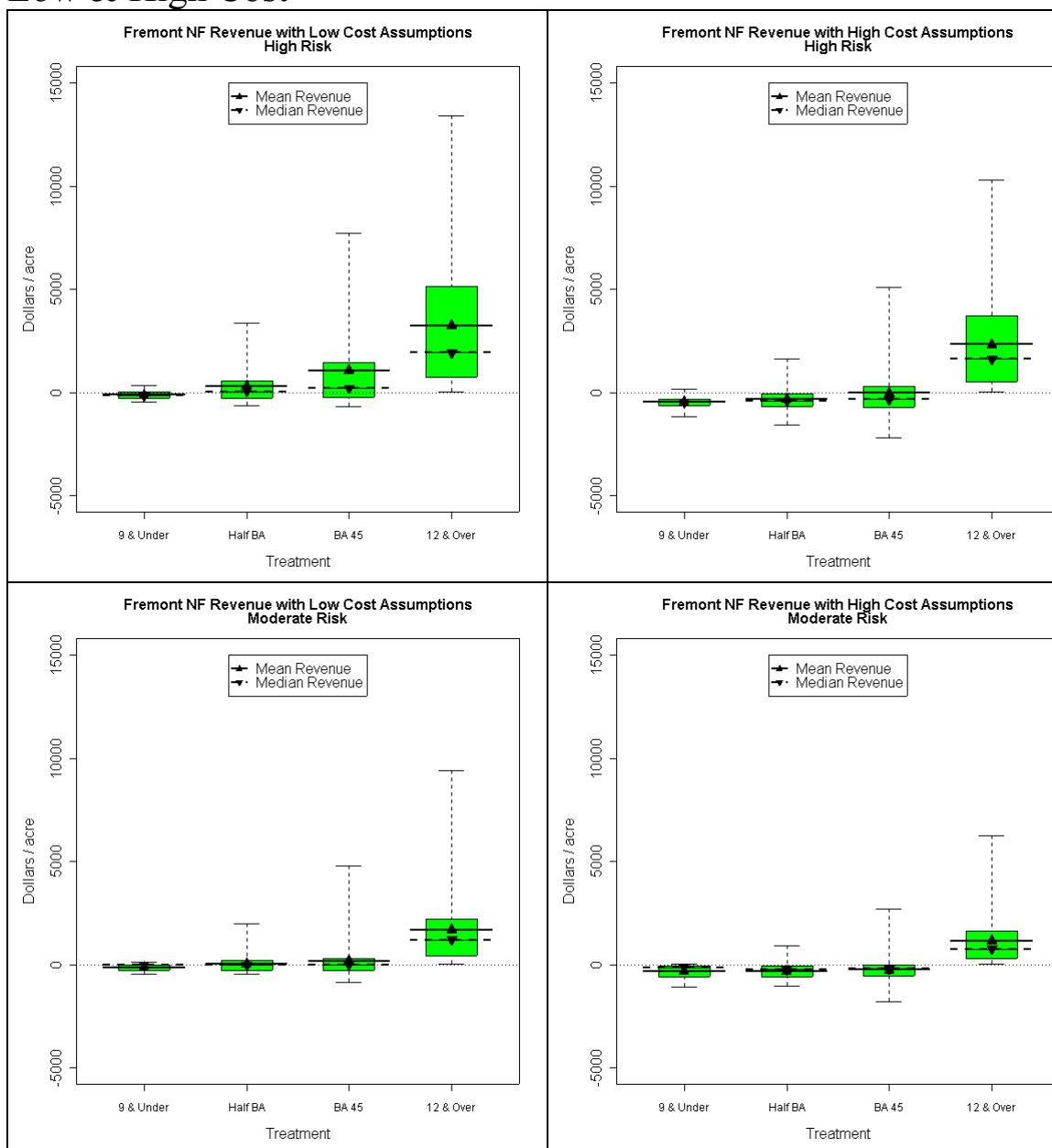
fremont 2000 Without Regen Moderate Risk Groups
Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change
	trees	change	%change	inches	change	%change	sqft	change	%change				
NoAction	757			6.7			88						
9&Under	56	-701	-92.6	14.2	7.5	111.7	64	-25	-28	-65	0	-65	-3
HalfBA	35	-722	-95.3	17.2	10.5	156.3	44	-44	-50	-174	0	-152	0
BA45	80	-677	-89.4	16	9.3	138.4	44	-44	-49.9	-139	0	-155	20
12&Over	730	-27	-3.6	4.6	-2.1	-31.2	42	-47	-53	-80	6	-99	-29
WildFire	1	-757	-99.9	16.6	9.8	146.2	1	-88	-99	-236	0	-171	48

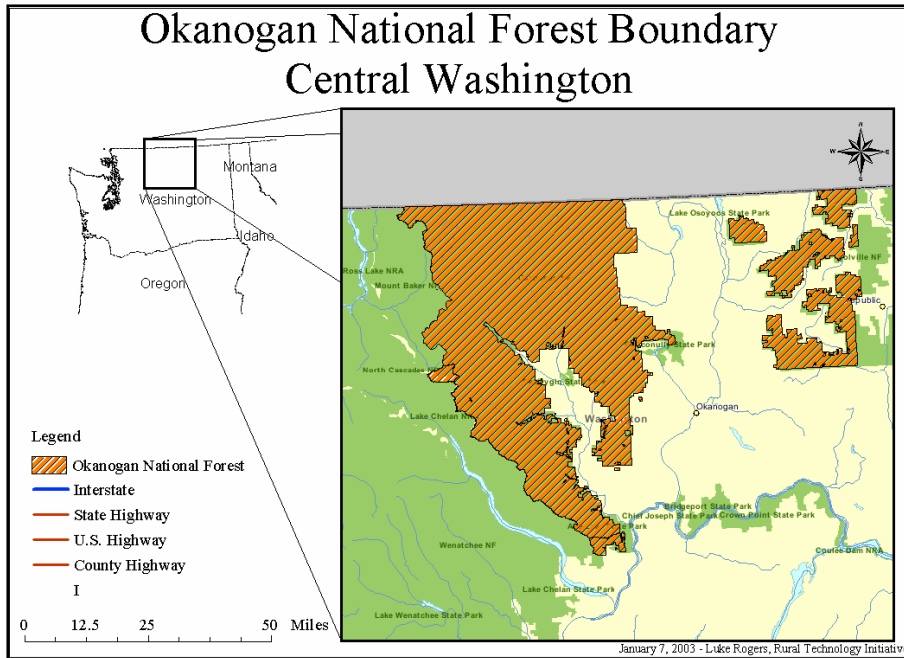
Fremont – High & Moderate Risk Stands: Economics, Low & High Costs



Fremont – High Risk & Moderate Risk Stands: Economics, Low & High Cost



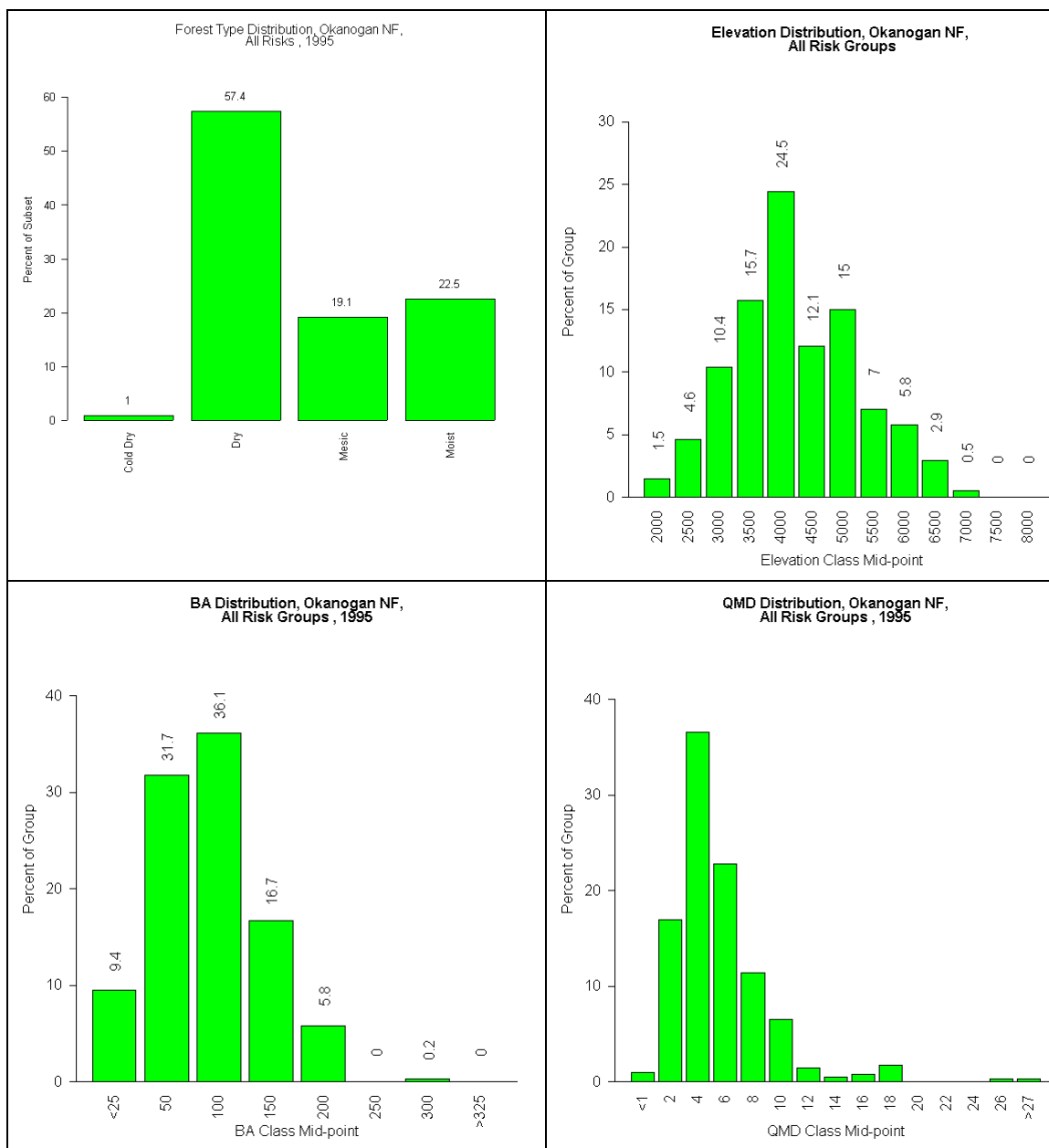
Appendix B Okanogan National Forest Map and Results



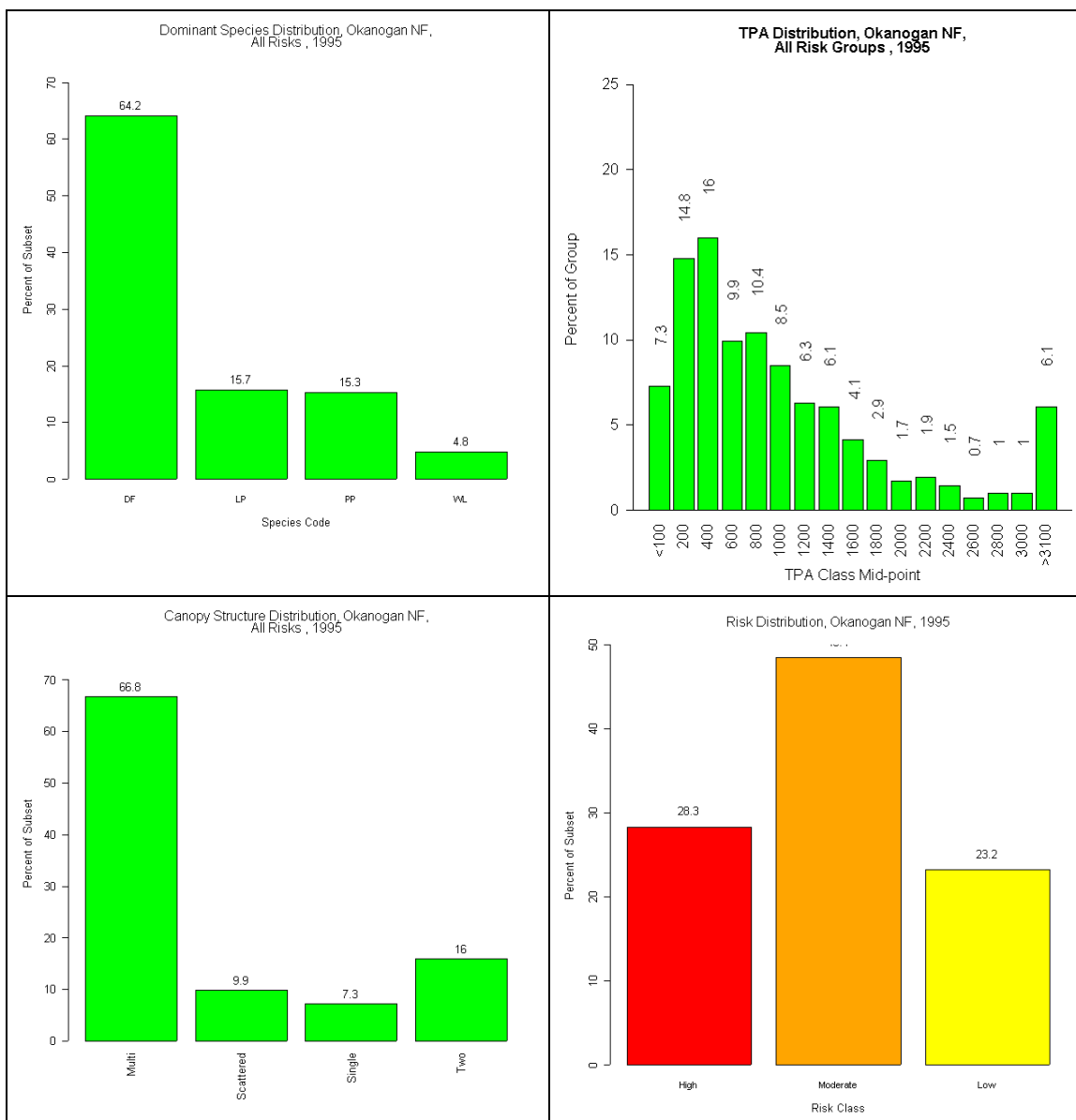
Okanogan National Forest Risk Classes

Risk Class	Stands	Percent
High Risk	117	28.33
Moderate Risk	200	48.43
Low Risk	96	23.24
Total	413	

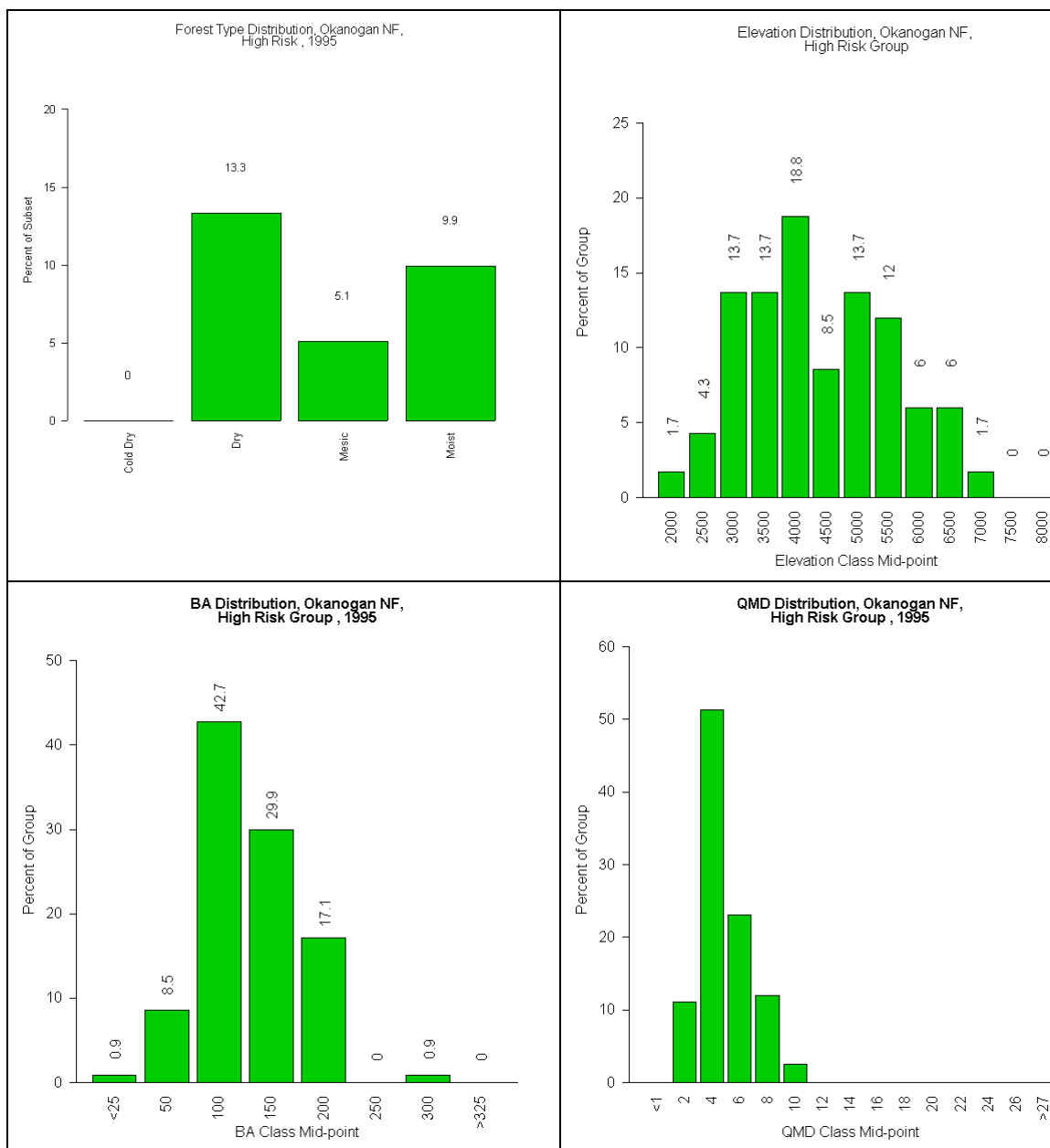
Okanogan: Forest type, Elevation, Basal area, QMD



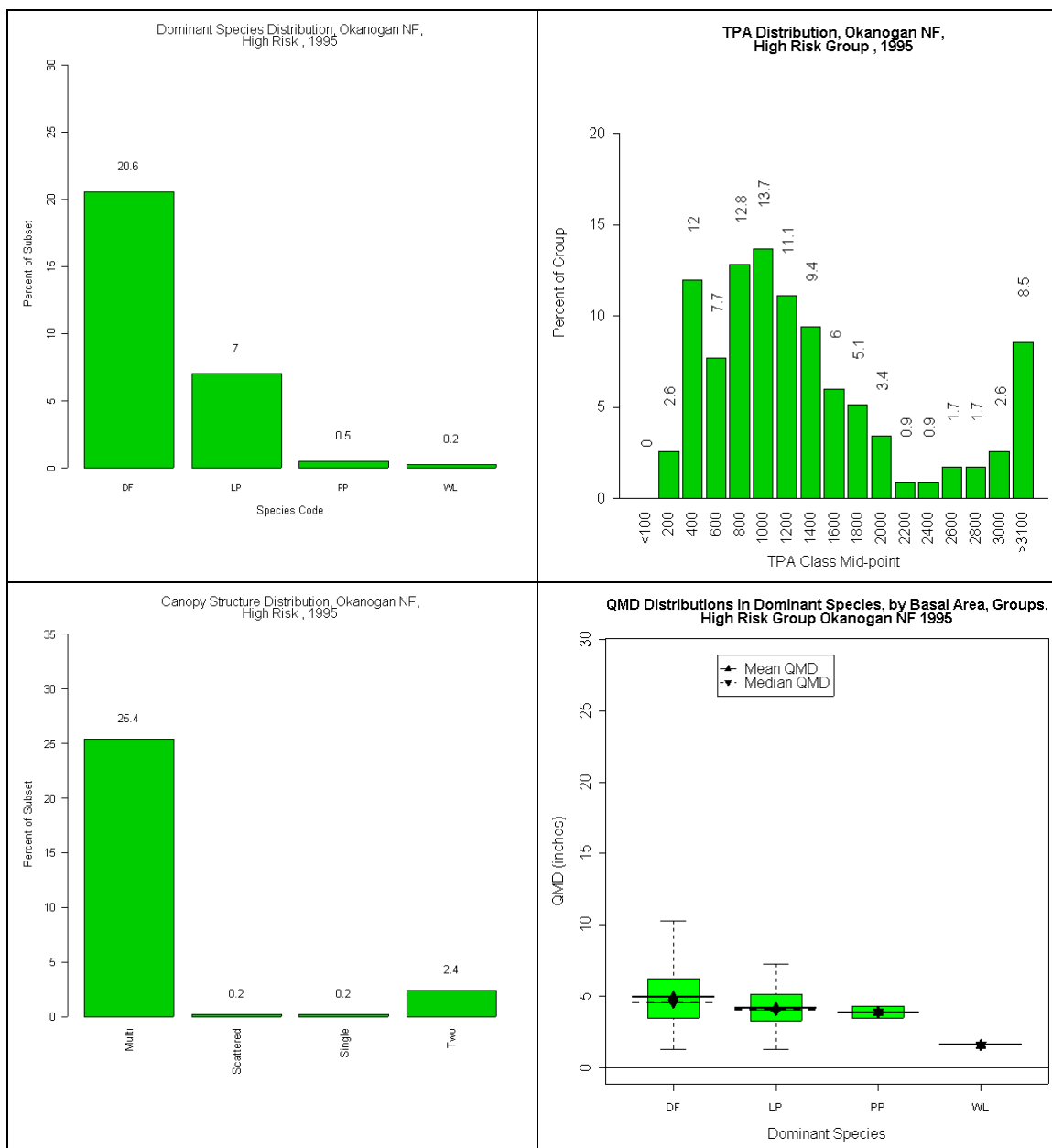
Okanogan: Species, TPA, Canopy structure, Fire risk



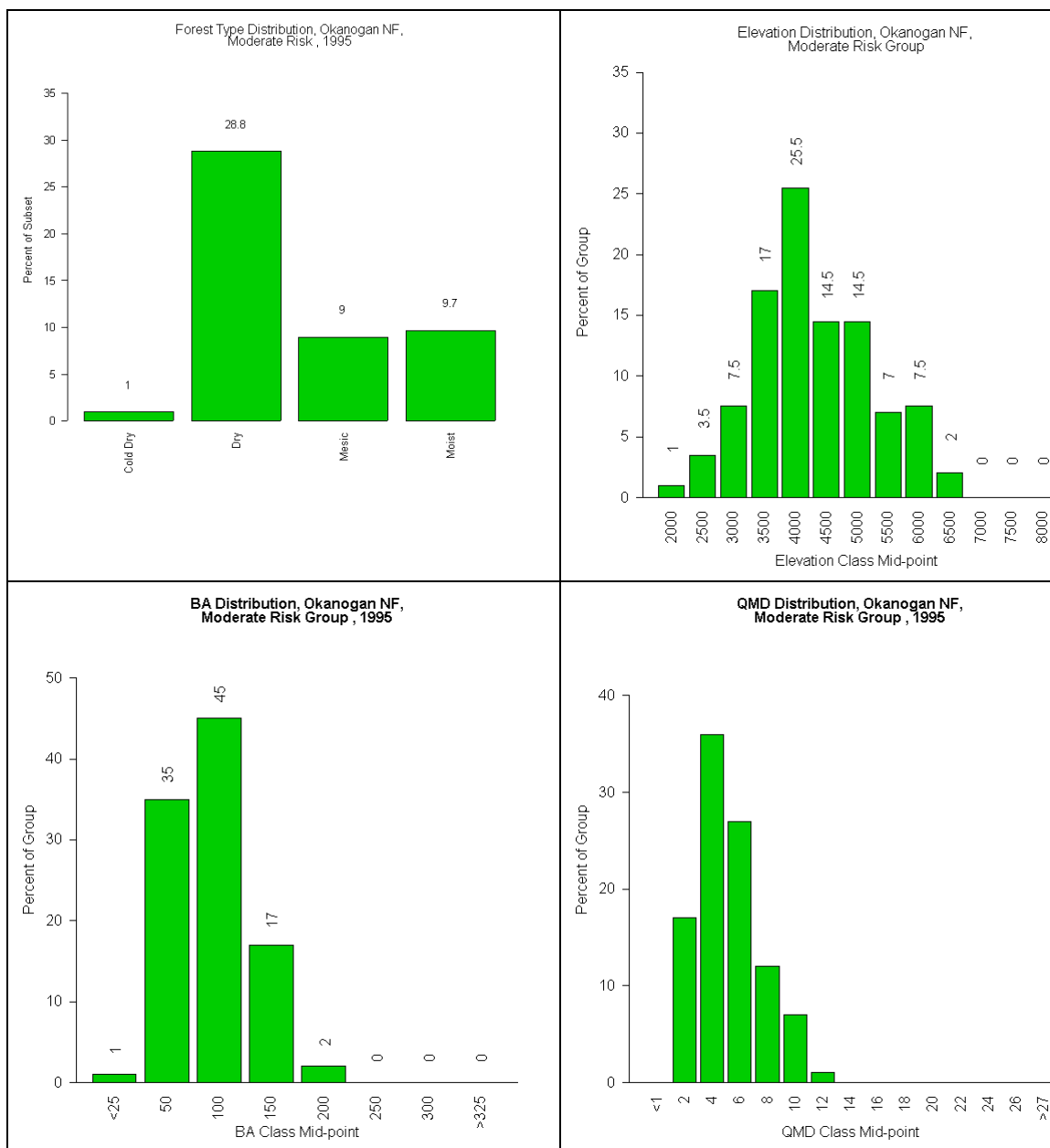
Okanogan - High Risk Stands: Forest type, Elevation, Basal area, QMD



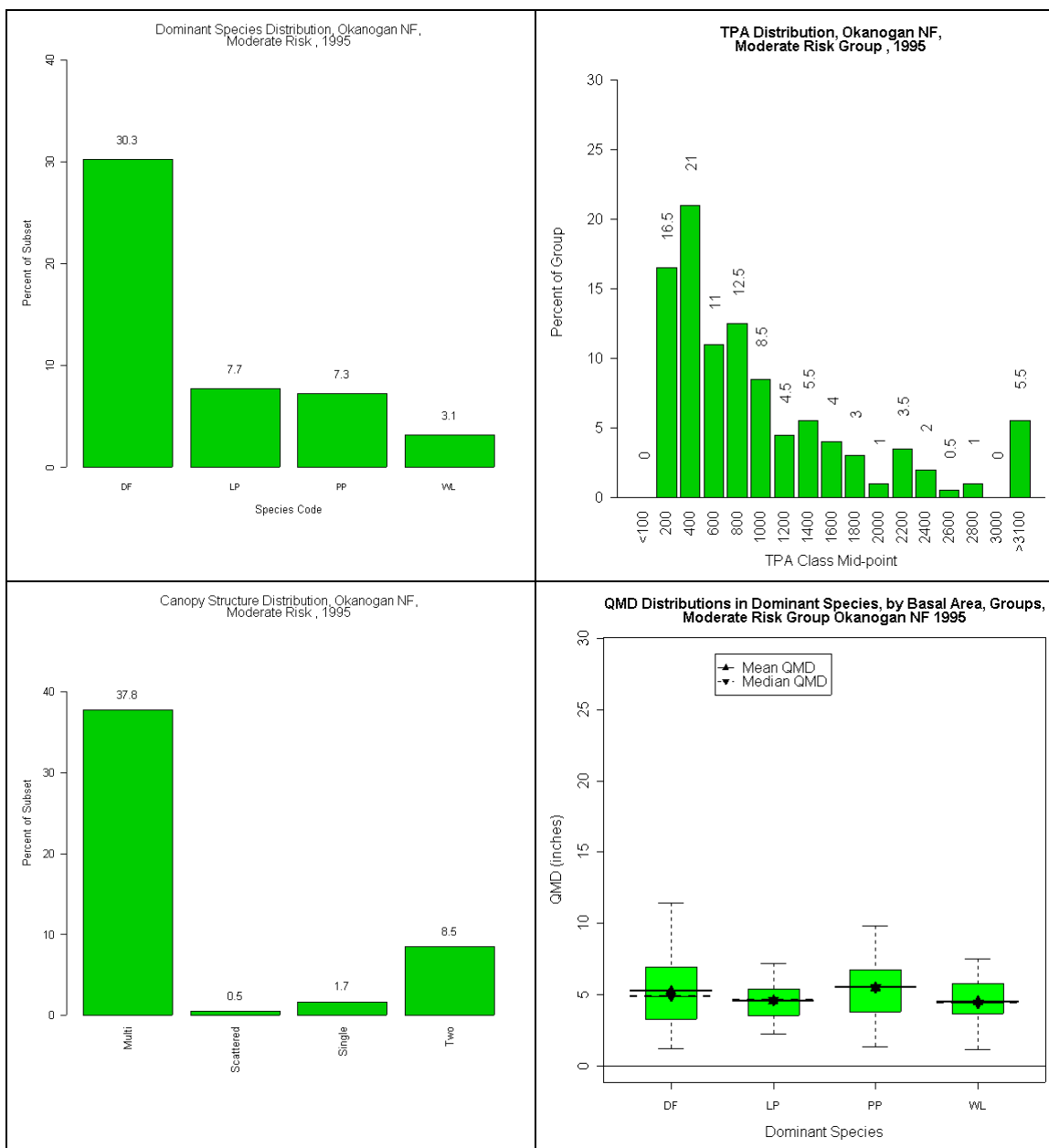
Okanogan - High Risk Stands: Species, TPA, Canopy Structure



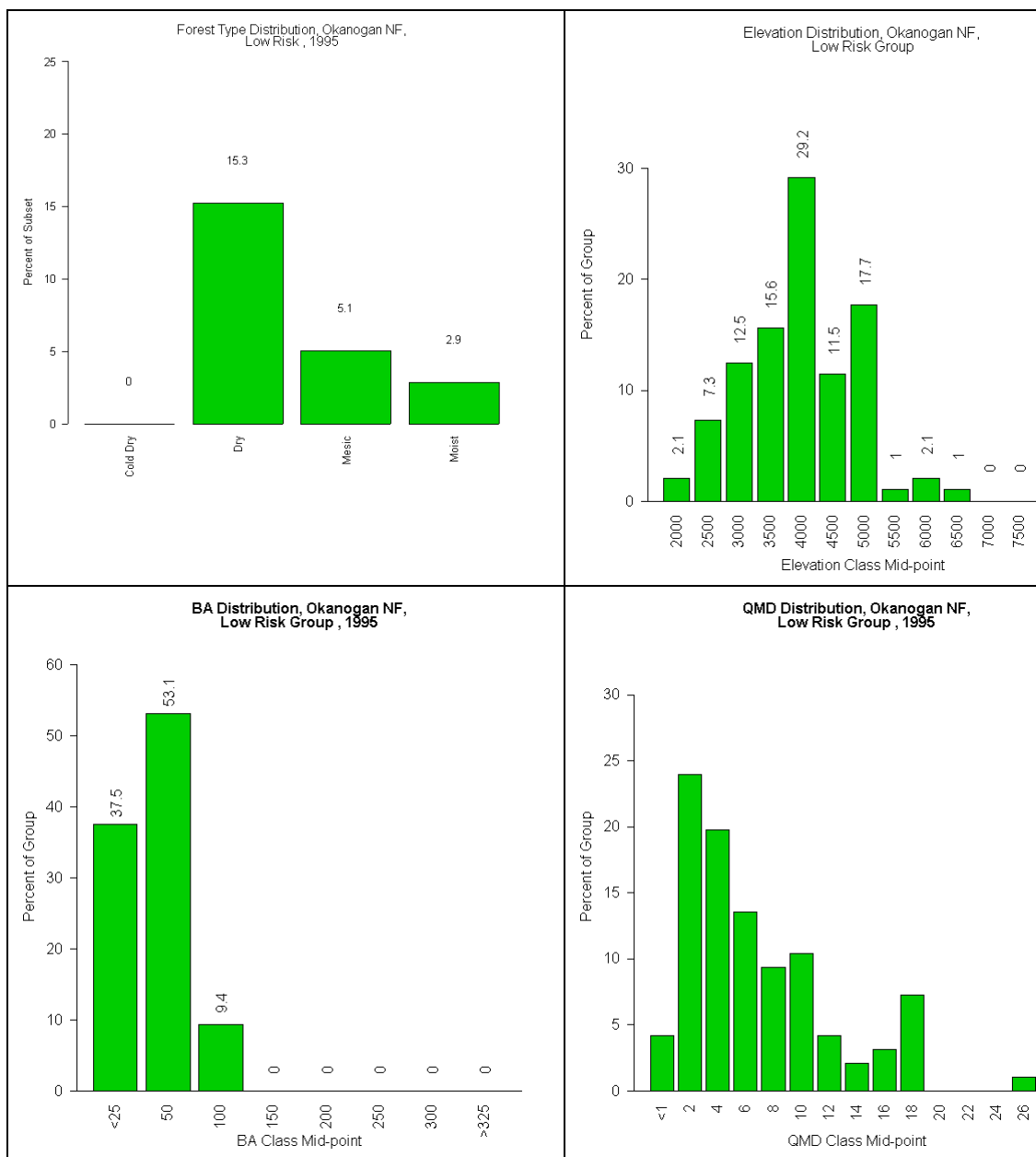
Okanogan - Moderate Risk Stands: Forest type, Elevation, Basal area, QMD



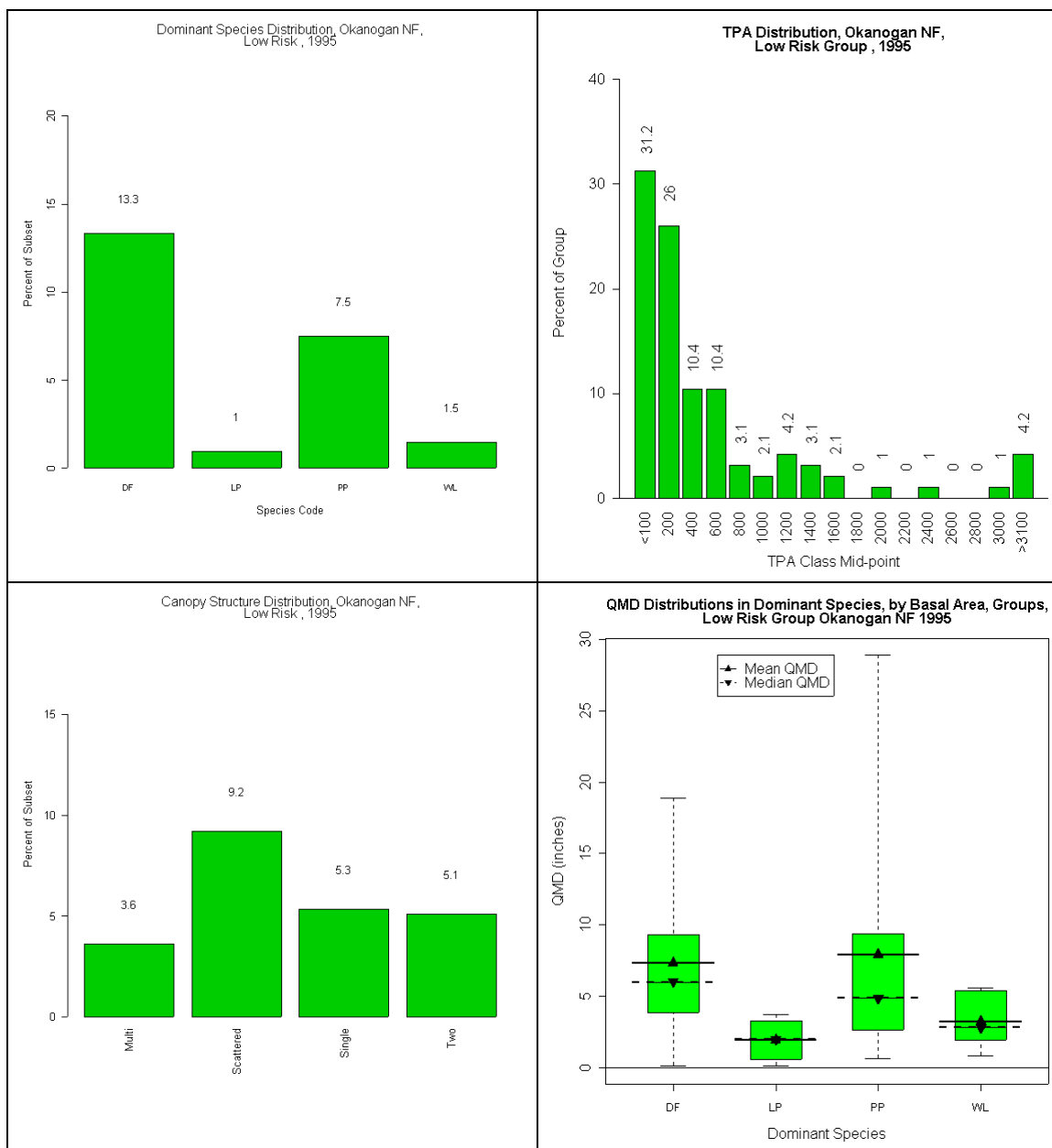
Okanogan - Moderate Risk Stands: Species, TPA, Canopy Structure



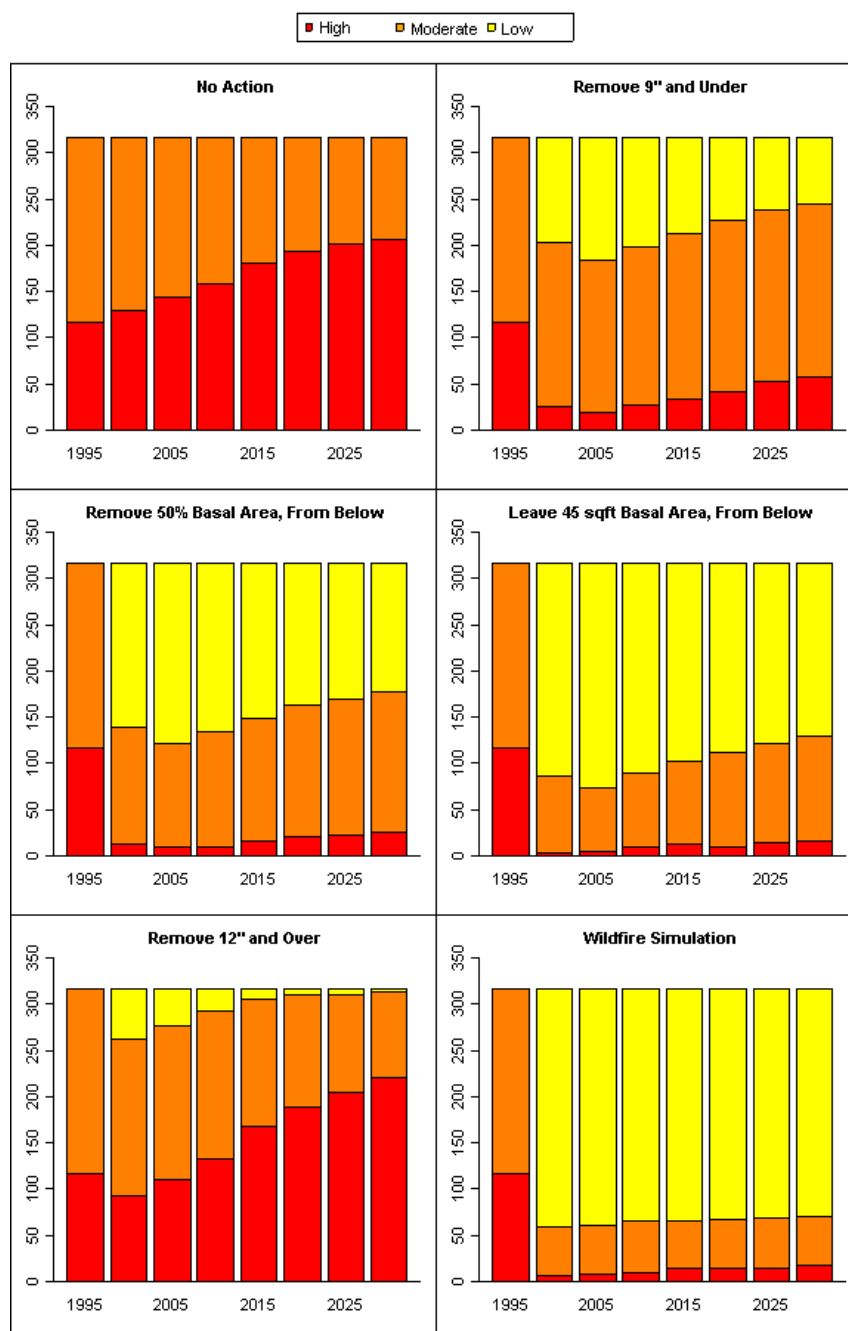
Okanogan - Low Risk Stands: Forest type, Elevation, Basal area, QMD



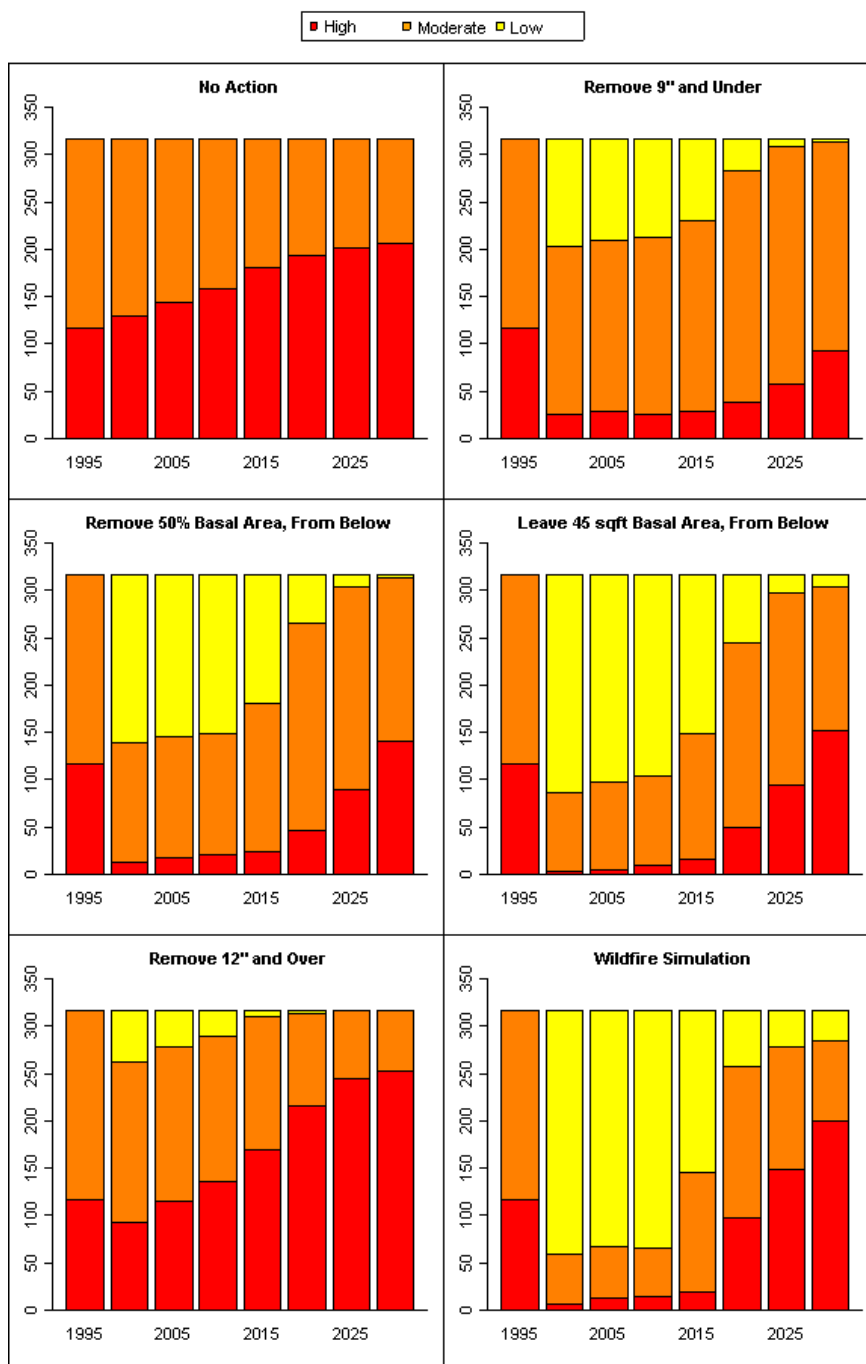
Okanogan - Low Risk Stands: Species, TPA, Canopy Structure



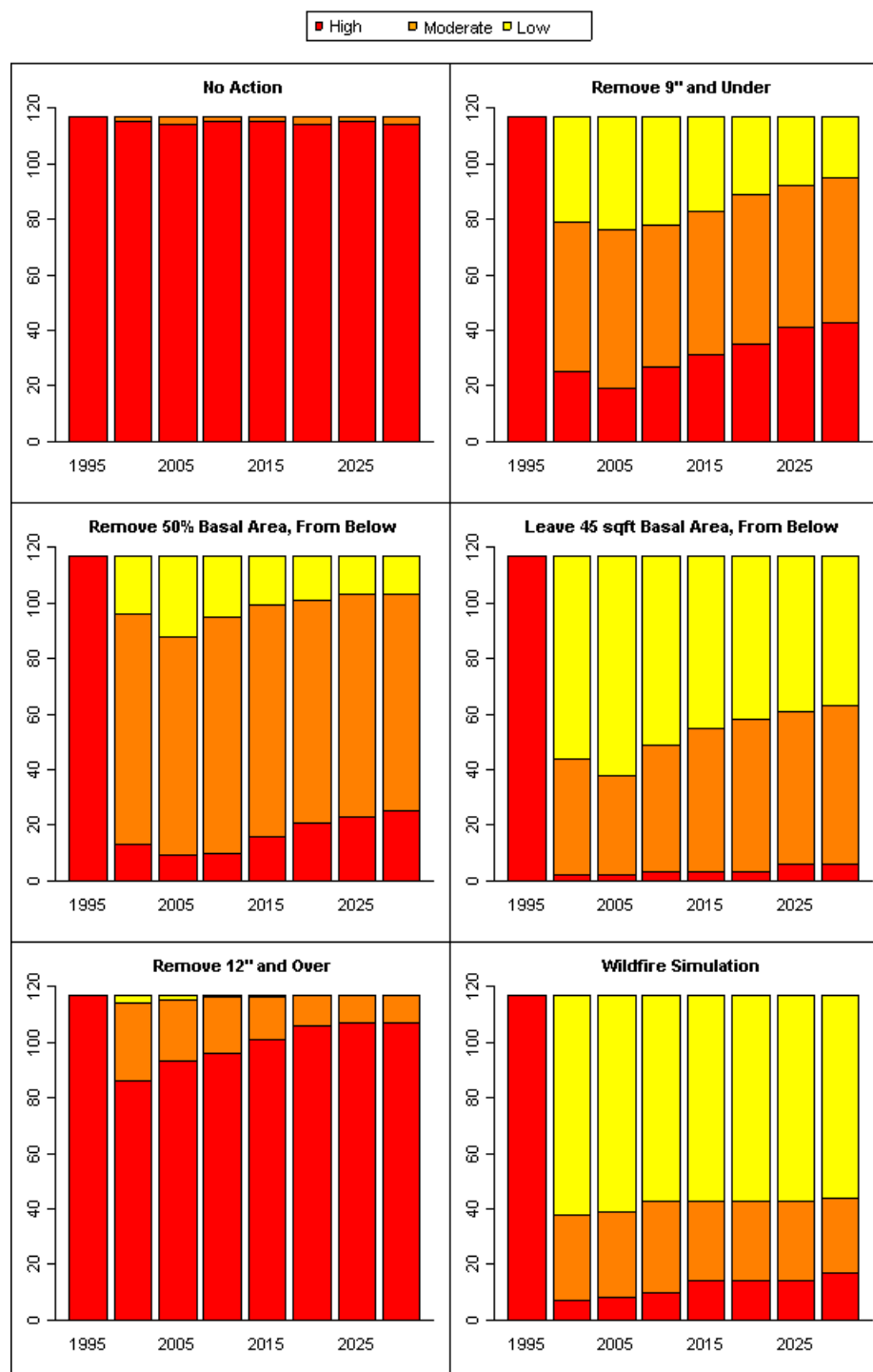
Okanogan - High & Moderate Risk Stands: Fire Risk without regeneration



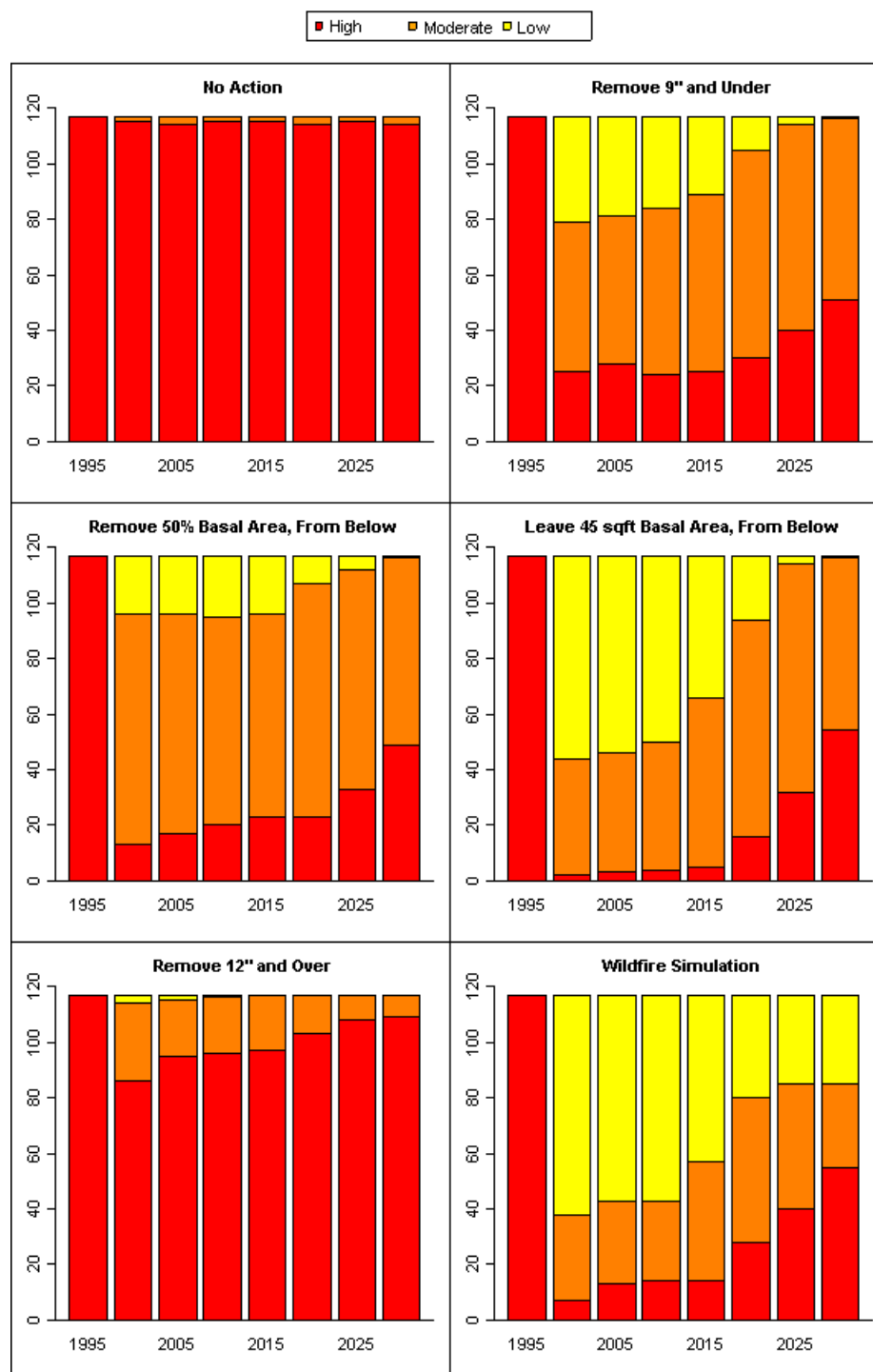
Okanogan - High & Moderate Risk Stands: Fire Risk with regeneration



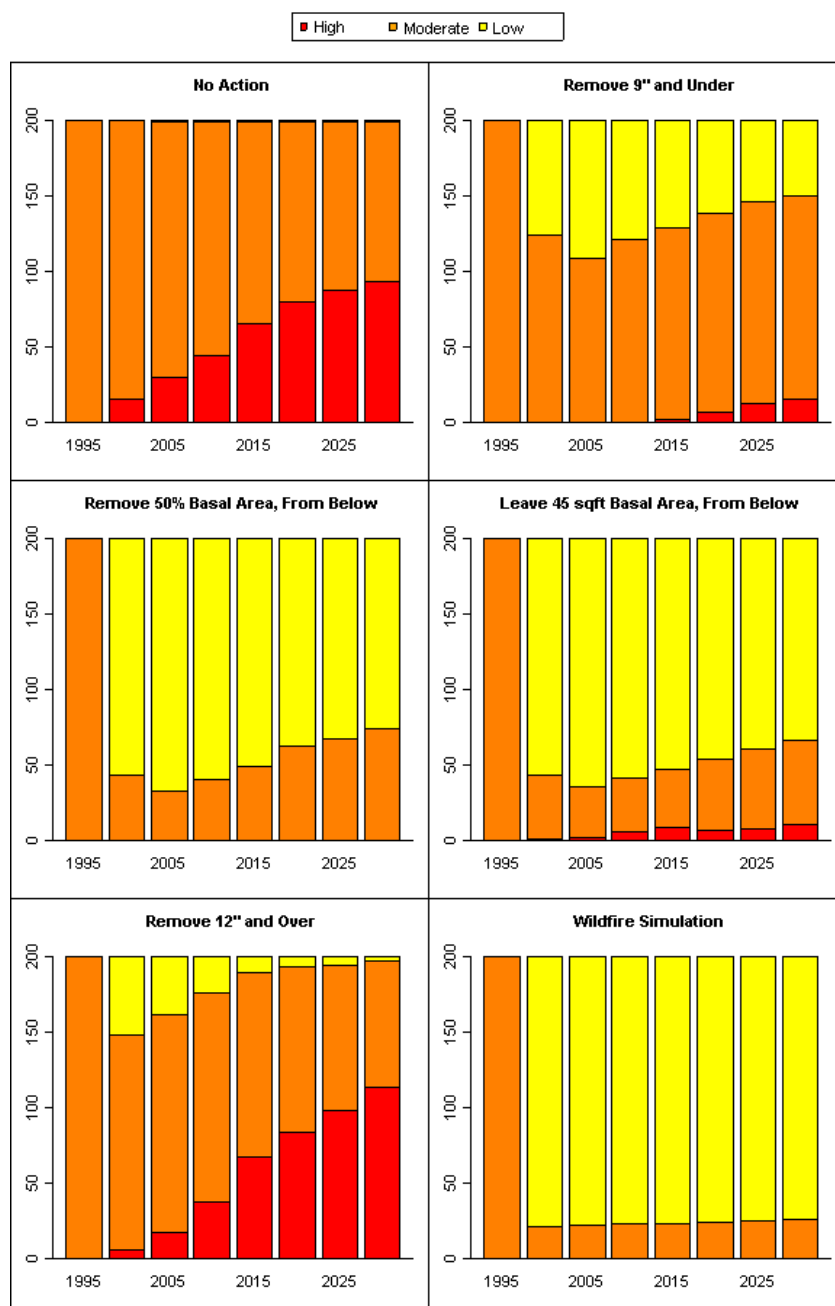
Okanogan - High Risk Stands: Fire Risk without regeneration



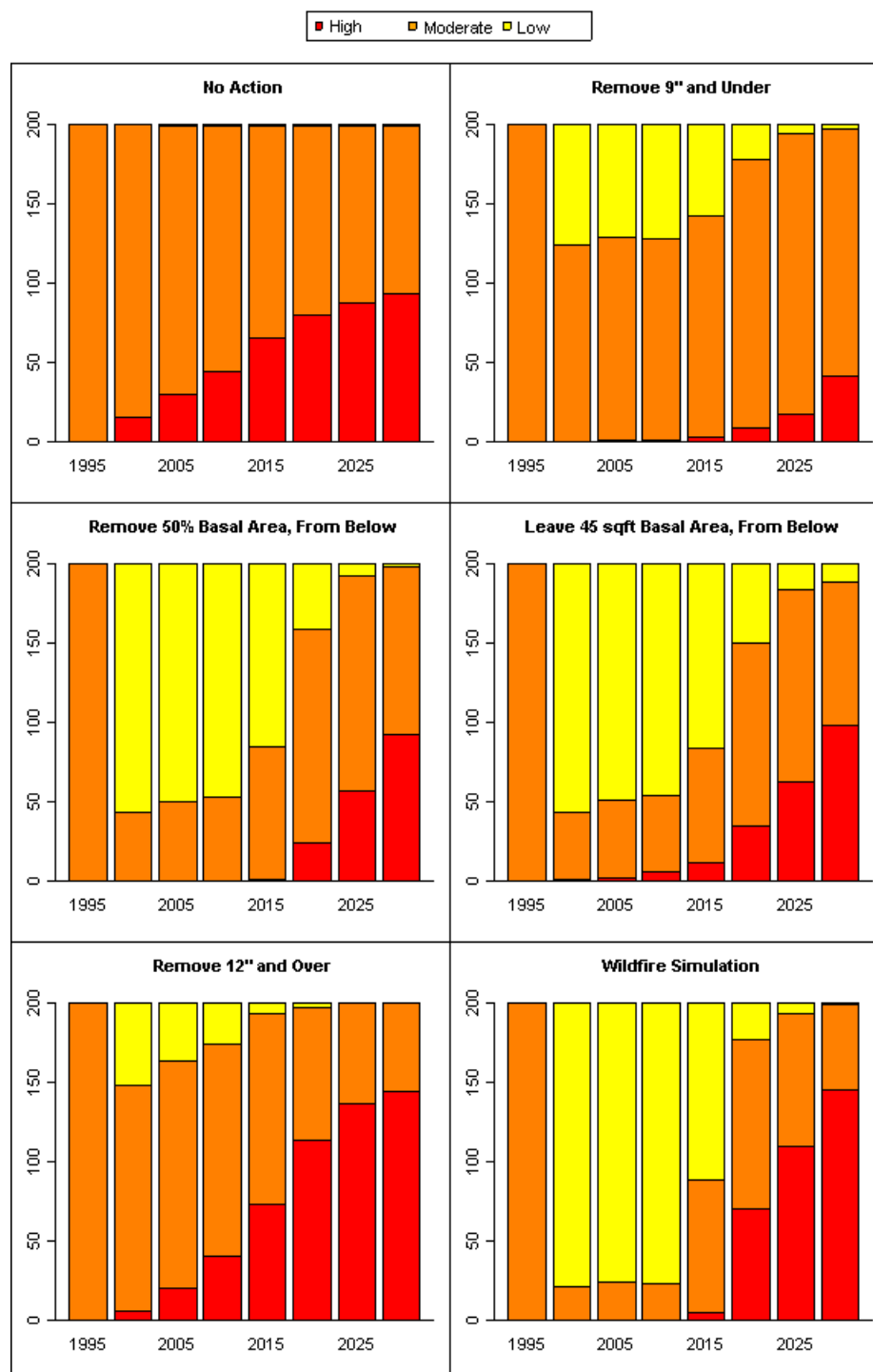
Okanogan - High Risk Stands: Fire Risk with regeneration



Okanogan - Moderate Risk Stands: Fire Risk without regeneration



Okanogan - Moderate Risk Stands: Fire Risk with regeneration



Okanogan – Fire Risk Reduction Metrics

okanogan 2000 Without Regen High & Moderate Risk Groups

Median Treatment Effects

Treatment	Median TPA			Median QMD			Median BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	855			5			110							
9&Under	63	-792	-92.6	13.7	8.8	175.9	68	-43	-38.8	111	26	-139	13	4
HalfBA	37	-817	-95.6	15	10	201.6	55	-55	-49.9	178	13	-218	15	9
BA45	39	-816	-95.5	14.6	9.6	193.4	45	-65	-59.3	230	3	-231	34	24
12&Over	817	-37	-4.4	3.7	-1.3	-25.9	51	-59	-53.7	55	92	-110	-4	-8
WildFire	1	-854	-99.9	13.6	8.6	172.7	1	-109	-98.9	226	39	-218	26	8

okanogan 2000 Without Regen High & Moderate Risk Groups

Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1153			5.3			114							
9&Under	66	-1087	-94.3	13.9	8.7	164.7	71	-43	-37.8	111	26	-139	13	4
HalfBA	61	-1092	-94.7	16.1	10.8	205.3	57	-57	-50	178	13	-218	15	9
BA45	117	-1036	-89.9	15.5	10.2	194.2	45	-70	-60.9	230	3	-231	34	24
12&Over	1122	-31	-2.7	3.8	-1.5	-28	64	-51	-44.3	55	92	-110	-4	-8
WildFire	40	-1113	-96.5	13.1	7.8	148.7	23	-91	-79.8	226	39	-218	26	8

okanogan 2000 Without Regen High Risk Groups

Median Treatment Effects

Treatment	Median TPA			Median QMD			Median BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1075			4.7			133							
9&Under	69	-1006	-93.6	12.8	8.2	175.8	70	-63	-47.4	37	26	-66	5	1
HalfBA	62	-1013	-94.2	13	8.3	179.2	66	-66	-50	21	13	-76	2	2
BA45	44	-1031	-95.9	13.6	9	192.5	45	-88	-66.1	73	2	-94	11	6
12&Over	1035	-41	-3.8	3.8	-0.9	-18.7	77	-56	-42.1	3	86	-27	0	0
WildFire	0	-1075	-100	8.9	4.3	91.4	0	-132	-99.7	47	39	-73	3	3

okanogan 2000 Without Regen High Risk Groups

Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1346			5			138							
9&Under	74	-1272	-94.5	13.4	8.4	167.7	75	-63	-45.8	37	26	-66	5	1
HalfBA	93	-1254	-93.1	14.2	9.2	183.2	69	-69	-50	21	13	-76	2	2
BA45	94	-1252	-93	15.2	10.2	202.9	45	-93	-67.5	73	2	-94	11	6
12&Over	1315	-31	-2.3	3.9	-1.1	-21.4	88	-50	-36.2	3	86	-27	0	0
WildFire	71	-1275	-94.7	8.9	3.9	78.2	34	-104	-75.3	47	39	-73	3	3

okanogan 2000 Without Regen Moderate Risk Groups

Median Treatment Effects

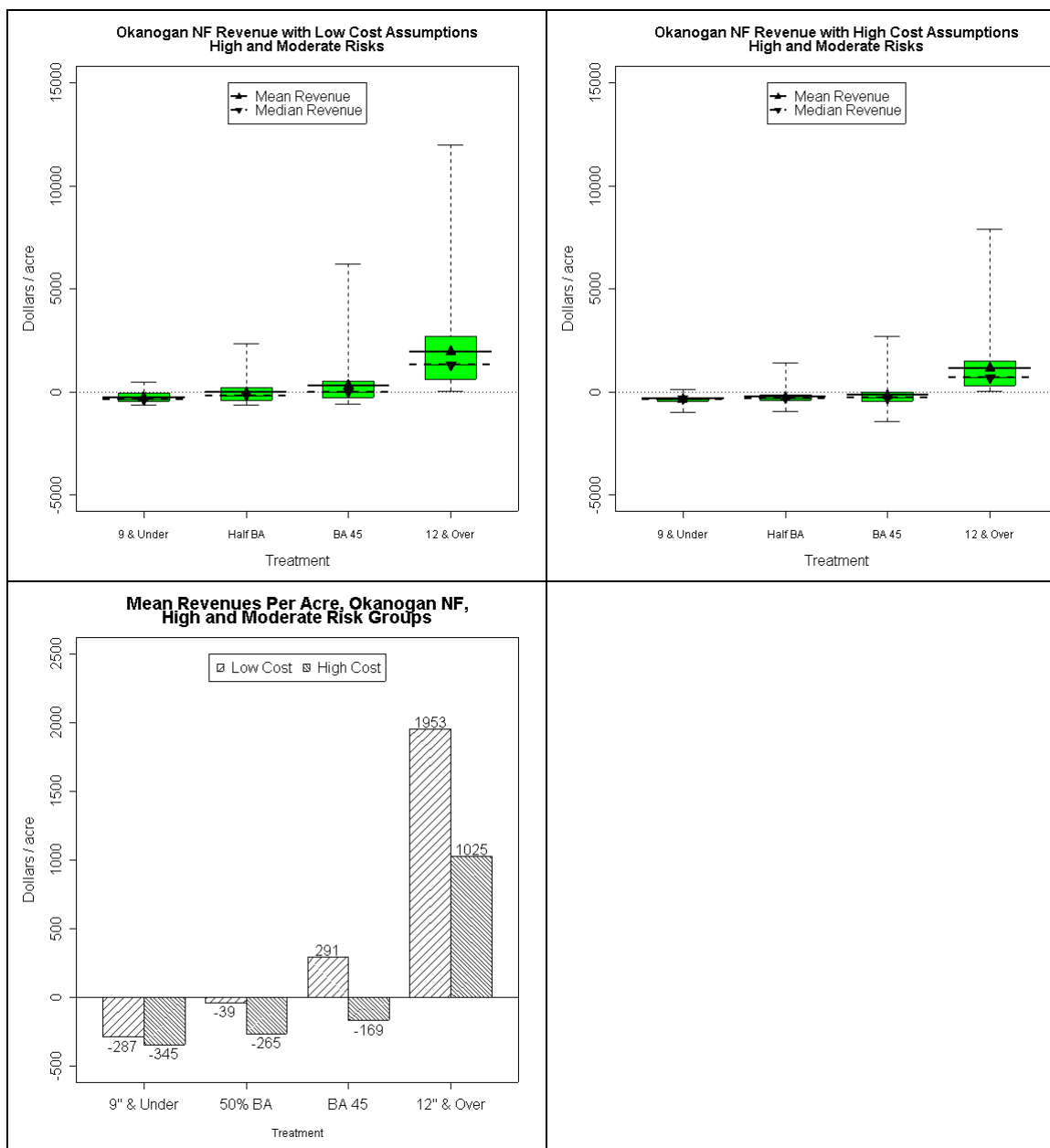
Treatment	Median TPA			Median QMD			Median BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	701			5.2			97							
9&Under	59	-642	-91.6	14.1	8.9	170.8	68	-29	-30.1	74	0	-73	8	3
HalfBA	30	-670	-95.7	16.6	11.4	218.2	48	-48	-50.1	157	0	-142	13	4
BA45	35	-666	-95.1	15.4	10.2	196.2	45	-52	-53.4	157	1	-137	23	16
12&Over	674	-27	-3.8	3.6	-1.6	-30.3	42	-55	-56.7	52	6	-83	-4	-8
WildFire	1	-700	-99.9	15.4	10.1	194.8	1	-95	-98.5	179	0	-145	23	5

okanogan 2000 Without Regen Moderate Risk Groups

Mean Treatment Effects

Treatment	Mean TPA			Mean QMD			Mean BA			Risk change to Low	High Risk Plots	Multi Str. Change	PP Change	WL Change
	trees	change	%change	inches	change	%change	sqft	change	%change					
NoAction	1040			5.4			100							
9&Under	61	-979	-94.2	14.3	8.8	163.1	69	-32	-31.5	74	0	-73	8	3
HalfBA	43	-997	-95.9	17.2	11.8	217.2	50	-50	-50	157	0	-142	13	4
BA45	130	-910	-87.5	15.7	10.3	189.5	45	-56	-55.7	157	1	-137	23	16
12&Over	1009	-30	-2.9	3.7	-1.7	-31.5	49	-51	-50.8	52	6	-83	-4	-8
WildFire	22	-1018	-97.9	15.5	10.1	186.8	17	-84	-83.5	179	0	-145	23	5

Okanogan – High & Moderate Risk Stands: Economics, Low & High Cost



Okanogan – High Risk & Moderate Risk Stands: Economics, Low & High Cost

