A COHESIVE STRATEGY FOR PROTECTING PEOPLE AND SUSTAINING NATURAL RESOURCES: PREDICTING OUTCOMES FOR PROGRAM OPTIONS

Wendel Hann, USDA Forest Service Fire Management, Gila, NM, whann@fs.fed.us
Mark Beighley, USDA Forest Service Fire Management, Washington DC
Peter Teensma, US Department of Interior, Washington DC
Tim Sexton, Interagency Fire Center, USDA Forest Service, Boise, ID
Mike Hilbruner, USDA Forest Service Fire Research, Washington DC

Abstract: Analyses were conducted of fire and fuel management options for 172 million hectares (424 million acres) of Forest Service and Interior public lands in the contiguous lower 48 states. A landscape dynamics model was calibrated based on fire regime condition class (FRCC). A linked set of predictive coefficients was developed to assess outcomes for people and ecosystems. These outcomes indicate that use of a landscape restoration approach with a budget level of 850 to 900 million dollars per year, with a mix of 2/3 to non-wildland urban interface (NWUI) maintenance and restoration, with 7 to 8 million acres of treatment per year, and 1/3 to wildland urban interface (WUI), with 300 to 500 thousand acres of treatment, would stop the increase in risk to both communities and ecosystems. Emphasizing fuel management in WUI alone, without a landscape context, was not effective in reducing risk to people because of risks to WUI from surrounding and adjacent landscapes. WUI alone resulted in the inability to effectively use relatively low cost wildland fire use, because of lack of risk reduction in landscapes between NWUI landscapes and WUI landscapes, as well as substantial degradation to ecosystems. The landscape restoration approach prioritizes landscapes based on integrated risks to people and ecosystems, uses the historical or natural range of variability as a reference for the characteristic regime, reduces risk on surrounding and adjacent landscapes of uncharacteristic fire and firebrand production, as well as reduces intermingled WUI risks, and identifies the most cost-effective spatial and temporal mix of mechanical, hand, prescribed fire, and wildland fire use. Effectiveness includes reduction of risks to people and ecosystems, as well as reducing risks of escaped prescribed fires or wildland fire use, or of unwanted wildland fires (wildfires) escaping initial attack. Program options were also assessed that can arrest or reduce increases in risk to communities or ecosystems, and in priority areas.

Key words: wildfire, wildland fire use, fuel management, wildland urban interface, landscape ecology, fire ecology

Hann, Wendel; Beighley, Mark; Teensma, Peter; Sexton, Tim; Hilbruner, Mike. 2004. A Cohesive Strategy for Protecting People and Sustaining Natural Resources: Predicting Outcomes for Program Options. Text plus tables, figures, and references. Presented at "Fire, Fuel Treatments, and Ecological Restoration Conference; 2002 16-18 April; Fort Collins, CO. 36 p. [Electronic publication on http://www.frcc.gov].

INTRODUCTION

The analyses reported in this paper are based on assessment of strategic options on Forest Service and Interior public lands (FSINTL) to reduce risk to people and restore wildland ecosystem health. The Forest Service and Interior agencies developed a strategy titled "Restoring Fire Adapted Ecosystems on Federal Land, A Cohesive Strategy for Protecting People and Natural Resources" as a policy context for purpose, prioritization, and planning for restoration and maintenance of fire adapted ecosystems on FSINTL (USDA and USDI 2002a). This policy was integrated with the 10-year comprehensive strategy for the "National Fire Plan" (USDA and USDI 2002b). This was preceded by separate USDI and USDA cohesive strategy documents addressing program levels and consequences, in addition to formulation of context for purpose, prioritization, and planning (USDI 2002, USDA 2001). The same type of analyses methods used for this paper were also conducted for these previous two efforts, with program levels, outcomes, assumptions, and methods included in the text and appendices. Both efforts were generated as a response to recommendations from the General Accounting Office (GAO) in a report titled "Western National Forests, A Cohesive Strategy is Needed to Address Catastrophic Wildfire Threats" (USGAO 1999). These recommendations have since been re-emphasized and analyzed in further depth by the GAO in a report titled "Wildland Fire Management, Improved Planning Will Help Agencies Better Identify Fire-fighting Preparedness Needs" (USGAO 2002).

Initial analyses conducted by Hann and Bunnell (2001) to assess program levels and consequences on National Forests and Grasslands in the lower 48 states were conducted in response to the GAO (1999) report and for a 1999 Joint Fire Sciences conference on fire management technologies. The methods and model development for assessing program levels and consequences in that initial assessment were the precursors to those in the subsequent USDA Forest Service, DOI, and for the combined USDA and USDI cohesive strategy analyses reported in this paper.

Much of the impetus for the development of methods to assess fire and fuel management options at a national scale were based on the need to assess implications of policy and recommendations from the Federal Fire Policy (USDA and USDI 1995), Federal Fire Policy Review (USDI and others 2001), and "Policy Implications of Large Fire Management" (USDA 2000). In concert, findings from the Interior Columbia Basin Ecosystem Management Project (ICBEMP) provided a spatial and quantitative preview of the severity of uncharacteristic wildland fire risks that could potentially occur on a national scale, as well as development of multi-scale modeling tools to address these types of issues (Keane et al. 1996, Quigley et al. 1996, Hann et al. 1997, 1998). In addition, initial findings relative to the severity of uncharacteristic wildland fuel and fire risk conditions across the lower 48 states provided the data that became the foundation for this analysis (Hardy et al. 2001, Schmidt et al. 2002).

Prediction of outcomes for the various proposed fuel treatment programs for reducing risks to people and natural resources were based on a fire regime condition class (FRCC) disturbance and succession-fuel dynamics model (Hann and Bunnell 2001). The model was developed to predict the rates of change of one FRCC to the next; as well as the probability of different types of disturbance, advancing rates of succession, or changing one condition class to another. Various effects on people and natural resources were predicted from the inter-relationship of fire regime, fire regime condition class, insects and disease, grazing, timber management, prescribed fire, mechanical treatments, associated vegetation conditions, roads, and human populations.

STUDY AREA

The focus area used in this prediction of outcomes included all USDA Forest Service and the Department of the Interior lands (FSINTL) within the conterminous lower United States (CONUS, excludes Alaska and Hawaii)—representing approximately 172 million hectares (424 million acres). The description and characterization of the study area was based on the coarse scale maps and data developed by Hardy et al. (2001) and Schmidt et al. (2002). Forest Service and Interior lands occur in 1,377 4th code hydrologic units (subbasins) across CONUS out of a total of 2,112 subbasins (65%). Subbasins are subdivisions of basins containing the watersheds of a typical river system (such as Bitterroot River or Upper Arkansas River) that typically range from about .4 to .8 million hectares (1 to 2 million acres) in size. However, about 1/3 (463) of the subbasins have less than 10 percent of their area in Forest Service and Interior lands, while another 1/3 (444) have greater than 50 percent. Another third (470) have between 10 and 50 percent Forest Service and Interior land area. Not surprisingly, most (389) of the subbasins with less than 10 percent FSINTL occur in the 37 central and eastern states, while most (406) of the subbasins with greater than 50 percent FSINL occur in the 11 western states.

METHODS

Model Development Background

The landscape succession and disturbance model used for this analysis was previously developed for an example assessment of Forest Service management options in the contiguous lower 48 states (CONUS) (Hann and Bunnell 2001) using the Vegetation Dynamics Development Tool (VDDT) (Beukema and Kurz 2000) in association with the coarse scale maps and data for national fire planning and fuel management (Hardy et al. 2001, Schmidt et al. 2002). The model that was developed used fire regime condition class (FRCC) as states and incorporated probabilities for succession, unplanned disturbances (such as fire), and planned disturbances (such as mechanical and prescribed fire restoration).

Egler (1954) was first to develop the concepts used for modeling multiple succession and disturbance outcomes. These concepts were incorporated with other information into the development of conceptual succession and disturbance models by Noble and Slatyer (1977). Kessell and Fischer (1981) and Keane et al. (1989) predicted response over time of the interactions of vegetation succession and disturbance dynamics by combining the conceptual succession and disturbance models with ecosystem specific information in computer models. As space and time pattern and process concepts developed in the field of landscape ecology, these models were further advanced (Forman and Godrun 1986, Turner et al. 1989, 1994). Tausch et al. (1993) applied this type of modeling for multiple state and transition outcomes in rangelands. The accumulation of this long history and wide variety of kinds of spatial and temporal landscape modeling were fully implemented to support an assessment of management options that included characterization of the historical range and variation, as well as future outcomes of management options for the Interior Columbia Basin Ecosystem Management Project (ICBEMP) by Keane et al. (1996) Hann et al. (1997, 1998, and 2001), and Hemstrom et al. (2001).

Much of the conceptual understanding for development of the FRCC model and associated effects predictions came from the comprehensive scientific assessment and evaluation of management alternatives for the ICBEMP (Quigley et al. 1996, 1997, 1999). Dynamic relationships of landscape vegetation, disturbance, and hydrologic regimes were linked with aquatic and terrestrial habitat and species population characteristics to characterize interactions and project future outcomes (Hann et al. 1997, Hemstrom et al. 2001, Lee et al. 1997, Raphael et al. 1998 and 2001, Rieman et al. 2001, Wisdom et al. 1999 and 2000,). Similar linkages were developed with social and economic variables to characterize interactions and project future outcomes (Haynes and Horne 1997, Crone and Haynes 2001). Methods for costs and effectiveness were based on Hann et al. (2001). These basic predictive relationships between ecological, social, and economic variables for the ICBEMP were then recalibrated for Forest Service and Interior public lands of the lower 48 states (Hann and Bunnell 2001, Hardy et al. 2001, Schmidt et al. 2002).

For this analysis the definitions of fire regimes and condition classes were refined slightly from those in Hann and Bunnell (2001) (tables 1 and 2). The Hann and Bunnell (2001) FRCC model was first calibrated for the historical range of variability (HRV) across Forest Service and Interior lands of the lower 48 states. This was considered to be a 400-year period with a similar climate to the current, following the conceptual definition for HRV of Morgan et al. (1994). Following this calibration, the model was then calibrated to simulate the changes from pre-Euro-American settlement (1700s in the East; 1800s in the West) to the current period. For future management scenarios, the model was then calibrated for varying levels of fuel and ecosystem restoration for various management regions, such as wildland urban interface (WUI), non-wildland urban interface (NWUI), wilderness, roadless, or other lands. However, the model was developed using relationships of a landscape context, such that their association with other management regions affected the management region outcomes. For example, WUI is typically intermingled within a NWUI landscapes and affected by unwanted wildland fires (wildfires) from the surrounding and adjacent landscapes (Hann and Strohm 2001).

Determination of average rates of succession between each condition class for the fire regimes was the first step in the calibration. This was followed by calibration of the disturbance probabilities to fit the definition of the fire interval and severity definition of the regime. HRV was simulated with 10 runs (to get average, maximum, and minimum) that included stochastic variation to account for natural variation in year-to-year climate and multiple pathways. Results were reviewed and inputs were adjusted until succession and disturbance probability combinations were found that represented the fire regimes.

The model was then calibrated from the late 1800s to the present by activating disturbances associated with post-Euro-American settlement, fire suppression, and management activities. The methods for this calibration were similar to those for calibration of HRV such that 10 runs per simulations were conducted until the projected conditions at the year 2000 and the trends of condition class and wildland fire graphs were similar to those of the published literature (Agee 1993, Hardy et al. 2001, Schmidt et al. 2002).

Future scenarios were calibrated using the combined understanding gained from the HRV and post-settlement calibration, with adjustments for future management scenario projections. The base future management scenarios included modeling a no treatment option (zero fuel treatment and no resource management) (program 1), the fiscal year 2000 level combined with other resource activities (such as vegetation management, wildlife habitat restoration, and watershed restoration) representing pre-national fire program cohesive strategy levels (program 2), the continuation of current management using the fiscal year 2002 levels of national fire plan cohesive strategy prescribed fire and fuel management combined with other activities (program 3) and several other options of different mixes of WUI and NWUI emphasis and increasing levels of treatment (table 3). Because the current and cohesive strategy level of activities were known entities, in comparison to the HRV and post-settlement calibrations, these future options were relatively simple to calibrate. In addition to the options assessed for all Forest Service and Interior lands in the lower 48 states we also assessed the outcome for a typical prioritized landscape in the west. This was conducted in order to demonstrate the value of prioritizing landscapes and implementing the landscape strategy irrespective of the total budget level.

Attributes for projections of risk to people and property, severe event degraded ecosystems, and relative risks of smoke/air quality, native species endangerment, stream/watershed, and soil degradation, were all developed using correlation of trends in landscape condition classes and assumptions similar to relationships found within ICBEMP (Quigley et al. 1999), but adjusted for conditions in the western U.S. and CONUS (Bailey 1995, Elmore et al. 1994, Flatherer et al. 1994 and 1998, Hardy et al. 2001, Leenhouts 1998, Mangan 1999, Menakis et al. 2003, McNab and Avers 1994, Rockwell 1998, Schmidt et al. 2002).

Specific information on relationships and coefficients were developed using information from Allen and Hoekstra (1992), Andrews et al. (1989), Caprio and Graber (2000), Crone and Haynes (2001), Elmore et al. (1994), Finney (1998), Flatherer et al. (1994 and 1998), Gruell (1983), Hann et al. (1997 and 1998), Hardy et al. (2001), Haynes and Horne (1997), Hemstrom et al. (2001), Landres et al. (1999), Lee et al. (1997), Leenhouts (1998), Mangan (1994), Menakis et al. (2000), Morgan et al. (1994 and 1996), Raphael et al. 1998 and 2001, Reinhardt et al. (1997), Rieman et al. (2001), Schmidt et al. (2001 In Press), Tausch et al. (1993), Wisdom et al. (1999 and 2000). Hann and Bunnell (2001) provide detailed discussion of the use of this information to develop relationships and coefficients.

For this paper similar methods were used for the projection of the risk indexes as used by Hann and Bunnell (2001): such as people and property, severe event degraded ecosystems, smoke/air quality, native species endangerment, watershed, and the summary index of risk to communities (RTC), and risk to ecosystems (RTE). However, for this cohesive strategy the risk outcomes were all scaled between 0 and 1 to allow for easier comparison between different types of risk. Hann and Bunnell (2001) describe methods for development of these variables, which are generally based on coefficient associations of the variables with underlying ecological, social, and economic conditions or trends. Hann et al. (2001) describe in detail the process for development of these coefficients in the ICBEMP. Risk to people and property was based on the relationship between firefighter fatalities and property losses associated with amount of uncharacteristic wildland fire events. The amount of severe event degraded ecosystems was projected based on the correlation of uncharacteristic wildland fire events with high-risk conditions. Relative risk of smoke/air quality was associated with tons of particulates produced for both wildland fire and prescribed fire events. Native species endangerment patterns were correlated with the number of species of concern and cumulative effect patterns associated with loss of habitat quantity and quality. Stream, watershed, and soil risks were correlated with effects of uncharacteristic wildland fires and other disturbances.

Behavior and effects of wildland fire, native species endangerment, air quality degradation, watershed impairment, and risk to people and property are landscape variables that are strongly affected by conditions on other land ownerships intermingled or adjacent to FSINTL. Many of the underlying conditions (such as weather, fuels, ignition source, land use, roads, human disturbance, housing density, and human values) affecting these landscape variables vary in amount of effect and extent of effect depending on multi-scale variation in ecological and social conditions (Hann et al. 1997). Consequently the response of these variables on FSINTL as a result of restoration may not be as positive as would be expected.

Forest Service-Interior Cohesive Strategy Model Components

Four components tend to drive the outcomes for the underlying variables influencing risks to people and ecosystems: 1) FSINTL composition of current FRCC within the analysis area; 2) the selection of a landscape risk reduction strategy versus a stand or WUI focus strategy; 3) ratio of mechanical, prescribed fire, wildland fire use, suppression resources, and associated restoration and maintenance activities (weed control, habitat restoration, and watershed restoration); and 4) the succession and unplanned disturbances with the largest probabilities. We have discussed calibration of the succession and unplanned disturbance (such as fire) probabilities previously. Additional discussion of the first three components is needed to explain adjustments and assumptions that were developed in order to predict logical outcomes.

Forest Service and Interior Lands Composition

The USDA Forest Service Fire Effects Project (Northern Fire Laboratory, Missoula, MT) developed the CONUS and western U.S. current FRCC coarse-scale composition maps (Hardy et al. 2001, Schmidt et al. 2002, Menakis et al 2003, Menakis et al. 2004). In addition to this data, they also developed associated information on historical vegetation, current vegetation, historical fire regimes, population density, and wildfire occurrence.

The fire regime, FRCC, and associated data used for the USDA Forest Service cohesive strategy analysis of fuel treatment scenarios for the conterminous United States (CONUS) (Lower 48 States) was from Hardy et al. (2001) and Schmidt et al. (2002) (table 4). This data was also used for the USDI (2001) cohesive strategy analysis of scenarios, but was non-spatially adjusted to attempt to improve resolution of FRCC in rangelands. For the combined USDA and USDI (2002) cohesive strategy analyses reported in this paper, Menakis et al. (2003, 2004) developed improved maps of FRCC that incorporated the estimated current distribution of cheatgrass (*Bromus tectorum*) in one analysis (2003) and determined FRCC using a relative method with improved data for rangelands (2004) in another (Table 4).

Hardy et al. (2001), Schmidt et al. (2002), Menakis et al. (2003), and Menakis et al. (2004) provide an indication of confidence and uses for the FRCC and associated data. Because of the coarse-scale (1 square km) nature of the data, they recommend that the FRCC data only be used as a relative index to compare relative risk between large areas (such as regions or states) and that absolute estimate of area be used with caution. In addition, they indicate that because of this coarse-scale nature of the data, FRCC 2 or 3 may be substantially underestimated because of the scattered small patch nature of invasive plants, exotic insect and disease mortality, uncharacteristic native insect and disease mortality, poor canopy closure resolution in woodlands and rangelands, history of excessive livestock grazing, and other similar disturbance processes. This was also consistent with findings on scales of this type of data and related model simulation outcomes in the Interior Columbia Basin and other geographic areas (Hann et al. 1997, Hessburg et al. 1999, Keane et al. 1996, 1998, 2000, and 2002, Morgan et al. 1996, Wisdom et al. 2000).

As part of methods development we conducted sensitivity testing of the model to varying levels of current condition class inputs. We found that use of the current FRCC estimates from Hardy et al. (2001) and Schmidt et al. (2002), Menakis et al. (2003), or Menakis et al. (2004) produced results that appeared to be driven by the large amount of condition class 1. The large amount of condition class 1 caused poor sensitivity to change from different levels of restoration activities. Of even more concern, this large amount in condition class 1 appeared to suffer from the cautions of Hardy et al. (2001), Schmidt et al. (2002), Menakis et al. (2003), and Menakis et al. (2004) concerning under-estimation of condition classes 2 and 3. One of the specific problems that appeared to have developed was that modeling outcomes of program options (budget level and area treated) require that estimates of amounts of different condition classes be used in an absolute rather than relative sense. This conflicted with the recommended use of the coarse-scale data.

Consequently, we decided to assess a number of finer scale FRCC mapping projects in concert with limited ground truth in order to estimate finer scale composition. Results indicated that the coarse-scale mapping may have substantially underestimated condition class 3 and overestimated condition class 1 (Table 5) (Hann 2004, Hann et al. 2003, Hann and Strohm 2003, McNicoll and Hann 2004). Fine-scale analyses of plot data and landscape simulation also supports this type of adjustment (Hann et al. 1997, Keane et al. 2002). We estimated that FRCC 1 was approximately double and FRCC 3 approximately one half (22 and 42 respectively) of what they would be if mapped with finer-scale data. These values were then rounded to the nearest 5 per cent (table 6). To validate this relationship, limited ground truth and reconnaissance evaluation of landscape scale FRCC was conducted in selected geographic areas. The limited ground truth confirmed that the general adjustments were in “the ball park” of what would be expected from finer-scale data and modeling.

Landscape Versus Wildland Urban Interface or Stand Strategy

Modeling coefficients used to predict fire risk and effects are very different in association with the spatial characteristics of the restoration implementation strategy. The context of the surrounding and adjacent landscapes drives uncharacteristic fire behavior and severity, rather than the stand or WUI area (Hann and Strohm 2003, Finney and Cohen 2003, Scott and Reinhardt 2001). In contrast, vulnerability of the site or stand determines potential effects (Reinhardt et al. 1997), while vulnerability of structures determines their potential vulnerability (Cohen 2000). However, the surrounding or adjacent uncharacteristic fire behavior and severity, if of sufficient magnitude, will overshadow low or moderate vulnerability of an embedded stand or site resulting in severe effects (Hann and Strohm 2003, Turner et al. 1994), as well as overwhelming low or moderately vulnerable structures with firebrands and heat resulting in structure loss (Finney and Cohen 2003). The reverse is not the case; i.e. site, stand, or structure low or high vulnerability conditions overwhelming landscape scale surrounding or adjacent conditions. In addition, the landscape approach provides time for fire control and other efforts to be effective on fires ignited in surrounding or adjacent landscapes. Consequently a landscape approach to design of restoration and associated fire and fuel management strategies has much higher coefficients for reducing risks of uncharacteristic fire behavior and severity to both people and ecosystems.

Strategies that focus only on risk reduction in WUI, stands, or sites that do not address connectivity to the surrounding and adjacent landscapes have low coefficients for reducing risks of uncharacteristic fire behavior and severity.

WUI or stand risk reduction strategies focus the restoration and fire and fuel management energy within those specific areas and often attempt to buffer these areas from wildfire and other unplanned landscape processes (such as windthrow, insect/disease mortality, and erosion) with relatively narrow (such as 1/8 to 1 mile) restored areas that have low resistance to fire control and low hazard of producing firebrands. There are multiple reasons this strategy has low coefficients in terms of reducing risk of uncharacteristic fire behavior and severity to WUI or stand ecosystem conditions. A primary reason is that wildfire and other unplanned disturbances often gain in intensity as the disturbance moves across the landscape. For example, a wildfire that starts some distance from the subject WUI or stand, escapes initial attack, is driven by wind and in uncharacteristic fuel and weather conditions, can gain much more in severity by the time it reaches the green strip and WUI or stand area, than if it were to have actually started within the WUI or stand area. Associated with this process the small size of the buffer or stand area provides little protection from mass firebrands and spot fires. For example a fire crew attempting to hold a fire line in a narrow buffer or stand has little time to react to mass firebrands and spot fires that jump the line within a narrow band between the line and the structures or sensitive stand area. This approach also puts the fire crew in danger of being caught between the head of the fire and mass spot fires. In addition, the focus of WUI and stand risk reduction strategies is typically the heaviest fuel concentrations in forested stands rather than on the fuel mosaic as a whole, which includes the surrounding and adjacent grasslands, shrublands, woodlands, and forests. For example, a fire that starts in grasslands or shrublands in fine fuels can spread rapidly and gain intensity moving into wood and brush fuels of woodlands generating increasing intensity and firebrands and then moving into forests where it rapidly shifts to a running crown fire. In contrast, a fire starting in forest fuels may have a relatively low rate of spread and not generate enough intensity to carry into the crown. The landscape strategy substantially reduces the risk of a wildfire gaining in speed or severity and throwing mass firebrands and spot fires into WUI, thus giving fire crews time and conditions to anchor fire lines into defendable areas, by managing the landscape matrix as a whole.

Another key component of the landscape strategy versus the WUI or stand strategy includes multi-scale prioritization (Hann and Bunnell 2001, Hann et al. 2001). The landscape restoration approach prioritizes landscapes based on integrated risks to people and ecosystems using a set of core variables that are compatible and based on consistent methods from an interagency and national perspective. Design for treatment of stands, patches, and WUI areas within the priority landscapes are identified by assessment of FRCC risk and other key variables to design the most effective spatial pattern to reduce risk at area, surrounding landscape, and adjacent landscape levels (Hann and Strohm 2003, Finney and Cohen 2003).

In contrast, the WUI or stand focus strategies typically prioritize projects based on perceptions of risk from knowledge of recent wildfire events, local public emphasis, and risk variables and data that are defined locally, thus not allowing for comparison of priorities at national, regional, or sub-regional scales. Of even more concern some strategies may use a WUI or stand focus, or lack of consistent data for risk comparisons, to promote a hidden agenda, such as desire for road access, forest products, and more forage; or the reverse, such as reduced access, no mechanical equipment, and no products from public lands. From a landscape strategy perspective these agendas can be by-products of the prioritization and design, but should not take away from the cost-effectiveness of risk reduction to people and ecosystems.

Mechanical, Prescribed and Wildland Fire Use, and Associated Treatments

In the context of the landscape strategy an effective mix of mechanical, hand cutting, prescribed fire, and wildland fire use treatments are critical to assignment of high coefficients for risk reduction. Adjacent to WUI or sensitive stands or sites, mechanical or hand cutting methods may be the only options of pre-treatment before pile burning or broadcast burning, or they may be the only options where burning can't be accomplished because of air quality or other considerations. In landscapes with embedded WUI wildland fire use may never be an option and prescribed fire can only be used in a limited way, while mechanical or hand cutting with pile burning are options. Mechanical treatment followed by prescribed fire may be the best option for landscapes adjacent to WUI landscapes, which provide a buffer between WUI landscapes and landscapes where wildland fire use is an option. This would be desirable since prescribed fire has much lower probability for escapes than wildland fire use (Hann and Bunnell 2001, Hann et al. 2001). The key for a landscape strategy is to design the most cost-effective spatial and temporal application of the treatment tools that mimic or represent the natural regime and conditions. The natural or historical regime provides a reference for characteristic conditions to determine the magnitude of uncharacteristic conditions. Effectiveness includes reducing risks of escaped prescribed fires or wildland fire use or unwanted wildland fires (wildfires) escaping initial attack, as well as reduction of risks to people and ecosystems.

Assumptions for Modeling Option Outcomes

One of the key benefits to the landscape strategy is the ability to achieve multiple positive outcomes for what may appear to be conflicting objectives (Hann and Bunnell 2001, Hann et al. 2001). For example, implementing both mechanical treatments and protecting fish and wildlife, roadless and wilderness areas, and aesthetics may appear to be in conflict; producing natural fire effects that sustain native fire-adapted plants and reducing fuels to characteristic levels through use of prescribed fire and wildland fire use appear to be in conflict with sustaining air quality. However, from a landscape perspective these conflicts can usually be removed through spatial and temporal separation. For example, quality fish and wildlife habitats, and roadless and wilderness areas, are typically not the same landscapes that have priority uncharacteristic conditions with need for road access to use mechanized equipment in WUI areas and surrounding landscapes. Mechanized equipment and road access can be focused on WUI landscapes, with prescribed fire and wildland fire used scheduled in adjacent landscapes after the WUI landscapes have been restored.

In this FSINTL cohesive strategy analysis a landscape prioritization approach was assumed for options 3, 4, 5, 6, and 8. Options 1 and 2 do not have sufficient funds to treat adjacent landscapes that provide a buffer between WUI landscapes and NWUI wilderness/roadless landscapes, and option 7 focuses most funds at the WUI interface therefore precluding sufficient treatment of adjacent landscapes. Option 4 appears to be borderline in achieving a landscape strategy because of high (67 percent) emphasis on WUI vs. NWUI, which may preclude a landscape strategy. We assumed that with careful step-down prioritization and planning, flexibility in applying funds at landscape scales, and monitoring and adaptive management option 4 could be successfully implemented under a landscape strategy.

Key landscape strategy assumptions were developed for the different cohesive strategy options in order to assign coefficients (tables 7 and 8). The assumptions and coefficients for those options with a landscape strategy were based on the applied principles of landscape ecology (Hann et al. 1997, Hann et al. 2001). These principles include: 1) landscape are complete (they are wall-to-wall); 2) landscape are dynamic in space and time; 3) landscapes have characteristic patterns; 4) landscapes are connected (components link across space); and 5) landscapes are cumulative (integrate human and other actions through time). These basic principles provide a framework for development of the key assumptions and coefficients for this analysis. Basic assumptions for planning and implementation of an option with a landscape strategy include:

1) Use of reference condition approach with natural or historical range of variability and FRCC as a key variable.
2) Prioritization of landscapes based on multi-scale integrated risks to FRCC, WUI, uncharacteristic wildland fire occurrence, air, water, species, and ecosystem sustainability.
3) Use of the cohesive strategy as context and template for prioritization and planning.
4) Design, and implement to improve by at least one FRCC improvement in each prioritized WUI or NWUI landscape.

5) Five year transition from current methods of prioritization, planning, project design, and monitoring to a landscape strategy.

The assumption related to the reference condition and prioritization follow concepts and findings outlined by Rieman et al. (2000), Hann and Bunnell (2001), and Hann et al. (2001). The five-year transition period was identified because we recognize that the current methods for prioritization, planning, and implementation of fuel management and ecosystem restoration programs and projects are usually not integrated among fire and other resource functions or across scales. The development and implementation of these prioritization, planning, and implementation processes, and associated technologies, are assumed to occur in a 5-year transition period.

Key to successful implementation of a landscape approach are the multi-scale linkages between different administrative levels of agency organizations. These roles are assumed to occur as follows:
National –prioritization and prediction/monitoring of accomplishments, conditions, and cumulative effects at a national scale; provide consistent methods for core data and consistent data for ecoregion province, hydrologic subbasin, and administrative unit scales.
Regional/State – coordination and consistency of prioritization, planning, and implementation monitoring methods and data with adjacent regions/states and between administrative units within regions/states.
Administrative Unit (Forest, Resource, Land, and Fire Management Planning Unit) –prioritization and prediction/monitoring of accomplishments, conditions, and cumulative effects for local units and watersheds/landscapes; Land Management/Fire Management Planning; coordination and consistency of prioritization, planning, and implementation monitoring methods and data with adjacent administrative units and between local units within the administrative unit.
Local Unit – project planning, treatment design, implementation, and implementation monitoring.

These assumptions lead us to the need for consistency in prioritization, planning, and implementation monitoring data. Core data for prioritization, planning, and implementation monitoring of status, risk, and opportunity include: FRCC, HRV Departure, wildfire occurrence, wildland urban interface, watershed and air, native species, and ecosystem sustainability. Additional local variables can be added at region/state, administrative unit, and local unit scales.

We developed four specific assumptions that serve as a basis for the condition class, disturbance, and associated attribute modeling:

Assumption 1—step-down prioritization would identify priority watersheds (or landscapes) to be restored. The watersheds would be selected based on wildland urban interface risk, wildfire occurrence risk, and high composition of Fire Regimes I and II, with opportunities for maintenance of low risk and reduction of high risk conditions. However, once a priority watershed was selected, restoration activities would be designed to maintain and restore habitats and regimes across all Forest Service and Interior lands within the watershed. This would achieve a landscape approach to restoration and avoid a fragmented outcome associated with the fragmented landscape pattern that often occurs in association with history of land use and variation of these conditions with elevation, terrain, and road access. In turn this landscape approach reduces the risk of large wildfire spread and restores native species habitats and hydrologic and air regimes at a watershed scale, thus providing positive outcome to all resources.

Assumption 2—based on aquatic native species strongholds and vulnerability of wildlife species, air quality and hydrologic regimes to the combination of land use, human activities, and proposed restoration; the step-down prioritization would result in an integrated design as described by Reiman et al. (2000), Hann and Bunnell (2001), and Hann et al. (2001) . This assures that areas with vulnerable native species or ecosystems would not be selected for restoration activities that could cause a short-term decline in these resources; or these short-term risks would be mitigated. This also assures that watersheds selected for restoration would be restored in an integrated fashion, such that vegetation and fuel restoration activities would be paralleled with the necessary road, stream, and watershed restoration activities that would cumulatively result in a healthy watershed.

Assumption 3—project planning and monitoring will occur within a national core data framework that can be used to continually update and project FRCC and other risk variables. This update and projection system will be used to evaluate cumulative effects and trend towards most cost-effective landscape scale risk reduction and delivery of benefits at multiple administrative scales.

Assumption 4—future projections assumed a minor level of continuation of increasing drought and warming temperatures in all scenarios. However, for the future projections of the cohesive strategy it was assumed that a landscape approach to restoration would occur. This would result in a re-patterning of the fuels and vegetation such that present contiguous high risk fuel bodies would be restored to a pattern somewhat similar to that of HRV, resulting in lower risk of uncharacteristic wildland fire events or continuation of uncharacteristic succession/disturbance momentum. For the cohesive strategy, this assumption resulted in slowing of succession to higher risk condition classes and lowering risk of large uncharacteristic wildland fire events.

Assumptions for Modeling A Prioritized Landscape

The simulated landscape represents a typical western U.S. forest-range landscape dominated by fire regime groups 1, 2, and 3 with most of the area in condition classes 2 & 3 with WUI both intermingled and on the boundary with FS and Interior lands. We assumed a similar condition class composition for the current time period as across all FS and Interior lands. In addition we developed a mock-up of a prioritization table for this area (table 9). Also we developed assumptions for planning treatment and design (table 10).

We assumed that a typical landscape (watershed) in the western U.S. would be about 100,000 acres in size. For modeling coefficients we were able to use the various risk indexes as they were developed for the coarse scale, since they were a relative value. A simple multiplication any absolute indexes (area or dollars) by 0.0002358 (100,000 acres/424,000,000 acres) was used to determine the absolute value for the typical landscape. This typical landscape would differ in the eastern U.S. and be much smaller in size. However, with coordinated restoration and management of intermingled or adjacent state and private lands the results could be very similar in trend to this example of a typical western landscape.

Predicted Outcomes

The following variables were predicted using coefficients and relationships described by Hann and Bunnell (2001) and relationships of costs and effectiveness described by Hann et al. (2001) but adjusted for the FSINTL of the contiguous lower 48 states.

Fire Regime Condition Class
- Wildland-urban interface (WUI)
- Non-Wildland-urban interface (NWUI)

Unwanted Wildland Fire (wildfire)
- Wildland-urban interface (WUI)
- Non-Wildland-urban interface (NWUI)

Restoration and Maintenance Treatment
- Wildland-urban interface (WUI)
- Non-Wildland-urban interface (NWUI)

Restoration and Maintenance Cost
- Wildland-urban interface (WUI)
- Non-Wildland-urban interface (NWUI)

Potential Net Income From Restoration Produced Products
- Wildland-urban interface (WUI)
- Non-Wildland-urban interface (NWUI)

WUI Risk to People and Property
Wildfire Suppression Cost Index
Native Species Endangerment Risk
Air and Smoke Risk
Water and Soil Risk
Altered Sites Risk
Historical (natural) Range of Variability (HRV) Departure Risk
Ecosystem Health (sustainability-resiliency) Risk
Landscape Health Risk
Cost Index

RESULTS AND DISCUSSION

Outcomes for All Forest Service and Interior Lands

Examples of the detailed 100-year average and variation simulation results from this model are provided in Hann and Bunnell (2001). We will focus results and discussion for this paper on comparison of the different options at the 15-year period and strategies for implementation of a landscape approach. Program options 1, 2, and 7 produce a decline in condition class 1 lands after 15 years (table 11). Options 3 and 4 maintain lands in condition class 1 at the current estimated 20 percent level, while options 5, 6, and 8 increases amount of land in condition class 1. The relative risk to people and property substantially increases for options 1, 2, 3, and 7, with options 4 and 6 maintaining the current level or risk, and options 5 and 8 reducing the risk (figure 1). Although option 7 focuses a high budget toward WUI risk reduction the lack of emphasis on the landscape surrounding WUI and adjacent NWUI landscapes increases risk from large fires.

In a relative sense risk to ecosystems is currently much higher than risk to people and property because of the large extent of degraded lands; .35 compared to .15 (table 11). Options 1, 2, 3, 4, and 7 all result in substantial increase in this risk (figure 2). Options 5 and 6 tend to maintain risk at current levels, while option 8 substantially reduces the risk.

Trends of costs indexes (table 11 and figure 3) have a similar trend as the ecosystem risk index, because of uncharacteristic fuel conditions associated with degraded ecosystems. Options 1, 2, and 7 all result in substantial increase in wildfire and associated costs. Options 3 and 4 tend to maintain the current levels of wildfire and associated costs, while options 5, 6, and 8 reduce amount of wildfire and associated costs at successively higher amounts; to about 40 percent reduction from current. In the Northwest and Northern Rocky Mts. Hann et al. (2001) found that savings from reduced costs of wildfire suppression would repay one-third of the integrated landscape restoration and maintenance costs and reduce risk of property loss and severe accidents to firefighters by one half over the short-term implementation period, while over the long-term, all costs would be more than recovered. For FSINTL in the lower 48 states our results indicate that options 1, 2, and 7 would not repay the cost of suppression in reduced wildfire and management costs. In contrast options 4, 3, 6, 5, and 8 successively increase in their ability to repay costs over shorter time periods (table 11 and figure 3).

Results from predictions of native species endangerment risk indicate somewhat less sensitivity to conditions on FSINTL than for the previously discussed risk indices (table 11). The current risk was found to be similar to that of overall ecosystem risk (.35 for both). This would be expected since condition of degraded habitats would follow similar trends as condition classes 2 and 3. However, all options except for 8 indicated an increase in risk. These trends occur because the home range for many of the species at risk includes critical areas that are not on Forest Service and Interior lands (such as valley bottoms). In addition, many of the features causing decline of species at risk populations or degradation of habitats may not be restored as part of fire-adapted ecosystem restoration (such as roads and off road vehicle disturbance or riparian restoration). Consequently, many of these conditions, critical to sustaining or improving native species populations and habitats that will not be restored will continue to cause decline in populations and habitat conditions. The only option that substantially improves conditions for native species at risk was option 8. This occurs because conditions were restored to a high enough level across large landscape extents of FSINTL that were substantial enough to affect the overall risk across all lands.

Smoke and air quality risk trends were very similar to native species endangerment trends. Current levels of relative risk are slightly less than for ecosystems as a whole, and for native species endangerment risk (table 11). This is generally because there are lower levels of current smoke and other particulate production as compared to historical or natural regimes. However, the amount of non-wildland smoke related particulates (vehicle and industrial emissions) tend to compete with wildland smoke particulates within regulated amounts. Options 2, 3 5, and 7 all resulted in increased risk from smoke to air quality, primarily from wildfire (table 11). Risks were maintained similar to current levels in options 3, 5, and 6, while 8 was the only option to substantially reduce risk. In a similar vein as native species at risk air quality is affected by all land ownerships, not just FSINTL. Option 8 results in large extents of FSINTL with lowered risk, thus substantially reducing the overall risk at airshed levels.

Current watershed and soil risks were somewhat less than ecosystem risks as a whole (table 11, .25 compared to .35). This is generally related to the small nature of site or stream course water and soil impairments that tend to be compensated for by unimpaired conditions on the larger surrounding landscape. In addition, landscape scale water and soil degradation that is a result of uncharacteristic soil cover (such as juniper invasion in sagebrush/grass) or uncharacteristic fire severity, often follow temporally behind increasing risks of fire regime condition class and HRV departure. Consequently, future risks may increase dramatically as larger extents degrade as a result of declining soil cover and large uncharacteristic wildfires. The trends of the options were similar to those of native species endangerment and smoke and air quality, with options 1, 2, 4, and 7 all resulting in increasing risk. Options 3, 5, and 6 maintained the current levels of risk, and option 8 substantially reduced risks to watersheds and soil.

Trends in permanent alteration and degradation of site quality for wildlands were substantially different from other variables (table 11). The current amount of alteration was estimated at about five percent of the Forest Service and Interior lands. This may be an underestimation, given findings in the Interior Columbia Basin (Hann et al. 1997). However, trends of options indicate that all options, except for 8, will result in double or tripling of areas with uncharacteristic wildfire that permanently degrades soil, invasions of exotics plants (such as cheatgrass) increasing risk of uncharacteristic wildfire, loss of soil from uncharacteristic soil cover (such as juniper invasion in sagebrush/grass), or loss of critical dominant ecosystem components (such as whitebark pine).

Overall HRV departure was found to be about 80 percent (table 11). Response trends were very similar to ecosystem health, which would be expected since HRV departure is an associated measure of potential for ecosystem sustainability (Hann and Bunnell 2001, Hann et al. 1997, 1998, 2001). Options 2, 3, and 7 result in increased risk, while options 3 and 4 tend to maintain risk at current levels. Options 5 and 6 reduce current risk, and option 8 substantially reduces risk.

Outcomes for Forest Service and Interior Prioritized Landscapes

Rieman et al. (2000) and Hann et al. (2001) demonstrated the value of prioritizing landscapes (watersheds) for integrated restoration in the ICBEMP, and Hann and Bunnell (2001) demonstrated the value of prioritization at a national scale. These results were confirmed by local landscape level assessment findings of Hann and Strohm (2003) and McNicoll and Hann (2004). The results from our assessment of a typical western U.S. landscape prioritized for restoration demonstrates how rapidly benefits can be realized at a local scale (figure 4). In this FSINTL cohesive strategy analysis we evaluated the results of the options as a whole to determine if our assumptions on which options can achieve a landscape strategy appeared to be sound. We have high confidence that options 5, 6, and 8 can be successfully implemented with a landscape strategy and produce the associated predicted outcomes. Our initial assumption that options 1 and 2 do not have sufficient funds to treat adjacent landscapes that provide a buffer between WUI landscapes and NWUI wilderness/roadless landscapes was confirmed. Option 7 focuses most funds at the WUI interface and preclude landscape scale mosaic treatments that could reduce risk from adjacent landscapes. Option 4 was found to be at more risk than we originally though of being able to successfully achieve a landscape strategy because of the high emphasis on WUI versus NWUI. However, with the assumptions of high emphasis on consistent step-down prioritization and planning, flexibility in applying funds at landscape scales, and monitoring and adaptive management, we decided to retain it as a landscape strategy option.

Using condition class 1 as a measure of response indicates that even given the current level of funding (option 3 or 4) a prioritized landscape could be restored to a predominance of condition class 1 within 15 years (figure 4). This would be the case even though the trend of options 3 and 4 across all Forest Service and Interior lands would not change. Responses would be substantially improved in the prioritized landscape than for the average outcomes in option 8 (highest option).

Much of the rapid response in a prioritized landscape depends on strategic scheduling of restoration and maintenance followed by wildland fire use (figure 5). Hann and Strohm (2003) and McNicoll and Hann (2004) both found the amount of restoration required in a landscape fitting the high priority assumptions was about 20 to 25 percent depending on the objective, and that maintenance of about 5 percent was required to not loose ground during the implementation period. The implementation period was typically 5 to 10 years. In the simulations for this analysis (figure 5) we found that the most effective strategy to produce rapid response of condition class 1 was to restore and reduce high-risk polygons adjacent to WUI, followed by restoration of accessible high-risk polygons in a landscape matrix that would reduce the rate of large fire spread within the landscape and from adjacent landscapes. In combination maintain the low risk polygons. As these efforts reduce the risk of large fire spread develop and implement a fire management plan for wildland fire use. Once the restoration objectives have been reached, somewhere between 10 and 30 years, a combination of light-on-the-land mechanical at the WUI, prescribed fire, and fire use can achieve an average of 2% per year to maintain the landscape.

From a WUI risk, large fire, and connected landscape perspective there are three types of landscapes: WUI landscape, NWUI adjacent landscape, and NWUI landscape buffered from the WUI landscape by the NWUI adjacent landscape (Hann and Strohm 2003). Trends of maintenance, restoration and wildland fire use with associated costs are interrelated and differ substantially between these three types of landscapes (figures 6, 7, and 8, table 12). Reduction of risk to a WUI landscape depends not only on restoration and reduction of risks adjacent to WUI and in the WUI landscape matrix, but also on reduction of risk from adjacent NWUI landscapes. The ability to use substantial wildland fire use in NWUI landscapes (often wilderness and roadless) depends on having a NWUI landscape buffer for the WUI landscape. NWUI landscapes adjacent to WUI landscapes often have critical values for municipal watersheds, habitats, and visuals that are very important to the public. Adjacent NWUI roadless and wilderness landscapes are often located in rugged terrain with potentials for uncharacteristically high fuel loading and summer storms and spring snow runoff where uncharacteristic fires can cause serious damage to water, soil, and critical habitats, as well as drive large wildfire runs into the WUI landscapes. It is critical that a successful cohesive strategy design the interrelated mix of priorities, scheduling, and treatments that can address the linkages between these different types of landscapes.

Trends of maintenance, restoration, fire use, and costs (M&RC) compared to wildfire suppression, prevention, initial attack, and associated structure losses and rehabilitation, and costs (SP&RC) have very different response curves (figures 6, 7, and 8); the M&RC curve rapidly increasing and then rapidly decreasing to a maintenance level; the SP&RC steadily declining following implementation of restoration and maintenance activities. The total cost index follows a somewhat similar trend to the M&RC curve during the first 5 to 10 years, but then becomes more similar to the PS&RC curve. The no treatment SP&RC curve has a relatively straight and increasing cost pattern.

The WUI landscape restoration tops out at approximately a 2 million dollar cost index in year 4 and 5, with a total restoration cost of about 7.4 million, dropping to a maintenance level of about 100,000 per year after year 10 (figure 6). The no treatment SP&RC curve has a relatively straight and upward trend to about year 30 when it flattens out. No treatment costs substantially outweigh costs of M&RC and SP&RC within this type of landscape. Restoration was dominated in the areas adjacent to WUI by mechanical, hand cutting, and prescribed fire treatments (typically hand piling), while mechanical and prescribed fire (typically broadcast burning) was dominant in the high-risk polygons with access throughout the WUI landscape. Prescribed fire and wildland fire use were dominant in other areas of the WUI landscape matrix.

In contrast, the NWUI landscape buffered from the WUI landscape tops out at only a 550,000 dollar cost index in years 4 and 5, with a total restoration cost of about 2.8 million (figure 8). The no treatment SP&RC curve has a relatively straight and upward curve till about year 15 when it flattens out, but because of risks to the adjacent NWUI and WUI landscapes of large fire spread, still has substantial associated costs that can be repaid through restoration and risk reduction. Restoration was dominated in the boundary areas, adjacent to the NWUI buffer landscapes, by hand cutting and prescribed fire treatments (both hand piling and broadcast burning), while wildland fire use was dominant throughout the rest of the landscape except in polygons where uncharacteristic hazards needed to be reduced with prescribed fire in order to allow fire use without severe negative effects.

As would be expected, the NWUI landscape buffers between the WUI and NWUI landscapes have intermediate trends (figure 7). The M&RC tops out at about 1.6 million during years 4 and 5, with a total restoration cost of about 5.1 million (figure 7). The no treatment SP&RC has a straight and upward curve till year 15 to 30 when it flattens out. Because of adjacent risks to WUI landscapes of large fire spread risks of high cost can be repaid through restoration and risk reduction. Restoration was dominated in these areas by mechanical and prescribed fire (typically broadcast burning) on the boundary areas with access, while prescribed fire and wildland fire use were dominant in other areas of the landscape matrix.

We would reemphasize that the landscape strategy of prioritization, scheduling, and design was found to be critical to development of a successful cohesive strategy to reduce risk to both people (communities) and ecosystems. People (communities) and the WUI were interrelated with ecosystems, even at long distances, and ecosystems were interrelated to people and the WUI. The successful strategy must account for the three different types of WUI and NWUI landscapes and their interrelationships with a mix of restoration, maintenance and wildland fire use appropriate for each type of landscape. Our broader scale prediction of outcomes is also supported by the landscape specific outcomes of Hann and Strohm (2003) and McNicoll and Hann (2004).

MANAGEMENT IMPLICATIONS

We conclude this paper with the following observations:

1) Nationally, the scale and distribution of unwanted wildland fires (wildfires) on FSINTL with associated risks to people (communities) and ecosystems will likely continue to escalate until uncharacteristic (hazardous) fuels, associated degraded ecosystem conditions, and high risk landscapes (watersheds) have been treated using a landscape strategy.

2) Prioritizing landscapes for restoration and maintenance can produce measurable and noticeable results at local levels, even though they might not appear to be substantial at the national scale.

3) Treatments should be strategically placed within a landscape strategy context to provide increased efficiency and effectiveness.

4) Unwanted wildland fires (wildfires) often impact the people (community) and ecosystems across large extents. Management programs that include landscape strategy treatments in both WUI and NWUI landscapes will likely be more successful at reducing the interrelated risks to both people and ecosystems.

5) Specifying a mix of funds to WUI and NWUI at a national level may preclude efficient design at local levels. Integrated fire, fuel, and resource prioritization and planning on local land and resource planning units linked to guidance from region, state, and national planning will likely provide the most efficient design.

6) Specifying a focus on restoration of condition class 3 at a national level may preclude maintenance of condition class 1 and low cost restoration of condition class 2. This will likely result in higher cost and reduce ability to produce a net increase in condition class 1 with reduced costs and risks at landscape scales.

Tables

Table 1 - Natural (historical) fire regime classes from Hardy et al. (2001) and Schmidt et al. (2002) as interpreted by the authors for this analysis

Fire Regime Class	Frequency (Mean Fire Return Interval)	Severity	Modeling Assumptions
I	0 – 35 years, Frequent	Surface Mixed	Open forest or savannah structures maintained by frequent fire; also includes frequent mixed severity fires that create a mosaic of different age post-fire open forest, early to mid-seral forest structural stages, and shrub or herb dominated patches (generally < 40 hectares (100 acres)).
II	0 – 35 years, Frequent	Replace-ment	Shrub or grasslands maintained or cycled by frequent fire; fires kill non-sprouting shrubs such as sagebrush which typically regenerate and become dominant within 10-15 years; fires remove tops of sprouting shrubs such as mesquite and chaparral, which typically resprout and dominate within 5 years; fires typically kill most tree regeneration.
III	35 – 200 years, Infrequent	Mixed Surface	Mosaic of different age post-fire open forest, early to mid-seral forest structural stages, and shrub or herb dominated patches (generally < 40 hectares (100 acres)) maintained or cycled by infrequent fire.
IV	35 – 200 years, Less Infrequent	Replace-ment	Large patches (generally > 40 hectares (100 acres)) of similar age post-fire shrub or herb dominated structures, or early to mid-seral forest cycled by infrequent replacement fire.
V	> 200 years, Rare	All Types	May have large patches (generally > 40 hectares (100 acres)) of similar age post-fire shrub or herb dominated structures, or early to mid to late seral forest cycled by rare replacement fire. In systems with little fire or only creeping torching fire effects the composition and structure may be very complex.

Table 2 – Fire regime condition classes (FRCC) from from Hardy et al. (2001) and Schmidt et al. (2002) as interpreted by the authors for this analysis. Historical Range of Variability (HRV) is the variability of regional or landscape composition, structure, and disturbances, during a period of time of several cycles of the common disturbance intervals, and similar environmental gradients, referring, for the United States, to a period prior to extensive agricultural or industrial development. Natural Range of Variability (NRV) - the ecological conditions and processes within a specified area, period of time, and climate, and the variation in these conditions, that would occur without substantial influence from mechanized equipment (synthesized from Hann and others 1997, Landres and others 1999, Morgan and others 1994, Swetnam and others 1999, Swanson and others 1994).

Class	NRV or HRV Departure	Description
Condition Class 1	None, Minimal, Low	Vegetation composition, structure, and fuels are similar to those of the natural or historical regime and do not pre-dispose the system to risk of loss of key ecosystem components. Wildland fires are characteristic of the natural or historical fire regime behavior, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are within the natural or historical range of variability. Smoke production potential is characteristic of the natural system.
Condition Class 2	Moderate	Vegetation composition, structure, and fuels have moderate departure from the natural or historical regime and predispose the system to risk of loss of key ecosystem components. Wildland fires are moderately uncharacteristic compared to the natural or historical fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are outside the natural or historical range of variability. Smoke production potential is moderately uncharacteristic compared to the volume and duration of the natural system.
Condition Class 3	High	Vegetation composition, structure, and fuels have high departure from the natural or historical regime and predispose the system to high risk of loss of key ecosystem components. Wildland fires are highly uncharacteristic compared to the natural or historical fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are substantially outside the natural or historical range of variability. Smoke production potential is highly uncharacteristic in comparison to the natural or historical volume and duration.

Table 3 – Program options for prediction of effects for the Forest Service and Interior cohesive strategy.

Program Options	Budget Level Millions of $	Percent Focus of Funds		Treatment in Thousands of Hectares (thousands of acres)	
		RTC	RTE	RTC	RTE
1 – no treatment	0	0	0	0	0
2 – FY 2000, Traditional Fuel Management Strategy	150	10	90	8 (20)	137 (338)
3 – FY 2002 Budget, RTE Emphasis, Landscape Strategy	400	33	67	124 (306)	1246 (3080)
4 – FY 2002 Budget, RTC Emphasis, Landscape Strategy	400	67	33	162 (400)	621 (1,535)
5 – Increase Budget, Decrease RTC, Stop Increase in RTE, Landscape Strategy	1,200	50	50	648 (1,600)	3113 (7,692)
6 – Increase Budget, Stop Increase in RTC, Stop Increase in RTE, Landscape Strategy	870	31	69	162 (400)	3113 (7,692)
7 – FY 2002 Budget, Emphasis on RTC, WUI Buffer Strategy	400	90	10	217 (537)	188 (465)
8 – Increase Budget, Decrease RTC, Decrease RTE, Landscape Strategy	1,400	43	57	315 (778)	4670 (11,538)

FY – fiscal year
RTE – risk to ecosystem
RTC – risk to communities (WUI)

Table 4. Fire Regime Condition Classes (FRCC) from Hardy et al. (2001) and Schmidt et al. (2002), Menakis et al. (2003), and Menakis et al. (2004) for 424 million acres of Forest Service and the Department of the Interior public lands across the CONUS lower 48 states.

FRCC	Version	CC1%	CC2 %	CC3 %	Total %
Hardy et al. 2001, Schmidt et al. 2002	2000	46	37	17	100
Menakis et al. 2003	Adjusted for Cheatgrass	44	34	22	100
Menakis et al. 2004	Relative FRCC	42	28	30	100

Table 5. Fire regime condition classes (FRCC) from finer scale landscape analyses on Forest Service and Interior public lands.

FRCC	Area	Ecosystems	CC1%	CC2 %	CC3 %	Total %
Hann et al. 2003	Interior Columbia Basin	Semi-desert to shrub-steppe to forest to alpine	16	57	27	100
Hann 2004	Western U.S. Samples	Southwest, Great Plains, Great Basin, Rocky Mts.	5	20	75	100
McNicoll & Hann 2004	Box Creek Watershed	Sagebrush to mixed conifer to alpine	12	35	53	100
Hann and Strohm 2003	Trout West Watershed(s)	Ponderosa pine to mixed conifer	2	90	8	100

Table 6. Fire regime condition classes (FRCC) adjusted for this analysis by the authors for 424 million acres of Forest Service and Interior public lands across the CONUS lower 48 states to account for finer scale conditions with a comparison to the most recent coarse-scale mapping (Menakis et al. 2004). The adjustment attempts to account for differences between coarse- and fine-scale data.

FRCC	Version	CC1%	CC2 %	CC3 %	Total %
This Analysis	Adjusted by Authors	20	35	45	100
Menakis et al. 2004	Relative FRCC – Most Recent Coarse-scale Version	42	28	30	100

Table 7. Assumptions for prioritization, planning, and implementation monitoring core data in order to achieve predicted effects of scenarios for the cohesive strategy. Assume to be implemented within 5 year transition period.

Planning Scale	Type of Planning	Variables	Extent	Methods	Scale	Accuracy
National	Program Strategy & Budget	Core	CONUS & Alaska Complete	Consistent LANDFIRE	30-meter pixel aggregate	60-80%
Administrative Unit	Forest, Land, and Fire Management	Core Plus Administrative Plan	Administrative Unit & Cumulative Effects Area	Compatible w/ Core Data Standards	30-meter/ stand polygon	70-90%
Local	Project	Core Plus Local Planning	Project Landscape/ Watershed	Compatible w/ Core Data Standards	30-meter/ stand polygon	100% for Treated Polygons; 80% other.

Table 8. Assumptions for restoration and maintenance of fire-adapted federal public lands to simulate outcomes for budget and emphasis options.

Option	Name	Prioritization & Design Strategy	WUI Landscape	NWUI Landscape
1	No Treatment No Action (0 million)*	Non-applicable (0:0)** (0:0)***	SR-90 R0/0/0	SR-90 R0/0/0
2	FY 2000 Level (150 million)	Traditional (10:90) (15:140)	SR-50 R-0.1/0.3/0.3	SR-50 R-0.5/0.9/0.9
3	FY 2002 Level RTE Emphasis (400 million)	Landscape (33:67) (130:270)	SR-90 R-1/2.5/2.5	SR-90 R-1/1.8/1.8
4	FY 2002 Level RTC Emphasis (400 million)	Landscape (67-33) (270:130)	SR-90 R-2.5/7.5/7.5	SR-90 R-0.5/1/1
5	Decrease RTC; Maintain RTE (1,200 million)	Landscape (50:50) (600:600)	SR-90 R-6/18/18	SR-90 R-2/4/4
6	Maintain RTC Maintain RTE (870 million)	Landscape (31:69) (270:600)	SR-90 R-2.5/7.5/7.5	SR-90 R-2/4/4
7	Emphasis on WUI (400 million)	WUI Focus (10:90) (360:40)	SR-90 R-1/0.6/0.6	SR-90 R-0.5/.2/.2
8	Decrease RTC: Decrease RTE (1, 400)	Landscape (600:800)	SRA-90 R-8/22/22	SR-90 R-4/6/6

* (total fuel management budget)
** (WUI: NWUI fuel budget percentage)
*** (WUI: NWUI fuel budget in millions)
FY – fiscal year; Oct 1 – Sept 30
RTE – risk to ecosystems
RTC – risk to communities
SR-xx –suppression resources available at xx percent of most efficient level
R-x/x/x – ratio of maintain (CC1): restore (CC2); restore (C3); ratios determined by most cost-effective combination of maintain and restore of CC1, 2, and 3 for the option; effectiveness measured by WUI landscape people and ecosystem risk and NWUI landscape ecosystem risk; costs measured by sum of fire and fuel management maintenance, restoration, fire suppression, other resource management vegetation-fuel management contributions, and burned area rehabilitation

Table 9. Assumptions on Risk and Opportunity Prioritization for prioritization of a watershed for restoration.

Risk/Opportunity Variable	Rating
Landscape (watershed) fire regime condition class	2 or 3
Wildfire occurrence risk	M or H
Wildland urban interface risk*	M or H
Long-term smoke risk to air quality	M or H
Short-term smoke risk to air quality from restoration	L
Long-term water and soil risk from uncharacteristic fire	M or H
Short-term water and soil risks from restoration	L
Long-term native species risk from uncharacteristic fire/habitats	M or H
Short-term native species risks from restoration	L
Altered sites from uncharacteristic wildfire or soil cover	M or H
Cost-effectiveness	H
Urban interface state & private risk reduction collaboration	M or H

*Wildland urban interface risk defined as the amount of perimeter risk of the watershed sustaining an unwanted wildland fire with uncharacteristic behavior, effects, firebrand spotting into WUI (within perimeter of structures and utilities), and associated degradation of air, water, habitats, and aesthetics.

Table 10. Assumptions on planning and treatment design for the assessment of outcomes for the prioritized landscape.

Assumption
20-40% of watershed treated with prescribed fire, mechanical, or wildland fire use in first 10 years with associated weed control and maintenance in order to improve by at least one fire regime condition class
Treatment patch selection based on priority for reducing uncharacteristic wildfire spread, fire regime condition class, and ecosystem benefits
Treatment design mimics or represents natural landscape terrain/patch patterns

Table 11. Results of 8 options across all 172 million hectares (424 million acres) Forest Service and Interior lands in the contiguous lower 48 states after 15 years.

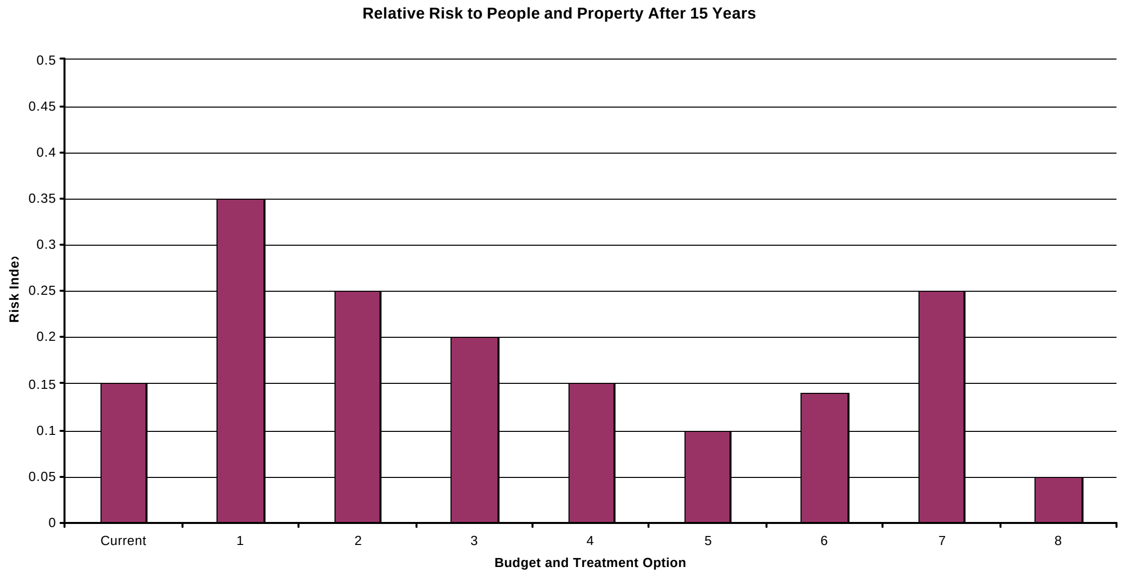
Option	CC 1	CC 2&3	P&P	NSE	S&AQ	W&S	ALT	HRV Dep	EH	UWF	M&RC	SP&RC
Current	20	80	.15	.35	.3	.25	.05	.8	.35	.34	390	3,046
1	15	85	.35	.5	.35	.35	.15	.85	.44	.47	0	3,674
2	15	85	.25	.45	.35	.3	.15	.85	.42	.41	150	3,265
3	20	80	.2	.4	.3	.25	.15	.8	.38	.33	400	2,582
4	20	80	.15	.45	.35	.3	.15	.8	.41	.37	400	2,804
5	30	70	.1	.4	.3	.25	.1	.7	.35	.24	1,200	1,991
6	30	70	.14	.4	.3	.25	.1	.7	.37	.28	868	2,171
7	15	85	.25	.5	.35	.3	.15	.85	.43	.43	400	4,050
8	50	50	.05	.25	.2	.2	.05	.5	.24	.15	1,400	1,200

CC 1 – percent fire regime condition class 1 after 15 years
CC 2 & 3 – percent fire regime condition class 2 and 3 after 15 years
P&P – wildland urban interface (WUI) risk to people and property
NSE – native species endangerment risk; habitat and populations
S&AQ – smoke and air quality risk
W&S – water and soil risk
ALT – altered sites; degraded soils
HRV Dep – risk of natural (historical) range of variability departure
EH – ecosystem health and sustainability risk
UWF – unwanted wildland fire and cost index M&RC – maintenance and restoration cost index (millions of dollars)
M&RC – maintenance and restoration cost index
SP&RC – suppression, prevention, initial attack, rehabilitation, and property loss cost index (millions of dollars)

Table 12. Results for restoration of a typical high priority western U.S. WUI landscape (watershed) after 15 years.

Option	CC 1	CC 2&3	P&P	NSE	S&AQ	W&S	ALT	HRV Dep	EH	M&RC	SP&RC
Current	20	80	.15	.35	.3	.25	.05	.80	.35	.11	.09
15 yr	70	30	.1	.2	.15	.1	.05	.70	.24	.09	.08
30 yr	80	20	.005	.15	.1	.1	.04	.60	.20	.02	.02
100 yr	90	10	.001	.05	.05	.05	.01	.40	.11	.01	.01

CC 1 – percent fire regime condition class 1 at 15 years
CC 2 & 3 – percent fire regime condition class 2 and 3 at 15 years
P&P – wildland urban interface (WUI) risk to people and property
NSE – native species endangerment risk; habitat and populations
S&AQ – smoke and air quality risk
W&S – water and soil risk
ALT – altered sites; degraded soils
HRV Dep – risk of natural (historical) range of variability departure
EH – ecosystem health and sustainability risk
M&RC – maintenance and restoration cost index
SP&RC – suppression, prevention, initial attack, rehabilitation, and property loss cost index
NA – not applicable to index calculation



Figures

Figure 1. Risk to people and property on Forest Service and Interior lands for comparison of cohesive strategy budget and treatment options on 172 million hectares (424 million acres) in the contiguous lower 48 states.

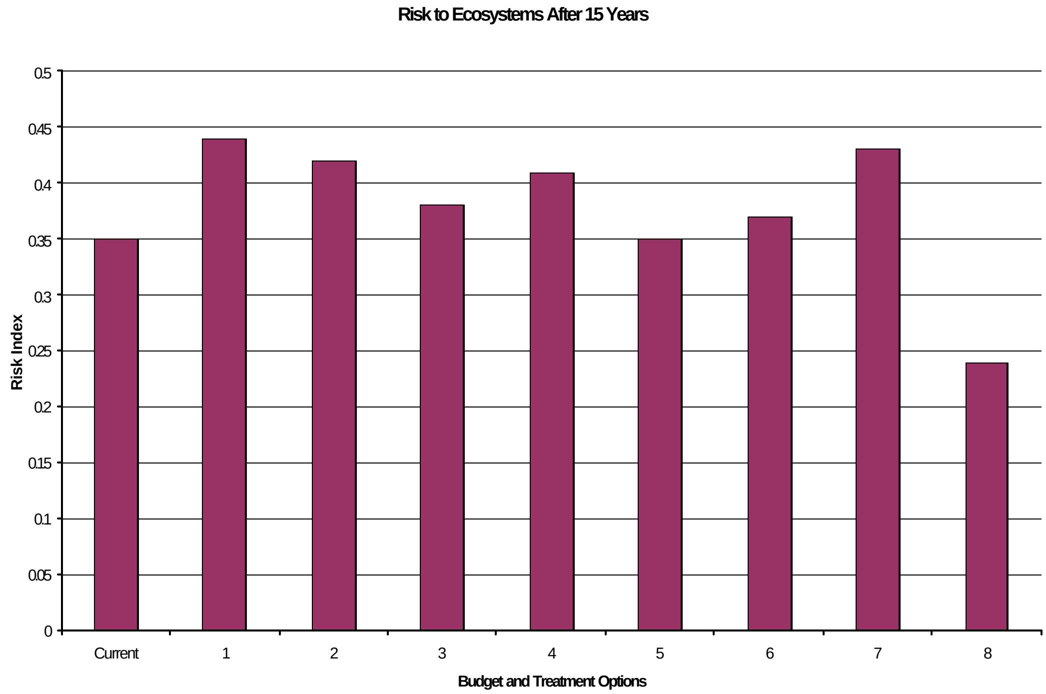


Figure 2. Risk to ecosystem health and sustainability on Forest Service and Interior lands for comparison of cohesive strategy budget and treatment options on 172 million hectares (424 million acres) in the contiguous lower 48 states.

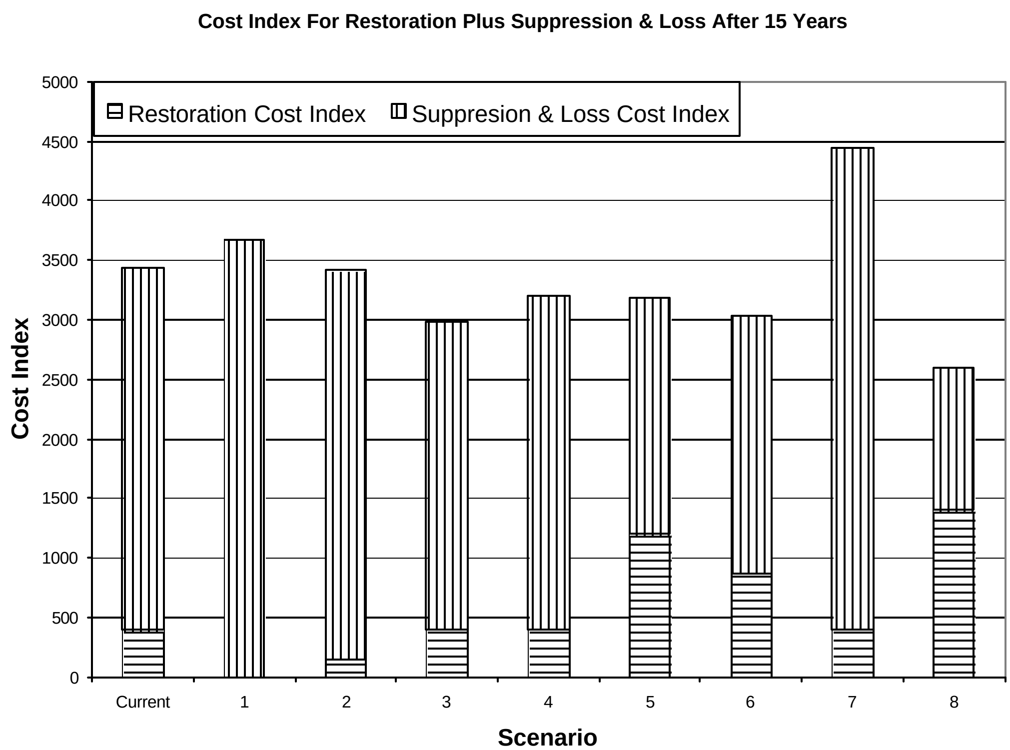


Figure 3. Restoration plus suppression and loss cost index on Forest Service and Interior lands for comparison of cohesive strategy budget and treatment options on 172 million hectares (424 million acres) in the contiguous lower 48 states.

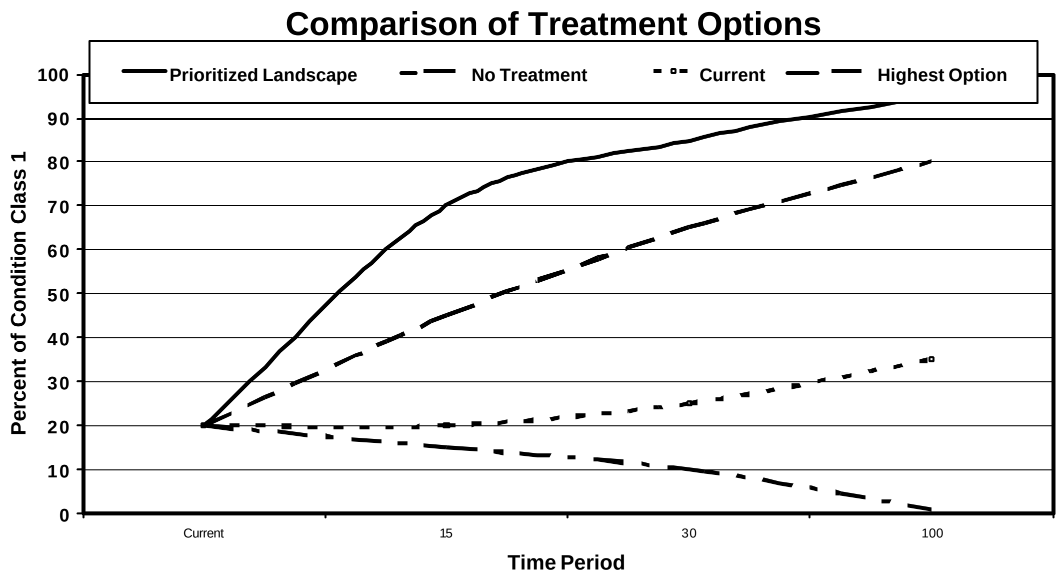


Figure 4. Trends of condition class 1 on a typical western U.S. Forest Service and Interior landscape (watershed) prioritized for restoration, compared to no treatment, current levels, and highest option trends across all 172 million hectares (424 million acres) of Forest Service and Interior Lands. Results illustrate the value of prioritizing landscapes and focusing restoration efforts within these areas rather than scattering treatments across the whole land base. Applies to restoration in options 3, 4, 5, 6, and 8. Not applicable to options 1, 2, and 7 because of insufficient funds to treat adjacent landscapes (watersheds) that provide a buffer between WUI landscapes (watersheds) and wilderness and roadless landscapes (watersheds).

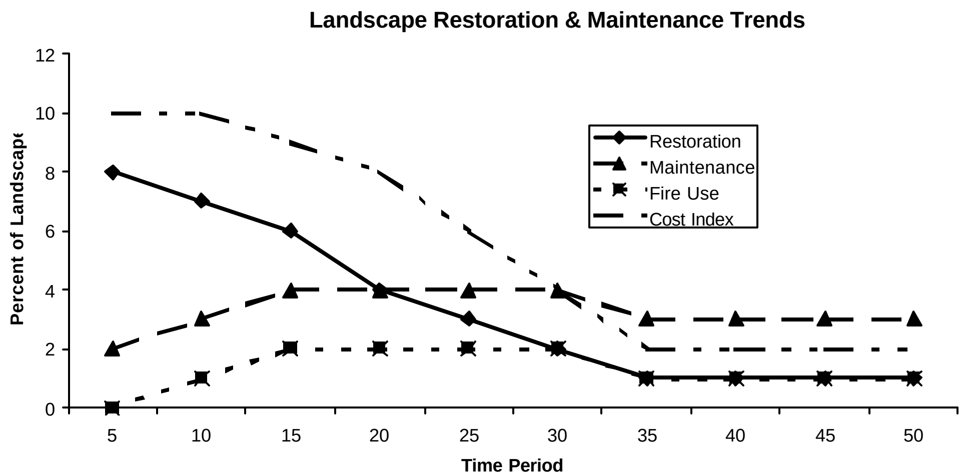


Figure 5. Percent of land that can be treated with restoration, maintenance, and wildland fire use on a typical western U.S. Forest Service and Interior landscape (watershed) prioritized for restoration. Results illustrate the strategy of conducting restoration followed by a ramp-up of maintenance and wildland fire use with associated trends in decrease of cost. Applies to restoration in options 3, 4, 5, 6, and 8. Not applicable to options 1, 2, and 7 because of insufficient funds to treat adjacent landscapes (watersheds) that provide a buffer between WUI landscapes (watersheds) and wilderness and roadless landscapes (watersheds).

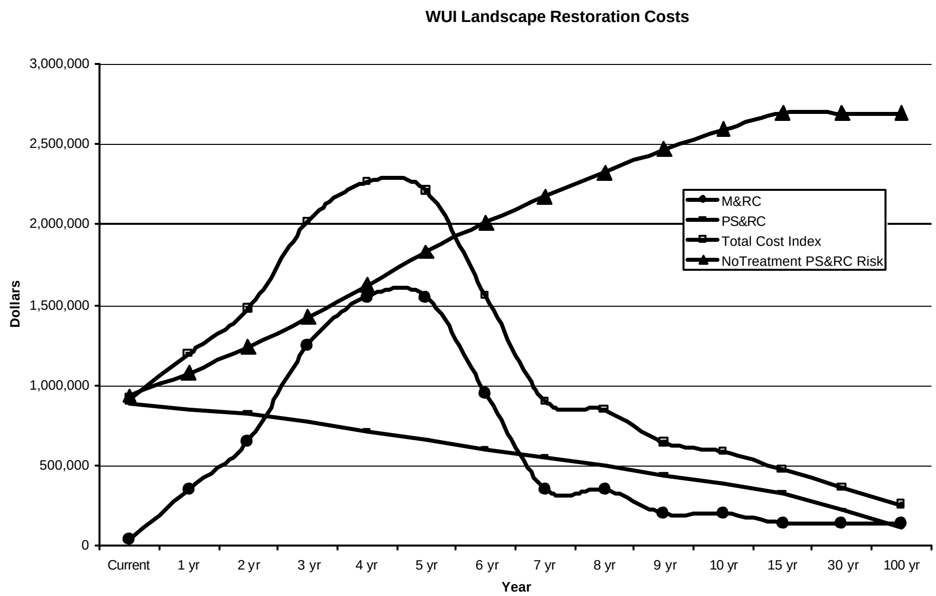


Figure 6. Trends of maintenance, restoration, and wildland fire use and associated costs (M&RC) over time in a typical western U.S. wildland urban interface (WUI) landscape (watershed) prioritized for restoration, with associated trends of suppression cost risks (PS&RC), total cost (sum of M&RC and PS&RC), and no treatment cost risk (PS&RC). Applies to restoration in options 3, 4, 5, 6, and 8. Not applicable to options 1, 2, and 7 because of insufficient funds to treat adjacent landscapes (watersheds) that provide a buffer between WUI landscapes (watersheds) and wilderness and roadless landscapes (watersheds).

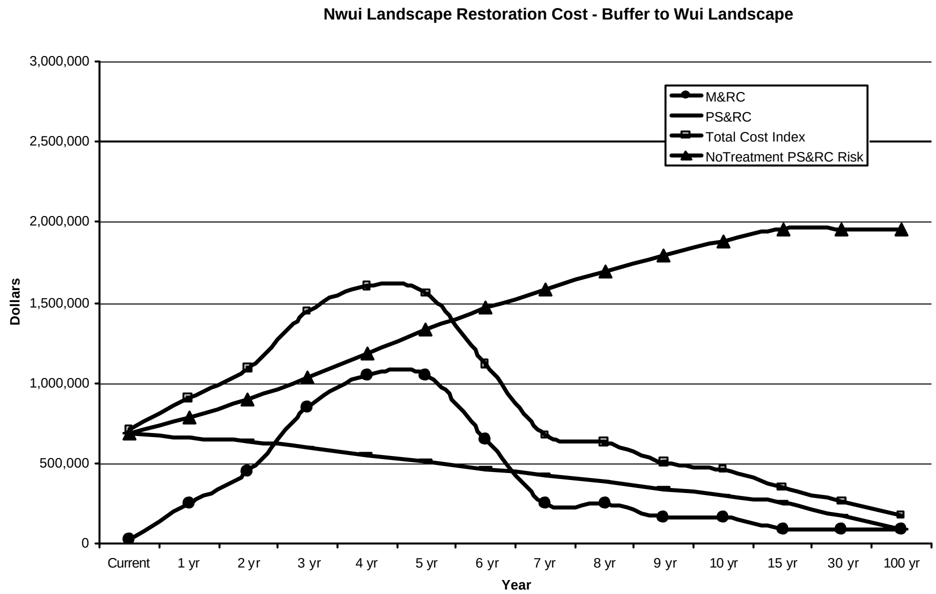


Figure 7. Trends of maintenance, restoration, and wildland fire use and associated costs (M&RC) over time in a prioritized non-wildland urban interface (NWUI) adjacent to a wildland urban interface (WUI) landscape (watershed). Also associated trends of suppression cost risks (PS&RC), total cost (sum of M&RC and PS&RC), and no treatment cost risk (PS&RC). Applies to restoration in options 3, 4, 5, 6, and 8. Not applicable to options 1, 2, and 7 because of insufficient funds to treat adjacent landscapes (watersheds) that provide a buffer between WUI landscapes (watersheds) and wilderness and roadless landscapes (watersheds).

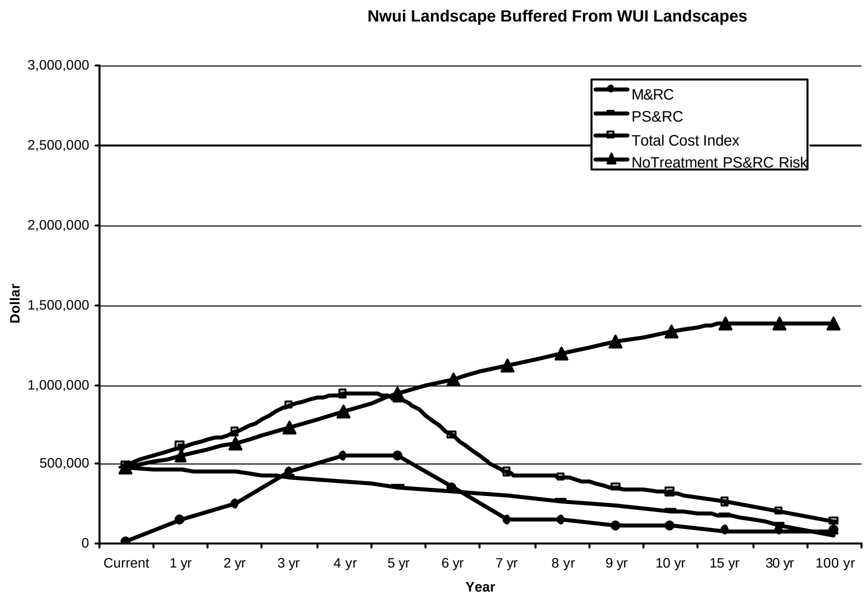


Figure 8. Trends of maintenance, restoration, and wildland fire use and associated costs (M&RC) over time in a prioritized non-wildland urban interface (NWUI) buffered by NWUI landscapes from WUI landscapes. Also associated trends of suppression cost risks (PS&RC), total cost (sum of M&RC and PS&RC), and no treatment cost risk (PS&RC). Applies to restoration in options 3, 4, 5, 6, and 8. Not applicable to options 1, 2, and 7 because of insufficient funds to treat adjacent landscapes (watersheds) that provide a buffer between WUI landscapes (watersheds) and wilderness and roadless landscapes (watersheds).

Literature Cited

Agee, James K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Allen T.F.H.; Hoekstra, T.W. 1992. Toward a unified ecology. New York: Columbia University Press. 384 p.

Andrews, Patricia L., Chase, Carolyn H. 1989. BEHAVE: fire behavior prediction and fuel modeling system—BURN sub-system, Part 2. USDA For. Serv. Gen. Tech. Rep. INT-260. 93 p.

Bailey, Robert G. 1995. Description of the ecoregions of the United States. 2d ed. revised and expanded. Misc. Pub. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p. + United States [Ecoregions] map; 1:7,500,000.

Beukema, S.J., and W.A. Kurz. 2000. Vegetation dynamics development tool and user's guide, version 4.0. ESSA Technologies Ltd., Vancouver, BC, Canada.

Caprio, A.C., Graber, D.M. 2000. Returning fire to the mountains: can we successfully restore the ecological role of pre-Euroamerican fire regimes to the Sierra Nevada? In: Cole, D. N.; McCool, S.F. 2000. Proceedings: Wilderness Science in a Time of Change. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 12 p.

Cohen, Jack. D. 2000. Preventing disaster: home ignitability in the wildland-urban interface. Journal of Forestry 98 (3): 15-21.

Crone, Lisa K., Richard W. Haynes. 2001. Socioeconomic evaluation of broad-scale land management strategies. Forest Ecology and Management. 153: 147-160.

Egler, F.E. 1954. Vegetation science concepts. I. Initial floristic composition, a factor in old-field vegetation development. Vegetatio. 4:412-417.

Elmore, D.W., Kovalchik, B. L. Jurs, L.D. 1994. Restoration of riparian ecosystems. *In*: Everett, R.L. (compiler). Volume 4: Restoration of stressed sites, and processes, Eastside Forest Ecosystem Health Assessment, pages 87-92.. Gen. Tech. Rep. PNW-GTR-330. Portland, OR: USDA, Forest Service, Pacific Northwest Research Station. 123 p.

Flather, C.H., Joyce, L.A., Bloomgarden, C.A. 1994. Species endangerment patterns in the United States. Gen. Tech. Rep. RM-GTR-241. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 42 p.

Flather, C.H., Knolwes, M.S., Kendall, I.A. 1998. Threatened and endangered species geography: characteristics of species hotspots in the conterminous United States. BioScience 48(5): 365-376.

Finney, Mark A. 1998. FARSITE: Fire Area Simulator —Model development and evaluation. USDA Forest Service General Technical Report RMRS-GTR-4. 47 p.

Finney, Mark A. and Jack Cohen. 2003. Expectation and evaluation of fuel management objectives. In proceedings *Conference on Fire, Fuel Treatments and Ecological Restoration: Proper Place, Appropriate Time*. April 16-18, 2002, Ft. Collins, Colorado. Gen. Tech. Rep. RMRS-GTR-XXX. Ft Collins, CO: U.S. Department of Agriculture, Forest Ser-vice, Rocky Mountain Research Station, xx p. [In Press].

Forman, Richard T.T., Godron, Michael. 1986. Landscape Ecology. John Wiley and Sons. NY. 619 pages.

Gruell, George E. 1983. Fire and vegetative trends in the Northern Rockies: interpretations from 1871-1982 photographs. Gen. Tech. Rep. INT-158. U.S. Department of Agriculture, Forest Service. Intermountain Forest and Range Experiment Station, Ogden, UT. 117 p.

Hann, W.J. 2004. Mapping fire regime condition class: a method for watershed and project prioritization, planning, and implementation. October, 1999 Tall Timbers Fire Ecology Conference, Kananaskis, Alberta. [In Press].

Hann, W.J., Bunnell, D.L. 2001. Fire and land management planning andimplementation across multiple scales. International Journal of Wildland Fire. 10(3&4): 389–403.

Hann, Wendel.J., Strohm, Diane J. 2003. Fire regime condition class and associated data for fire and fuels planning: methods and applications. In proceedings *Conference on Fire, Fuel Treatments and Ecological Restoration: Proper Place, Appropriate Time*. April 16-18, 2002, Ft. Collins, Colorado. Gen. Tech. Rep. RMRS-GTR-XXX. Ft Collins, CO: U.S. Department of Agriculture, Forest Ser-vice, Rocky Mountain Research Station, xx p. [In Press].

Hann W.J.; Jones, J.L.; Karl, M.G. [et al.]. 1997. Landscape dynamics of the basin. In: Quigley TM, Arbelbide SJ, technical editors. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: volume 2. Gen Tech Rep PNW-GTR-405. Portland (OR): U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. p 337-1055.

Hann W.J., Jones, J.L., Keane, R.E., Hessburg, P.F., Gravenmier, R.A. 1998. Landscape dynamics. Journal of Forestry. 96(10): 10-15.

Hann, W.J., Hemstrom, M.A., Haynes, R.W., Clifford, J.L., Gravenmier, R.A. 2001. Costs and effectiveness of multi-scale integrated management. Forest Ecology and Management. 153: 127-145.

Hann, W. J., Wisdom, M.J., Rowland, M.M. 2003. Disturbance Departure and Fragmentation of Natural Systems in the Interior Columbia Basin. USDA Forest Service Research Note. Pacific Northwest Station, Portland, Oregon. [In press].

Hardy, Colin C., Schmidt, Kirsten M., Menakis, James P., Samson, R. Neil. 2001. Spatial data for national fire planning and fuel management. International Journal of Wildland Fire. 10(3and4): 353-372.

Haynes, Richard W., Horne, Amy L. 1997. Chapter 6: Economic assessment of the Basin. In: Quigley, Thomas M.; Arbelbide, Sylvia J., tech. eds. 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: volume 4. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 vol: 1715-1869. (Quigley, Thomas M., tech. ed.; The Interior Columbia Basin Ecosystem Management Project: Scientific Assessment).

Hemstrom, M.A., Korol, J.J., Hann, W.J. 2001. Trends in terrestrial plant communities and landscape health indicate the effects of alternative management strategies in the interior Columbia River basin. Forest Ecology and Management 153: 105-126.

Hessburg P.F., Smith, B.G., Kreiter, S.D. [et al.]. 1999. Historical and current forest and range landscapes in the interior Columbia River basin and portions of the Klamath and Great Basins. Part 1: linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. Gen.Tech. Rep. PNW-GTR-458. Portland (OR): U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 357 p. Keane R.E.; Long D.G.; Menakis, J.P.; Hann, W.J.; Bevins, C.D. 1996. Simulating course-scale vegetation dynamics using the Columbia River Basin Succession Model–CRBSUM, General Tech. Rep INT-GTR-340. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, 50 p.

Keane, Robert E., Arno, Stephen F., Brown, James K. 1989. FIRESUM-an ecological process model for fire succession in Western conifer forests. Gen. Tech. Rep. INT-266. Ogden, UT: US Dept. of Ag., Forest Service, Intermountain Research Station. 76 p.

Keane, Robert E., Long, Donald G., Menakis, James P. [et al.]. 1996. Simulating course-scale vegetation dynamics using the Columbia River Basin Succession Model—CRBSUM. Gen. Tech. Rep. INT-GTR-340. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 50 p.

Keane, Robert E., Garner, Janice L., Schmidt, Kirsten M., Long, Donald G., Menakis, James P., and Finney, Mark A. 1998. Development of input data layers for the FARSITE fire growth model for the Selway-Bitterroot Wilderness Complex, USA. Gen. Tech. Rep. RMRS-GTR-3. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 66 p.

Keane, Robert E., Mincemoyer, Scott A., Schmidt, Kirsten M., Long, Donald G., Garner, Janice L. 2000. Mapping vegetation and fuels for fire managementon the Gila National Forest Complex, New Mexico, [CD-ROM]. Gen. Tech. Rep. RMRS-GTR-46-CD. Ogden, UT: U.S. Department of Agriculture, Forest Ser-vice, Rocky Mountain Research Station, 126 p.

Keane, R.E., Rollins, M.G., McNicoll, C.H., Parsons, R.A. 2002. Integrating Ecosystem Sampling, Gradient Modeling, Remote Sensing, and Ecosystem Simulation to Create Spatially Explicit Landscape Inventories: The Landscape Ecosystem Inventory System. USDA Forest Service Rocky Mt Research Station, Ft Collins, CO. RMRS-GTR-92.61 pages.

Kessell, SR, Fisher WC. 1981. Predicting postfire plant succession for fire management planning. Gen. Tech. Rep. INT-94. Ogden (UT): U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Kurz, W.A., Beukema, S.J., Klenner, W., Greenough, J.A.; Robinson, D.C.E., Sharpe, A.D., Webb, T.M.2001. TELSA: The tool for exploratory landscape scenario analyses. J. Computers and Electronics in Agriculture. Presented at "The Application of Scientific Knowledge to Decision making in Managing Forest Ecosystems," May 3-7, 1999, Asheville, NC, USA. 17 p.

Landres, P.B., Morgan, P., Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications. 9(4): 1179-1188.

Leenhouts, Bill. 1998. Assessment of biomass burning in the conterminous United States. Conservation Ecology [online] 2(1):1-22. URL: http//www.consecol.org/vol2/iss1/art1.

Lee, Danny C., Sedell, James R., Rieman, Bruce E. [and others]. 1997. Broadscale assessment of aquatic species and habitats. In: Quigley, Thomas M.; Arbelbide, Sylvia J., tech. eds. 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: volume 3. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 vol: 1057-1713. (Quigley, Thomas M., tech. ed.; The Interior Columbia Basin Ecosystem Management Project: Scientific Assessment).

Mangan, R. 1999. Wildland fire fatalities in the United States: 1990-1998. Tech. Rep. 9951-2808-MTDC: USDA Forest Service, Missoula, Montana. 14 pp.

McNab, W. Henry, Avers, Peter E., comps. 1994. Ecological subregions of the United States: section descriptions. Washington, DC: U.S. Department of Agriculture, Forest Service.

McNicoll, Cecilia H., Wendel J. Hann. 2004. Multi-scale Planning and Implementation to Restore Fire Adapted Ecosystems, and Reduce Risk to the Urban/Wildland Interface in the Box Creek Watershed. October, 1999 Tall Timbers Fire Ecology Conference, Kananaskis, Alberta. [In Press].

Menakis, J.P., Cohen, J., Bradshaw, L. 2000. Mapping wildland fire risk to flammable structures for the conterminous United States. In: L.A. Brennan, et al. (eds.) National Congress on Fire Ecology, Prevention, and Management Proceedings, No. 1. Tall Timbers Research Station, Tallahassee, FL.

Menakis, James P., Dianne Osborne, Melanie Miller. 2003. Mapping departure from historic natural fire regimes caused by cheatgrass in the Great Basin. In proceedings *Conference on Fire, Fuel Treatments and Ecological Restoration: Proper Place, Appropriate Time*. April 16-18, 2002, Ft. Collins, Colorado. Gen. Tech. Rep. RMRS-GTR-XXX. Ft Collins, CO: U.S. Department of Agriculture, Forest Ser-vice, Rocky Mountain Research Station, xx p. [In Press].

Menakis, James P., Melanie Miller, Thomas Thompson. 2004. Mapping relative fire regime condition class for the western states. In Press: Proceedings of the 10th Biennial Forest Service Remote Sensing Applications Conference – Remote Sensing for Field Users. April 5-9, 2004. Salt Lake city, Utah. Ed. Jerry D. Greer. American Society for Photogrammetry and Remote Sensing (ASPRS). 12 pages.

Morgan, P., Aplet, G.H., Haufler, J.B. [et al.]. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. In: Sampson, N.; Adams, D.L., eds. Assessing forest ecosystem health in the inland west. New York: Haworth Press, Inc.: 87-111.

Morgan, P., Bunting, S.C., Black, A.E. [et al.]. 1996. Fire regimes in the interior Columbia River basin: past and present. Contract report. On file with: U.S. Department of Agriculture, Forest Service; U.S. Department of Interior, Bureau of Land Management; Interior Columbia Basin Ecosystem Management Project, 112 E. Poplar, Walla Walla, WA 99362.

Noble, I.R., Slatyer, R.O. 1977. Postfire succession of plants in Mediterranean ecosystems. In: Mooney, H.A.; Conrad, C.E., eds. Proceedings of the symposium-- environmental consequences of fire and fuel management in Mediterranean climate ecosystems. Gen. Tech. Rep. WO-3. Washington, DC: U.S. Dept. of Ag. Forest Service: 27-36.

Quigley, Thomas M., Haynes, Richard W., Graham, Russell T., tech. eds. 1996. Integrated scientific assessment for ecosystem management in the interior Columbia basin and portions of the Klamath and Great basins. Gen. Tech. Rep. PNW-GTR-382. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 303 p. (Quigley, Thomas M., tech. ed.; The Interior Columbia Basin Ecosystem Management Project: Scientific Assessment.)

Quigley, Thomas M., Arbelbide, Sylvia J., tech. eds. 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: volume 4. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 vol. (Quigley, Thomas M., tech. ed.; The Interior Columbia Basin Ecosystem Management Project: Scientific Assessment).

Quigley, Thomas M., Gravenmier, R.A., Hann, W.J. [and others]. 1999. Scientific evaluation of supplemental EIS alternatives by the Science Integration Team. Report on File. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Raphael, M.G., Marcot, B.G., Holthausen, R.S., Wisdom, M.J. 1998. Terrestrial species and habitats. Journ. For. 96(10):22-27.

Raphael, M.G., Wisdom, M.J., Rowland, M.M. [et al.]. 2001. Status and trends of habitats of terrestrial vertebrates in relation to land management in the Interior Columbia River Basin. Forest Ecology and Management 153: in press.

Reinhardt, Elizabeth, Keane, Robert E. , Brown, James K. 1997. FOFEM user's guide. Gen Tech. Rep. INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 65 p.

Rieman, B.E., Lee, D.C., Thurow, R.F., Hessburg, P.F., Sedell, J.R. 2000. Toward an integrated classification of ecosystems: defining opportunities for managing fish and forest health. Environmental Management. 25(4): 425-444.

Rieman, Bruce, Peterson, James T., Clayton, James, Howell, Philip, Thurow, Russell, Thompson, William, Lee, Danny. 2001. Evaluation of potential effects of federal land management alternatives on trends of salmonids and their habitats in the interior Columbia River Basin. Forest Ecology and Management. 153: 43-62.

Rockwell, D. 1998. The nature of North America: rocks, plants, and animals. New York: The Berkley Publishing Group. 379 p.

Schmidt, Kirsten M, Menakis, James P., Hardy, Colin C., Bunnell, David L. , Hann, Wendel J. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-GTR-87CD/WWW. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. [In Press.]

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 94:1189–1206.

Swanson, F.J., J.A. Jones, D.O. Wallin, J.H. Cissel. 1994. Natural variability-implications for ecosystem management. Pages 80-94 *in* Volume II Ecosystem management: principles and applications. General Technical Report PNW-GTR-318, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Tausch, Robin T., Wigand, Peter E., Burkhardt, J. Wayne. 1993. Viewpoint: plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the quaternary? Journal of Range Management. 46(5): 439-447.

Turner, M.G., O'Neill, R.V., Garner, R.H., Milne, B.T. 1989. Effects of changing spatial scale on the analysis of landscape pattern. Landscape Ecology. 3: 153-163.

Turner, Monica G., Hargrove, William W., Gardner, Robert H., Romme, William H. 1994. Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. J. of Vegetation Science. 5:731-742.

USDA (US Department of Agriculture Forest Service). 2000. Policy implications of large fire management: a strategic assessment of factors influencing costs. USDA Forest Service, Washington D.C. 43 p. www.fs.fed.us/fire .

USDA (U.S. Department of Agriculture, Forest Service). 2001. Protecting people and sustaining resources in fire-adapted ecosystems: a cohesive strategy. The Forest Service Management Response to General Accounting Office Report, GAO/RCED-99-65. USDA Forest Service, Washington D.C. 86 pp. www.fs.fed.us/fire .

USDA, USDI (U.S. Department of Agriculture Forest Service, U.S. Department of the Interior). 2002a. Restoring fire adapted ecosystems on federal land, a cohesive strategy for protecting people and natural resources. National Interagency Fire Center, Boise, ID. [Draft On File]. www.nifc.gov .

USDA, USDI (U.S. Department of Agriculture Forest Service, U.S. Department of the Interior). 2002b. A collaborative approach for reducing wildland fire risks to communities and the environment, 10-year comprehensive strategy. US Department of Agriculture Forest Service, US Department of Interior, Washington DC. 21 p. www.fireplan.gov .

USDA, USDI (U.S. Department of Agriculture Forest Service, U.S. Department of the Interior). 1995. Federal wildland fire management, policy and program review– final report. National Interagency Fire Center, Boise, ID. 45 pp. www.nifc.gov/fire_policy.

USDI (U.S. Department of the Interior). 2001. Integrating fire and natural resource management – a cohesive strategy for protecting people by restoring land health-Final Draft. On File USDI Land Management Agencies (BLM, NPS, FWS, BIA, BOR), Washington D.C. 52 p.

USDI and others (U.S. Department of Interior, U.S. Department of Agriculture Forest Service, and other fire policy affected agencies and National Association of State Foresters (NASF)). 2001. Review and update of the 1995 federal wildland fire management policy. National Interagency Fire Center, Boise, ID. 78 p. www.nifc.gov .

USGAO (U.S. General Accounting Office). 1999. Western National Forests: a cohesive strategy is needed to address catastrophic wildland fire threats. GAO/RCED-99-65. US General Accounting Office, Washington DC. 60 p. www.gao.gov .

USGAO (U.S. General Accounting Office). 2002. Wildland fire management, improved planning will help agencies better identify fire-fighting preparedness needs. GAO-02-158. US General Accounting Office, Washington DC. 32 p. www.gao.gov .

Wisdom, M.J., Wales, B.C., Holthausen, R.S., Hargis, C.D., Saab, V.A., Hann, W.J., Rich, T.D., Lee, D.C., Rowland, M.W. 1999. Wildlife habitats in forests of the interior northwest: history, status, trends , and critical issues confronting land managers. Transactions of 64 th North American Wildlife and Natural Resources Conference. 79-93.

Wisdom, M.J., Holthausen, R.S., Wales, B.C. [et al.]. 2000. Source habitats for terrestrial vertebrates of focus in the interior Columbia Basin: broad-scale trends and management implications. USDA Forest Service General Technical Report PNW-GTR-485. Pacific Northwest Research Station, Portland, Oregon.