Coupled Natural and Human Systems in Fire-Prone Landscapes: Interactions, Dynamics, and Adaptation

INTRODUCTION AND KEY QUESTIONS

Wildland fire policies in the U.S. are fragmented and broken and crying out for socio-ecological studies and solutions. A leading fire historian recently declared the "wildland-urban interface", a cornerstone concept in U.S. wildland fire policy, to be a "dumb term for a dumb problem" (Pyne 2008). The U.S. approach to dealing with wildfire has been to fragment the fire-prone landscape problem into a "wildland-urban interface (WUI)" under the influence of fire management agencies and a fire-prone wildland problem under the influence of land managers. The two fire worlds are often seen as socially, economically and institutionally separate, yet, they are clearly part of a single interconnected socio-ecological landscape. Lack of understanding of these connections can lead to policies that are suboptimal or even maladaptive (McCaffery 2004, Janssen et al. 2007). For example, fire suppression has increased the risk of high-severity fire and draws limited resources away from necessary ecological restoration work in wilder parts of the landscape (Pyne 1997). The cumulative effects of human activities, new policies, and climate change are making the problems worse and more costly. Despite the importance of this coupled-natural and human system (CNHS), very few studies of fire-prone systems have been conducted by integrated teams of social and ecological scientists. We seek to address that deficiency.

Our goal is to use systems models, integrated research, and collaborative learning to improve our understanding of how humans adapt (or not) to living in fire-prone forests and to learn how policies could be made more effective. Maladaptation by humans to fire-prone environments can come from poor understanding of ecological dynamics, risk-avoidance behaviors and people's limited ability to perceive risk (McCaffery 2004), as well as a rational discounting of perceived risk relative to other benefits gained from living in or near wildlands (e.g., Donovan et al. 2007). Strategies to adapt to fire-prone landscapes, such as fuel reduction activities, have emerged, but they can also lead to unintended consequences. For example, fuel treatments can increase carbon emissions (Mitchell et al. 2009) and increase invasive species, which in turn exacerbate the likelihood of high severity fire (Troy and Kennedy 2007). Fire suppression and fuel treatments may also lead to unintended *social* consequences, such as cultivating a false sense of security that may encourage greater development in or near fire-prone wildland areas and, in effect, subsidize risky behavior of homeowners who settle in fire-prone forests. **Our integrated socio-ecological approach will advance understanding of these complexities and feedbacks.**

Much of the expansion of the wildland-urban interface (WUI) in fire-prone landscapes has occurred in the western US, where the social and ecological systems are rapidly changing and spatially complex. But, interactions of humans and nature occur over a broader physical and social space than that defined the WUI. For instance, wildfires often start in wildlands and burn into the WUI and the management objectives across this gradient differ and compete for scarce resources. The wildlands and the WUI are an ecologically and socially interconnected system and policies that do not recognize these connections can have unintended consequences. **Our whole-landscape approach will focus on one of the core issues of fire policy problems.**

Social networks and institutions (Figure 1), which play a significant role in fire protection and conservation, must now adapt to a new fire management situation that includes wildfire use (variable suppression), WUI growth, climate change, and biodiversity concerns. **A novel**

dimension of our proposal is to learn how social networks and institutions affect the adaptive behavior of landowners and managers in fire-prone landscapes.

This study will focus on the adaptive behaviors of land management/landscape **actors** and the role of **institutions** and **social networks** in adaptation within a fire-prone landscape of central Oregon. Actors are the individual landowners and agencies that directly manage and shape the landscape. Institutions are the mechanisms that shape social norms and rules and mediate the behaviors of actors(Friedman and Hechter 1988). Social networks are sets of individuals and institutions and the interdependencies between them (e.g., information exchanges, resource transactions, beliefs and values) (Laumann and Knoke 1987). The presence of diverse social institutions and networks can increase the ability of coupled human-natural communities to adapt to disturbance (Folke et al. 2002). The proposed research will address three major questions:

1) **How do land management policies, social networks and institutions, and actor decisions interact to influence landscape dynamics and produce intended and unintended consequences for biodiversity and ecosystem services (e.g. carbon)?**

2) **How sensitive are landscape outcomes to feedbacks from social networks, socioeconomic institutions, landscape patterns, and alternative policies?**

3) **How might external drivers such as climate change and market forces alter landscape dynamics and the production of ecosystem goods and services?**

To address our questions we will use a spatial, systems approach, focusing on **feedbacks** within and between natural and human systems (Figure 1). We will explore interactions and evaluate scenarios using a relatively simple whole-system, multiagent model that integrates ecological, economic, and social variables (Figure 1). The whole-system model will be supported by: 1) component simulation models (e.g. fire behavior, development); 2) retrospective analysis of wildfire; 3) human surveys; and 4) analyses of landscape actors and social networks involved in wildfire and natural resources management. **Our study area in the eastern Cascade Range is ideal for this research. It has a diversity of land uses and actors (federal, private and tribal), a variety of social institutions, a range of fire-prone forest types, a recent history of wildfire, considerable social change, and highly**

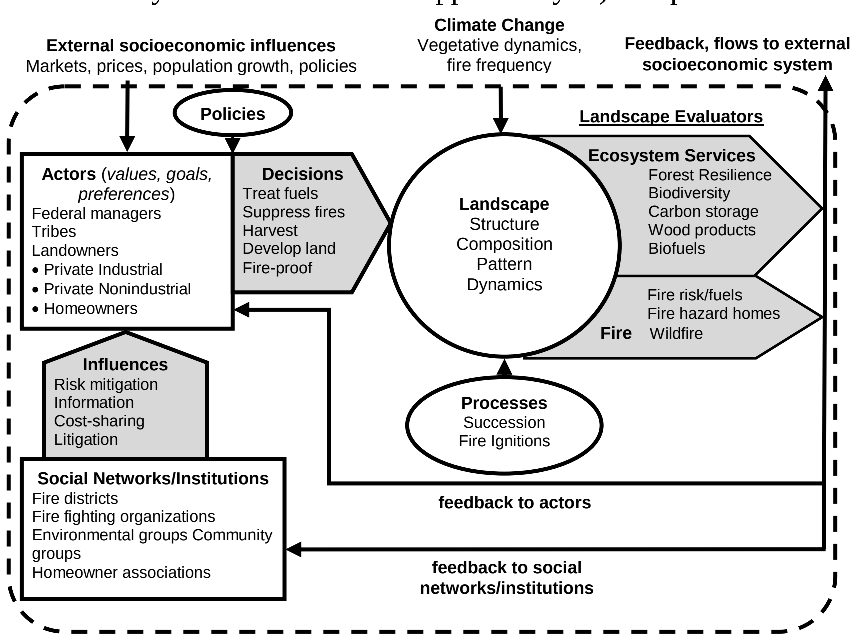

Figure 1. Coupled natural and human fire-prone system.

valued biodiversity. We will address our research questions at multiple spatial scales ranging from forest stands and rural communities to the entire landscape. The study area has been the focus of several recent ecological and socioeconomic studies that provide a solid foundation of data and scientific knowledge. We have assembled a broad, multidisciplinary team of university and Forest Service scientists with expertise in integrated systems modeling (Bolte and Spies); landscape ecology (Spies and Kennedy); silviculture (Bailey); fire modeling (Ager); anthropology (Charnley); sociology (Shindler, Hammer); political coalitions (Steel); economics and land use change (Albers, Kline), and wildfire education (Shindler). Our project management style, systems approach, and collaborative learning approach will help insure a high level of integration and impact.

BACKGROUND

Understanding fire-prone landscapes as a CNHS is important for several reasons: (1) they occur in many parts of the world; (2) humans are increasingly settling in these environments and homes are being destroyed by wildfire; (3) the area of fire is increasing in response to fuel accumulation and climate change (Westerling et al. 2006); (4) governments are spending billions of dollars on wildfire suppression, fuel treatments and post-wildfire recovery. In addition, the tradeoffs among ecosystem services in these landscapes are not well understood. For example, fuel treatments to reduce risk of high severity fire may also increase carbon emissions, even when wildfires are considered (Mitchell et al. 2009).

Several authors have hypothesized that fire-prone systems exhibit complex behaviors characterized by time lags (e.g., fire suppression leads to fuel buildup) (Chapin et al. 2003, Troy and Kennedy 2007), feedbacks and perverse incentives (e.g., subsidies of fuel treatment may encourage further development) (Rideout 2003), and indirect effects (e.g., fuel treatments in the WUI may reduce fuel reduction efforts in other more ecologically important parts of the landscape) (Troy and Kennedy 2007). These systems are further complicated by spatial and temporal complexity both in the biophysical and human components. For example, most fire-prone landscapes are characterized by vegetation and topographic mosaics that vary in fire regime including likelihood of high severity fire (Spies et al. 2006). Furthermore, the fuel pattern is not static, changing as a result of succession and natural and human disturbances. Similar complexity occurs on the human side where landscapes are a mixture of different actors (landowners) whose decisions are strongly influenced by social networks (e.g., fire protection and environmental groups) with different goals, management practices, and awareness of fire risk. Moreover, actor behavior can change over time as a result of demographic, economic and social forces including formal and informal learning.

Studies of risk perception indicate that individuals' awareness of and personal experiences with a hazard, and their understanding of the costs and benefits of taking risk-mitigating action, may be important factors in influencing their behavior (McCaffrey 2004). More specifically, decisions to take fire mitigation actions also depend on the extent to which landowners view their lands as vulnerable to wildland fire (Fried et al. 1999, Winter and Fried 2000), and the extent to which wildland fire is perceived as a risk that is controllable, catastrophic, or potentially fatal (McCaffrey 2004). Forest landowners who live in fire-prone forests as well as homeowners located in the WUI could bear greater responsibility for reducing fire risk and appear willing to pay for both public and private risk-reduction (Fried et al. 1999). Home ignitability—a function of materials, design, and fuel located within the immediate vicinity of homes—may be the principal factor in private property losses during wildfires (Cohen 1999, Cohen 2000). Thus, reducing fuel beyond immediate home sites may have little effect on likelihood of loss. Consequently, reducing fuels on federal lands to protect homes may be less effective than inducing homeowners to modify their immediate home sites.

Landowner decisions in fire-prone landscapes are characterized by two features: uncertainty about the timing, location, extent, and severity of future wildfires, and the location of their land within the biophysical and human landscape mosaics. Economic decision literature emphasizes irreversibility in decision making under risk or uncertainty (e.g. Dixit and Pindyck 1994). Both land management decisions, including development, and the impact of severe wildfire, can be irreversible. The spatial arrangement of land tenures (Bergmann and Bliss 2004), the values and uses of adjacent lands (Kline and Alig 2005, Albers 1996), and the perceived fire risk on site and on nearby lands all influence land management decisions. The spatial nature of our study and focus on factors that influence land use decisions, including intermediate social institutions, will allow us to explore these issues.

Although the WUI gets much of the attention, it is only one part of an ecologically and socially connected landscape. For example, ecosystem behavior and policies in wildlands can affect the WUI (e.g., fires initiated in wildlands can burn into settled areas), and focusing resources in the WUI can reduce resources available for meeting policy goals for the wildlands (e.g., ecological restoration). In the Pacific Northwest, large areas of old-growth forests in wildlands in semi-arid landscapes have been lost to fire and have not received the level of fuel treatment that many believe is necessary to reduce fire risk (Spies et al. 2006). Whole landscape studies are needed to better understand these interactions

From the social science perspective, wildfire research has focused largely on land management agencies (Canton-Thompson et al. 2006, Dale 2006), including public perceptions of their actions (Monroe et al. 2006, Toman et al. 2005), and individual landowners, especially homeowners (McCaffrey 2006). **Our study will significantly broaden the social component of fire-prone landscape research by examining understudied landowners (family forest owners and tribes), and the social networks and institutions (e.g., environmental organizations) that mediate land management actions and are important in relating social theory to social transformation (Giddens 1984, Castells and Cardoso 2006)**.

STUDY AREA

Given its ecological and social diversity and recent history, central Oregon is one of the best places in the U.S. to study fire-prone coupled systems. It also has a strong base of landscape research and existing spatial data bases. The 3.3 million ha region lies on the east slope of the Cascade Range, running from the crest on the west to the edge of the sagebrush steppe on the east (Figure 2). This ecologically diverse region could be viewed as a 50- to 100-km wide ecotone running from cold, wet subalpine forest types to very dry shrub-steppe (annual precipitation runs from >2000 mm to < 300 mm). The dominant forest type is ponderosa pine (*Pinus ponderosa*), which covers 1/3 of the area.

Fire Regimes. Fire regimes of the area are diverse, ranging from frequent low-severity fires (4-11 years) in the ponderosa pine type to infrequent (250 years) high-severity fires in the mountain hemlock type (Bork 1984, Simon 1991). Historically, the mixed-conifer types probably had low- to-moderate-severity fires at intervals of 5-25 years (Agee 1998, McKenzie et al. 2000). Recent research suggests that moderate- to high-severity fire may account for a larger share of fires than previously thought for this type (Hessburg et. al. 2005). Large wildfires account for most of the burning in the study area (Figure 2). For example, between 1910 and 2002 a mere 10% of the fires accounted for 74% of the total burned area (156,648 ha) on the Deschutes N.F. (Finney 2005). Fire frequency and loss of old-growth forest has been especially high in this region during the last decade. Between 1994 and 2003, thousands of hectares of old-growth forest in the eastern Oregon Cascades were lost to high- severity fire (Spies et al. 2006).

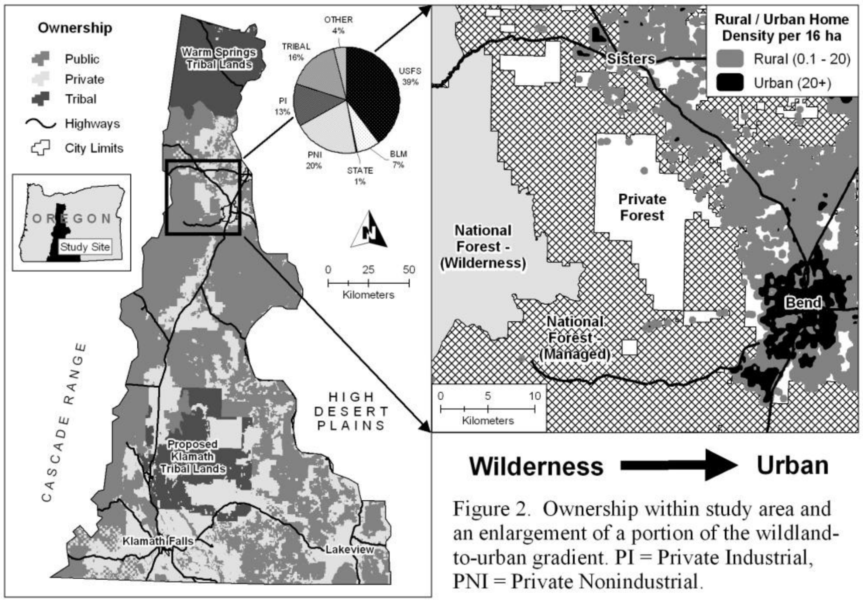

Figure 2. Ownership within study area and an enlargement of a portion of the wildland-to-urban gradient. PI = Private Industrial, PNI = Private Nonindustrial.

Biodiversity. The biodiversity of this region is quite high given its ecotonal character. We will focus on six key components: habitat suitability for three species of wildlife (Northern Spotted Owl (*Strix occidentalis caurina)*, mule deer (*Odocoileus hemionus*), and White-headed Woodpecker (*Picoides albolavartus*)), potential for invasive species, landscape-level forest resilience, and forest structural diversity. The Northern Spotted Owl is a federally listed species whose range covers parts of the western portion of the study area, mainly in the mixed- conifer zone. Owl habitat is characterized by dense, multi-layer forests with large trees—exactly the kind of forest that develops under fire suppression and which is at high risk to loss from high-severity fire (Spies et al. 2006). Protecting owl habitat has significantly altered forest management on federal lands in the region in the last 15 years. Mule deer, a popular game species, is more common in lower elevation ponderosa pine forests where development pressures on private lands may be strongest. The effects of concentrated fuel treatments on private lands and nearby federal lands could reduce forage and hiding cover for the species and negatively affect its winter range. The White-headed Woodpecker is listed as a sensitive species in Oregon. Its habitat is characterized by mature to old-growth ponderosa pine forests, much of which has been lost to logging, wildfire, fire suppression and development. Invasion by non-native plants is a serious concern in the study area. Invasive plants can alter fire regimes (Whisenant 1990, Brooks et al. 2004), displace native plant species (Ortega and Pearson 2005) and degrade wildlife habitat (Trammell and Butler 1995), yet forest managers face a paradox when it comes to controlling the spread of invasive plants. The very stand conditions brought about by fire exclusion and that pose a high risk for severe wildfire also appear to limit the spread of invasive species (Keeley 2006). Fire-resilient landscapes are characterized by forest structures and composition that promote fire regimes that are consistent with the long-term dynamics of vegetation communities. Historical practices including logging and fire suppression have probably shifted the distribution of risk toward higher severity fire.

Socioeconomic conditions. The socioeconomic and landscape context varies markedly across the study region. It includes the rapidly developing, amenity-oriented sub-region of Bend/Sisters to the more rural, natural resource extraction-oriented sub-region around Lakeview, and the semi-rural area of Chiloquin-Klamath Falls with its strong tribal presence and history. Before the recent economic downturn, Deschutes County, including Bend and Sisters, was the 14th fastest growing metropolitan area in the U.S., culminating a three decade, 271% increase in population. The Bend/Sisters region best epitomizes the "new West" (Hansen et al. 2002) in Oregon with declines in natural resource extractive industries; increased tourism, outdoor recreation, and amenity-based in-migration (Judson et al. 1999, Laskin 2004, Preusch 2004). The Klamath Falls/Chiloquin region has experienced slower population growth—30% since 1970—yet still has received notable in-migration of retirees and second-home buyers. Its geographic similarities with the Bend/Sisters region indicate that it could experience similar rapid growth in the future. Lake County, including Lakeview, has experienced lower population growth—23% since 1970, with its economy remaining focused on extractive industries. Just 2.4% of the three-county area is classified as WUI, although it varies considerably by county with WUI comprising 9.3% of Deschutes, 2.4% of Klamath, and just 0.1% of Lake. However, 82% of the housing units in the study area are located in the WUI. Although the WUI occupies a relatively small area, it draws a disproportionately large part of available management resources with the potential effect of reducing resources for fuel treatments in the much larger area of wildlands surrounding the WUI.

Actors. Landscape actors fall into five landowner types (Table 1 and Figure 1). Although private landowners control less than 50% of the land base, they may exert disproportionately greater influence on landscape dynamics because they can undertake a wider range of land-altering actions than public owners. The holdings of private industrial forest owners are large, frequently adjacent to public lands and important for maintaining habitat connectivity and open space. However, private industrial ownership is undergoing massive change with virtually every major forest products company divesting of its timberlands by converting those assets to Real Estate Investment Trusts and selling them to Timber Investment Management Organizations (Block and Sample 2001). These changes create uncertainties about the management of these lands, and conservation challenges, if some of these lands are subsequently developed. On the other hand non-industrial private forest owners (i.e. family forests) control 2.2 million acres, or 14% of total forestland in eastern Oregon (Butler 2006, pers. comm.), are more often located in or near the WUI, and have more diverse objectives than timber production and profit maximization including ecological stewardship, recreation, and lifestyle amenities (Kline et al. 2000). This ownership category is also rapidly expanding, family forestland acreage grew up to 60% over the past 10 years in some Oregon counties as a result of timberland disinvestment by private industrial forest owners (Azuma et al. 2004). Homeowners, the third type of private landowner, have the smallest total acreage but represent the largest number of individuals and have a strong influence on federal land management.

Federal land management agencies control the majority of the land in the study area (Figure 2). Their forest management actions thus have a major impact on the wildlands, adjacent private forest owners, and homeowners living in the WUI. Federal land management with respect to fire often is focused on the WUI to protect structures associated with rapid population growth and development. As a result, some communities in the region that historically had strong timber sectors linked to federal timber supplies are pursuing new opportunities to develop restoration economies that support fuels reduction and restoration of fire-adapted ecosystems on federal lands.

In the northern portion of the study area, the Confederated Tribes of Warm Springs Reservation consists of about 640,000 acres. Of the three groups involved, two, the Wasco and Warm Springs, originally lived in the Columbia River Valley and the third, the Paiutes, lived in southeastern Oregon. The tribally-owned Warm Springs Forest Products Industries harvests nearly 42 million board feet of timber per year with Forest Stewardship Council and Rainforest Alliance sustainability certification. The Klamath Tribes have partial management authority over some 690,000 acres of national forest lands that were part of their reservation lands until 1954 when the Federal Government terminated recognition of the tribe as a sovereign entity and seized its reservation lands through condemnation proceedings (Wolf 2004). Although Federal recognition of the Klamath Tribe was restored in 1986, timber harvests by the Forest Service soared during the 1980s depleting the former tribal lands. A management plan has been developed for these tribal lands (Johnson et al. 2008).

Table 1. Major human actors, goals, potential actions, influencing factors, and data sources.

Actors	General goals	Potential actions	Influencing factors	Data sources
Federal land managers (Deschutes, Fremont-Winema NF, BLM)	Reduce fire hazard Ecosystem services	Fuel treatment Fire suppression Timber harvest	Costs, Risks Protecting structures Public acceptance User demands Laws and policies	Interviews Management plans
Klamath and Warm Springs Tribes	Financial return Reduce fire haz. Ecosystem services	Timber harvest Fuel treatment Grazing Fire suppression	Commodity prices Costs, Risks	Interviews Management plans
Industrial private landowners	Financial return Reduce fire hazard Habitat	Timber harvest Fuel treatment Development Fire suppression	Commodity prices Costs, Risks Land use values Laws and policies Neighbors	Interviews Management plans Literature
Non-industrial private landowners (no mills)	Reduce fire hazard Financial return Recreation Amenities, Habitat	Fuel treatment Timber harvest Development	Costs, Risks, prices Land use values Laws and policies Personal preferences Social norms, Neighbors	Statistical surveys Interviews Literature
Homeowners (lots < 1 ha)	Reduce fire hazard Recreation Amenities	Structure fire-proofing Landscape fire-proofing	Costs, Risks Laws and policies Personal preferences Social norms	Interviews Literature Statistical surveys

Institutions. A variety of traditional and emergent community-level and regional social institutions and organizations influence land use decisions by each of the categories of landscape actors. Rural fire protection districts are a proximate example of these mediating institutions among landscape actors. These rural fire departments, unlike their urban counterparts, are staffed by area residents on a volunteer basis, yet in most cases retain primary responsibility for structure protection during wildfire events. These districts are adapting to increasing fire intensity and size, the greater number of structures to protect with the growth of the WUI, and the transformation of Federal and State wildfire management policies that in certain cases may not include initial attack and fire suppression. Homeowner associations, watershed councils, recreation groups, and environmental organizations are also influential social institutions that mediate the attitudes and behaviors of landscape actors. Environmental groups can have a strong influence on federal actors through litigation to stop fuel treatments.

Social Networks. Social networks are sets of individuals and/or groups and the ties that exist between them. These ties facilitate the exchange of information and can serve to influence the opinions of individuals, depending on the strength of relationships. The existence and character of social networks have bearing on the resilience of complex human-natural systems (i.e., the ability to absorb disturbance and still be capable of self-organization, learning and adaptation) (Carpenter et al. 2001). A diversity of social networks and institutions may influence how communities learn, store knowledge and experience, create flexibility in problem solving and balance power among interest groups (Folke et al. 2002; Scheffer et al. 2000; Berkes and Folke 1998). Within communities social networks can encompass a range of relationships including those among and between family members, neighbors, private landowners, public land managers, local government personnel and groups such as property and land owner associations and conservation or environmental groups.

HYPOTHESES

Our research activities will be guided by hypotheses that will be evaluated using our simulation model, statistical analyses of survey data, and other submodels (see page 2 for full text of questions).

Q1 (How do policies, social networks...actors interact to produce…unintended consequences..?)

- H1. Efforts to suppress all fires increase the risk of high-severity fire but effects will be variable due to interactions among weather, topography, and fire behavior.
- H2. Actor groups will have different degrees of influence on landscape-level ecosystem services (e.g. carbon) and fire risk as a result of different historical legacies of management and wildfire, environment, land values, and spatial context.
- H3. A policy of prioritizing fuel treatments in the WUI reduces needed restoration activity in wilder parts of the landscape;
- H4. Management actions to reduce risk of high severity fire will increase carbon emissions

Q2 (How sensitive are landscape outcomes to feedbacks…landscape patterns…and…policies?)

- H4. Government expenditures on fuel reduction and wildfire suppression in the WUI discourage adaptive behaviors (i.e., privately funded fuel treatments) in private landowners by encouraging those actors to discount fire risk relative to other values such as amenities.
- H5. Actor behavior and effects on landscapes are associated with social network characteristics, residence time in region, personal values, and experience with wildfire.

Q3. (How might external drivers…alter landscape dynamics and ...services?)

- H6. Changes in disturbance regimes resulting from climate change will increase the occurrence of highly flammable vegetation across these landscapes.
- H7. Management responses to climate change will vary by landowner and social network.
- H8. Policies driven by markets for carbon will result in different outcomes for biodiversity and ecosystem services than markets driven by biofuels.

METHODS AND APPROACH

Integrative modeling and synthesis (Envision). Our major hypotheses will be tested using Envision, an established multiagent model (Bolte et al. 2007, Hulse et al. 2008) specifically designed to allow exploration of the interactive dynamics and feedbacks of coupled natural and human systems in a spatially explicit, scenario-driven, policy-centric framework. **We will: 1) develop spatially-explicit agent representations for the study area through a combination of demographic analyses, surveys and interviews with actors; 2) adapt existing forest vegetative succession and fire models into Envision's analysis framework, driven by plausible climate change scenarios; 3) incorporate existing landscape production models describing habitat quality for spotted owls, white-headed woodpeckers, mule deer, and coarse filter measures of biodiversity; 4) adapt**

existing approaches for modeling economic landscape productions related to carbon sequestration, biofuel production, resource extraction and development; 5) develop new approaches for incorporating social network influences on actor behavior 6) articulate a robust set of policy options and management alternatives that provide tests of our hypotheses; and 6) develop a set of scenarios for analyzing and assessing alternative land management policy options on trajectories of landscape change. Multiagent models such as Envision have emerged recently as a useful paradigm for representing human behaviors and decision-making (Brown et al. 2005, Parker et al. 2003, Janssen and Jager 2000, Ostrom 1998) within the context of analyzing biocomplex interactions (Beisner et al. 2003, Holling 2001, Jager et al. 2000, Levin 1998, O'Neill et al. 1986). Multiagent modeling is a broad endeavor, relevant to many fields and disciplines with interest in modeling the behavior of autonomous, adaptive agents (actors). **We choose Envision for this study because it provides a unique capability to explicit represent policy alternatives, is spatially explicit, allows integration of multiple submodels, allows rich representation of both individual actor and institutional interaction and behaviors, and can model uncertainty in scenario outcomes via monte-carlo support. Furthermore, we have already used this model successfully and are actively expanding its capabilities.** Envision allows a rich description of human behaviors related to land management decision-making through the three-way interactions of *agents*, who have decision making authority over parcels of land, the *landscape* which is changed as these decisions are made, and the *policies* that guide and constrain decisions (Figure 3). In Envision, agents are entities that make decisions about the management of particular portions of the landscape for which they have management authority, based on balancing a set of objectives reflecting their particular values, mandates, and the policy sets in force on the parcels they manage. These values are correlated with demographic characteristics and, in part, guide the process agents use to select policies to implement. Policies consistent with agents' values are more likely to be selected. Policies in Envision capture rules, regulations, and incentives and other strategies promulgated by public agencies in response to demands for ecological and social goods, as well as considerations used by private landowners/land managers to make land use decisions. They contain information about site attributes defining the spatial domain of application of the policy, whether the policy is mandatory or voluntary, goals the policy is intended to accomplish, and the duration for which the policy, once applied, will be active at a particular site. Envision represents a landscape as a set of polygon-based geographic information system (GIS) maps and associated information containing spatially explicit depictions of landscape attributes and patterns.

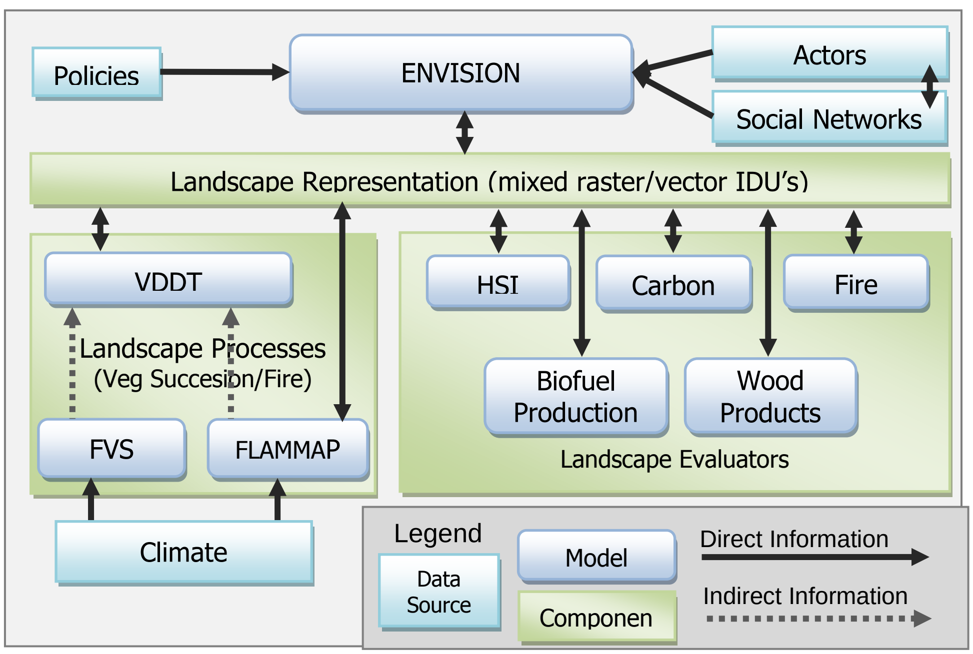

Figure 3. Model Linkages

As agents assess alternative land management options, they weigh the relative utility of potentially relevant policies to determine what policies they will select and apply at any point in time/space, if any. Once applied, a policy outcome is triggered, modifying site attributes, resulting in landscape change. Policies may also be constrained to operating only with selected agent classes (e.g., homeowners, owners near federal lands, owners with scenic views etc.).

The key elements in Envision are a landscape representation, actors, policies, landscape evaluators and autonomous landscape processes and feedbacks. Envision uses a “pluggable” architecture that allows conformant models of landscape productions and autonomous landscape change processes to be included in its simulations and provide information that can be fed back into actor policy selection and decision-making. These models can span ecological, economic or socio-cultural dimensions. Autonomous landscape change models are used to model processes that are not a result of human decision-making, but rather are independent of that decision-making. Characterizing emergent scarcity or fire risk to valued landscape productions is an important aspect of Envision that is one factor that may influence actor decision-making. Envision allows user definition of which productions are considered valuable in a given study area. From previous work in Oregon’s Willamette Valley (Hulse et al. 2002, Bolte et al. 2007), we have developed a variety of conformant models spanning economic, social and ecological dimensions. The research proposed here will add new evaluative models to examine habitat production, fire risk, and economic production related to biofuels, resource extraction, land development and carbon in fire-prone landscapes, as well as new representations of social network feedbacks influencing land management.

<u>Socioeconomic system components</u>. Socioeconomic research will focus on examining the behaviors and actions of the different actor groups with regard to land use change, forest management, fire risk mitigation, and ecosystem services and use this information to develop algorithms to represent these potential actions within the Envision modeling framework (Table 1). The research will account for a range of influencing factors including (1) landowners’ perceptions of landscape conditions, carbon, biodiversity, and fire risk; (2) ecological knowledge of fire; (3) past forest management practices and other actions used to mitigate risk or protect property and structures; (4) motivations and constraints influencing management and adaptation to fire; and (5) institutions and social networks and their influence on landowners. **A novelty of the research is the study of the role of institutions and social networks in shaping landowner perceptions, behaviors, and actions regarding wildfire risk, and incorporation of this information into a multiagent model**. The research will compare actor behavior and the role of institutions and social networks as they vary within the region by social and landscape context. We will identify and map the influence of institutions and social networks on actor groups and examine how these interact with other factors to influence actors’ adaptive capacities and management actions.

The socioeconomic research will draw on a range of social and economic theory and conceptual frameworks, such as advocacy coalition (Sabatier 1988; Sabatier and Jenkins-Smith 1993, 1999), spatial game theory (Albers et al. 2006; Amacher et al. 2006; Busby et al. in review; Busby and Albers forthcoming), bounded rationality (Kahneman 2003), and collaborative learning (Daniels and Walker 2001), to guide the collection and analysis of data describing actors, their behavior, and influencing factors. Combining several strains of social science theory and novel empirical data, the methods used to examine actor behavior will include an integration of: (1) spatial economic-decision analysis of actors’ forest management activities; (2) surveys and in-person interviews to document actor goals, behaviors, and key influences, and analysis of other secondary (e.g., GIS) data documenting actor management activities and influencing factors; and (3) interviews, case studies, surveys, and other methods to document how institutions and social networks influence actors to pursue fire risk mitigation activities and other forest management actions that influence forest structure. Behavioral relationships from qualitative and quantitative analysis will be interpreted as factors in decision analysis and serve as input for the Envision model to enable direct examination of how they influence landscape outcomes.

Each general actor type will be characterized by a set of general goals determined to influence their specific decision objectives and described by a set of decision rules incorporating actor goals, preferences, landscape feedbacks, and institutional and social network influences and constraints. These decision rules will incorporate uncertainty (Dixit and Pindyck 1994), risk attitudes, spatial externalities (Albers 1996), and other aspects of decisions specific to fire risk (Yoder 2004; Reed 1984, 1987; Hof et al. 2000). Each decision rule will depend on the values and perspectives relevant to that actor and that location. For example, a private industrial forest owner's decisions might be determined by production input and output prices including the value of selling land for development, while a homeowner's decisions may be a function of perceived risk, access to environmental amenities (e.g. proximity to outdoor recreation), and the costs associated with homeowners insurance, fire-safe technologies, and fuel-treatments. For each actor type, the structure of decision rules will be homogeneous, but that homogeneity does not imply that each actor within each general actor type will be assumed to make the same decision. An advantage of the multi-agent model approach is its ability to incorporate heterogeneity in actor preferences, location-specific attributes of decisions, and across-agent externalities in a coherent structure. Envision extends this further by incorporating stochasticity into individual actor decision processes and providing a Monte Carlo analysis capability to examine the effects of this stochasticity on overall system behavior. This structure will allow us to compare landscape outcomes that derive from different assumptions and theories about how actors make decisions when facing fire risk. The analysis will inform ongoing debate about appropriate decision frameworks. Similarly, we will be able to simulate actor decisions with different sets of information or policies surrounding climate change or with different climate change scenarios, to capture the sensitivity of landscape outcomes to information and policy as climate changes.

We will gather data about actor behavior from several sources. Two workshops (see Outreach Plan) will be held where key community stakeholders and researchers will collaborate to develop variables and potential decision rules for the model. More detailed information about private landowners will be obtained from statistically based landowner surveys and qualitative interviews. The data will include information about landowner goals, management practices, demographics, perceptions of fire risk, participation in social networks (e.g. rural fire protection districts, community wildlife protection plans). Landowner sampling allows us to explore the association between survey responses and spatial data such as tax lots, vegetation, and wildfire risk. For other actors, formal, in-person interviews will be conducted with a purposeful sample of federal, industrial, tribal land managers, and homeowner associations. The interviews will be designed to obtain much of the same type of information collected about landowners. Existing secondary databases and GIS layers will be examined to determine fire and management history, such as hazardous fuel reduction, timber harvest, and grazing.

We will gather data about institutions and social networks using formal, in-person interviews with purposive samples of official actors (e.g., federal, industrial, and tribal land managers) and unofficial actors (e.g., private landowners, interest groups, community leaders, etc.) to identify institutions and social networks that influence the ways actors view, respond, and adapt to wildfire risks via fire management, fuel reduction, and risk mitigation programs. Interviews will be designed to obtain data about land management practices with regard to fire; management goals and motivations; experiences with fire; perceived constraints to management; risk perception and ecological knowledge; participation in social institutions and how it influences adaptive behavior; and spatial/neighbor interactions and spatial risk perceptions. We will use the interviews to help design questionnaires to be used in the collection of survey data from random samples of official and unofficial actors. We identify correlations between identified social networks, wildfire risk perceptions, management behaviors, and support for risk mitigation activities. We will use a monitoring and evaluation protocol to verify qualitative and quantitative findings. We will conduct a series of focus groups with members of social networks to discuss study outcomes and ground-truth their relevance and the extent to which they represent the communities of interest. This feedback procedure will enable us to verify findings and adapt our process. All data collection procedures involving human participants will be conducted by Oregon State University researchers and approved by the OSU Institutional Review Board.

Land use and development Envision algorithms will draw upon econometric modeling of development based on historical data of land use change in eastern Oregon (Lettman 2004). Land use change trajectories generated by the Envision scenarios will be compared to trajectories derived from spatial econometric modeling of actual land-use change and development. Previous research in the study region provides prototype econometric models of land use and development using detailed spatial data describing existing development densities, population growth, urban proximity, road networks, and other landscape factors (Kline et al. 2007). Land use and development modeling for the proposed study will build upon this previous work by estimating new models using updated development data, as well as a richer set of explanatory variables incorporating fire risk, natural amenities, flammability of structures and sites, and other factors not addressed in previous work.

Landscape Dynamics. We will use forest succession and fire models to simulate how actor decisions, ecological processes, and external drivers such as climate change affect the structure and dynamics of simulation landscapes (See analysis section). We will integrate state-transition succession and mechanistic wildfire spread models within Envision to create a model with unique capabilities. State and transition models (e.g. Vegetation Dynamics Development Tool (VDDT)) are widely used in characterizing vegetation dynamics, are well-suited for examining complex coupled natural and human systems (Chapin et al. 2003), are relatively robust in the face of uncertainty in fire regimes (Keane et al. 2004), and suited for studying well differentiated policy alternatives (Barrett 2001). An initial set of vegetation states, transitions, and disturbance regimes have already been developed in VDDT for the study area (Wimberly and Kennedy 2008) and a sensitivity analysis has been done (Keane et al. 2006, Wimberly and Kennedy 2008). To help set the statistical parameters that guide the behavior of this model, we will use more detailed forest growth and succession models (e.g., FVS) and fire behavior models. Successional pathways will also include effects of ungulate herbivores and invasive species based on geographic and disturbance types that increase the risk of growth of invasive understory plants. Fuel treatments by actors will be applied at the polygon level and treated as disturbances that alter the state and path of stand development and fuel conditions. **While the vegetation model is relatively simple it well suited for integration into a more complex socio-ecological model and can represent feedback behaviors.** For example, high severity fire could create a post-fire succession with invasives that leads to more high severity fire.

The initial vegetation structure and composition of the landscape as of 2006 will be derived from a spatial model based on over two-thousand inventory plots, remote sensing and GIS. This model, which is based on a state-of-the-art imputation method (Ohmann and Gregory 2002), provides 30-m resolution estimates of forest structure and composition and be used to establish the fuel model types for the area (Pierce et al. 2009) and serve as inputs to define initial states for the succession model. A polygon layer of basic simulation units with a spatial resolution of 5 to 20 ha will be created from vegetation, topography, ownership, and management plans. To characterize environment-potential vegetation zones we will use an existing model of potential vegetation types, which has already been developed using CART methods (Rehfeldt et al. 2006, Prasad and Iverson 2006).

Wildfire events in will be simulated using the minimum travel time (MTT) fire spread algorithm developed by Finney (2002) and recently incorporated into Envision. This Envision-MTT linkage will be used to simulate spatially explicit wildfires that change polygon states based on fire intensity. A fire ignition and large fire event generator based on historical and future weather will be used to trigger wildfires and associated burn conditions (described below). The MTT algorithm replicates fire growth by the well-tested and widely used Huygens' principle where the growth and behavior of the fire edge as a vector or wave front (Sanderlin and Van Gelder 1977; Finney 2002; Richards 1990; Ager 2007, National Interagency Fire Center). Individual wildfires within Envision will be generated for each time step using a fire ignition and large fire event generator based on historical and future weather, the latter derived from downscaled GCM data. The simulation will focus on the prediction of large fire events since relatively few large fires account for the majority of the area burned in much of the western US landscapes. The daily data will be used to calculate the future fire scenarios through the Energy Release Component (ERC), one of the metrics incorporated into the National Fire Danger Rating System (Deeming et al. 1977). ERC has established thresholds for fire management planning where fire suppression becomes ineffective and ignitions generate large wildfires. Historical analyses of the relationship between energy release component and large fire events will be used to generate discrete large wildfire events during the peak wildfire season. For each fire event, wildfire burn conditions will be sampled from either past or future daily weather data to determine parameters for wind speed, wind direction, fuel moistures, and burn period. Weather data from recent extreme fire events on the two respective national forests will also be used to calibrate and refine weather scenarios. Given a set of burn conditions, Envision will call the MTT algorithm to simulate the specific fire(s) and the vegetation states will be updated using a rule set that specifies effect of fire intensity on vegetation.

Climate Change. Climate change will affect both vegetation succession and disturbance regimes. We will use MC1, dynamic global vegetation model (Bachelet et al 2003, Lenihan et al. 2003) to simulate climate change effects on ecosystems as broad physiognomic vegetation types, the movement of carbon, nitrogen, water, and fire disturbance. We will then translate the broader changes projected by MC1 into community types (e.g. ponderosa pine, lodgepole pine) in the state-transition models based on empirical information and expert opinion. Climate change scenarios will be represented by different states and transitions within the vegetation model and different patterns of potential vegetation types on the landscape. Migration effects will not be modeled for the 50 year horizon. We assume that much of the near-term effect of climate change is expected to be manifest in larger, more severe fires as a result of longer fire seasons and larger burned area (Westerling et al. 2006). We will use downscaled GCM weather streams to predict fire occurrence and weather and mechanistically model these fires within the project area (Maurer and Hidalgo, 2008). High resolution observed meteorological data will be obtained from the gridded the National Center for Atmospheric Research, North American Regional Reanalysis for a 30 year period (1980-2008). Gridded data will be further interpolated to 80 m horizontal resolution using bias correction for temperature and precipitation using output from Parameter-elevation Regressions on Independent Slopes Model (Daly et al. 1994), and for relative humidity and wind speed using Remote Automated Weather Station data. The daily data will be used to calculate the future fire scenarios through the ERC. Daily output from 15 different GCMs for the period 1971-2000, from the 20th century coupled simulations (20C3M), and for the end of the 21st century (2081-2100) from the middle-of-the-road emission scenario (SRES-A1B) will be acquired from the Program for Climate Model Diagnosis and Intercomparison. By incorporating high resolution gridded weather data and coarse resolution climate change information from GCMs, future weather scenarios for late-21st century will be generated.

Wildfire impacts. In addition to the wildfire modeling effects described above, we also calculate landscape wildfire risk metrics (Finney 2005, Ager et al. 2007) at periodic time steps to both inform actors of the current expected threat to ecological and property values. Comparisons between expected wildfire impacts and actual as realized by Envision simulations will reveal how actors perceive and respond to wildfire risk as currently portrayed by land management agencies. These comparisons will potentially reveal how human behavior at the actor level contributes to landscape scale wildfire risk and or losses. The MTT algorithm, as incorporated into Randig (Ager et al. 2007), will also be used to generate burn probability/intensity maps and calculate spatially explicit risk metrics.

Fire risk to homes. Fire risk to homes will be quantified with burn probability/intensity outputs. Because structure ignition models have not been incorporated into landscape fire simulators (Finney and Cohen, 2003), surrogate metrics need to be employed. The Oregon Department of Forestry has outlined clearance rules for all structures in the WUI (ODF 2006). To quantify wildfire risk to residential structures, we will calculate the average burn probability by flame length category for pixels within a 45.7 m radius of the individual structures. The 45.7 m radius represents a 15.2 m radius for the structure itself and a 30.5 m radius fuel break around each structure. While this method will not predict home ignition, it will provide an indication of how risk reduction actions might affect wildfire likelihood and intensity in the vicinity of structures (Butry and Donovan 2008).

Biodiversity. For the focal wildlife species (see study area section) we will develop habitat suitability index models that incorporate stand and landscape level features (McComb et al. 2002, Spies et al. 2007). We will build these models using information from the literature, expert opinion and data from wildlife surveys and permanent forest inventory plots in which native and non-native plant species information has been collected. Where empirical data exist we will evaluate models using the approach of Spies et al. (2007). Late-old structure will also be quantified using definitions used by land management agencies. Scenarios will be tracked for landscape composition of these measures to evaluate the different land management scenarios. We will calculate landscape risk measures for different components of biodiversity. Risk will be defined as a function of the probability of a fire and loss based on flame length (Ager et al. 2007) and will include both ecological benefits and losses from wildfire (Finney 2005).

Carbon and other ecosystem services. Additional landscape evaluators (Figure 1) will include carbon storage, timber and biofuel production. Carbon storage is particularly important issue in forest management. A carbon dynamics model for forest management activities and wildfire has been incorporated into Envision using the algorithms in STANDCARB (Harmon et al. 2009). The model will include forest products and decomposition in landfills. Timber volume and biofuel production will be estimated from the area treated and the structure of the vegetation classes in any time period. These metrics will also be included in the expected loss calculations.

Characterizing restoration and fuel treatment effects. Management activities will span objectives that range from forest landscape restoration (i.e. re-introducing wildfire), to creating defensible zones for protection of WUI's. Spatial treatment strategies will vary according to objectives. Fuel treatments will be modeled as changes in vegetation states and trajectories that reflect reduced surface and canopy fuel loads and be informed by use stand-level modeling and retrospective studies of recent wildfires in central Oregon. Such observations and a meta-analysis of these events will allow the refinement of model parameters for the region, with a focus on the problematic area of transitional forest types (e.g., the dry mixed-conifer type) and type ecotones. We will reconstruct and examine small-scale, stand-level fire behavior consistent with BEHAVE model parameters. We will obtain data from management agencies and where needed augment with field data collection on fuel consumption (reconstructed), burn severity patterns and post-fire recovery and stand dynamics. Field work will focus on spatial and temporal patterns that otherwise are not well understood nor modeled. To better quantify longevity of treatments and their cascading effects to stand dynamics (Fiedler et al. 2004). These fundamentals must be better understood to enhance function of the larger Envision modeling effort. We will model stand-level growth, fuel accumulation, changes in socioeconomic value and fire behavior with existing FVS and the fire and fuels extension, using the custom fuel models where necessary.

Land management decision making. We approach land management decision-making analysis through the use of the Envision multiagent model. Envision uses *scenarios*, consisting of alternative policy sets, agent characterizations and preferences, and landscape feedbacks to model the decision-making behaviors of landowners and resulting landscape dynamics. We will explore the impact of different decision rules, including various risk attitudes and models of risk, on the spatial evolution of the landscape. To form a benchmark, we will draw on the socioeconomic research described above to parameterize the decision rules to approximate the land use changes and management witnessed in recent years in the study region. Scenario drivers will include 1) alternate policy sets reflecting conventional fire suppression strategies, fuel treatments, and land development alternatives; 2) agent preferences for incorporating landscape feedbacks reflecting fire risk aversion and attitudes towards conservation values into their decision-making process; and 3) growth and development pressure under varying estimates of climate change impacts.

Policy sets used in these scenarios will be derived from existing policies currently in place in the study area and new policies currently being considered to address changing perceptions of fire suppression and fuel management in the region. Agent characterization and decision preferences will be derived from the socioeconomic research described above. Landscape feedbacks will be incorporated using Envision's capability for coupling to spatial models representing vegetative growth and succession processes, fire generation and spread, and habitat production.

Decisions about mitigating the risk of fire damage provide an important link to landscape functions which, in turn, inform subsequent decisions. One particular feedback loop in this framework concerns the development of the WUI and fire risk. Current regulations and public opinion encourage public forest landowners to focus fuel treatments and fire suppression in the WUI to protect nearby residential values. Preliminary theoretical modeling finds that that implicit subsidy, especially when paired with disaster relief programs, encourages people to move to the WUI and to be less sensitive to the risks involved in living there. We will examine by using Envision to project population dynamics and examine how such adverse incentives contribute to fire risk, the ability to suppress fires, and the public acceptance of prescribed or natural fire in the WUI. Those factors, in turn, could conspire to increase the probability of catastrophic fires in or near the WUI while the emphasis on WUI spending reduces the amenity values and increases risk to forests outside the WUI.

Based on analysis of the recent trends in the housing market in recreation-based economies, we will develop population growth estimates that reflect landscape characteristics such as amenities and ecosystem services. In the simulations, a large, stand-replacing fire will reduce ecosystem services and therefore reduce population growth, reflecting another feedback between the natural and human systems. We will also explore several related interactions that could contribute to the evolution of the landscape and WUI. First, because fire insurance in this region is not related to the risks faced, homeowners may rely too heavily on purchased insurance rather than risk-mitigating behavior like fuels treatment and fire-safe building. Because fuel treatment on one parcel contributes to the public good in that it reduces fire risk on nearby parcels, the reliance on insurance implies a higher level of fire risk incurred by all. Second, residential land values and in-migration are a function of local natural amenities that large fires can destroy. We will examine the interaction of migration, amenities, fire events, and risk with particular emphasis on how amenities contribute to the primary feedback loop between public subsidies for risk reduction and increased risk of fire. Third, building off of ongoing research on risk and invasive species, we will incorporate the feedback loop between land management decisions, the rise of invasive species, and the resulting increase in fire risk and decrease in environmental services/amenities. The multiagent model provides a unique platform for examining feedbacks between the natural and the human systems such as these, over time.

As above, actor decision rules are largely a function of benefits and costs. Within this forest-dominated landscape, the expansion of markets for carbon or biofuels could become relevant. Sequestered carbon, at the right price, could provide incentives to forest landowners to maintain trees rather than harvest and conduct fuel treatments. Similarly, should biofuels production become financially viable, landowners could have an incentive to conduct more fuel treatments. Scenarios will include trends in carbon and biofuel prices that could lead to different patterns of forest management. Because the cost of producing biofuels depends on their location relative to roads and biofuel plants, the spatially-explicit model will reveal changes in forest fuel and fire spatial patterns as a function of those markets.

ANALYSES

Scenario Definitions. We will develop 6-8 scenarios that represent different behaviors of actors within the system and conditions imposed by external forces including climate change and changes in wood and energy markets. The specific details of the scenarios will be developed after preliminary analysis of actor characteristics and influences, interviews with policy makers and landowners, and refinement of model capabilities. Scenarios will be related to the major hypotheses that we discuss above and will include examples related to (1) removing public subsidies of fire suppression and fuel treatments; (2) reducing suppression activity; (3) degrees of influence of social networks and economic factors; and (4) climate change and carbon markets. See Table 2 for more detail.

Analysis of Results. We will organize these inputs into eight primary scenarios that examine a 2 x 2 x 2 analysis design of 1) climate change (no change/expected change), 2) landscape management strategies (existing/adaptive policies and approaches) and 3) degree of coupling between landscape feedbacks and agent decision-making (strongly/weakly coupled feedback process) to allow the exploration and identification of the impact of these interacting factors on landscape pattern and landscape production trajectories within stochastic envelopes defining each scenario using Envision's Monte Carlo capabilities. Envision will run these scenarios on 3-4 simulation landscapes that represent ecological and socioeconomic variation across the study area. Candidate landscapes include Bend-Sisters; Chiloquin-Klamath Tribal lands; and Lakeview and surrounding forests (Figure 2). Simulation landscapes will be about 200,000 ha in size with a minimum spatial mapping unit of 4-0 ha, and will explore a time horizon of 50 years. Within each scenario analysis, we anticipate making about 500 runs to adequately characterize the range of system responses within the scenario. We will utilize the Monte Carlo results to conduct 1) a sensitivity analysis of scenario

Table 2. Representative scenario drivers and inputs to scenario development.

Scenario Driver	Modeling and Policy Inputs/actions
Fire suppression	• Inclusion/removal of public subsidies for fire suppression • Varying degree and pattern of suppression efforts
Fuel Treatment and Structural Fire Proofing	• Timber removal for wood products, Biofuels treatments • Prescribed burns
Land Manager Preferences	• Fire risk perception, attitudes towards biodiversity, and ecosystem services • Institutional influences, Demographic shifts and ownership transfers
Climate Change	• Alteration of fire regimes affecting fire severity, size and location
Growth and Development	• Compact/dispersed development patterns in the WUI • Interactions of population growth rates and production of ecosystem services
Markets	• Carbon, biofuels, wood products markets and trends

inputs to assess its impact on system behavior, and 2) a variant/invariant analysis exploring emergent spatial patterns of land use across runs to identify those policies that are robust in producing desirable patterns and corresponding landscape productions targeted by this research.

RESULTS FROM PRIOR NSF RESEARCH

J. Bolte. *Interactions of riparian pattern, policy and biocomplexity in coupled human/riverine systems*. (Award No. 0120022). This project developed a multiagent model of landscape change based on coupled economic and ecological values of landowners/managers in large river floodplains. It incorporated empirical research on 1) complexity of floodplain fish and wildlife communities, 2) development of alternative landscapes, and 3) quantification of human behaviors, consequences for riverine resources, and adaptations to resource scarcity. We developed a multiagent model, Envision, to determine the impacts of human land use activities in the flood plains of large rivers. Envision was used to evaluate the effectiveness of land use, economic, and conservation policies to meet socioeconomic and ecological goals in Oregon, adjacent to the Eugene-Springfield metropolitan area. Results identified portions of the landscape that always vary in 2050 conditions regardless of approach or scenario, and those which never vary, regardless of approach or scenario. Results indicate those portions of the landscape whose trajectories vary in the modeled results are more amenable to policy influence than those that do not (Hulse et al. 2008, Bolte et al. 2007). This grant partially supported 2 Ph.D. and 2 MLA graduate students. **J. Bolte.** *The interactions of climate change, land management policies and forest succession on fire hazard and ecosystem trajectories in the wildland-urban interface.* (NSF Award No. 0816288). This project is developing models and tools for applying Envision to fire-prone landscapes in Oregon's Willamette Valley. As such, it is highly synergistic with the work proposed here; it has resulted in the developing of several key models that will be utilized in the proposed project, including an Envision-compliant VDDT adapter for vegetative succession modeling, an adapter for the FLAMMAP fire model used here, and an approach for incorporating down-scaled climate change scenarios into this analysis. The work proposed here significantly leverages and extends this work into highly fire-prone landscapes with complex wildland-WUI biodiversity issues. **This proposal is distinctive from the Willamette Valley project in several ways including its focus on: 1) social network influences on land management and adaptation, 2) representing social networks in multiagent models, and 3) use of collaborative learning methods and strong public outreach.**

B. Steel and B. Shindler. *Changing expectations for science and scientists in natural resource decision making: A case study of the Long-term Ecological Research (LTER) program* (Award No. 0427494). This national study of LTER scientists, natural resource managers, natural resource NGOs, and members of the public examined preferred roles for science and scientists in the natural resource management and policy process. The two most popular roles for scientists for all four groups were working "closely with managers to integrate scientific results" and "interpreting the results of research for others involved in the process" – descriptions of a "post-normal" science role. Scientists and managers were not supportive of an advocacy role for scientists. In summary, respondents in all four groups were likely to agree that integrative roles are more preferable than any of the other roles, including the minimalist traditional role of just reporting results (Steel et al., forthcoming; Steel et al., 2008).

T. Spies. *Long-term ecological research at the H.J. Andrews Experimental Forest (LTER 6).* (Award No. 0823380). This recently funded project continues long-term studies of forest and stream ecosystems. One of the major goals is to evaluate ecosystem responses to potential future change in drivers—especially climate. Spies is responsible for developing new digital models of vegetation structure using LiDAR and assessing landscape change with various simulation models. Early accomplishments including developing a spatial model of canopy heterogeneity and biomass.

EDUCATION AND OUTREACH PLAN

The capacity of complex socio-ecological systems to adapt to disturbance is partly related to the diversity of social institutions and networks that can learn, store knowledge and experience and create flexibility in problem solving (Berkes and Folke 1998, Sheffer et al. 2000, Folke et al. 2002). Consequently, **the overall goals of our education and outreach efforts are: 1) to improve society's awareness and understanding of the complexities of coupled natural and human systems in fire-prone landscapes, and 2) to foster inter-community relationships and networks for continued learning about CNHS and improved capacity for future adaptation to change.** We will accomplish these goals through a collaborative learning process involving the actors, institutions and researchers that comprise our community of interest. Our efforts will consist of the following activities, some of which also serve as data collection opportunities:

1. **Two workshops in which key community stakeholders and the researchers work together to develop variables, decision rules, and scenarios;**
2. **One public workshop to engage the community of interest in learning about adaptation of humans in fire-prone under climate change;**
3. **One international workshop with scientists from Australia and other CNHS fire projects (there are at least 2 now) to explore socio-ecological systems and adaptation science;**
4. **Two new university modules on land management for CHNS in fire-prone landscapes for upper-level undergraduates and graduate students;**
5. **A set of communication strategies designed to facilitate further development of an informal network of actors, institutions and scientists that will continue to address CNHS issues.**

The initial workshops will bring together actor groups and institutions in our model: local public land managers, private landowners, environmental advocates, county government representatives, tribe members, forest restoration and management technicians and program staff at conservation and community development groups. We will make a special effort to reach out to underserved communities (i.e., tribal members). Our extensive network of personal and professional contacts in the study region provides ample partners for hosting workshops. We will choose partners with proven track records connecting people as well as science and management information. Possible partners include: OSU Extension, Klamath Watershed Partnership, Upper Deschutes River Coalition, Fire Learning Network, Project Wildfire, Oregon Small Woodlands Association, Friends of the Metolius, Black Butte Ranch Homeowners Association. Workshops will be managed by a professional facilitator with experience in the sciences. We will also record the workshops so we can refer back to participants' comments for clarification. All workshops will take place in a central location in the study area, such as the Oregon State University Cascades Campus in Bend.

Evaluation of workshops will be completed by all participants. Each activity will begin with a discussion about goals for the workshop. At the close of the activity, the goals will be reviewed and participants will determine if goals have been met. Researchers will be participants in these activities, so this will truly reflect an evaluation from all involved. The public workshop will be a forum for sharing our preliminary findings with the actors and soliciting input on interpreting the results for each individual local community, as well as asking for ideas for incorporating the findings into policy and decision-making. By asking participants for this input, the workshops become another stage in data collection (i.e., further study of how actors adapt to complex change). These activities will also engage community members in learning about fire-prone landscapes.

The international scientific workshop will involve 3-4 scientists from Australia (see letters) and scientists from other funded NSF CHNS projects that deal with fire. The workshop will address key scientific issues in the study of adaptation and feedbacks in fire-prone landscapes under climate change. It will also focus on ways of integrating social and ecological systems in agent-based models. The workshop will advance the scientific basis of human adaptation in disturbance prone systems and identify scenarios of landscape change in different socio-ecological systems. The workshop is tentatively planned for 2013 in Bend, Oregon. A publication on lessons and research challenges for fire prone landscapes as CNHS will be produced.

University modules on land management in fire-prone landscapes will be developed for two courses offered at Oregon State University in the College of Forestry: a junior-level course titled "Managing for Multiple Resource Values" and a senior- and graduate-level course titled "Managing at the Wildland Urban Interface." Researchers on this team are responsible for teaching both courses and will develop the modules for maximum learning about CNHS, modeling, and study results. Modules will be developed by summer 2012.

Communication tools for disseminating and sharing information will be developed. Examples include to two- or four-page "highlights" papers for discussing landscape management concepts and a video production featuring a success story from the study area. These tools will be developed by researchers with extensive experience in the study communities, with input from participants where possible. These strategies will better equip managers for outreach about this CNHS, as well as facilitate network-building for continued discussion and learning. A web presence will be also established through the Institute for Natural Resource at Oregon State University. In conjunction with OSU Libraries, the Institute supports the Oregon Explorer (http://oregonexplorer.info), a series of web portals to a natural resources digital library that provides a single access point to Oregon natural resources information. We make a special effort to use this site to reach out to high schools and higher education programs with Native American students. We will also promote the use of the model on the website in in-classroom projects about ecosystem complexity developed with the assistance of the OSU Extension 4-H Wildlife Steward's K-12 program.

MANAGEMENT PLAN

Drs. Bolte and Spies will serve as co-coordinators of the project. Bolte will serve as the lead PI for OSU and be responsible for the development of the integrated Envision model and reporting to NSF. Spies will be responsible for coordinating the ecological and social research components as well as developing the biodiversity metrics. Dr. Albers will be responsible for developing the landowner decision rules, spatial influences on decisions, the economics of forest management, and influences of carbon and biofuels markets. Dr. Hammer will be responsible for research on social institutions and will contribute to the development of the decision rules for how institutions influence actor decisions. Drs. Steel and Shindler will be responsible for the study of social networks and institutions and homeowner behavior. Dr. Shindler, who has extensive experience in fire education and Dr. Olsen (Postdoc) will also be responsible for the education and outreach effort. Drs. Charnley and Fischer (Postdoc) will be responsible for the survey of non-industrial landowners, contributing to the development of the decision rules of the actors and the collaborative learning efforts. Dr. Bailey will be responsible for characterizing the effects of fuel treatments on fire risk and succession, retrospective studies of wildfires in the region, and working with land managers to help develop fuel treatment characterizations in the model. Dr. Kennedy will be responsible for developing the parameters for the state-transition model and for characterizing landscape dynamics under different scenarios and disturbance regimes of current and alternative future climates. Dr. Kline will be responsible for land development modeling and contributing to the integration of economic and social influences on actors. Dr. Ager will be responsible for studies of fire behavior and risk associated with different landscape management strategies and for helping to parameterize the fire behavior in the succession model. Quarterly meetings will be held to for progress review and planning. We will develop a wiki and website that allows sharing of information and data. Periodic field trips will be made to the study area to meet with actors and other stakeholders.

EXPECTED PROJECT SIGNIFICANCE

Intellectual Merit: 1) Integrated, multidisciplinary nature of the project and collaborative learning approach maximizes opportunities to advance understanding of coupled-natural and human systems; 2) Novel focus on the role of social networks and institutions in mediating adaptations and responses of actors to fire will lead to new insights about risk perception and adaptation; 3) The study area is particularly well suited for analysis of complex interactions in fire-prone landscapes because it contains a mosaic of wildlands, WUI, diverse landowners, and diverse and conflicting management goals; 4) Inclusion of external forces of markets and climate change in system and scenarios will help identify relative importance of internal versus external drivers and increase knowledge of how changes in boundary conditions can shift system behavior.

Broader Impacts: 1) The collaborative learning will enable our findings to reach the landowners, managers, and institutions that have the greatest potential to change how humans adapt to fire-prone landscapes; 2) Fire-prone landscapes are a globally significant CNHS; 3) Inclusion of tribal lands will give broader recognition and understanding of the modern day role of Native Americans in natural systems; 4) Software, spatial data bases, and web-based tools will enable stakeholders, managers, students, researchers, and secondary educators to better understand complex systems; 7) The international scientific workshop will help us evaluate the global generalities of our findings; 8) Provides training and learning for undergraduates and graduate students in socio-ecological systems.