Chapter 8: Simulating Mortality From Forest Insects and Diseases

Alan A. Ager, Jane L. Hayes, and Craig L. Schmitt[1]

Abstract

We describe methods for incorporating the effects of insects and diseases on coniferous forests into forest simulation models and discuss options for including this capability in the modeling work of the Interior Northwest Landscape Analysis System (INLAS) project. Insects and diseases are major disturbance agents in forested ecosystems in the Western United States, and over time, are responsible for major changes in forest composition and structure. Incorporating their effects into forest simulation models is difficult, especially the representation of large, episodic insect epidemics. Much empirical data on insect mortality is available for modelers, and an array of mortality models have been incorporated into indivdual tree growth simulators. Scaling these models to simulate epidemics on landscapes requires, among other things, parameters that describe the amplitudes and periodicities of pathogen/pest population cycles. Incorporating insect and disease effects into forest simulation models makes it possible to explore ways to minimize epidemic conifer mortality and secondary interactions with other disturbances. In addition, the inclusion of other resource goals and financial considerations makes it possible to analyze the costs and benefits of forest management activities that target stands with high risk of mortality. We discuss options for modeling insect and disease mortality within the INLAS project.

Keywords: Forest insects and diseases, forest stand simulation, tree mortality, landscape simulation.

---

[1] **Alan A. Ager** is an operations research analyst, and **Jane L. Hayes** is a research biological scientist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, **Craig L. Schmitt** is a plant pathologist, U.S. Department of Agriculture, Forest Service, Blue Mountains Pest Management Service Center, 1401 Gekeler Lane, La Grande, OR 97850.

Introduction

Simulating the potential impacts of insects and diseases on forests like those in the Blue Mountains of northeast Oregon is challenging. Defoliators (Torgersen 2001), bark beetles (*Dendroctonus* spp.) (Hayes and Daterman 2001), mistletoe (*Arceuthobium* spp.) (Parks and Flanagan 2001), and root diseases (Thies 2001) all have unique population dynamics, epidemiology, and effects on forest vegetation. Interactions among these disturbance agents as well as with management activities and physical disturbances such as wildfire and windthrow are also significant. Collectively, insects and diseases are major determinants of forest composition and structure over time, and thus warrant serious attention in forest planning and landscape simulation efforts (Quigley et al. 2001). Previous federal and state planning efforts may have underestimated the potential effects of insects and diseases in projections of future forest conditions, which may have reduced the effectiveness of these plans (Gast et al. 1991).

In this paper, we review methods to model conifer mortality caused by major forest insects and diseases within the framework of landscape planning models such as those described in Ager (Chapter 3), Bettinger et al. (Chapter 4), and Hemstrom (Chapter 2). Much of this work involves integrating and parameterizing existing mortality and risk models implemented elsewhere, such as in the Forest Service Forest Vegetation Simulator (FVS) (Wykoff et al. 1982). However, major gaps exist in the area of modeling spatial spread rates data for some insect species, and the process of simulating the complex cycles of insect populations and disease centers on a large landscape is a challenge for any landscape planning effort. The following discussion treats forest insects separately from forest diseases. We focused on major pests in the Blue Mountains based on historical survey data (Gast et al. 1991) with the broad goal of summarizing existing tools, identifying major gaps, and proposing research and development to create a robust set of methods for modeling mortality caused by forest insects and diseases.

Extensive descriptions and reviews of insects and diseases and their effects on forest trees in the Blue Mountains can be found in Filip et al. (1996), Gast et al. (1991), Hayes and Daterman (2001), Parks and Flanagan (2001), Thies (2001), and Torgersen (2001). Aerial survey maps of insect infestations provide a detailed chronology of infestations over a 50-year period for the Blue Mountains (USDA FS 2003a).

Insect Mortality Models

Pertinent aspects of insect biology in the context of landscape planning models center on the dynamics of infestations and include the periodicity and amplitude of the infestation cycles, the spatial pattern of the initial infestation centers, and the resulting damage they cause in terms of mortality and reduced vigor. The divergent life histories of the major mortality-causing insects complicate an integrated modeling approach in landscape planning models.

Tree-level mortality models for the major mortality-causing insects are all implemented in FVS extensions that are described in detail elsewhere (USDA FS 2003b) There are many case histories of modeling insect- and disease-caused mortality at the stand (e.g., Cameron et al. 1990, Gast et al. 1991; also see Hayes and Daterman 2001, Torgersen 2001), and to a lesser extent, landscape scale (Beukema et al. 1997, Eager and Angwin 1997, Graetz 2000, Smith et al. 2002). Landscape simulations are usually accomplished by imputing tree lists for stands where data are incomplete. Insect mortality models can be built ad hoc in FVS when no formal model exists by using the COMPUTE statements and the event monitor to trigger mortality on specific host trees when stand conditions meet an established susceptibility criterium. The existing FVS model extensions differ in their state of validation and complexity and require many parameters to trigger outbreaks and regulate the mortality. Recent efforts have focused on simulating multiple pests (e.g., Roberts 2002, Roberts and Weatherby 1997), examining interactions among pests (e.g., Eager and Angwin 1997), and modeling the spatial spread of insects (e.g., Smith et al. 2002). The use of the FVS Parallel Processor (Crookston and Stage 1991) vastly simplifies the modeling of insect spread among stands within the FVS system.

Modeling endemic insect mortality requires parameters that define stand and tree susceptibility and mortality rates among the tree type within the stand. Modeling epidemics implies a spatial extent beyond an individual stand, and additional parameters are required to control (1) triggering of an outbreak; and (2) duration, intensity, and frequency of occurrence (Roberts and Weatherby 1997). In the case of the westwide pine beetle model (Beukema et al. 1997), a spatially explicit model that considers stand contagion, parameters also are needed to control the rate of spread. Parameters needed to simulate insect epidemics are described individually below.

Determining Susceptibility Levels to Epidemic Events

Stand susceptibility models use stand attributes such as average size and density of host species and physical site factors including ecoclass, slope, aspect, and elevation in determining susceptibility to insect outbreaks. In a few cases, spatial information such as the distance to the nearest infestation also is considered (e.g., Shore et al. 2000). In FVS, stand susceptibility models can be built and implemented by using FVS COMPUTE statements that calculate relevant stand metrics (Roberts and Weatherby 1997).

Triggering an Outbreak

Outbreaks can be triggered as a function of susceptibility levels or by using assumptions about intrinsic insect population cycles (Monserud and Crookston 1982). The resultant mortality is dependent on other factors such as susceptibility levels and outbreak duration and intensity. Epidemic triggers can be regulated independently of endemic mortality by changing the probability of the two levels of mortality and associated intensity of the outbreaks. Some FVS model extensions have keywords that specify whether stands are part of widespread or local outbreaks. Assumptions that are tailored to specific insect pests are usually made about the interval between outbreaks and their duration. The outbreak is manifested in mortality if susceptibility conditions are appropriate. Roberts and Weatherby (1997) provide examples of simulating insect outbreaks by using the FVS extensions.

Duration of Outbreaks

Population dynamics, spread, and host availability affect duration of infestations. The FVS insect extensions have defaults for duration. For instance, the default for Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) pest extension (Marsden et al. 1994) is 4 years in the Blue Mountain variant. In the western spruce budworm (*Choristoneura occidentalis* Freeman) extension (Crookston et al. 1990, Sheehan et al. 1989), the duration is related to a hazard rating system where low hazard generates a 5-year, moderate a 10-year, and high a 15-year duration. Management activities that alter susceptibility after an outbreak begins can alter the duration. Mortality of the host also affects duration of outbreak.

Intensity of Outbreaks

Intensity is usually expressed as a function of the number of host trees killed by tree species and diameter class per FVS cycle. Some models such as the Western Spruce Budworm Extension can incorporate other types of damage like top kill and decreased growth from defoliation. Intensity is modeled in concert with spread rate among stands as part of simulating an epidemic. Damage is affected by using mortality functions in the FVS extensions, either within an FVS extension or within outside software.

Spread

At least two methods have been applied to simulate the spread of an insect epidemic. One approach uses Monte Carlo methods that simulate gradual growth of the infestation among the population of stands in the simulation (Roberts and Weatherby 1997). This approach does not consider stand contagion but rather uses random selection of stands that meet susceptibility criteria. The probability of an infestation can be changed in this process to alter the rate at which stands become infested. Multiple probabilities can be used in a similar Monte Carlo process to trigger low-level endemic mortality as well as large epidemics. A more sophisticated approach to insect spread that considers stand contagion was developed in the westwide Pine Beetle Model (Beukema et al. 1997, Smith et al. 2002). Stands are simultaneously simulated by using the FVS parallel processor, and stand-to-stand spread of beetles is simulated.

Disease Mortality Models

The major tree diseases in the Blue Mountains are root disease and dwarf mistletoe. Although dwarf mistletoe is primarily modeled as causing growth reduction, root disease is simulated as causing mortality. Principal root diseases include Armillaria root disease caused by *Armillaria ostoyae*, laminated root rot caused by *Phellinus weirii* (Murr.) Gilb., Annosus root disease caused by *Heterobasidion annosum* (Fr.) Bref., and black stain root disease caused by *Leptographium wageneri* Kendrick M.J. Wingfield. Extensive reviews of these diseases and their occurrences in the Blue Mountains can be found in Hagle and Goheen (1986), Hessburg et al. (1994), Campbell and Liegel (1996), Filip et al. (1996), and Thies (2001). Fundamental differences in the biology between insects and diseases call for different modeling methods. Although contagion is a factor with diseases, the spread is too slow to consider as part of a landscape process (e.g., 2 feet per year). Diseases can be modeled as endemic mortality, meaning that the mortality is chronic, not episodic, and mortality is an intrastand or intrapolygon, rather than an interstand or interpolygon process. In contrast to disease, the most important component in simulation models for insects is the relationship between mortality and management activities. High levels of management activities can bring about more infections and mortality (Thies 2001), whereas in insect pests, management is largely viewed as a way to reduce spread.

As with insects, extensive modeling capability for diseases exists in FVS (Frankel 1998, Hawksworth et al. 1995). The western root disease model in FVS simulates the effects of Armillaria root disease, laminated root rot, and Annosus root disease (Frankel 1998). Considerable effort is required to build keyword files and calibrate these models for application on large landscapes. Management to control diseases (e.g., boron treatments) can be simulated with FVS extensions. Given the slow rate of disease spread, many of the concerns with insect pests in terms of interstand spread and cyclical epidemics are not an issue with diseases.

Insect and Disease Risk Models

The previous discussion focused on the modeling of tree mortality from insects and diseases. Depending on the overall objectives, the insect and disease considerations in landscape planning can often be addressed by using only measures of infestation or infection risk rather than predicting actual tree mortality. Risk models measure the long-term outlook for the effects from pests and offer a relatively simple approach to characterize forest conditions in terms of a latent potential to experience mortality, and are often used when tree-level mortality modeling is not practical. Numerous risk rating models for insects and diseases have been developed and widely applied in coniferous forests in the intermountain West and elsewhere (see Hayes and Daterman 2001, Hessburg et al. 1994, Lehmkuhl et al. 1994, Steele et al. 1996). These models are typically used in watershed or National Environmental Policy Act (NEPA)-related analysis to help identify susceptible stands and assign treatment priorities. Most models output categorical values that measure relative risk, and a few quantify risk in probabilistic terms. Risk assessments are used to identify treatment priorities to reduce hazards from infestations or epidemics. Many, but not all of the models, have been tested through field validation and are published with accompanying software. Risk models have been added to FVS as event monitor applications for the mountain pine (*Dendroctonus ponderosae* Hopkins) and spruce (*D. rufipennis* (Kirby)) beetle. There is also integrated pest risk software that calculates multiple insect and disease risk ratings (Ager 1996, Hessburg et al. 1994, Scott et al. 1998).

Data requirements for the risk models differ ranging from coarse photointerpreted stand characteristics such as canopy closure to detailed stand metrics such as the basal area of host species within a specific diameter range. In addition, many models require physiographic inputs like slope, aspect, elevation, and other physical attributes. A number of risk models have subcomponents that independently measure risk from susceptibility to better assess probability of mortality.

Although risk models offer a rapid way to address insect and disease considerations in landscape planning projects, their shortcoming is that they generally do not consider population levels and cycles, and therefore only measure the longer term risk of an infestation and mortality.

Landscape Modeling Systems

State transition models of landscape vegetation (Hemstrom et al. Chapter 2) use discrete vegetation classes and transition probabilities to model change from succession, management, and disturbance (Kurz et al. 2000). In contrast to tree-level growth models like FVS, the growth and mortality of individual trees is encapsulated in the transition probabilities. The use of states and transitions reduces the complexity of landscape simulations, although there remains a significant challenge to estimate and validate transition probabilities. There are several case studies using a state and transition approach to modeling forest landscape change by using the Vegetation Dynamics Development Tool (VDDT) and the Tool for Exploratory Landscape Analysis (TELSA) (Kurz et al. 2000). A prototype TELSA model built for the Upper Grande Ronde considered insect mortality from spruce budworm and Douglas-fir beetle; and spruce beetle and mountain pine beetle in ponderosa (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*P. contorta* Dougl. ex Loud.). Insect epidemics were simulated, and mortality was represented by changing the vegetative state of infested stands based on host mortality. Parameters for simulating epidemics were obtained from data on historical infestations including USDA Forest Service, Pacific Northwest Region aerial survey maps (USDA FS 2003a) and other historical information (e.g., Gast et al. 1991). Pertinent information for each insect vector included periodicity of outbreaks and the percentage of host type infested during an outbreak. Initial results from this model show how different management scenarios change future extent and severity of insect epidemics and the effects of alternative forest management schedules.

Alternatives to the state and transition approach are stand-level models that use individual-based tree growth models to simulate multiple stands on a landscape. Incorporating insect- and disease-caused mortality into these models is relatively straightforward. For instance, a simple landscape simulation with insect and disease mortality can be built by simulating all the stands in a landscape with FVS and FVS pest extensions (Roberts and Weatherby 1997). This approach can be enhanced to consider spreading of infestations by using the FVS parallel processing extension, as in the westwide pine beetle model (Smith et al. 2002). When combined with the array of other FVS extensions and postprocessors (USDA FS 2003c), the multistand approach of using FVS and the parallel processing extension provides a flexible system that can address a variety of scenarios.

More complex are the stand-alone optimization models such as the Simulation and analysis of forests with episodic Disturbances (SafeD) model (Bettinger et al. Chapter 4, Graetz 2000, Wedin 1999), which derive their growth equations from FVS code but do not have direct linkages to FVS and the pest extensions. In SafeD, insect and disease mortality was modeled as an endemic process as part of stand growth (Wedin 1999), and epidemic or periodic mortality from insects or diseases was not considered.

Research Approach

Options for Different Modeling Frameworks

Each of the methods (FVS-related software, state transitions models, landscape simulation/optimization models) for simulating vegetation change for the INLAS project requires different amounts and kinds of development to enable modeling of insect and disease mortality. The major tasks required to incorporate insect- and disease-caused mortality by using FVS-related software approach (Ager Chapter 3) involve issues of local calibration and experience to run the FVS extensions for Douglas-fir beetle, western spruce budworm, Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough), and mountain pine beetle on lodgepole pine. Additionally, ad hoc models for mountain pine beetle on ponderosa pine, western pine beetle (*D. brevicomis* LeConte) on ponderosa pine, and spruce beetle on Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), such as those illustrated by Roberts and Weatherby (1997) for ponderosa pine, need to be evaluated on local stand conditions. A major part of this work will be estimation of parameters for epidemic lengths, periodicities, and spread rates for Blue Mountain conditions. For INLAS, we will experiment with FVS insect extensions in concert with the development of FVS-related landscape simulation tools.

Stand-alone landscape optimization models such as those described by Bettinger et al. (Chapter 4) pose a larger problem within the context of INLAS. Although modeling **endemic** mortality can be accomplished by using mortality functions derived from the literature, modeling epidemics in stand-alone optimization models will require substantial work and is probably beyond the scope of this project. A first step would be converting FVS insect extensions to run within other stand-alone programs. Parameters are then needed for epidemic lengths, periodicities, and spread rates for Blue Mountain conditions. With this accomplished, epidemics could be simulated much like wildfire as described by Bettinger et al. (Chapter 4), where simulations are stopped each decade to run the FARSITE fire model (Finney Chapter 9). Insect mortality could be simulated every cycle, with epidemic parameters carrying over from cycle to cycle. Supporting epidemic parameters described above, including spread rate, intensity, and duration, are needed. An alternative that would take advantage of many of the FVS insect and disease models could be achieved by using the pest extensions in FVS to process tree lists from a stand-alone optimization model at each cycle. Specifically the Douglas-fir beetle, western spruce budworm, and western pine beetle can be applied to tree lists generated by SafeD and used to trigger single-cycle tree damage and mortality. Components of the FVS insect and disease models that consider more than one cycle would need to be incorporated into the optimization model. For instance, the scheduling of periodic outbreaks could be implemented by writing the appropriate keyword files for FVS. The integration of insect and disease mortality into forest simulation/optimization models would provide a way to explore how different landscape goals are affected by these disturbance agents. Both stand and landscape goals can incorporate financial or other considerations to allow the estimation of the marginal cost of reducing insect and disease effects. Landscape goals also can be combined into multiobjective goals. For instance, stand goals would minimize susceptibility, whereas landscape goals could alter the spatial arrangement of susceptible stands to minimize spread (see Bettinger et al. Chapter 4). Landscape planning models can explore alternative scenarios by applying management activities targeting specific insect pests. Results from simulations could be applied by forest managers, pest management practitioners, and researchers concerned with landscape planning and simulation.

State and transition models require specific transitions to represent mortality of the different insect and disease agents (Hemstrom et al. Chapter 2). Like the other modeling approaches, the major part of this work is estimating characteristics of epidemics for Blue Mountain conditions. We discuss approaches to estimating these parameters below.

Estimating Parameters for Insect Epidemic Cycles

As mentioned earlier, a key component of any effort to model insect and disease mortality is parameters that describe the lengths, periodicities, and spread rate of epidemics for each insect of concern for local conditions. This section presents the result of a preliminary work to quantify these parameters by using data on past infestations. Although ultimately the size of epidemics is dependent on host type availability and secondary factors that influence epidemic growth (e.g., weather, spatial patterns of host, natural disturbance), realistic values must be used for epidemic cycles.

The importance of host availability and other factors is illustrated with historical conditions in the Blue Mountains. For example, it is assumed that the large historical outbreaks of western pine beetle have not been repeated in recent times owing to a decrease in large-diameter ponderosa pine. In contrast, infestations by defoliators have increased with the extent of defoliator host type (e.g., true firs) (e.g., Powell 1994). Spruce beetle epidemics are often triggered by wind events that result in a large number of downed spruce (e.g., Gast et al. 1991). Another example is Douglas-fir beetle, where trees weakened during defoliator outbreaks seem especially susceptible to Douglas-fir beetles (e.g., Wright et al. 1984). Hence, bark beetle activity is often observed after several years of budworm or tussock moth defoliation in the Blue Mountains.

Despite the dependence of outbreak size on host and other factors, we tried to gain some preliminary insight into the spatiotemporal patterns of insect epidemics by surveying historical outbreaks. For instance, it would be of interest to know how epidemics are manifested in terms of the numbers of individual infestation sites and the average size. Using data from the annual Aerial Insect Detection Survey conducted by the USDA Forest Service Pacific Northwest Region and Oregon Department of Forestry, we summarized and examined patterns of past insect infestations in the Blue Mountains. Additional information was obtained from Gast et al. (1991). These data clearly show the difference between epidemic and endemic infestations, and that endemic levels for one insect may exceed endemic levels for others (table 6, fig. 26). Bark beetles have relatively active endemic populations in the Blue Mountains compared to defoliators, and the acres affected during an epidemic range from a twentyfold to thirtyfold increase for some species, whereas others can cause a onefold to several hundredfold increase. Endemic levels of defoliators are so low that damage is not visible. Clearly, the defoliator cycles are high amplitude, and in the case of spruce budworm, have a long cycle. Although epidemics were characterized by increases in both infestation size and number of sites, the latter appears more important than the former. For instance, the individually mapped beetle infestations are all about 1.5 to three times larger for the epidemic versus endemic periods, whereas the number of polygons increased by an average of six times. We note that this difference could be an artifact of the mapping procedure. Also, the spatial arrangement of host stands could account for a major component of the size versus number contrast.

Table 6—Summary of aerial survey insect damage surveys showing population parameters[a]

Species	Population status	Average duration	Average periodicity	Number of polygons	Proportion of years	Average mapped unit	Total area
		– – – – – Years – – – – –			*Percent*	*– – – – Acres – – – –*	
Douglas-fir beetle	Endemic			108	43.75	70	7,560
	Epidemic	8	15	661	65.25	265	175,165
Fir engraver beetle	Endemic			137	79.20	190	26,030
	Epidemic	5	20	951	21.80	257	244,407
Western pine beetle	Endemic			108	75.00	143	15,444
	Epidemic	4	16	299	25.00	364	108,836
Mountain pine beetle in lodgepole pine	Endemic			68	70.80	200	13,600
	Epidemic	9	63	749	29.20	561	420,189
Mountain pine beetle in ponderosa pine	Endemic			216	78.70	154	33,264
	Epidemic	5	14	986	21.30	315	310,590
Spruce beetle	Endemic			23	85.40	225	5,175
	Epidemic	6+	Variable: disturbance-related	129	14.60	348	44,892
Douglas-fir tussock moth	Endemic			0	81.10	0	0
	Epidemic	3	9	353	18.90	557	196,621
Western spruce budworm	Endemic			0	56.60	0	0
	Epidemic	12	36	583	43.40	4,858	2,832,214

[a] Data were obtained between 1954 and 2001 and pertain to all forested lands in the Blue Mountains province. Low damage (BS-L and BS-1) for western spruce budworm were not included because they do not generally indicate host mortality.

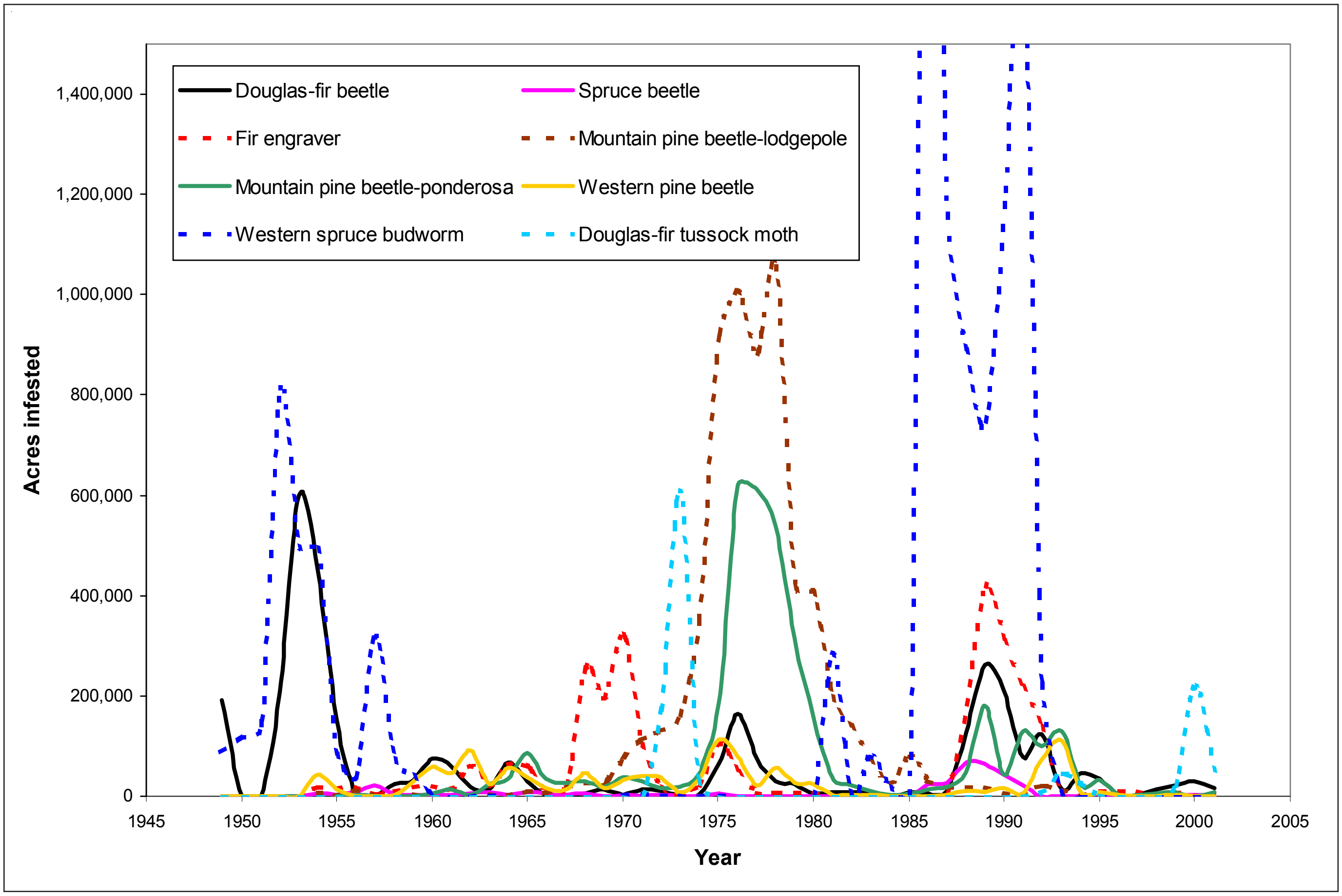

Figure 26—Acres infested with major insect pests as derived from aerial survey information and Gast et al. (1991). Peak values of about 3 million acres for western spruce budworm were truncated to improve visibility of other data. Budworm damage codes for low damage (BS-L, BS-1) were omitted.

At a minimum, table 6 and figure 26 illustrate qualitative features of insect infestations and illustrate the stochastic nature of this particular natural disturbance. In addition, the data show the relative importance of modeling spatial spread and contagion among the various insect pests. Defoliators like western spruce budworm that are capable of rapid spread over very large areas probably do not warrant detailed modeling of spread because most or all host are infested over a short period. In contrast, insects that have longer infestations per area affected (i.e., broad peaks, such as mountain pine beetle in lodgepole pine and fir engraver beetle [*Scolytus ventralis* LeConte in true fir]) show longer infestation periods per total acres infested, suggesting constraints to spreading are regulating these infestations more than in the western spruce budworm. Here, more detailed spread models might be warranted.

It should be noted that the data show population status data for the Blue Mountains as a whole, and it is possible to have localized epidemics that result in significant damage. Douglas-fir tussock moth epidemics have characteristically developed in several discrete and different areas within the Blue Mountains over the last century. However, in most cases, epidemic populations of various insects and associated damage develop concurrently or occur over large areas within the Blue Mountains.

One additional factor that must be considered with these data is that aerial survey sketch mapping has evolved over the years as new technology has been developed. For example, this new technology has allowed more accurate portrayal of discrete pockets of infestation, whereas in the early days of surveying, these were grouped in large polygons; thus, polygons have decreased in size and increased in number.

Proposed Work

The goal of incorporating insect and disease mortality in landscape simulation models in the context of INLAS is to better understand the long-term interactions of insects, disease, management, and other disturbances, and forest succession. Through the INLAS project, we will continue to investigate the historical epidemic data and try to produce parameters for each of the major insect pests. Work on diseases will probably be minimal given their relatively minor effect on mortality. We will explore methods to assess uncertainty in the insect epidemic data. Given a set of reasonable parameters, epidemics will be simulated by using the simulation framework described in Ager (Chapter 3) for the INLAS project area. These simulations will use the FVS pest extensions and will be completed for a set of management scenarios (Barbour et al. Chapter 1). The outputs will provide the data to examine how long-term levels of insect mortality might be affected by different intensities and kinds of forest management at the subbasin scale.

Acknowledgments

Helpful reviews of an earlier version of this paper were provided by Don Scott and Nick Crookston.

Metric Equivalents

When you know:	Multiply by:	To find:
Acres	0.405	Hectares
Feet	.3048	Meters

Literature Cited

Ager, A.A. 1996. Operations manual for UPEST. Pendleton, OR: U.S. Department of Agriculture, Forest Service, Umatilla National Forest. 16 p.

Ager, A.A. 2004. Stand-level approaches to simulating forest landscapes in the Western U.S. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 33-40. Chapter 3.

Barbour, R.J.; Ager, A.A.; Hayes, J.L. 2004. A framework for the development and application of INLAS: the Interior Northwest Landscape Analysis System. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1-16. Chapter 1.

Bettinger, P.; Graetz, D.; Ager, A.A.; Sessions, J. 2004. The SafeD forest landscape planning model. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 41-63. Chapter 4.

Beukema, S.J.; Greenough, J.A.; Robinson, D.C.E. [et al.]. 1997. The westwide pine beetle model: a spatially-explicit contagion model. In: Teck, R.; Moeur, M.; Adams, J., comps. Proceedings: Forest Vegetation Simulator conference. Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 126-130.

Cameron, D.E.; Stage, A.R.; Crookston, N.L. 1990. Performance of three mountain pine beetle damage models compared to actual outbreak histories. Res. Pap. INT-435. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.

Campbell, S.; Liegel, L., tech. coords. 1996. Disturbance and forest health in Oregon and Washington. Gen. Tech. Rep. PNW-GTR-381. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station and Pacific Northwest Region; Oregon Department of Forestry; Washington Department of Natural Resources. 105 p.

Crookston, N.L.; Colbert, J.J.; Thomas, P.W. [et al.]. 1990. User's guide to the western spruce budworm modeling system. Gen. Tech. Rep. INT-274. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 40 p.

Crookston, N.L.; Stage, A.R. 1991. User's guide to the parallel processing extension of the prognosis model. Gen. Tech. Rep. INT-281. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 87 p.

Eager, T.J.; Angwin, P.A. 1997. Forest health assessment–Piney analysis area, Holy Cross Ranger District, White River National Forest. In: Teck, R.; Moeur, M.; Adams, J., comps. Proceedings: Forest Vegetation Simulator conference. Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 116-120.

Filip, G.M.; Torgersen, T.R.; Parks, C.A. [et al.]. 1996. Insect and disease factors in the Blue Mountains. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests: 169-202.

Finney, M.A. 2004. Landscape fire simulation and fuel treatment optimization. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 117-131. Chapter 9.

Frankel, S.J., tech. coord. 1998. Users guide to the western root disease model, version 3.0. Gen. Tech. Rep. PSW-165. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 164 p.

Gast, W.R., Jr.; Scott, D.W.; Schmitt, C. 1991. Blue Mountains forest health report: new perspectives in forest health. Portland, OR: U.S. Department of Agriculture, Forest Service, Malheur, Umatilla, and Wallowa-Whitman National Forests. [Irregular pagination].

Graetz, D.H. 2000. The SafeD model: incorporating episodic disturbances and heuristic programming into forest management planning for the Applegate River watershed, southwestern Oregon. Corvallis, OR: Department of Forest Resources, Oregon State University. 127 p. M.S. thesis.

Hagle, S.K.; Goheen, D.J. 1986. Root disease response to stand culture. In: Schmidt, W.C., comp. Proceedings: future forests of the mountain West: a stand culture symposium. Gen. Tech. Rep. INT-GTR-243. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 303-308.

Hawksworth, F.G.; Williams-Cipriani, J.C.; Eav, B.B. [et al.]. 1995. Dwarf mistletoe impact modeling system user's guide and reference manual. Internal Rep. MAG-95-2. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Pest Management Methods Application Group. 120 p.

Hayes, J.L.; Daterman, G.E. 2001. Bark beetles (*Scolytidae* spp.) in eastern Oregon and Washington. Northwest Science. 75: 21-30.

Hemstrom, M.; Ager, A.A.; Vavra, M. [et al.]. 2004. State and transition approach for integrating landscape models. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 17-32. Chapter 2.

Hessburg, P.F.; Mitchell, G.R.; Filip, G.M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW-GTR-327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p.

Kurz, W.A.; Beukema, S.J.; Klenner, W. [et al.]. 2000. TELSA: the tool for exploratory landscape analysis scenario analysis. Computers in Electronics in Agriculture. 27: 227-242.

Lehmkuhl, J.F.; Hessburg, P.F.; Everett, R.L. [et al.]. 1994. Historical and current forested landscapes of eastern Oregon and Washington: Part I. Vegetation pattern and insect and disease hazard. Gen. Tech. Rep. PNW-GTR-328. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 88 p.

Marsden, M.A.; Eav, B.B.; Thompson, M.K. 1994. User's guide to the Douglas-fir beetle impact model. Gen. Tech. Rep. RM-250. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 9 p.

Monserud, R.A.; Crookston, N.L. 1982. A user's guide to the combined stand prognosis and Douglas-fir tussock moth outbreak model. Gen. Tech. Rep. INT-127. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 49 p.

Parks, C.G.; Flanagan, P.T. 2001. Dwarf mistletoes, rust diseases, and stem decays in eastern Oregon and Washington. Northwest Science. 75: 31-37.

Powell, D.C. 1994. Effects of the 1980s western spruce budworm outbreak on the Malheur National Forest in northeastern Oregon. R6-FI&D-TP-12-94. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Insects and Diseases Group. 176 p.

Quigley, T.M.; Hayes, J.L.; Starr, G.L. [et al.]. 2001. Improving forest health and productivity in eastern Oregon and Washington. Northwest Science. 75: 234-251.

Roberts, J.C. 2002. Using a multichange agent approach with the forest vegetation simulator on the Boise National Forest, Idaho. In: Crookston, N.L.; Havis, R.N., comps. Second Forest Vegetation Simulator conference. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 53-56.

Roberts, J.C.; Weatherby, J.C. 1997. Successional simulation using the Forest Vegetation Simulator and multi-pest scenarios for various levels of planning. In: Teck, R.; Moeur, M.; Adams, J., comps. Proceedings: Forest Vegetation Simulator conference. Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 111-115.

Scott, D.W.; Schmitt, C.L.; Ager, A. 1998. Analyzing insect and disease risks for watershed analysis with the UPEST risk calculator program. Rep. BMZ-98-1. La Grande, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest, Blue Mountains Pest Management Service Center. 18 p.

Sheehan, K.A.; Kemp, W.P.; Colbert, J.J.; Crookston, N.L. 1989. The western spruce budworm model: structure and content. Gen. Tech. Rep. PNW-GTR-241. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 70 p.

Shore, T.L.; Safranyik, L.; Lemieux, J.P. 2000. Susceptibility of lodgepole pine stands to the mountain pine beetle: testing of a rating system. Canadian Journal of Forest Research. 30: 44-49.

Smith, E.; McMahan, A.J.; Eager, T. 2002. Landscape analysis of the westwide pine beetle FVS extension. In: Crookston, N.L.; Havis, R.N., comps. Second Forest Vegetation Simulator conference. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 62-68.

Steele, R.; Williams, R.E.; Weatherby, J.C. [et al.]. 1996. Stand hazard rating for central Idaho forests. Gen. Tech. Rep. INT-GTR-332. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 29 p.

Thies, W.G. 2001. Root diseases in eastern Oregon and Washington. Northwest Science. 75: 38-45.

Torgersen, T.R. 2001. Defoliators in eastern Oregon and Washington. Northwest Science. 75: 11-20.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2003a. Forest health protection. http://www.fs.fed.us/r6/nr/fid. (November).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2003b. http://www.fs.fed.us/foresthealth/technology/products.htm. (November).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2003c. http://www.fs.fed.us/fmsc/fvs/index.php. (November).

Wedin, H. 1999. Stand level prescription generation under multiple objectives. Corvallis, OR: Department of Forest Resources, Oregon State University. 178 p. M.S. thesis.

Wright, L.C.; Berryman, A.A.; Wickman, B.E. 1984. Abundance of the fir engraver, *Scolytus ventralis*, and the Douglas-fir beetle, *Dendroctonus pseudotsugae*, following tree defoliation by the Douglas-fir tussuck moth. Canadian Entomologist. 116: 293-305.

Wykoff, W.R.; Crookston, N.L.; Stage, A.R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Chapter 9: Landscape Fire Simulation and Fuel Treatment Optimization

Mark A. Finney[1]

Abstract

Fuel treatment effects on the growth and behavior of large wildland fires depend on the spatial arrangements of individual treatment units. Evidence of this is found in burn patterns of wildland fires. During planning stages, fire simulation is most often used to anticipate effects of fuel treatment units. Theoretical modeling shows that random patterns are inefficient in changing large-fire growth rates compared to strategic designs. For complex landscapes, computational methods are being developed to identify optimal placement of fuel treatment units that collectively disrupt fire growth similarly to the strategic patterns. By combining these algorithms with forest simulations over long periods (say 50 years), the long-term effects of various treatment strategies can be compared.

Keywords: Fire simulation, fire modeling, fuel treatments.

Introduction

Large wildland fires are archetypal landscape phenomena. Landscapes are large land areas that encompass properties that vary at scales finer than the landscape as a whole (e.g., vegetation and topography). Wildland fires often encompass spatial and temporal domains that are large compared to the landscape properties critical to their behavior (fuels, weather, and topography). As fires advance across the landscape, they encounter fine-scale variability in fuels, topography, and weather that produces complex patterns of behavior and effects (see review by Finney 1999). Simulation models can accommodate such high-frequency variation in the fire environment and thereby help us understand movement and behavior of individual fires in complex conditions (Finney 1998). Simulation models are the main tools used to anticipate the effects management of vegetation and forests has on large fire growth and behavior. Fire simulations, however, must be coupled with vegetation or forest growth simulations if long-term consequences of wildland fires and management are to be addressed (Johnson et al. 1998, Keane et al. 1996, Sessions et al. 1999). This paper will first summarize fire modeling and fuel management techniques and then discuss methods for incorporating fire growth simulations and fuel management optimization into landscape forest simulations.

---

[1] **Mark A. Finney** is a research forester, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, P.O. Box 8089, Missoula, MT 59807.

Fire Simulations and Their Requirements

Wildland fire behavior has long been known to be a function of fuels, weather, and topography (Brown and Davis 1973). Fire behavior programs in use today, e.g., the fire behavior (BEHAVE) prediction and fuel modeling system (Andrews 1986), accept inputs for these factors and predict fire behavior characteristics. Fire behavior refers to the gross characteristics of fire, e.g., fireline intensity (kW/m, or power per unit length of the flaming front), spread rate (m/min^{-1}), spotting distance, fuel consumption (kg/m), and whether the fire is a surface or crown fire. These quantities are important to managing wildland fire fighting operations, to estimating ecological effects of fires, and to designing fuel treatments that change fire behavior. The BEHAVE program applies fire behavior models to a given point on the ground or in one dimension.

The Fire Area Simulator (FARSITE) program extends these models to calculate fire behavior in two dimensions or across an area of land. As a result, data on fuels, weather, and topography must be provided spatially, with weather and fuel moisture allowed to change with time. Fire behavior across two spatial dimensions varies by the relative direction of fire spread, e.g., heading with the wind or slope, or flanking normal or backing counter to the heading direction. Relative fire spread direction is important in determining the variability of behaviors and effects that occur as large wildland fires move across landscapes (Catchpole et al. 1982). Many techniques have been applied to the problem of two-dimensional fire growth (see reviews by Finney 1998, 1999). Techniques that represent the growth and behavior of the fire edge as a vector or wave front (Finney 2002a, Richards 1990, Sanderlin and Van Gelder 1977) produce less distortion of fire shape and response to temporally varying conditions than techniques that model fire growth from cell-to-cell on a gridded landscape. They are thus preferable for performing fire simulations for supporting fire management operations because they can realistically reflect changes in fire behavior resulting from suppression, fuel, and weather changes.

Fuel Management Activities and Changes to Fire Effects and Behavior at the Stand Level

Fuel management activities are designed to change the structure of wildland vegetation and biomass distribution for the purpose of altering potential fire behavior. The prescriptions and objectives for fuel management depend on the characteristics of the vegetation and fire regime. For forest ecosystems with low- and mixed-severity fire regimes (Agee 1998), fuel management prescriptions can be designed to improve survivability of trees following wildland fires, restore forest structure, and improve the success of fire suppression efforts. For high-severity fire regimes in brushland and forest ecosystems, fuel management objectives can change fire behavior, slowing overall fire growth and improving fire suppression. Fuel management techniques that have proven effective in changing wildland fire behavior and effects consist of prescribed burning (Davis and Cooper 1963, Deeming 1990, Helms 1979, Koehler 1993, Martin et al. 1989, Pollet and Omi 2002), thinning (Hirsch and Pengelly 1999, Keyes and O'Hara 2002), and other mechanical manipulation of living or dead vegetation (Brown and Davis 1973, Pyne et al. 1996). Forest fuel treatments that reduce canopy fuels must often be accompanied by surface fuel treatment; otherwise the surface fuel hazard can be increased (Alexander and Yancik 1977, van Wagtendonk 1996). There are three main targets of fuel management prescriptions that contribute to changes in discrete kinds of fire behavior (table 7).

The changes in potential fire behavior are produced at the stand level, or within the treated area. Fire behaviors before and after treatment can be modeled by using fire behavior prediction systems such as BEHAVE (Andrews 1986) and Nexus (Scott and Reinhardt 2001) to compare fire spread rates, intensities, and propensity for crown fire.

Although fuel management tends to produce immediate changes in fire behavior, fuel treatment effects are only temporary. Fuel conditions change over time as a result of fuel accretion, regrowth of understory vegetation, and ingrowth of young trees. More research

Table 7—General relationships among fuels, prescriptions, and intended changes to fire behavior from fuel treatments

Fuel target	Prescription	Change in fire behavior
Surface fuels (live grass and brush, and dead and downed woody material)	Prescribed burning, mechanical treatments remove, compact, or reduce continuity of surface fuels	Reduced spread rate and intensity, and limit ignition of tree crowns and other aerial fuels
Ladder fuels (small trees, brush, low limbs)	Thinning (small-diameter trees) and prescribed burning (scorching and killing small trees and brush) to decrease vertical continuity between surface and crown fuels	Limit ability for fire to transition from surface to crown fire by separating surface fuels from crown fuels
Canopy fuels (fine fuels like needles, and small twigs in tree crowns)	Thinning to reduce horizontal continuity of crowns (e.g., overstory thin)	Limit spread of crown fire

is required to understand the long-term efficacy of fuel treatments on fuel conditions and fire behavior so that scheduling of future management activities and maintenance can be determined.

Landscape Effects of Fuel Management

Landscape strategies for fuel treatments can be distinguished in terms of their intention to (1) contain fires or (2) to modify fire behavior. Fire containment has been attempted by arranging fuel treatments as fuel breaks (Agee et al. 2000, Green 1977, Omi 1996, Weatherspoon and Skinner 1996). Fuel breaks are designed to facilitate active fire suppression at predetermined locations by indirect tactics (e.g., burnout). An alternative is to modify fire behavior and fire progress across landscapes through strategic placement of treatments and patterns of treatments (Brackebusch 1973; Finney 2001a, 2001b; Hirsch et al. 2001). The latter strategy affords flexibility for integration into land management planning and does not rely on uncertainties of success in fire suppression to mitigate fire effects. The remainder of this paper will focus on strategic treatments.

Although behavior and effects of wildland fires can be changed within a particular treatment unit or stand, the behavior and progress of a much larger fire may not be affected by small treatment units. Fire progression maps often reveal that small units are circumvented by large wildland fires (Dunn 1989, Salazar and Gonzalez-Caban 1987) with little net effect on the overall growth of the fire (fig. 27). Instead, the progress of large wildland fires is only affected by treatments that are (1) comparable to the size of the fire or (2) by treatments that collectively disrupt the growth of fires (Brackebusch 1973, Finney 2001a, Gill and Bradstock 1998). Examples of landscape-scale effects of fuel management are evidenced in large national parks (e.g., Yosemite, Sequoia, and Kings Canyon) where fire management policies have allowed free-burning fires for nearly three decades (Parsons and van Wagtendonk 1996, van Wagtendonk 1995) and in Baja, California, chaparral where little fire suppression exists (Minnich and Chou 1997). Because large fires are of primary concern to fire and forest managers, the most important effects of fuel treatments can only be achieved if landscape-scale considerations are incorporated into

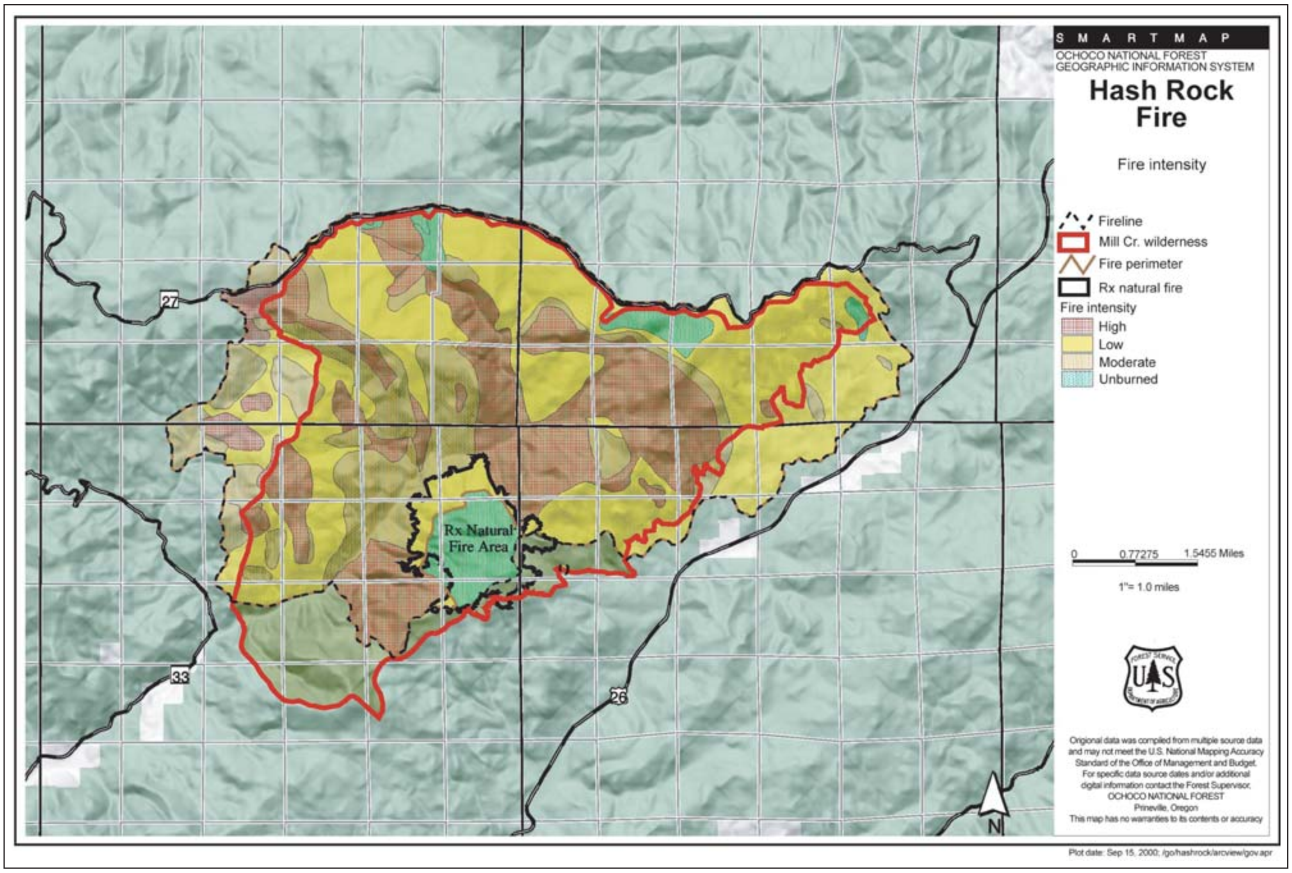

Figure 27—Fire severity at the Hash Rock fire (August 2000) near Prineville, Oregon. A prescribed natural fire (i.e., fire use for resource benefit) that occurred in 1995 produced important localized changes in fire behavior but had little effect on the progress of the Hash Rock Fire as a whole.

the design and positioning of fuel treatments (Brackebusch 1973, Deeming 1990, Omi 1996, Omi and Kalabokidis 1998).

The effects of individual fuel treatment units on large fires must be modeled through simulation. Aside from the minimally managed fire regimes in a few national parks and wilderness areas, no full-scale landscape fuel management activities have been attempted. Thus, our only indications as to the effectiveness of treatments and patterns come from theoretical and modeling activities, and occasional experience of using forest harvest patterns for fire suppression (Bunnell 1998). Brackebusch (1973) advocated a mosaic pattern of managed fuel patches to disrupt fire growth. Gill and Bradstock (1998) discussed the amount of randomly arranged prescribed burns needed to disrupt fire growth. Hirsch et al. (2001) proposed strategically locating fuel treatment units in a "smart forest" approach to harvest scheduling and location. Theoretical work on fuel patterns (Finney 2001a, 2001b) indicates that spatial patterns of fuel treatments are critical to fire growth rates (i.e., the rate of spread of large fires) (fig. 28). Here, random fuel treatments are very inefficient in changing overall fire growth rates. Compared to the partially overlapped pattern, randomly arranged treatments permit fire to easily move laterally around treatments unless large portions of the landscape are treated. This is further illustrated by a comparison of large fire growth rates across the entire range of treatments (fig. 29). If fire spread rate is reduced to one-fifth within the treatment unit compared to the untreated surrounding landscape (as a direct effect of the treatment

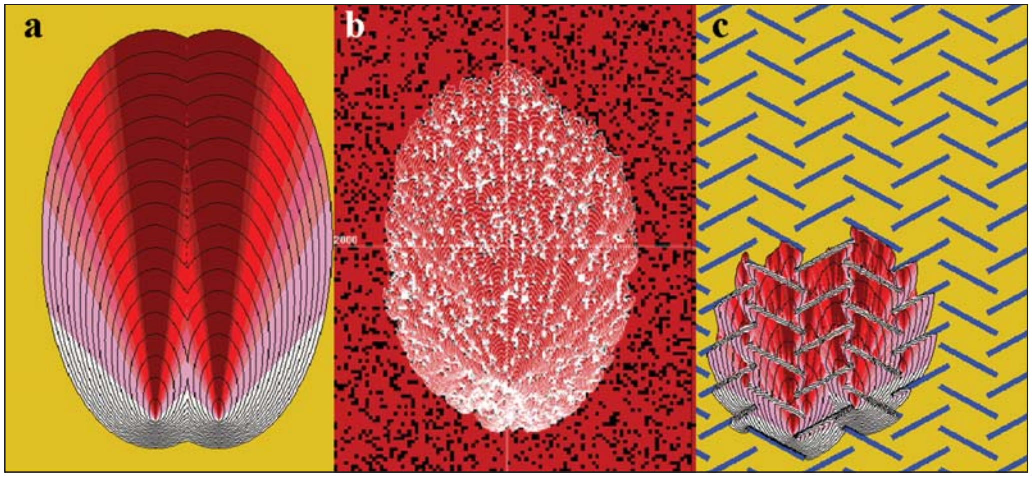

Figure 28—Simulations of fire growth on different theoretical fuel patterns. Compared to (a) no treatment, (b) random 20-percent treatment produces little effect on overall fire growth compared to (c) a theoretical partial-overlap treatment. Random arrangements are ineffective because the fire can circumvent treatment areas.

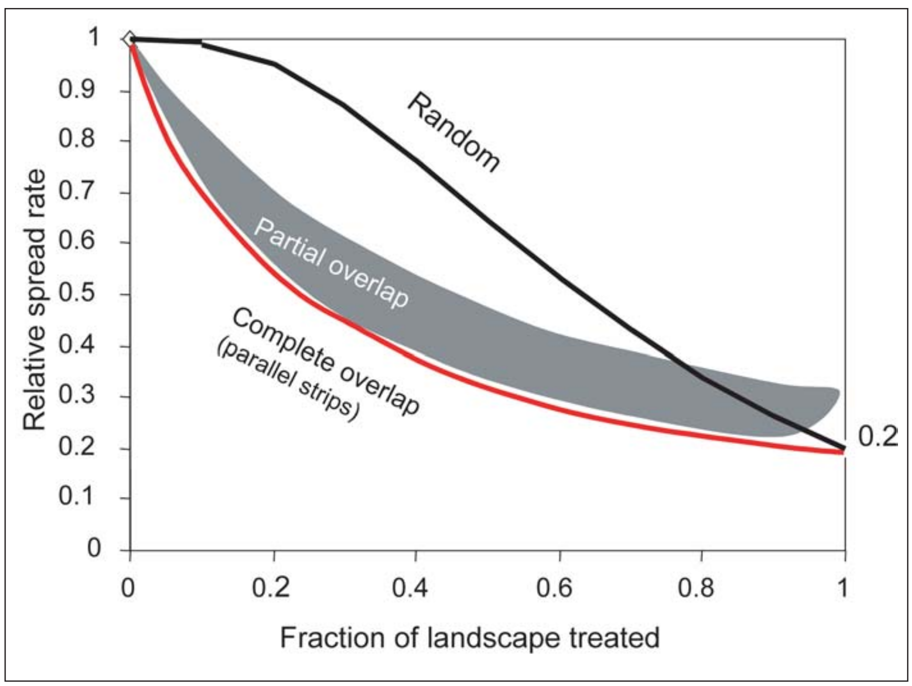

Figure 29—Overall fire spread rate as a function of treatment fraction for different spatial patterns of treatment units (from Finney 2001a, 2003) reduces relative spread rate to 0.2. Compared to patterns that require overlap among treatments, the random treatment pattern produces little reduction in overall fire spread until relatively large proportions of the landscape are treated (because fire goes around the treated patches).

prescription) 35-percent reduction in large fire growth rates is achieved by treating about 10 percent of the landscape in the strategic pattern compared to 50 percent in a random pattern (fig. 29). The strategic pattern is clearly more efficient (per area treated) than a random spatial arrangement of treatments. In nature, fire patterns created by free-burning fires in the large national parks and Baja (Minnich and Chou 1997, Parsons and van Wagtendonk 1996, van Wagtendonk 1995) obstruct fire growth because large percentages of the landscape are maintained by previous fires, despite the random locations of those fires and previously burned areas.

The effects of fuel and forest management activities on fire behavior are not restricted to the stand that is treated. Behavior characteristics of large wildland fires can be altered outside the treated area because of the way fire behavior changes depending on the relative fire spread direction. These constitute an "off-site" effect of treatments that are seen as changes in overall fire growth rate (fig. 28), flanking and backing fire burning with lower fireline intensity on the lee-side of treatment units (fig. 30), and in moderated fire effects on the lee-side of fuel changes (fig. 31). Such landscape-scale effects on large fires become important to the patch sizes and proportions of areas burned with different severities.

Effects of Spatial Locations and Patterns of Landscape Fuel Treatments

Despite the potential benefits of fuel management at the stand and landscape levels, limitations on the amounts and locations of treatment suggest that these activities must be carefully chosen to achieve the greatest effect and benefit. The problem might be approached as an optimization of effects given constraints on locations, amounts, and prescriptions that can be applied. Application of spatial optimization and strategies in forest management (Baskent 1999, Baskent and Jordan 1996, Snyder and ReVelle 1996) and fire management (Finney 2001a, Hirsch et al. 2001, Hof et al. 2000, Wilson and Baker 1998) is becoming more common. For a simple theoretical landscape consisting of two fuel types on flat terrain, a pattern of rectangular fuel treatment units can be optimized for size and placement (Finney 2001a). Such patterns are optimal in terms of efficiency and effectiveness in reducing large-fire growth rates compared to random fuel patterns (Finney 2001b, 2003). However, there are no analytical solutions to the optimization of fuel treatment locations on real landscapes that are complex in terms of fuels, topography, and weather. For real landscapes, where fuels, topography, and weather all differ, an optimization of this kind is complicated by the spatial and temporal nature of fire and its movement through a pattern of fuel treatments.

An optimization algorithm is under development for helping choose the placement of fuel treatments on real landscapes (Finney 2002b). One process now being considered consists of two steps: (1) use fire growth algorithms to identify the fastest travel routes across a landscape, and (2) use heuristic algorithms to optimize the locations and sizes of fuel treatments to block these routes. The fastest travel routes produced by fire growth algorithms suggest initial places for optimal placement of fuel treatments for delaying fire growth. The procedure requires the construction of a gridded landscape containing information on fuels and topography (fig. 32a). Specific weather conditions associated with the conditions targeted for fuel treatment performance, including wind direction, windspeed, humidity, and temperature are used to compute the fire behavior at each cell. Each cell contains fire spread rates in all directions assuming an elliptical fire shape (Finney 2002a) so that fire growth across the landscape can be computed from a generic ignition source. The fire growth algorithm is based on minimum fire travel time methods from graph theory (Finney 2002a, Moser 1991) that efficiently calculate fire growth and behavior for each cell (node) on the landscape. The paths producing the minimum fire travel time can then be processed to identify the "influence paths" or routes of fire travel

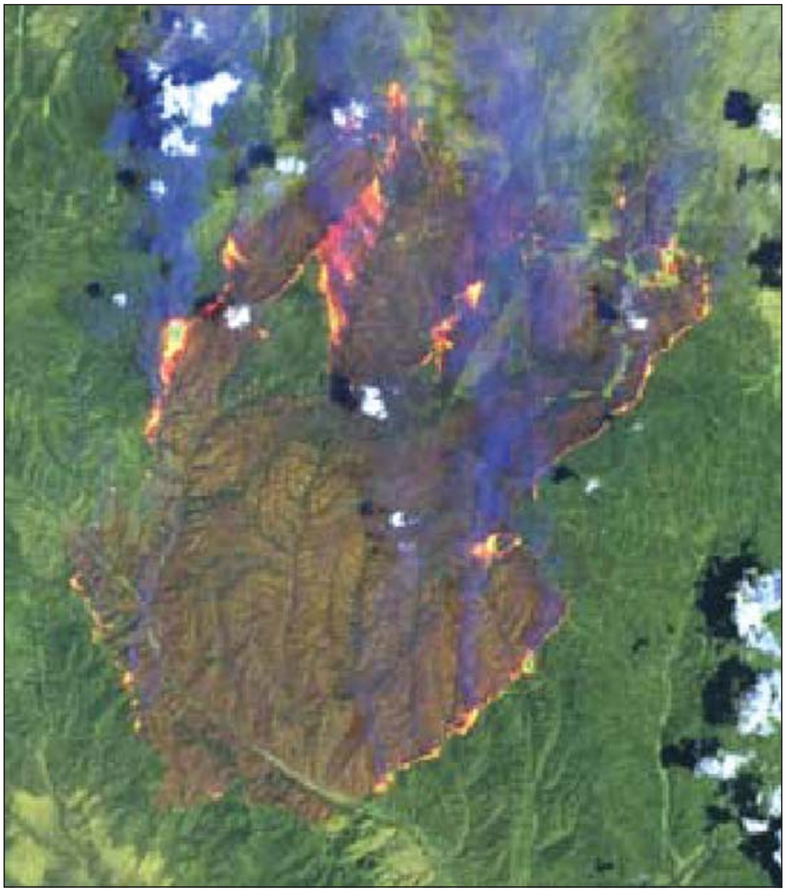

Figure 30—Landsat 7 image of the Rodeo fire in Arizona (June 21, 2002) showing interior fire fronts around arrow-shaped islands within the main fire. These occur where fire fronts join after circumventing the islands and are a landscape-scale effect of varying fuels and fire behavior.

Figure 31—A ridge within the Alder Creek fire (Montana 2000) showing offsite effect of rocky areas (arrows) on fire effects and behavior. Crown fire moved from lower left to upper right and could not burn areas on lee side of rocky patches (photo by Colin Hardy, USDA FS, Missoula Fire Sciences Lab).

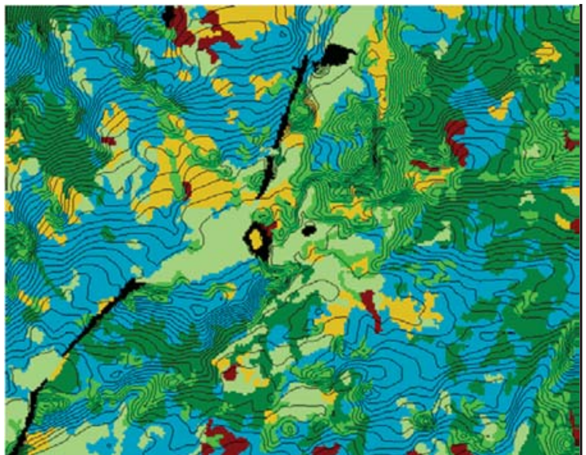

Figure 32a—Fuels and terrain data showing fire growth contours (progression in 1-hour time step from north to south).

Figure 32b—Fire influence paths calculated from fire growth algorithm. Given the ignition configuration (bottom of landscape), fire burning through paths of high influence (red) ultimately burns more land area than areas around them. These suggest places to place fuel treatment units because a large effect would be achieved by slowing fire spread through those areas compared to surrounding areas.

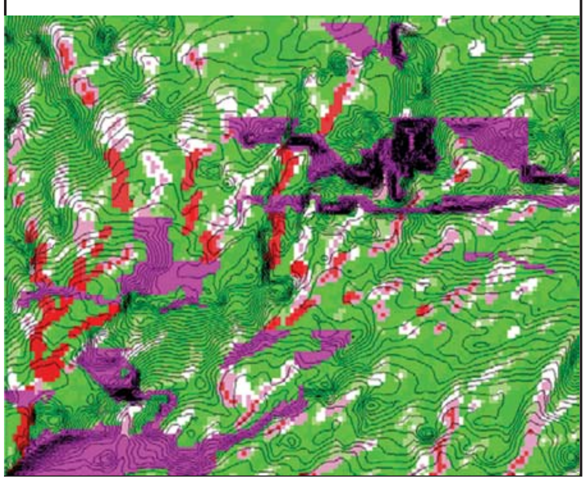

Figure 32c—Fuel treatments (fuchsia color) optimized by using a genetic algorithm for this landscape. Treatments cause fire growth to take twice as long as it would without treatments to cross this landscape while occupying about 15 percent of the total land area.

that account for the most area burned later in time (fig. 32b). These paths are the starting locations for treatment units because of the large influence that blocking those paths has on area burned. The exact number, sizes, and patterns of those treatments, however, must be obtained through the use of a heuristic algorithm (fig. 32c).

Heuristic algorithms are used to find spatially optimal fuel treatment unit sizes and locations. At present, a genetic algorithm (Goldberg 1989) is being developed for evaluating collections of fuel treatment units to determine their effectiveness and efficiency at changing overall fire growth rates. The challenging part of this problem is the sequential nature of fire movement. Fuel treatment units located upwind divert fire growth and change the priorities for fuel treatments downwind (sizes and locations). Furthermore, the optimal spatial pattern is not necessarily composed of locally optimal treatment units. In other words, the importance of each unit is only realized in context of the entire pattern. An approach to this problem involves the use of recursion, starting the algorithm at downwind locations and allowing it to recurse toward the ignition location. At each location, a population of "best" treatment units is selected based on the best populations from previous locations (i.e., upwind or closer to the ignition). The performance of individual treatment patterns is assessed by using the fire growth algorithm to compare fire travel times among treatment alternatives. The genetic algorithm (GA) is used to refine the population of individual treatment units within a horizontal strip, where each treatment unit has characteristics of vertical location and size. Ultimately, the optimal solution is selected from the treatments that produce the overall best effect. The algorithm consists of the following steps:

- Evaluate the fire growth by using the minimum travel time algorithm for the landscape without treatment.
- Divide the landscape into a series of strips of random width running perpendicular to the main fire spread direction.
- Starting with the downwind strip (i.e., farthest from the ignition), use GA to optimize the fuel treatment locations and unit sizes for each of the fuel treatment configurations obtained from the GA on previous strips. Applying the GA to each strip requires recursion into preceding strips to find the optimal treatment locations and sizes. Each treatment configuration in each strip is evaluated by using the minimum travel time algorithm.
- Within each strip, create populations of treatment locations and sizes to evaluate and improve by using the GA. Treatment unit sizes are obtained by infilling the fire growth contours from a starting point (e.g., an influence path) by using the differential spread rate owing to treatment.
- Pick the best overall treatment pattern from all strips that maximize the fire travel time across the landscape as a whole.

The above algorithm is being developed for handling spatial constraints on treatment area and local treatment effectiveness (i.e., within a given stand and stand type). So far, the algorithm appears to identify fuel treatment units that efficiently retard overall fire growth (fig. 32c).

Integration of Fire and Landscape Simulations

Long-term consequences of forest and fuel management activities on wildland fire behavior can only be understood by either large-scale experimentation or through simulation modeling. Until experimental or operational treatment areas have been established on the ground and monitored, simulation modeling will be the only method available.

Many landscape simulation approaches are currently used for spatially modeling fire and long-term future forest development (Johnson et al. 1998, Jones and Chew 1999, Keane et al. 1997, Mladenoff and He 1999, Sessons et al. 1996, Thompson et al. 2000). Some of these have been proposed for modeling effects of treatments and for optimizing the scheduling of fuel treatments. At present, these simulations do not permit control for fuel treatment spatial patterns. As the above analysis of simple landscape patterns suggests, however, fuel treatments at the landscape scale have topological effects that are critical to changing fire growth. Improvements to landscape simulations include the prescription, scheduling, and location of treatments dynamically in response to unpredicted disturbances (fire, insects, etc.). Furthermore, the simulation must have fine-scale resolution of landscape units, as either grids (raster) or small polygons, to retain the fine resolution of spatially variable fire effects (Finney 1999).

The intent of a new modeling effort is to modify the simulation approach (Simulation and Analysis of Forests with Episodic Disturbances [SafeD]) described by Sessions et al. (1999) and Johnson et al. (1998) to incorporate a spatial optimization for fuel treatments (Finney 2002b). The SafeD model has been used previously to examine how fuelbreaks performed in the presence of wildfire and forest change (Johnson et al. 1998, Sessions et al. 1999). Currently, SafeD (Graetz 2000) is a spatially explicit simulation/optimization tool that features a stand prescription generator (Wedin 1999), forest growth-and-yield modeling by using the Forest Vegetation Simulator (FVS), a heuristic method of allocating activities across a landscape with multiple constraints, and a spatially explicit fire growth model FARSITE (Finney 1998). Together, these models allow for scheduling of fuel and harvesting treatments, simulation of wildfire events and effects, growth and mortality of vegetation, surface and crown fuel development, and specification of stand- and landscape-level objectives. The landscape goal-seeking component of SafeD couples heuristic techniques with goal programming to find near-optimal sets of stand and landscape prescriptions. Multiple stand management objectives can be specified for the simulations. Mechanical and prescribed fire treatment effects are modeled in SafeD by manipulation of tree lists (lists of density by size and species of trees) and surface fuel components. Wildfire effects are created by fireline intensity maps created by FARSITE simulations that are activated by the SafeD model.

Several additions to the SafeD model will be required to permit spatial optimization of fuel treatments. Optimal fuel treatment locations will be determined by inclusion of a spatial treatment algorithm (e.g., Finney 2002b).

Research Applications

A project funded by the Joint Fire Science Program (http://www.nifc.gov/joint_fire_sci/jointfiresci.html) will make use of the SafeD simulation system to address landscape fuel treatment scheduling and potential effects for several study areas. These study areas are located in the Blue Mountains in eastern Oregon (one of the INLAS study sites), Sanders County in western Montana, the Sierra National Forest in California, and southern Utah. The landscapes were chosen as samples of different ecosystems, fire regimes, mixtures of landownership, and fuel and forest management issues and constraints to examine, in a practical sense, how the outcomes of landscape fuel treatment programs can be expected to differ. A series of simulations for these landscapes will be performed to address the following questions:

- How important is fuel treatment topology to the potential effects of treatments on real landscapes?
- For different fuel treatment amounts and patterns, what fuel treatment effects (e.g., fire sizes, burned area, severity) can be expected with no constraint on treatment location or prescription?
- What fuel treatment effects are possible given current restrictions on fuel and forest management activities?
- What are the tradeoffs in fuel treatment effectiveness possible by relaxing some of the constraints?

The results of this project are intended to lead to practical methods for guiding fuel treatment planning across landscapes and for helping identify constraints on needed management activities through cooperation among the many competing interests in wildland management.

Conclusions

The fire behavior models presently available can be used to simulate fire growth, behavior, and effects at the landscape scale. Effects of fuel treatments on changes in fire behavior can be modeled for a variety of prescriptions and environmental conditions. The fire simulations also have been used to examine spatial effects of fuel treatment patterns, suggesting that fuel treatment topology can be important to effects on fire growth and behavior. Fire growth simulation and heuristic algorithms are being combined as a means to find optimal patterns of treatments in highly variable conditions found on real landscapes. These optimizations are to be combined with landscape simulation and scheduling programs to examine likely effects of spatial fuel treatment programs on wildland fire behaviors and effects at the landscape scale.

Acknowledgments

This work was partly funded by the Joint Fire Science Program and the USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Fire Behavior Research Work Unit in Missoula, Montana.

English Equivalents

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Kilograms (kg)	2.205	Pounds
Kilowatts per meter (kW/m)	0.2889	British thermal unit per foot per second

Literature Cited

Agee, J.K. 1998. Fire strategies and priorities for forest health in the Western United States. In: Proceedings of the 13th fire and forest meteorology conference. Fairfax, VA: International Association of Wildland Fire, USA: 297-303.

Agee, J.K.; Bahro, B.; Finney, M.A. [et al.]. 2000. The use of fuelbreaks in landscape fire management. Forest and Ecology Management. 127: 55-66.

Alexander, M.E.; Yancik, R.F. 1977. The effect of precommercial thinning on fire potential in a lodgepole pine stand. Fire Management Notes. 38(3): 7-9, 20.

Andrews, P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system–BURN subsystem. Part 1. Gen. Tech. Rep. INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 130 p.

Baskent, E.Z. 1999. Controlling spatial structure of forested landscapes: a case study towards landscape management. Landscape Ecology. 14: 83-97.

Baskent, E.Z.; Jordan, G.A. 1996. Designing forest management to control spatial structure of landscapes. Landscape and Urban Planning. 34: 55-74.

Brackebusch, A.P. 1973. Fuel management: a prerequisite not an alternative to fire control. Journal of Forestry. 71(10): 637-639.

Brown, A.A.; Davis, K.P. 1973. Fire control and use. 2nd ed. New York: McGraw-Hill Book Company. 686 p.

Bunnell, D. 1998. Old-growth lodgepole pine and the Little Wolf Fire. In: Close, K.; Bartlette, R., eds. Proceedings of the 1994 interior West fire council meeting and program. Fairfax, VA: International Association of Wildland Fire, USA: 155-160.

Catchpole, E.A.; de Mestre, N.J.; Gill, A.M. 1982. Intensity of fire at its perimeter. Australian Forest Research. 12: 47-54.

Davis, L.S.; Cooper, R.W. 1963. How prescribed fire affects wildfire occurrence. Journal of Forestry. 61: 915-917.

Deeming, J.E. 1990. Effects of prescribed fire on wildfire occurrence and severity. In: Walstad, J.D.; Radosevich, S.R.; Sandberg, D.V., eds. Natural and prescribed fire in Pacific Northwest forests. Corvallis, OR: Oregon State University Press: 95-104. Chapter 8.

Dunn, A.T. 1989. The effects of prescribed burning on fire hazard in the chaparral: toward a new conceptual synthesis. In: Berg, N.H., tech. coord. Proceedings of the symposium on fire and watershed management. Gen. Tech. Rep. PSW-109. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 23-29.

Finney, M.A. 1998. FARSITE: Fire Area Simulator–model development and evaluation. Res. Pap. RMRS-RP-4. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Finney, M.A. 1999. Mechanistic modeling of landscape fire patterns. In: Mladenoff, D.J.; Baker, W.L., eds. Spatial modeling of forest landscape change: approaches and applications. Cambridge, United Kingdom: Cambridge University Press: 186-209.

Finney, M.A. 2001a. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. Forest Science. 47(2): 219-228.

Finney, M.A. 2001b. Spatial strategies for landscape fuel treatments. In: Bento, J.; Botelho, H., eds. Workshop on tools and methodologies for fire danger mapping: proceedings of a workshop. Vila Real, Portugal: Universidad de Traj-os-montes el Alto-Douro, Departamento Forestal: 157-163.

Finney, M.A. 2002a. Fire growth using minimum travel time methods. Canadian Journal of Forest Research. 32: 1420-1424.

Finney, M.A. 2002b. Use of graph theory and genetic algorithms for finding optimal fuel treatment locations. In: Viegas, D.X., ed. Proceedings of the 4th international conference on fire research [CD ROM]. Rotterdam, The Netherlands: Millpress Science Publishers.

Finney, M.A. 2003. Calculation of fire spread rates across random landscapes. International Journal of Wildland Fire. 12(2): 167-174.

Gill, A.M.; Bradstock, R.A. 1998. Prescribed burning: patterns and strategies. In: 13th conference on fire and forest meteorology. Fairfax, VA: International Association of Wildland Fire, USA: 3-6.

Goldberg, D.E. 1989. Genetic algorithms in search, optimization and machine learning. Boston, MA: Addison-Wesley Publishing Co. 432 p.

Graetz, D.H. 2000. The SafeD model: incorporating episodic disturbances and heuristic programming into forest management planning for the Applegate River watershed, southwestern Oregon. Corvallis, OR: Oregon State University. 127 p. M.S. thesis.

Green, L.R. 1977. Fuelbreaks and other fuel modification for wildland fire control. Agric. Handb. 499. Washington, DC: U.S. Department of Agriculture, Forest Service. 79 p.

Helms, J.A. 1979. Positive effects of prescribed burning on wildfire intensities. Fire Management Notes. 40(3): 10-13.

Hirsch, K.; Kafka, V.; Tymstra, C. [et al.]. 2001. Fire-smart forest management: a pragmatic approach to sustainable forest management in fire-dominated ecosystems. The Forestry Chronicle. 77(2): 357-363.

Hirsch, K.; Pengelly, I. 1999. Fuel reduction in lodgepole pine stands in Banff National Park. In: Neuenschwander, L.F.; Ryan, K.C., tech eds. Proceedings of the joint fire sciences conference and workshop. Boise, ID: University of Idaho: 250-256.

Hof, J.; Omi, P.N.; Bevers, M.; Laven, R.D. 2000. A timing oriented approach to spatial allocation of fire management effort. Forest Science. 46(3): 442-451.

Johnson, K.N.; Sessions, J.; Franklin, J.; Gabriel, J. 1998. Integrating wildfire into strategic planning for Sierra Nevada forests. Journal of Forestry. 96(1): 42-49.

Jones, J.G.; Chew, J.D. 1999. Applying simulation and optimization to evaluate the effectiveness of fuel treatments for different fuel conditions at landscape scales. In: Neuenschwander, L.F.; Ryan, K.C., tech. eds. Proceedings of the joint fire science conference and workshop. Boise, ID: University of Idaho: 89-95.

Keane, R.E.; Morgan, P.; Running, S.W. 1996. FIRE-BGC—a mechanistic ecological process model for simulating fire succession on coniferous forest landscapes of the northern Rocky Mountains. Res. Pap. RP-INT-484. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 122 p.

Keyes, C.R.; O'Hara, K.L. 2002. Quantifying stand targets for silvicultural prevention of crown fires. Western Journal of Applied Forestry. 17(2): 101-109.

Koehler, J.T. 1993. Prescribed burning: a wildfire prevention tool? Fire Management Notes. 53-54(4): 9-13.

Martin, R.E.; Kauffman, J.B.; Landsberg, J.D. 1989. Use of prescribed fire to reduce wildfire potential. In: Berg, N.H., tech. coord. Proceedings of the symposium on fire and watershed management. Gen. Tech. Rep. PSW-109. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 17-22.

Minnich, R.A.; Chou, Y.H. 1997. Wildland fire patch dynamics in the chaparral of southern California and northern Baja California. International Journal of Wildland Fire. 7: 221-248.

Mladenoff, D.; He, H.S. 1999. Design, behavior and application of LANDIS, an object-oriented model of forest landscape disturbance and succession. In: Mladenoff, D.J.; Baker, W.L., eds. Spatial modeling of forest landscape change: approaches and applications. Cambridge, United Kingdom: Cambridge University Press: 125-162.

Moser, T.J. 1991. Shortest path calculation of seismic rays. Geophysics. 56(1): 59-67.

Omi, P.N. 1996. Landscape-level fuel manipulations in Greater Yellowstone: opportunities and challenges. In: Greenlee, J., ed. The ecological implications of fire in Greater Yellowstone. Proceedings of the 2nd biennial conference on the Greater Yellowstone ecosystem. Fairfax, VA: International Association of Wildland Fire, USA: 7-14.

Omi, P.N.; Kalabokidis, K.D. 1998. Fuels modification to reduce large fire probability. In: Viegas, D.X., ed. 3rd international conference on forest and fire research and 14th conference on fire and forest meteorology. Industrial, Portugal: ADAI–Associacao para o Desenvolvimento da Aerodinamica: 2073-2088. Vol 2.

Parsons, D.J.; van Wagtendonk, J.W. 1996. Fire research and management in the Sierra Nevada. In: Halvorson, W.L.; Davis, G.E., eds. Science and ecosystem management in the national parks. Tucson, AZ: University of Arizona Press: 25-48 Chapter 3.

Pollet, J.; Omi, P.N. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire. 11(1): 1-10.

Pyne, S.J.; Andrews, P.L.; Laven, R.D. 1996. Introduction to wildand fire. 2nd ed. New York: John Wiley and Sons, Inc. 769 p.

Richards, G.D. 1990. An elliptical growth model of forest fire fronts and its numerical solution. International Journal of Numerical Methods in Engineering. 30: 1163-1179.

Salazar, L.A.; Gonzalez-Caban, A. 1987. Spatial relationship of a wildfire, fuelbreaks, and recently burned areas. Western Journal of Applied Forestry. 2(2): 55-58.

Sanderlin, J.C.; Van Gelder, R.J. 1977. A simulation of fire behavior and suppression effectiveness for operation support in wildland fire management. In: Proceedings of the 1st international conference on mathematical modeling. St. Louis, MO: [Publisher unknown]: 619-630.

Scott, J.H.; Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Res. Pap. RMRS-RP-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.

Sessions, J.; Johnson, K.N.; Franklin, J.F.; Gabriel, J.T. 1999. Achieving sustainable forest structures on fire-prone landscapes while pursuing multiple goals. In: Mladenoff, D.J.; Baker, W.L., eds. Spatial modeling of forest landscape change: approaches and applications. Cambridge, United Kingdom: Cambridge University Press: 210-255.

Sessons, J.; Johnson, K.N.; Sapsis, D. [et al.]. 1996. Methodology for simulating forest growth, fire effects, timber harvest, and watershed disturbance under different management regimes. In: Sierra Nevada Ecosystem Project; final report to Congress. Addendum. Davis, CA: University of California, Centers for Water and Wildland Resources: [Pages unknown].

Snyder, S.; ReVelle, C. 1996. The grid packing problem: selecting a harvesting pattern in an area with forbidden regions. Forest Science. 42(1): 27-34.

Thompson, W.A.; Vertinsky, I.; Schreier, H.; Blackwell, B.A. 2000. Using forest fire hazard modeling in multiple use forest management planning. Forest Ecology and Management. 134: 163-176.

van Wagtendonk, J.W. 1995. Large fires in wilderness areas. Gen. Tech. Rep. INT-GTR-320. In: Brown, J.K.; Mutch, R.W.; Spoon, C.W.; Wakimoto, R.H., tech. coords. Proceedings: symposium on fire in wilderness and park management. Odgen, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 113-116.

van Wagtendonk, J.W. 1996. Use of a deterministic fire growth model to test fuel treatments. In: Sierra Nevada Ecosystem Project; final report to Congress. Assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources: 1155-1165. Vol. 2.

Weatherspoon, C.P.; Skinner, C.N. 1996. Landscape-level strategies for forest fuel management. In: Sierra Nevada Ecosystem Project; final report to Congress. Assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources: 1471-1492. Vol 2.

Wilson, J.S.; Baker, P.J. 1998. Mitigating fire risk to late-successional forest reserves on the east slope of the Washington Cascade Range, USA. Forest Ecology and Management. 110: 59-75.

Chapter 10: Connection to Local Communities

Gary J. Lettman and Jeffrey D. Kline[1]

Abstract

The socioeconomic health of La Grande and other northeastern Oregon communities traditionally has been linked to the region's forests, which have provided economic activity related to timber outputs as well as recreation and other nontimber values. Forest management changes within the Interior Northwest Landscape Analysis System (INLAS) project area can affect socioeconomic changes in the region. This research will evaluate the regional economic impacts of current and alternative forest management alternatives implemented within the INLAS project area and describe prevailing attitudes and values toward forestry and forest management among the region's residents. The research will contribute to understanding the socioeconomic consequences of current and alternative forest management scenarios and can assist forest managers and policymakers in identifying potential compatibilities regarding joint production of multiple timber and nontimber forest outputs.

Keywords: Forest economics, input/output models, local economies, eastern Oregon.

Overview

The socioeconomic health of La Grande and other northeastern Oregon communities traditionally has been linked to the region's forests. Historically, lumber and wood products industries contributed significantly to the region's economic base. More recently, other forest resource-based industries, such as recreation and tourism, also have been recognized as important contributors to local economies. However, a two-thirds reduction in timber harvests in eastern Oregon (Oregon Department of Forestry 2001), coupled with poor economic conditions for the region's agriculture (Barney and Worth 2001), has led to increased concerns regarding the socioeconomic health of northeastern Oregon's communities. Current county-level unemployment rates in the region are between 8 and 16 percent (Bureau of Labor Statistics 2002). Alternative forest management scenarios could alter forest conditions and resource outputs in ways that result in both economic impacts to communities economically dependent on forestry activities, as well as

---

[1] **Gary J. Lettman** is a principal forest economist, Oregon Department of Forestry, 2600 State Street, Salem, OR 97301; and **Jeffrey D. Kline** is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

in quality-of-life impacts that affect residents and visitors who recreate in the region's forests.

Although assessments of alternative forest management practices often have focused on evaluating regional economic impacts resulting from timber outputs, Oregonians also increasingly recognize forests as important cultural resources. Recent population growth coupled with growth of nonforestry economic sectors has reduced the proportion of Oregonians who are directly involved with the economic aspects of forests and forestry (Kline and Armstrong 2001). These and other socioeconomic changes have led to greater environmental orientations toward forests (Schindler et al. 1993, Steel et al. 1994). Recent statewide surveys, for example, suggest that Oregonians place high values on clean air and water, wilderness, and wildlife (Davis et al. 1999). Growing urban populations also can increase demands for outdoor recreation. In another survey, Oregonians cited natural beauty and recreation opportunities as the attributes they most value about living in the state (Oregon Business Council 1993). Similar changes in public values and attitudes toward forests have been observed nationally (Bengston 1994, Davis et al. 1991, Egan and Luloff 2000, Schindler et al. 1993).

How attitudes and values regarding forests might change over time relative to concerns for other issues of regional or statewide interest can reveal the degree to which local communities will trade off forest values of different types with other public objectives. Recent survey data gathered during the ongoing economic turndown, e.g., suggest that Oregonians currently rate economic issues, such as education funding and the recession, as more important than forest management and environmental issues (Davis et al. 2001). Understanding the socioeconomic consequences of current and alternative forest management scenarios in the Interior Northwest Landscape Analysis System (INLAS) project area is important to evaluating resulting regional and statewide impacts. However, understanding Oregonians' attitudes and values regarding forests, and how they change over time, is important to evaluating what range of forest practices and policies will be politically feasible in the future. Together, the two types of information provide a socioeconomic context for evaluating what forest management alternatives are appropriate and can assist managers and policymakers in identifying potential compatibilities regarding joint production of multiple forest outputs.

Objectives

The objectives of this research are to (1) build and calibrate economic impact models for state, county, and local economies to analyze the economic effects of current and alternative forest management scenarios; and (2) describe attitudes and values among the region's residents toward forests and forest management and consider what changes in these might mean for public forest management and policy in the future.

Research Approach

The planned research involves two principal tasks: (1) evaluate the economic impacts of alternative forest management scenarios and (2) describe and examine public attitudes and values toward forests.

Evaluate Economic Impacts

The economic impacts of alternative forest management scenarios will be examined by using output data describing the volume of timber and other forest commodities produced under different scenarios as input data into economic models describing local and regional economic activity. Harvested timber volume and other forest commodity measures will be estimated from tree lists data produced by INLAS vegetation models at each modeling interval. The analysis will describe community and regional economic impacts resulting from different levels of timber volume and other forest commodities produced under the alternative INLAS forest management scenarios tested.

Two types of economic models could be used to examine the economic impacts of current and alternative forest management scenarios. The first is a commercially available economic modeling system such as the Impact Analysis for Planning (IMPLAN) social accounting and economic impact system (Lindall and Olson 1993). This approach would enable relatively quick and easy development of input/output models, after updating and validating county-level data supplied with the modeling system. Such models provide “snapshots in time” of local economies, and their resulting multipliers can be used to evaluate economic impacts of changes in forest management practices. A disadvantage to using these models is that analyses can be satisfactorily done only at the county level, not for individual communities. Such models also may not fully account for informal economic activity, such as undocumented trade and unreported income, which may be characteristics of some forest-based activities involving recreation and nontimber forest products for example.

A second approach is to develop economic impact models by using community or regional economic surveys. Unlike commercially available modeling systems, survey-based models could be constructed for individual communities of interest. However, their disadvantage is their greater complexity and higher cost. Constructing survey data models involves obtaining data on the impacts of local purchases and sales of each economic sector to demands in all other economic sectors, including imports purchased and exports sold.

The choice between using a commercially available modeling system, such as IMPLAN, versus using a survey-based approach will depend on assessing available funding and staffing resources at the outset relative to information needs of the greater INLAS research effort. The IMPLAN system currently is being used in socioeconomic assessments in Wallowa, Union, and Grant Counties, and opportunities may exist to build on this ongoing work.

Examining Public Attitudes and Values

Analyzing only the short-term impacts of alternative forest management scenarios on local and regional economies, and only in terms of dollar flows, provides an incomplete picture of the socioeconomic effects of different forest management activities on nearby communities. For example, user values for fish and wildlife resources, recreation values for activities like fishing and hiking, and preservation values for the forest are examples of nonfinancial economic values that should be considered in evaluating future management activities. Measuring residents’ willingness to pay for biodiversity and other nonmarket values through surveys is beyond the scope of work foreseen for INLAS. However, there are many examples of such analyses in published economics literature (Lettman 2001). These will be reviewed and summarized to illustrate some of the values people may hold for biodiversity and nonmarket forest outputs not generally included in financial-based economic analyses.

Additionally, telephone survey and focus group data already collected for the Oregon Department of Forestry (Davis et al. 2001) will be examined to help improve understanding of the attitudes and values of people in local communities toward forests and natural resource issues, and how these values might change over time. Because the data were collected for seven different regions in Oregon, including northeast Oregon, it will be possible to examine attitudes and values toward forest and natural resource management issues at the regional level and to compare regional and statewide focus group and survey results. In particular, survey results will be summarized for the northeast Oregon counties of Baker, Grant, Umatilla, Union, and Wallowa, and compared to results statewide.

The review and summary of public attitudes and values will not be linked directly to other INLAS models. Rather, they will provide background information describing the social context in which forest management and policy decisions are made.

Products and Users

The research will produce analyses of the regional economic impacts of alternative forest management scenarios and describe public attitudes and values toward forests. In particular, the economic impact analyses will produce economic impact multipliers and other quantitative results, whereas the examination of public attitudes and values will produce qualitative literature reviews, survey results, and other descriptive information. Specific products will include two reports: one report describing the regional economic impacts of current and alternative forest management and fire planning scenarios, as well as the technical aspects of the economic impact approaches taken; and one report describing public values and attitudes toward forests and forest management, which form the socioeconomic context in which management and policymaking will take place. Users of the information produced by this research will include the Governor of Oregon, the Oregon Departments of Forestry and Economic and Community Development, local community officials, national forest planners, and others concerned with the impacts of forest management on economic development and community stability.

Literature Cited

Barney and Worth, Inc. 2001. Inland Northwest economic adjustment strategy, 2001. Olympia, WA: Washington Department of Community, Trade, and Economic Development. 74 p.

Bengston, D.N. 1994. Changing forest values and ecosystem management. Society and Natural Resources. 7(6): 515-533.

Bureau of Labor Statistics. 2002. Local area unemployment statistics. Washington, DC. http://www.bls.gov/. (27 June 2003).

Davis, A.; Hibbits, T.; McCaig, P. 1999. Oregonians discuss forest values, management goals and related issues. Portland, OR: Forest Resources Institute. 19 p.

Davis, A.; Hibbits, T.; McCaig, P. 2001. A forestry program for Oregon: Oregonians discuss their options on forest management and sustainability. Portland, OR: Davis, Hibbitts and McCaig, Inc. 72 p.

Davis, L.S.; Ruth, L.W.; Teeguarden, D.; Henly, R.K. 1991. Ballot box forestry. Journal of Forestry. 89(12): 10-18.

Egan, A.F.; Luloff, A.E. 2000. The exurbanization of America's forests: research in rural social science. Journal of Forestry. 98(3): 26-30.

Kline, J.D.; Armstrong, C. 2001. Autopsy of a forestry ballot initiative: characterizing voter support for Oregon's Measure 64. Journal of Forestry. 99(5): 20-27.

Lettman, G.J., coord. 2001. Elliott State Forest management plan revision: connection to state and local economies. Salem, OR: Oregon Department of Forestry. 158 p.

Lindall, S.A.; Olson, D.C. 1993. Micro IMPLAN user's guide: version 91-F. Stillwater, MN: Minnesota IMPLAN Group, Inc. 417 p.

Oregon Business Council. 1993. Oregon values and beliefs: summary. Portland, OR: 39 p.

Oregon Department of Forestry. 2001. Oregon timber harvest reports, 1990-2000. Salem, OR. 3 p.

Schindler, B.; List, P.; Steel, B.S. 1993. Managing federal forests: public attitudes in Oregon and nationwide. Journal of Forestry. 91(7): 36-42.

Steel, B.S.; List, P.; Shindler, B. 1994. Conflicting values about federal forests: a comparison of national and Oregon publics. Society and Natural Resources. 7(2): 137-153.

Chapter 11: Conflicts and Opportunities in Natural Resource Management: Concepts, Tools, and Information for Assessing Values and Places Important to People

Roger N. Clark[1]

Abstract

The world today, in general, and natural resource management, in particular, seem to be about ever-increasing conflicts. As human populations grow, diversify, and move about the landscape, concerns mount about the impacts of people on water, forests, fish, wildlife, and other people. Strategies for resolving these impacts often result in polarized, either-or remedies, which lead to land use restrictions or closures. Controversy grows as people feel inappropriately excluded from areas and places they have used for years if not generations. In this paper, a number of concepts and approaches are briefly described for identifying and evaluating the values and places important to people. The work proposed as part of the Interior Northwest Landscape Analysis System project focuses on human population dynamics and the relationship between human uses and values and natural resources, with recreation used as a case example. This information, if used in the context of integrated planning, management, and research should help to develop and implement strategies for sustaining a more diverse array of biophysical and social options at multiple spatial and temporal scales.

Keywords: Recreation, integration, resource conflicts, population dynamics.

Introduction

The past 50 years have seen continuing and emerging conflicts in what people value and how they wish to use natural resources (Allen and Gould 1986). As our population grows and diversifies, demands on forests and other natural resources increase. Alarms are sounded from many quarters about the negative effects of people on a variety of values that accrue from public and private lands. Also as scientific information expands, new questions arise about the interactions (both positive and negative) between people and

[1] **Roger N. Clark** is a research social scientist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, 400 N 34th St., Suite 201, Seattle, WA 98103.

the natural resources upon which we depend for our survival and lifestyles. Just how real these problems are is subject to debate. Opposing interest groups' perspectives, concerns about the ideological positions of managers and scientists, and conflicting data make the public even more skeptical about who can be trusted to deal with the complex problems we face.

Many people are dissatisfied with how decisions are made about management of lands they care about (Wondolleck 1988, Wondolleck and Yaffee 2000). Management of roads and trails, riparian areas, and threatened and endangered species increasingly leads to difficult problems where the perception often prevails that **people must go**. This perception can lead to restrictions and closures that limit public access to resources such as valued places for recreation. Taking care of one system (i.e., social, biophysical, or economic) often leads to disenfranchising another. Polarization leads to either-or solutions to complex problems. This often leads to less than optimal solutions with clear winners and losers. Better ways are needed to identify not only the conflicts but also the compatibilities between biophysical and social values and uses. Many have argued that until we embrace people as being a part of ecosystems, rather than apart from, we will continue to breed conflict rather than accommodation (Clark et al. 1999).

Conflicts regarding forest values typically involve the interaction among three key elements: **people** (their distribution, values, organization, and behavior), **places** (both the geographic and symbolic sense), and **processes** (both ecological processes as well as human activities and institutions that affect people, places, and their interactions) (Stankey and Clark 1992). As we seek to better understand these conflicts and to more effectively fashion solutions that prevent or at least mitigate them, it is important that we understand how different management programs will affect each element. Conversely, we need to understand how changes in these elements can affect management programs. For example, how do changes in forest conditions affect employment opportunities in rural communities or the availability of recreation sites? How do changes in local populations or land use rules affect adjacent forests and forest management activities?

The work described in this paper focuses on ways to better understand the relationship between people and natural resources. What people value, their perspectives and perceptions, and what they actually do and where they do it must be considered. Approaches, tools, and information are needed to help managers, scientists, and citizens work through problem framing and problemsolving to identify and implement options that are less polarizing than at present (Wondolleck 1988; Yankelovich 1991, 1999).

The Interior Northwest Landscape Analysis System (INLAS) project is intended to assemble and apply concepts, frameworks, models, and other tools to enable resource managers to address complex biophysical and social values and uses at multiple scales. Some concepts and tools already exist, whereas others are needed to enable scientists and managers to better understand what concerns people have and how they can be better included in planning and management processes.

The work described in this paper will address three components: (1) What frameworks and concepts exist that can be applied to understand the relations between human concerns, values, and uses and biophysical conditions and processes? (2) What changes are occurring in the human population and what significance might that have for use and management of the area? and (3) How can places that are important to people for things such as recreation be identified, described, and evaluated with respect to other biophysical resources and uses?

Component 1: Frameworks and Concepts

There are various frameworks and concepts that provide ways to identify, understand, and evaluate the values and places important to people and how these interact with other resources. Several such concepts that seem to have value for the INLAS project are briefly described here.

Interactions and Integration

Periodically, particular words and phrases take on a special if uncertain significance to people. Integration is one such example. It is used in many circles and implies certain conditions or actions to those who use it. In research, we frequently cite the need for "better integration," or the desire for "integrated approaches" or "integrated teams." Nevertheless, exactly what makes something integrated remains elusive. In the absence of some clarity about and shared expectations for what we expect from integration, we run the risk of perpetuating another round of confusing rhetoric and meaningless slogans best suited to bumper stickers (Clark et al. 1999).

A more holistic understanding about human-natural resource interactions is needed. Such understanding will provide the foundation for developing and implementing integrated resource management programs and practices. There are many reasons why integrated approaches are increasingly desired.

- **The world is complex**. Either-or approaches are no longer tenable and can be unnecessarily divisive (owls vs. jobs, timber vs. recreation, fish vs. dams, riparian restoration vs. public access or recreation use). We need to embrace a wide range of values and uses to find ways to reject either-or solutions to complex problems. To understand multifaceted systems, we need models and approaches that allow us to isolate and explain the interactions within and among its parts. As we attend to biological and physical factors, we also must deal with the social, cultural, economic and institutional aspects of environmental values and uses. However, these things cannot only be considered after the fact as add-ons or things to mitigate for or against.
- **Substantive areas (basic processes, problems, issues, policies) require it**. Integrated approaches are about complex processes, connections, and interrelationships. Stewardship and sustainability involve relationships between people, their environments, and processes that link them. Disciplinary, fragmented research (even if in sum all the parts are included) does not add up to understanding the complexity of the whole.
- **Traditional institutions often fragment rather than unite**. Such institutional behavior exists in education, management, and research organizations. Diverse perspectives are valid, and if we can tie them together, we will reveal new knowledge and provide answers to complex questions facing society.

This project focuses on improving understanding of how systems (biophysical, ecological, human) interact and the effects one has on the other. Lack of such knowledge leads to loss of options as a **tyranny of small decisions** are made to resolve perceived problems as conflicts occur between the biophysical and social systems. Ideology rather than science often guides such decisions. Past research and development have generally been disciplinary where experts start from world views, beliefs, etc. within like disciplines. We have an opportunity to better understand how these complex systems function together. This will lead to better understanding of when, where, and how multiple uses can be allowed without unacceptable adverse effects of one on the other.

For example, the recreation resource is unusual because it represents the combination of most, if not all, physical and biological resources and their management. Past management has tended to focus primarily on recreation and other public uses apart from all other resources. Expanding recreational and other opportunities for the public and addressing potential conflicts require an improved understanding of the complex system of which recreation is a part (Clark 1987).

There are various questions to be addressed regarding the interactions between people and natural resource values and uses. The basic question is under what conditions can public access and use of high-quality recreation settings and sites be provided without adverse effects on biophysical conditions and functions such as in riparian areas? To understand this, we need to better appreciate how these systems interact. How do these interactions vary at different spatial and temporal scales? What is acceptable both from a biophysical and social perspective? Moreover, we need improved frameworks and knowledge about the cumulative effects on and from recreation use and management, as well as on and from riparian use and management (Clark and Gibbons 1991).

Problem Framing Is a Critical First Step and Must Be Ongoing

Inadequately framed problems are a major obstacle to designing successful projects to better understand human-natural resource interactions (Bardwell 1991; Clark et al. 1999, in press; Senge 1990). Several things that might be considered to improve effective problem framing are briefly described below.

It is important not to commit to a particular direction until one gets the questions right. This means that we need to step back from individual or disciplinary definitions and join with other interests to ensure that we are not solving the “wrong” problem. We must learn from one another about how we define landscapes so that we can jointly determine opportunities and redefine problems and then develop explicit questions to drive joint actions.

To be effective, problem framing and resolution must include diverse perspectives and value systems. Because landscape values and meanings are highly variable, there is no “correct” definition. Although this suggests that diversity may be an obstacle, it may be an opportunity as well. What can unite us is recognition of the power of both individual and collective perspectives. Processes that are inclusive increase the possibility of improved understanding, greater representativeness in public participation, an opportunity to learn, and eventually identifying better ways to get desired outcomes (Wondolleck 1988).

A number of things make designing and implementing integrated approaches hard to do (Clark et al. 1999, in press). Ideologies and beliefs (world views) condition how we think and act (Socolow 1976). Such ways of thinking can become problematic if not dealt with constructively, but can enrich dialogue and problemsolving if embraced upfront. Striving to get answers and solutions before clarifying the questions and problems often derails the best intended efforts (Bardwell 1991). Scientific language and expertise make it difficult for interested citizens to easily engage in processes and activities that affect them. Technology can be a means to desired ends but can be a hindrance if the wrong questions are under study.

Problem framing is difficult and often inadequate to identify new questions and understanding. A major challenge is to understand the needs and questions to be addressed before lines are drawn on maps and data collection started. Such problem framing is the most important, yet least well-done step, particularly if all interested parties are not included up front. Problem framing must account for the world views and ideologies people have, or these will limit or preclude effectiveness in the longer run. Problem framing must be iterative and adaptive; it takes time and patience. If done well, clear and shared expectations will result.

To be effective, problem framing must account for diverse ways of knowing and diverse forms of knowledge. In this sense, scientific knowledge is only one component. It is necessary but not sufficient for understanding relationships between biophysical and social systems.

Landscapes Are in the Eye of the Beholder[2]

A central problem facing INLAS is to determine the scale of an area to understand the people-resource interactions (Clark et al. 1999, Jensen and Bourgeron 2001). Landscapes such as that represented by INLAS, and places within them, have meanings to people at every conceivable scale. Which is the “right” scale depends (Clark et al., in press). It takes on a different meaning for people who live in the region or beyond vs. those who live nearby. It differs for people who may care about but never visit the area. And for people who actually set foot on the land and visit the area, there may be strong attachments to particular places. The appropriate scale from a human perspective may not match nicely with biophysical considerations, at least within present planning and scientific approaches.

There is no one right definition for what a landscape is or the scale(s) appropriate for understanding relationships between humans and natural resources. Various needs and questions will define the appropriateness of landscape meanings and scales of analysis. Sometimes these needs are defined by scientists, and at other times by resource managers, and at still others by citizens. Technical definitions are important for technical analyses but not necessarily important to everyone; they often are a means to unclear ends.

In a sense, the meanings that landscapes hold are determined by those viewing the landscape or by interacting with it in other ways. Each meaning is different, not better or worse. To fully understand the values and meanings landscapes produce requires that analyses be inclusive of the people that interact with the landscape in diverse ways.

People think and act at multiple scales for many reasons (Stankey and Clark 1992). There is no one way to divide time and space that will account for the multiple values, concerns, and uses that people bring to the understanding of natural resources. Some ways to think about how landscapes can be considered from a social science perspective are briefly described below.

- **A suite of values is of importance to people**. There are a number of values that are important to people as they think about and use forests and other landscapes. These include commodity, public use, amenity, environmental quality, spiritual, and health values. Such values are attached to landscapes by different types of people and at different scales. For example, recreation can be thought of as people using microsites such as campsites or as driving for pleasure across larger landscapes. Moreover, the array of values often blends biophysical, economic, and social domains in different combinations across space, people, and time. This means that to understand the meaning and importance of these values requires expertise beyond the biophysical sciences.

[2] This section is adapted from Clark et al. (in press) and Stankey and Clark (1992).

- **People organize in many ways**. There are a variety of ways to think about how people (individuals) are combined at different scales and how a social organizational hierarchy can be described. These include individuals, family and household groups, neighborhoods, communities, counties/boroughs, states/provinces, nations, and ultimately, the globe. The interests people hold in the landscape at different scales and the decisions they make about how they interact with the landscape may cut across these different levels. Each level or scale is characterized by different emergent properties, such that the next higher scale is not simply an aggregation of the units at the next lower scale. There are often mismatches between these organizational units and biophysical scales that will need to be reconciled before any analysis begins if an integrated solution is desired.
- **People act at multiple spatial scales**. These include microsites, areas (e.g., a grove of trees, meadows), drainages, watersheds, landscapes (e.g., the Upper Grande Ronde), regions (e.g., the Blue Mountains), continents, and the globe. It is important to consider such ways of defining scales because different social, cultural, and institutional properties may emerge at each scale. Appropriate scales may be defined by the processes at work, interactions within and between components of complex biophysical and social systems, and policy and scientific needs.
- **Human lives and activities consider multiple temporal scales**. Ways of defining time include the past, today, tomorrow, weeks, seasons, years, decades, and generations. These may or may not coincide with how time is considered by specialists concerned with biophysical phenomena. Differences between biological and social scales of significance are frequently at the root of conflict—such as when forest plans are considered over a 50-year timeframe but budgets are appropriated annually. Considerations of time often influence how acceptable people believe forest management practices to be. Who can wait, e.g., for newly harvested forests to become old growth when people only live for a few decades?
- **Beware the ecological fallacy when drawing conclusions about people**. Meanings cannot simply be aggregated upward; people may define an entire watershed as a suitable place for timber harvesting, yet hold claims to spiritual, aesthetic, and recreational meanings at the site level. What may be true at a higher scale, such as the county level, may not be so at lower scales, such as the communities in the county; the attributes of a transportation system may not apply to the individual roads within; qualities of a dispersed recreation area may differ when one looks at specific sites; and the distribution of meanings across a landscape cannot necessarily be summed to arrive at an overall assignment of landscape meanings. It is likely in many cases that different processes work at different scales. The perspectives people have when they think at different scales influence judgments about the appropriateness and acceptability of change. In addition, what may be acceptable at one scale may not be so at another.

Habitats for People

In the INLAS project, recreation will be used as a case example for understanding the relationship between human uses and values and other resource uses and values. Recreation was chosen because of manager interest and the existence of methods for identifying recreation places people use.

Many of the concepts from the wildlife habitat literature (Thomas 1979) apply to recreation (Clark 1987, 1988). Several of these might be considered when managing for recreation habitats. Understanding these concepts could help managers evaluate the potential effects of alternative strategies and prescriptions on recreational opportunities (Clark and Stankey 1979).

- People have “home ranges.” Resident populations tend to center recreation in the community; other users are migratory (tourists) and frequent sites well beyond their home ranges. The size of the home range is influenced by the relative availability of recreational opportunities desired by the population, competition among users for these opportunities, and mode and duration of travel.
- People use definable “travel corridors.” Natural topographic features and human-created corridors channel air, water, critters, and people. The intersection of corridors (water crossings, power corridors, dams) or flows within them often reveals conflicts and compatibilities between public values and uses and other resource values. Access in general is constrained by travel routes (roads and trails) and by physical-biological conditions, such as steep slopes, dense vegetation, and bodies of water. Knowledge of present and potential travel corridors should help predict the effects of management practices on recreational use patterns.
- People are “territorial.” They form strong attachments to favorite and often-visited places and usually do not wish to see them changed. It is important to identify the location and characteristics of such sites before any on-the-ground management occurs.
- “Hiding cover” is particularly important at campsites. People generally want privacy and quiet, and they try to separate themselves from other parties and from evidence of other resource uses. This seems to be as true for people in moderately developed areas as it is for people who prefer dispersed settings and wilderness.
- “Critical habitat” might be defined as a combination of attributes considered absolutely necessary for some types of recreation values and uses.
- “Edges” seem to influence recreational use. For example, sites near natural or artificial openings and riparian and coastal areas all appear to be used more frequently than other locations.
- People like “diversity” in the sites they visit and the activities they engage in.
- Site “preferences” may differ from actual “requirements.” Requirements are elements essential to recreation; preferences add quality to a recreational experience. However, preferences for some people may be requirements for others.
- Habitats are “dynamic,” and both natural changes and human-caused disturbances influence the nature of recreational settings. Indeed, the type and location of recreation activities can change with physical alterations. Such change can be managed both spatially and temporally to achieve desired goals.
- “Adaptation” occurs as recreation habitats are changed. Users can choose to stay in such areas and alter their expectations or move on (thus becoming “displaced”) if the changes exceed their accepted limits. Although either outcome may be appropriate, the potential consequences of both should be evaluated to avoid destruction of irreplaceable opportunities.

These concepts can help us think about how people relate to landscapes at multiple scales and improve our ability to understand the effects of policy options and management practices on existing and potential public values and uses.

Settings and Places Important to People

People form strong opinions about places and the characteristics of places at multiple scales. They also are concerned about the appropriateness of resource management uses (in time and space) (Clark and Stankey 1979). Legacies on the land from past management (road management, area closures, timber harvesting) affect judgments in different ways. It is hard for some people to relate to large landscapes when they are concerned about favorite places. Place attributes and meanings (at multiple scales) influence choices people make (Clark and Downing 1985). However, the meanings people attach to specific places, and which define critical habitat needs, are often not correlated with certain types of biogeographical features mapped by biologists.

A variety of factors influence recreation use patterns (Clark 1988). Some of these are described below.

- The places where people choose to recreate are important. Most people tend to have special places they visit repeatedly (Clark et al. 1984). Often these are places people used as children and those where they now take their children. These places may be large landscapes or small sites. Favorite and often-visited sites are definable, and people form strong attachments to them (Clark et al. 1984, Clark and Stankey 1986). In many areas, recreationists have established their own campsites, and they are concerned about the relation between other resource uses and these sites; many want their favorite campsites protected from the effects of logging (or other resource uses) (Clark and Downing 1985, Clark and Stankey 1986, Clark et al. 1984).
- The type of access is the key to most recreation and strongly influences use patterns. For example, as a group, people who recreate in roaded forest lands want roads of various designs and standards, but they do not need to be paved in all cases.
- Site attributes affect, in many often predictable ways, how recreationists make choices (McCool et al. 1985, Stankey and McCool 1985). Some attract (scenery) or detract (bugs and poisonous snakes); some facilitate (road pullouts) or constrain (steep terrain) (Clark and Stankey 1986). Attributes that have been determined to be particularly important in dispersed areas include water (marine, riparian, lakes, streams), trees (of various species, densities, and age), flat areas, naturalness (or natural appearing), and privacy from others not in one's own party (much like wilderness users). Knowledge of these attributes aids in determining what is possible, desirable, or necessary at a particular location to protect, enhance, or create opportunities for recreation.

Recreation (both in terms of our choice of activity and places) often plays a major role in where people choose to live and take vacations. Relatively easy access to diverse natural environments explains why many people have chosen to reside where they do. The forests, lakes, streams, mountains, and all the associated wildlife provide a rich backdrop for the diverse recreation people seek. Special places and favorite activities provide the temporary retreat from pressures at work and at home.

So when managers of public (and in some cases private) lands consider changing what users have known and valued about those special places, users become alarmed. People remember other places that have been lost for one reason or another (Clark and Stankey 1979). Many questions come to mind: What will the changes mean to one's family? How long will it take before one can go there again? Do managers know about the places people like and why they like them? Can favorite places be protected? These and other questions are important because the places people value are more than rock, dirt, and trees that can easily be replaced. They have special meaning that even the best manager cannot easily discern (Downing and Clark 1979).

Acceptability—of What, for Whom, Why

Natural resource management programs are considered to be sustainable when they are ecologically sound, economically feasible, and socially acceptable. Social acceptability is an essential aspect of any successful implementation effort. The social acceptability judgment process is critical to the efforts to manage natural resource systems on an integrated, multiple-value basis. For instance, any given practice is likely evaluated on the basis of potential alternatives as well as the consequences of any given alternative on other resources, values, and benefits. If a proposal to limit public access to riparian corridors, e.g., is presented solely as a means of restoring aquatic habitat, some particular patterns of acceptability will emerge. However, if the proposal also includes the impacts such closures will have on historical recreation, then it is likely that some other pattern of acceptability will emerge. At present, such multiresource issues typically lack full consideration of social acceptability assessments, with the result that public opposition increases.

Understanding is limited about the factors affecting the formation of acceptability judgments, their resistance to change, and the conditions that lead to change. A conventional premise is that public judgments are primarily influenced by the level and accuracy of the technical and scientific information held by different citizen interests, or that they are predominantly the reflection of adverse aesthetic judgments. Existing research on social acceptability indicates that judgments are the product of a complex, multifaceted, and dynamic process, of which information—in the technical-scientific sense—or aesthetic appearances are only a part. The judgment formation process is greatly affected by the belief systems of individuals. In addition, the trust associated with individuals or organizations making decisions can have a major effect on what is and is not acceptable.

The nature and extent of change acceptable to recreationists and other forest users differs (Clark and Stankey 1979; Stankey et al. 1985, 2003). People seem to have different expectations for “macro” versus “micro” sites, and the microsite seems more susceptible to adverse change; i.e., management activities acceptable in the general area (such as evidence of logging or roads or restoration activities) may be considered intolerable at a campsite.

Acceptance of change varies both in time and space and depends on many factors (Kakoyannis et al. 2001, Shindler et al. 2002). Judgments about the acceptability of change depend on its nature, extent, cause, and location with respect to specific areas, the meanings people attach to landscapes at different scales, and places people value.

> The research community has a significant role in helping create a more socially acceptable brand of forest management. Not that there is an insufficient amount of either theoretical research or applied research already to draw from. What is in short supply, however, is (1) well-defined, manager-friendly frameworks for conducting more socially acceptable processes and (2) the institutional will (i.e., commitment, time, and resources) for experimentation and implementation (Shindler et al. 2002).

Component 2: Population Dynamics[3]

The Pacific Northwest is experiencing rapid and far-reaching population changes (McCool et al. 1997). Population growth and redistribution affect both urban and rural areas. Accompanying this growth and change is a climate of increasing conflict over the region's once-abundant natural resources. Much of this conflict centers on changing societal values and expectations regarding the things public lands should produce (McGranahan 1999). Moreover, there is increased competition for the commodities, amenities, and recreational opportunities provided by those public lands.

Given this dynamic and challenging context, it is important to understand both how the population is changing and the potential implications these changes have for the management of forest lands in the Pacific Northwest (Troy 1998). As certain communities shift from rural to suburban or urban, what changes are likely to occur in attitudes and public uses regarding natural resource issues? What are the factors that are driving migration from urban to rural areas? Are the motivations for in-migration to rural communities driven by economic concerns or by the amenities of small towns and natural resources?

The fundamental concept driving the analysis of population dynamics is that changes in the makeup of human populations will be accompanied by changes in the attitudes and uses of residents toward the management of forest lands whether public or private. In addition, these changing attitudes and uses will have a profound influence on the actions of management agencies. Making the connection between attitudes, public uses, and changing social conditions will help managers respond to and anticipate the needs of local and regional residents. Ultimately this type of knowledge can help managers respond to challenges and opportunities at various geographic scales and for various user groups.

This assessment will provide a detailed description of the population dynamics in the region and selected areas such as INLAS. Ways to understand, articulate, and display the multiple and interrelated changes occurring within the region will be explored. Data from sources such as the U.S. Census and Internal Revenue Service will be used to develop graphical and interaction-oriented approaches to describe the population dynamics. Adopting this approach will allow for an analysis of the factors driving more localized changes as well as an examination of how local areas might influence and be influenced by regional population dynamics. The graphical approach will enhance our ability to engage in a broader dialogue regarding the nature of these changes.

Beyond a basic description, there is a need to address why the observed changes matter. Thus, a second focus will produce a series of propositions regarding how the changing character of the region's population may influence shifts in acceptability of forest management practices. Making this link between population dynamics, public uses, and attitudes will require the use of existing data as well as the possible collection of new information on resident attitudes toward natural resource management if time allows. This second product also will involve a focused examination of specific subregions within Oregon and Washington, including INLAS. The choice of communities will be made to highlight issues for areas that are currently experiencing rapid change along with those that have relatively slower rates of change.

---

[3] This work is being conducted by Theron Miller and Steve McCool at the University of Montana's School of Forestry in conjunction with the author.

Population change in rural areas has significant implications for the acceptability of various land management actions (e.g., treatment of fuels, use of fire, and management of wildlife). Where public lands are intermingled with private, rapidly developing lands, there are significant questions about how newly arriving individuals, with potentially different ties to public landscapes than long-term residents, will be attached to these landscapes, and how those attachments may affect acceptability of forest management.

In addition, population growth and redistribution have implications for demand of recreational opportunities provided on public lands. Because the in-migrating population may have characteristics different from existing residents, their patterns of participation in recreation may differ. As a result, the character and distribution of the supply of existing facilities and opportunities may no longer be adequate for the "new" population.

Beyond the benefits to individuals directly involved in management, this type of analysis could help provide an avenue for involvement of community leaders and concerned citizens. The process of understanding the many social changes to an area can facilitate both community learning and assist in efforts of problemsolving.

Component 3: Place–Based Analyses of Recreation Use

As described earlier, knowing the sites people use in forests is important for understanding the potential interactions between this use and other resource values and uses. In this project, we will focus on recreation as one example of human use taking place in the INLAS area.

Recreational uses often compete with timber, wildlife, fisheries, and other resource uses for the same sites (Clark 1988, Clark et al. 1984). An understanding of the relationships between recreation and other uses of forested lands is required for effective multiresource management. Important questions needing answers include: Who are the visitors of specific areas? What are the activities in which they engage? When do they engage in these activities? Where do they engage in these activities? What site characteristics influence where they go? What are the effects on recreation in areas where other resource uses are managed and vice versa? How important are these effects from the perspective of the public and land managers? What concepts, frameworks, and management tools exist or might be developed to help mitigate adverse effects?

> Knowing the importance forest visitors attach to particular features of recreational settings (called "site attributes") is the foundation of effective recreation management. Without information about these attributes, land managers cannot maintain or enhance desirable qualities, nor can they prevent or mitigate damage to recreational values as a result of other forest uses, such as timber management. There is a need for a better understanding of what attributes can be avoided and positive effects enhanced. Attributes constitute the features that define an area or site as a recreational resource. Knowing what these attributes are, their relative importance to recreationists participating in different activities or seeking different experiences, and the sensitivity of the attributes to change is essential input to integrated resource management.
>
> Alterations in settings induced by nonrecreational resource uses can greatly change the type of recreational opportunities available. Conversely, maintaining the essential attributes of a particular recreational opportunity setting might represent a significant constraint on other uses. For example, a management objective to maintain semiprimitive or primitive recreation opportunities would limit the nature and extent of timber harvest activities appropriate in the area (Clark and Stankey 1979). Understanding these interdependencies is essential to the integration of different resource allocations and to minimizing conflict (Clark and Gibbons 1991, Clark and Stankey 1986).

We must understand the complex system of which recreation is a part. There remains, however, a lack of comprehensive knowledge and site-specific guidelines to facilitate effective integration of recreation and other resource uses at multiple temporal and spatial scales. Part of the problem is the limitation of knowledge about just where people go and what the characteristics are of those places. In this project, the author and colleagues developed and applied methods for several watersheds in eastern Washington that will be used to locate and characterize sites used by the public in parts of the INLAS area.

This assessment of places that people use will include:

- Locate specific places along formal and informal roads in several subareas of the INLAS project area where there is trace evidence of public use (including but not limited to recreation).
- Use a global positioning system to establish the location of sites identified.
- Complete a written description of the sites.
- Take photos that can be used to classify the site and its surroundings (at the microlevel and macrolevel).
- Describe and document the relationship between the sites identified and evidence of resource management activities.
- Create geographical information system data layers to allow analysis of the interrelationships between public use and other forest values and uses and forest management activities.

Knowledge of important recreation sites and their attributes will assist managers in evaluating the consequences of changes because of other resource uses on dispersed recreation opportunities (Brown et al. 1978, Clark and Stankey 1986). Such information will aid in developing strategies to prevent or mitigate undesirable impacts on biophysical resources while taking advantage of positive changes to provide a desired range of public benefits.

Expected Outcomes and Products

This work will provide three major types of products:

- Syntheses of available frameworks and concepts and how they might be used in the context of integrated research and development and management at multiple scales in areas such as INLAS.
- Empirical information about regional and local population migration and a framework to evaluate the potential effects of population changes on places people use and their acceptance of management practices.
- A description of specific places for parts of INLAS that are used by the public. This will be useful as a stand-alone product, but its best use will be in the context of an integrated approach to assessing the interactions between biophysical and social values and uses in areas such as INLAS.

It is yet to be determined how this information will be integrated with other biophysical information.

Users of Information

Both public and private resource policymakers and managers should find the information useful for designing, implementing, and evaluating options at multiple scales. The primary beneficiaries of this research effort will be natural resource managers of federal, state, and private lands. They will benefit from a clearer understanding of the dynamic populations and attitudes within the areas that they operate and the types of places that are important to existing and future populations. This will be particularly helpful for managers in areas currently experiencing rapid population changes and conflicts between human and other uses. Managers in other areas could use the results of this research to anticipate future changes.

The ultimate beneficiary of this information is the public who depends on the resource values and uses provided by areas such as those represented by INLAS.

Conclusions

Whether intended or not, almost all forest management activities affect public values and uses. The effects of management are not necessarily negative and largely depend on people's preferences and expectations. However, effective multiresource management demands an understanding of the interactions among public and other uses.

In addition, changes in human populations have significant implications for the use and management of diverse natural resources. It is not just how many people are leaving the area or moving in but what values and expectations they have for nearby as well as distant forests and rangelands.

Furthermore, it is critical to have detailed, place-based analysis of human and natural resource interactions. Information about public use—the where, who, when, why, and how—enables planning processes to consider human and natural resource interactions at multiple spatial and temporal scales.

From this brief overview, it seems evident that a holistic, systems perspective is needed to help integrate public uses such as recreation with other resources. The recreation resource, in particular, is unusual, compared to some resources, in that it is represented by the combination of all other physical and biological resources and how they are managed. The complex interrelationships among these resources have important implications for recreational opportunities and use (Clark et al. 1984).

The questions posed earlier can be resolved with a more holistic perspective that recognizes the nature of potential onsite interactions between public uses and other resources. Past management has focused primarily on public uses such as recreation apart from other uses. Expanding opportunities for the future and addressing the potential for onsite conflicts and ways to resolve them require an improved understanding of the complex system of which human concerns are an integral part. The overriding question is not whether human values and uses should be integrated with other resource uses, but where, when, and how such integration can be achieved.

It is critical that approaches developed to understand these interactions consider people and their uses at multiple scales. We must begin to make connections between biophysical and human systems, or we will continue to fall victim to extreme, polarized, solutions to resolving complex problems (Clark and Gibbons 1991).

Almost everything resource managers do, whether planned or not, will affect opportunities for the public. People react to this reality as they anticipate or discover undesirable changes in areas and at sites they value. Professionals must be sensitive to how what they do affects people and places people value. Failure to do so could easily lead to further polarization and loss of manager credibility as well as support for agency or landowner programs.

Unfortunately, there are few specific guidelines and little detailed information to facilitate such integration and few tested approaches for managing potentially incompatible uses at specific locations. There are, however, a variety of concepts and frameworks that can be used to address some of the questions listed earlier. These tools will provide aids to help managers, citizens, and scientists work through problemsolving for complex and controversial issues; rarely, however, will they provide definite answers.

Literature Cited

Allen, G.M.; Gould, E.M., Jr. 1986. Complexity, wickedness, and public forests. Journal of Forestry. 84(4): 20-23.

Bardwell, L. 1991. Problem-framing: a perspective on environmental problem-solving. Environmental Management. 15(5): 603-612.

Brown, P.J.; Driver, B.L.; McConnell, C. 1978. The opportunity spectrum concept and behavioral information in outdoor recreation resource supply inventories: background and application. In: Lund, G.H.; LaBau, V.J.; Ffolliott, P.F.; Robinson, D.W., tech. coords. Integrating inventories of renewable natural resources: Proceedings of the workshop. Gen. Tech. Rep. RM-55. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 73-84.

Clark, R.N. 1987. Recreation management: a question of integration. Western Wildlands. 13(1): 20-23.

Clark, R.N. 1988. Enhancing recreation opportunities in silvicultural planning. In: Schmidt, W.C., comp. Proceedings: future forests of the mountain West: a stand culture symposium. Gen. Tech. Rep. INT-243. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 61-69.

Clark, R.N.; Downing, K.B. 1985. Why here and not there: the conditional nature of recreation choice. In: Stankey, G.H.; McCool, S.F., comps. Proceedings, symposium on recreation choice behavior. Gen. Tech. Rep. INT-GTR-184. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 61-70.

Clark, R.N.; Gibbons, D.R. 1991. Recreation. In: Meehan, W.R., ed. Influences of forest and rangeland on salmonid fishes and their habitats. Spec. Publ. 19. Bethesda, MD: American Fisheries Society: 459-481. Chapter 13.

Clark, R.N.; Koch, R.W.; Hogans, M.L. [et al.]. 1984. The value of roaded, multiple use areas as recreation sites in three national forests of the Pacific Northwest. Res. Pap. PNW-319. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 40 p.

Clark, R.N.; Kruger, L.E.; McCool, S.F.; Stankey, G.H. [In press]. Landscape perspectives. Res. Pap. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Clark, R.N.; Stankey, G.H. 1979. The recreation opportunity spectrum: a framework for planning, management, and research. Gen. Tech. Rep. PNW-98. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 32 p.

Clark, R.N.; Stankey, G.H. 1986. Site attributes—a key to managing wilderness and dispersed recreation. In: Proceedings: national wilderness research conference. Gen. Tech. Rep. GTR-INT-212. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 509-515.

Clark, R.N.; Stankey, G.H.; Brown, P.J. [et al.] 1999. Toward an ecological approach: integrating social, economic, cultural, biological and physical considerations. In: Johnson, N.C.; Malk, A.J.; Sexton, W.T.; Szaro, R., eds. Ecological stewardship: a common reference for ecosystem management. Oxford, United Kingdom: Elsevier Science Ltd. 3: 297-318.

Downing, K.B.; Clark, R.N. 1979. Users' and managers' perceptions of dispersed recreation impacts: a focus on roaded forest lands. In: Ittner, R.; Potter, D.R.; Agee, J.K.; Anschell, S., eds. Recreational impact on wildlands: Proceedings of a conference. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; U.S. Department of the Interior, National Park Service, Pacific Northwest Region: 18-23.

Jensen, M.E.; Bourgeron, P.S., eds. 2001. A guidebook for integrated ecological assessments. New York: Springer-Verlag, Inc. 536 p.

Kakoyannis, C.; Shindler, B.; Stankey, G.H. 2001. Understanding the social acceptability of natural resource decisionmaking processes by using a knowledge base modeling approach. Gen. Tech. Rep. PNW-GTR-518. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.

McCool, S.F.; Burchfield, J.A.; Allen, S.D. 1997. Social assessment of the basin. In: Quigley, T.M.; Arbelbide, S.J., tech. eds. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1873-2000. Chapter 7. Vol. 4. (Quigley, T.M., tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

McCool, S.F.; Stankey, G.H.; Clark, R.N. 1985. Choosing recreation settings: processes, findings, and research directions. In: Stankey, G.H.; McCool, S.F., comps. Proceedings: symposium on recreation choice behavior. Gen. Tech. Rep. INT-GTR-184. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 1-8.

McGranahan, D.A. 1999. Natural amenities drive rural population change. Agric. Econ. Rep. 781. Washington, DC: U.S. Department of Agriculture, Food and Rural Economics Division, Economic Research Service. 24 p.

Senge, P.M. 1990. The fifth discipline: the art and practice of the learning organization. New York: Currency Doubleday. 423 p.

Shindler, B.; Brunson, M.; Stankey, G.H. 2002. Social acceptability of forest conditions and management practices: a problem analysis. Gen. Tech. Rep. PNW-GTR-537. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 68 p.

Socolow, R.H. 1976. Failures of discourse: obstacles to the integration of environmental values into natural resource policy. In: Tribe, L.H.; Schelling, C.S.; Voss, J., eds. When values conflict: essays on environmental analysis, discourse, and decision. Cambridge, MA: Ballinger Publication Co.: 1-33.

Stankey, G.H.; Clark, R.N. 1992. Social aspects of new perspectives in forestry: a problem analysis. The Pinchot Institute for Conservation Monograph Series. Milford, PA: Grey Towers Press. 33 p.

Stankey, G.H.; Clark, R.N.; Bliss, J. 2003. Fostering compatible forest resource management: the conditional nature of social acceptability. In: Monserud, R.A.; Haynes, R.W.; Johnson, A.C., eds. Compatible forest management. Dordrecht, The Netherlands: Kluwer Press: 453-480.

Stankey, G.H.; Cole, D.N.; Lucas, R.C. [et al.]. 1985. The limits of acceptable change (LAC) system for wilderness planning. Gen. Tech. Rep. INT-176. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 37 p.

Stankey, G.H.; McCool, S.F., comps. 1985. Proceedings: symposium on recreation choice behavior. Gen. Tech. Rep. INT-GTR-184. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 106 p.

Thomas, J.W., tech. ed. 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 533. Washington, DC: U.S. Department of Agriculture, Forest Service. 512 p.

Troy, L.R. 1998. Recent human migration to the interior Columbia basin and implications for natural resource management. Missoula, MT: University of Montana. 75 p. M.S. thesis.

Wondolleck, J.M. 1988. Public lands conflict and resolution: managing national forest disputes. New York: Plenum Press. 263 p.

Wondolleck, J.M.; Yaffee, S.L. 2000. Making collaboration work: lessons from innovation in natural resource management. Washington, DC: Island Press. 277 p.

Yankelovich, D. 1991. Coming to public judgment: making democracy work in a complex world. Syracuse, NY: Syracuse University Press. 290 p.

Yankelovich, D. 1999. The magic of dialogue: transforming conflict into cooperation. New York: Simon and Schuster. 236 p.

Chapter 12: Analysis and Modeling of Forest-Land Development at the Wildland/Urban Interface

Jeffrey D. Kline[1]

Abstract

Population growth and resulting land use changes are becoming increasingly important factors in forest management and fire planning as forests are converted to residential and other developed uses. This part of the Interior Northwest Landscape Analysis System (INLAS) project examines low-density residential and other development at the wildland/urban interface in the area surrounding the INLAS project area. The research contributes to an integrated analysis of fire risk by describing where humans are located on the forest landscape, how they are likely to manage the portion of the landscape they occupy, how the spatial distribution of humans will change in the future, and what their expectations will be regarding forest management and policy and fire planning.

Keywords: Wildland/urban interface, urbanization, land use change.

Overview

Increasingly important factors in forest management and fire planning are population growth and the impacts resulting land use changes can have on forests as they are converted to residential and other developed uses. In-migration of people to rural areas in the Pacific Northwest is resulting in increasing numbers of residences on forest landscapes. Forest-land conversion to developed uses essentially is a permanent change resulting in the interspersion of nonforest land uses with forest, and often fragmenting forest landscapes into smaller parcels of land. These processes can result in longer lasting ecological and economic impacts than forest cutting and fire, where regrowth and succession may overcome temporary loss of forest. Ecological impacts can include direct loss of habitat or changes in habitat quality. Economic impacts can include less intensive forest management for commercial timber resulting in reduced economic output on private lands. Analysis and modeling of existing and potential low-density residential and other development at the wildland/urban interface can anticipate where these

[1] **Jeffrey D. Kline** is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

changes are likely to occur in the future. Such research can contribute to an integrated analysis of fire risk by describing where humans are located on the forest landscape, how they are likely to manage the portion of the landscape they occupy, how the spatial distribution of humans will change in the future, and what their expectations will be regarding forest management and policy and fire planning.

A Brief Literature Review

What researchers and policymakers refer to as the wildland/urban interface is characterized by relatively low-density residential and other development on forest landscapes. Researchers and policymakers hypothesize that such development has the potential to increase the threat of wildfire associated with increased human habitation and activity in forests (Lorensen et al. 1993). Many forestry analysts also feel that increasing numbers of residences located in forested landscapes are leading to increasing costs owing to wildfire and overburdening firefighting resources that are redirected to save homes instead of containing fires (Milloy 2000). Along with the potential for increased wildfire threat and increased firefighting costs is the increased potential for significant loss of life and property. The 2001 fire season in the Pacific Northwest provided numerous examples of the particular challenges associated with fighting forest fires near homes (e.g., Cockle 2001, Larabee 2001, Quinn 2001).

In addition to these direct implications for fire planning, low-density residential and other development on forested landscapes can have fewer direct implications regarding forest management. For example, researchers believe that forest lands located within the wildland/urban interface become less productive as a result of their fragmentation into smaller and smaller management units, potentially diminishing the economies of scale in timber production (Row 1978). Forest tract size has been negatively correlated with the likelihood of commercial timber management (Thompson et al. 1981) and the propensity of forest owners to harvest timber (Cleaves and Bennett 1995). Lower harvest rates and less likelihood of commercial timber management also have been correlated with increasing population densities (Barlow et al. 1998, Wear et al. 1999).

As people migrate into forested areas, the characteristics and forest management objectives of newer more urban-minded forest-land owners also may change. It is believed that many nonindustrial private forest-land owners are motivated by amenity, recreation, and other nontimber objectives in addition to or in place of timber production objectives when making forest management decisions (Binkley 1981; Bowes et al. 1984; Dennis 1989, 1990; Englin and Klan 1990; Hyberg and Holthausen 1989; Kuuluvainen et al. 1996; Max and Lehman 1988; Newman and Wear 1993; Strang 1983; Swallow and Wear 1993). Such nontimber objectives have been shown to be important factors motivating nonindustrial private forest-land owners in the Pacific Northwest (Johnson et al. 1997; Kline et al. 2000a, 2000b). Smaller forest tract sizes and changing characteristics of forest-land owners can alter the manner in which private forest lands are managed and affect the potential range of management and policy options available to forest managers and policymakers regarding fire-risk reduction on private forest lands.

A potential secondary impact of development at the wildland/urban interface is overall changes in people’s values and attitudes toward forestry. A growing number of social scientists believe that the Nation is experiencing rapid and significant changes in forest values (Bengston 1994) and attitudes concerning forest management (Davis et al. 1991, Schindler et al. 1993). Researchers observe that increasing migration of urbanites to rural areas is resulting in a shift in forest values and a push for forestry policies and practices that reflect changing forest values (Egan and Luloff 2000). Increasing development at the wildland/urban interface may be accompanied by a declining empathy toward timber industries and increasing demands for outdoor recreation and the protection of forest amenities and wildlife. Research suggests that these processes could be taking place in the Pacific Northwest (Kline and Armstrong 2001). Such changes could have implications regarding the political climate in which forest management and policy and fire planning decisions are made.

A common approach to multidisciplinary landscape-level analysis of socioeconomic and ecological processes has been to treat humans largely as exogenous to the forest landscape. Land use change analyses commonly have been used in multidisciplinary studies to delineate discrete forest and nonforest or forest and urban land use categories for integration with other landscape-level models describing socioeconomic and ecosystem processes and conditions (see, e.g., Bockstael 1996, Kline et al. 2001, Turner et al. 1996). Similar discrete treatments of land use can be found in Bradshaw and Muller (1998), Chomitz and Gray (1996), Helmer (2000), and Nelson and Hellerstein (1997). These models generally use spatially referenced land use data to estimate logit or probit regression models describing the timing and location of changes among discrete land use categories.

For many applications, a discrete treatment of land use may be appropriate when the processes under study are relatively insensitive to low levels of human habitation of land. However, in other applications, when socioeconomic and ecological processes may be sensitive to a range of human habitation, discrete land use categories may inadequately characterize the spatial and temporal interactions of humans as agents affecting the landscape-level processes under study. In the case of wildfire threat on forested landscapes, relatively low-density human habitation can be of particular interest. Wear and Bolstad (1998) offer an alternative to discrete land use change analysis by describing the “spatial diffusion” of human populations throughout a landscape. They use data describing building densities to identify explanatory variables useful in predicting building densities. Although Wear and Bolstad (1998) ultimately use their spatial diffusion model to project changes among discrete land use categories, Kline et al. (in press) show that their methods can be adapted to describe potential future building density scenarios that also can serve as inputs into landscape-level models.

Objectives

The objectives of the research are to (1) develop empirical spatial models of low-density residential and other development at the wildland/urban interface for select areas in eastern Oregon, (2) use the empirical models to describe likely future development scenarios based on projections of future population growth and in-migration, and (3) integrate potential future development scenarios with other INLAS submodels describing ecological conditions and processes and fire risk. The research is intended to provide information concerning (1) what socioeconomic and geographic factors have contributed to increased in-migration in eastern Oregon; (2) how these factors have influenced the spatial distribution of people; and (3) how institutional factors, such as land use zoning, have affected that spatial distribution.

Research Approach

Empirical models describing historical and future low-density residential and other development at the wildland/urban interface will be estimated for select areas in eastern Oregon. Model estimation will rely on building density data based on aerial photointerpretation similar to that described in Azuma et al. (1999) for western Oregon. The Oregon Department of Forestry currently is working to gather building density data for eastern Oregon. When available, these data will enable analysis and modeling of building density by using the methods of Wear and Bolstad (1998) and Kline et al. (in press). Empirical models will be estimated describing historical land use or building density changes as a function of socioeconomic and geographic variables. The empirical models will be used to project future building density scenarios based on projected changes in socioeconomic variables, such as population, included in the models. The projections will be used to create geographic information system maps (GIS) describing future building density scenarios, enabling projections to be integrated with other INLAS submodels describing ecological conditions and processes and wildfire threat.

The analytical method will closely follow methods used by Kline et al. (in press) to project potential future building density scenarios for western Oregon as part of the Coastal Landscape Analysis and Modeling Study (CLAMS) (Spies et al. 2002). In that analysis, a negative binomial model was estimated describing the spatial distribution and rate of change in historical building densities in western Oregon as a function of a gravity index of development pressure, existing building densities, slope, elevation, and existing land use zoning. A gravity index was used to describe the spatial proximity of land to existing cities of varying population sizes. The resulting empirical model was used to project pixel-level changes in building densities based on projected future population growth of cities included in the gravity index computation. The projected building density changes were applied to a 1995 building density map to describe the future spatial distributions of buildings for successive modeling periods (fig. 33). The building density maps are key inputs in other socioeconomic and ecological submodels comprising CLAMS.

If historical building density data are not available, analysis and modeling will be accomplished by using existing socioeconomic data available from the U.S. Bureau of the Census and other sources to develop empirical models of human migration (e.g., Amacher et al. 1998, McGranahan 1999, Swanson 1986). Analysis will focus on describing historical spatial variation in population densities and other socioeconomic variables, and in describing potential future changes in the spatial distributions of people across the INLAS study landscape. Landscape-level projections of future spatial distributions of people would be accomplished by simulating future forest-land development scenarios based on existing land use zoning maps and projections of future population (e.g., Bradshaw and Muller 1998, ECONorthwest 2000). Projections of future populations will be obtained from published U.S. Census figures or estimated from in-migration models. This alternative analysis would result in GIS maps describing future population density scenarios, enabling projections to be integrated with other INLAS submodels describing ecological conditions and processes and wildfire threat.

Products

Anticipated products include relatively fine-scale GIS maps of potential future low-density residential and other development at the wildland/urban interface for select regions of eastern Oregon, including the INLAS study area. The maps will be used both as standalone products and for integration with other INLAS submodels describing ecological conditions and processes and fire risk. For example, the maps will identify where forest land is most likely to be taken out of active management for timber production, enabling timber production submodels to account for a potentially diminishing forest-land base. The maps also will be used to identify locations within the INLAS study area where wildfire poses the greatest risk of significant loss of life and property, which may have implications for the types and locations of potential management prescriptions proposed and analyzed by INLAS researchers.

In addition to maps of potential low-density development will be descriptive analysis and projections regarding potential changes in the socioeconomic characteristics of the population of eastern Oregon, including the INLAS study area. Analysis will include discussion regarding the potential impacts of socioeconomic change on regional public

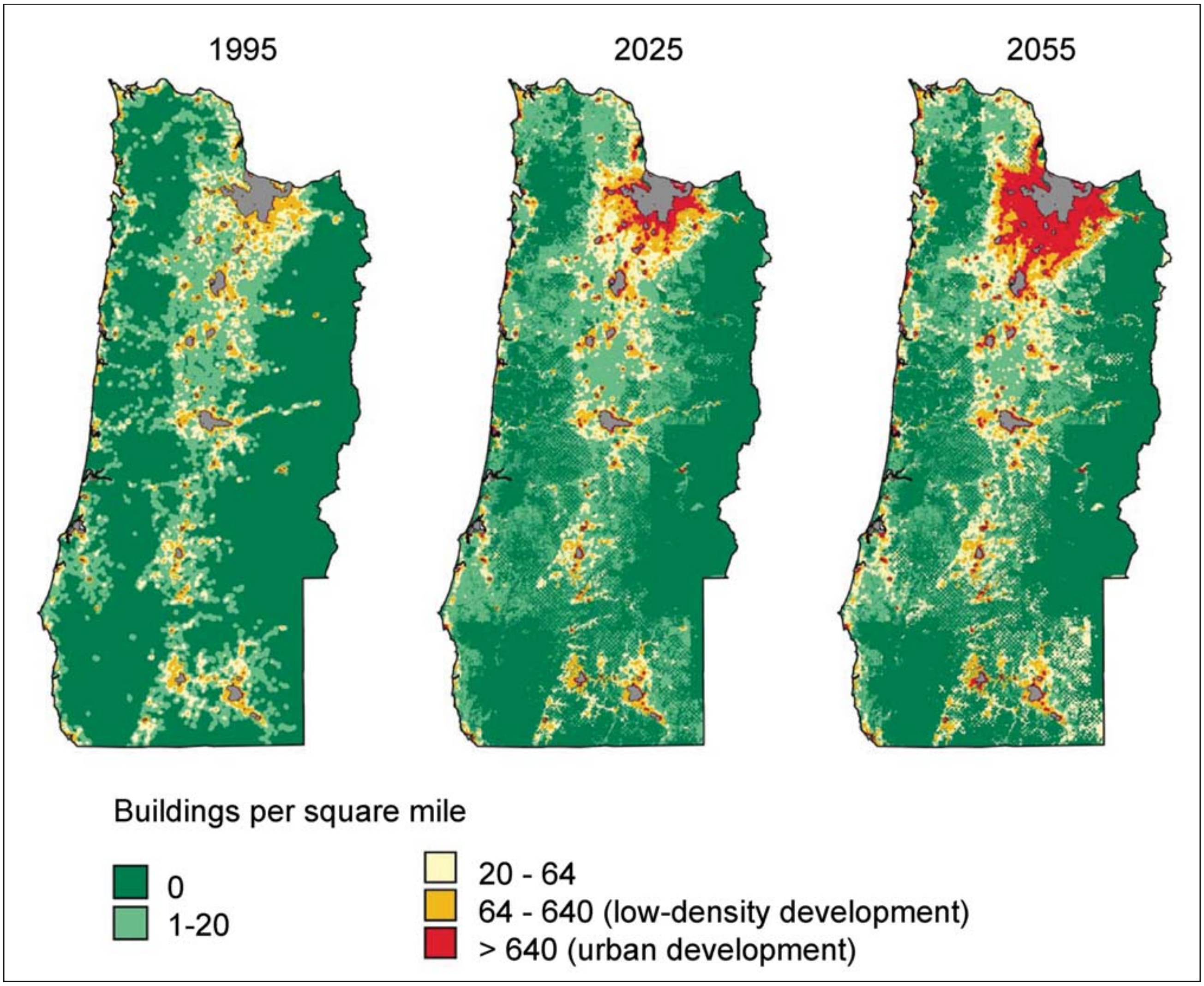

Figure 33—Base year and projected building density categories in western Oregon created for the Coastal Landscape Analysis and Modeling Study. Note: Based on negative binomial model projections of building density change applied to 1995 base year map. Existing urban development in 1995 base year shown in gray.

demands regarding outdoor recreation and forest amenities, and public perceptions and attitudes regarding forest management and policy and fire planning goals and strategies. This analysis would be largely descriptive and contribute to providing the socioeconomic context in which forest management and policy and fire planning will take place. Other anticipated products include at least one technical journal article describing the analytical approach and one nontechnical report describing the analysis and its implications for forest management and policy and fire planning.

Users

The users of the information produced by this research include national forest and land management agencies; state agencies; nonprofit organizations concerned with forests, fire, and land use change; and researchers seeking to integrate land use change information into landscape-level analyses of ecological conditions and processes. Geographic information system maps of potential future low-density residential and other development at the wildland/urban interface for select regions of eastern Oregon will serve as key inputs into other INLAS models of ecological conditions and processes.

Literature Cited

Amacher, G.S.; Cruz, W.; Grebner, D.; Hyde, W.F. 1998. Environmental motivations for migration: population pressure, poverty, and deforestation in the Philippines. Land Economics. 74(1): 92-101.

Azuma, D.L.; Birch, K.R.; DelZotto, P. [et al.]. 1999. Land use change on non-federal land in western Oregon, 1973-1994. Salem, OR: Oregon Department of Forestry. 55 p.

Barlow, S.A.; Munn, I.A.; Cleaves, D.A.; Evans, D.L. 1998. The effect of urban sprawl on timber harvesting. Journal of Forestry. 96(12): 10-14.

Bengston, D.N. 1994. Changing forest values and ecosystem management. Society and Natural Resources. 7: 515-533.

Binkley, C.S. 1981. Timber supply from private nonindustrial forests. Bull. 92. New Haven, CT: School of Forestry and Environmental Studies, Yale University. 97 p.

Bockstael, N.E. 1996. Modeling economics and ecology: the importance of a spatial perspective. American Journal of Agricultural Economics. 78: 1168-1180.

Bowes, M.D.; Krutilla, J.V.; Sherman, P.B. 1984. Forest management for increased timber and water yields. Water Resources Research. 20: 655-663.

Bradshaw, T.K.; Muller, B. 1998. Impacts of rapid urban growth on farmland conversion: application of new regional land use policy models and geographical information systems. Rural Sociology. 63: 1-25.

Chomitz, K.M.; Gray, D.A. 1996. Roads, land use, and deforestation: a spatial model applied to Belize. The World Bank Economic Review. 10: 487-512.

Cleaves, D.A.; Bennett, M. 1995. Timber harvesting by nonindustrial private forest landowners in western Oregon. Western Journal of Applied Forestry. 10(2): 66-71.

Cockle, R. 2001. Northeast Oregon town threatened. The Oregonian. August 17. http://www.oregonlive.com/news/oregonian/index.ssf?/xml/story.ssf/html_standard.xsl?/base/front_page/9980493443448189.xml. (10 September).

Davis, L.S.; Ruth, L.W.; Teeguarden, D.; Henly, R.K. 1991. Ballot box forestry. Journal of Forestry. 89(12): 10-18.

Dennis, D. 1989. An economic analysis of harvest behavior: integrating forest and ownership characteristics. Forest Science. 35: 1088-1104.

Dennis, D.F. 1990. A probit analysis of the harvest decision using pooled time-series and cross-sectional data. Journal of Environmental Economics and Management. 18: 176-187.

ECONorthwest. 2000. Research report 1: density, development patterns, and definition of alternatives. Prepared for Willamette Valley Alternative Futures, Eugene, OR. On file with: ECONorthwest, 99 West 10th, Suite 400, Eugene, OR 97401.

Egan, A.F.; Luloff, A.E. 2000. The exurbanization of America's forests: research in rural social science. Journal of Forestry. 98(3): 26-30.

Englin, J.E.; Klan, M.S. 1990. Optimal taxation: timber and externalities. Journal of Environmental Economics and Management. 18: 263-275.

Helmer, E.H. 2000. The landscape ecology of tropical secondary forest in montane Costa Rica. Ecosystems. 3: 98-114.

Hyberg, B.T.; Holthausen, D.M. 1989. The behavior of nonindustrial private forest landowners. Canadian Journal of Forest Research. 19: 1014-1023.

Johnson, R.L.; Alig, R.J.; Moore, E.; Moulton, R.J. 1997. Nonindustrial private landowners' view of regulation. Journal of Forestry. 59: 23-28.

Kline, J.D.; Alig, R.J.; Johnson, R.L. 2000a. Forest owner incentives to protect riparian habitat. Ecological Economics. 33(1): 29-43.

Kline, J.D.; Alig, R.J.; Johnson, R.L. 2000b. Fostering the production of nontimber services among forest owners with heterogeneous objectives. Forest Science. 46(2): 302-311.

Kline, J.D.; Armstrong, C. 2001. Autopsy of a forestry ballot initiative: characterizing voter support for Oregon's Measure 64. Journal of Forestry. 99(5): 20-27.

Kline, J.D.; Azuma, D.L.; Moses, A. [In press]. Modeling the spatially dynamic distribution of humans in the Oregon (USA) Coast Range. Landscape Ecology.

Kline, J.D.; Moses, A.; Alig, R.J. 2001. Integrating urbanization into landscape-level ecological assessments. Ecosystems. 4(1): 3-18.

Kuuluvainen, J.; Karppinen, H.; Ovaskainen, V. 1996. Landowner objectives and nonindustrial private timber supply. Forest Science. 42: 300-308.

Larabee, M. 2001. Fire brings urban peril into focus. The Oregonian. August 12. http://www.oregonlive.com/news/oregonian/index.ssf?/xml/story.ssf/html_standard.xsl?/base/front_page/9975309381909169.xml. (10 September).

Lorensen, T.; Birch, K.; Lettman, G. 1993. Wildfire prevention and control in areas of residential forest land development: an analysis of fire data. Tech. Bull. Salem, OR: Public Affairs Office, Oregon Department of Forestry. [Pages unknown].

Max, W.; Lehman, D.E. 1988. A behavioral model of timber supply. Journal of Environmental Economics and Management. 15: 71-86.

McGranahan, D.A. 1999. Natural amenities drive rural population change. Agric. Econ. Rep. 781. Washington, DC: U.S. Department of Agriculture, Economic Research Service. 24 p.

Milloy, R.E. 2000. Population trends heighten West's fire woes. New York Times. August 10: Sect. A: 10.

Nelson, G.C.; Hellerstein, D. 1997. Do roads cause deforestation? Using satellite images in econometric analysis of land use. American Journal of Agricultural Economics. 79: 80-88.

Newman, D.H.; Wear, D.N. 1993. Production economics of private forestry: a comparison of industrial and nonindustrial forest owners. American Journal of Agricultural Economics. 75: 674-684.

Quinn, B. 2001. Crews abandon 10 homes to Quartz Fire. The Oregonian. August 14. http://www.oregonlive.com/news/oregonian/index.ssf?/xml/story.ssf/html_standard.xsl?/base/front_page/99779015127150166.xml. (10 September).

Row, C. 1978. Economies of tract size in timber growing. Journal of Forestry. 78: 576-582.

Schindler, B.; List, P.; Steel, B.S. 1993. Managing federal forests: public attitudes in Oregon and nationwide. Journal of Forestry. 91(7): 36-42.

Spies, T.A.; Reeves, G.H.; Burnett, K.M. [et al.]. 2002. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. In: Liu, J.; Taylor, W.W., eds. Integrating landscape ecology into natural resource management. New York: Cambridge University Press.

Strang, W.J. 1983. On the optimal forest harvesting decision. Economic Inquiry. 11: 576-583.

Swallow, S.K.; Wear, D.N. 1993. Spatial interactions in multiple-use forestry and substitution and wealth effects for the single stand. Journal of Environmental Economics and Management. 25: 103-120.

Swanson, L.L. 1986. What attracts new residents to nonmetro areas? Res. Rep. 56. Washington, DC: U.S. Department of Agriculture, Economic Research Service. 15 p.

Thompson, R.; Thompson, P.; Jones, J.G. 1981. Classifying nonindustrial private forest land by tract size. Journal of Forestry. 81: 288-291.

Turner, M.G.; Wear, D.N.; Flamm, R.O. 1996. Land ownership and land-cover change in the southern Appalachian Highlands and the Olympic Peninsula. Ecological Applications. 6: 1150-1172.

Wear, D.N.; Bolstad, P. 1998. Land-use changes in southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems. 1: 575-594.

Wear, D.N.; Liu, R.; Foreman, J.M.; Sheffield, R. 1999. The effects of population growth on timber management and inventories in Virginia. Forest Ecology and Management. 118(1-3): 107-115.

Chapter 13: Evaluating Forest Products as Part of Landscape Planning

R. James Barbour, Douglas Maguire, and Ryan Singleton[1]

Abstract

The probability that harvest activities will occur on any piece of ground is a function of the accessibility of the ground (both physically and administratively), the costs of implementing the treatment, and the value of the removed material. We describe the concept of combining these three attributes to develop a utilization index that can be used to display where on a landscape timber harvest might be most fruitfully used to alter stand structural conditions. Displaying the three component parts of this index allows managers to understand that a particular polygon on the landscape is either a good candidate for timber removal or not. At least in theory, these same techniques could be applied to the collection of any number of nontimber forest products.

Keywords: Timber management, harvesting, financial analysis, wood utilization.

Introduction

Outputs from the Interior Northwest Landscape Analysis System (INLAS) modeling framework (Barbour et al. Chapter 1) will help policymakers, managers, and the public understand the capacity of subbasin-sized landscapes (about 500,000 acres, or about 202 300 hectares) located in the interior Northwest to deliver ecological, social, and economic benefits including the potential to remove timber and nontimber forest products.[2]

---

[1] **R. James Barbour** is a research forest products technologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 620 SW Main, Suite 400, Portland, OR 97205. **Douglas Maguire** is an associate professor of silviculture, and **Ryan Singleton** is a research forester, Department of Forest Science, Oregon State University, Corvallis, OR 97331.

[2] Nontimber forest products (also referred to as special forest products) are defined as “species harvested from forests for other than timber commodities” (Vance et al. 2001). They can include “nonwoody species, such as mushrooms, ferns, and other understory plants; nonwoody parts of trees, such as cones, fruits, bark, foliage, and sap; and woody material such as firewood, poles, and boughs” (von Hagen and Fight 1999).

The INLAS framework tracks the vegetation on individual landscape units (polygons) and projects the quality and abundance of various resources under different management policies while considering dynamic disturbance processes (Hemstrom et al. Chapter 2, Bettinger et al. Chapter 4).

The goal of the INLAS utilization analysis is to develop a simple metric that is useful for displaying the quality and abundance of timber and nontimber forest products under different policy goals. We call this metric the “utilization potential” and use it to integrate information about the economic costs of harvesting, the administrative and physical ease of accessing each polygon, and the types and values of materials removed. The utilization potential under alternative management scenarios depends on both the current stand conditions and the long-term stand growth responses to proposed silvicultural treatments. The utilization analysis will characterize the quality and quantity of current timber and nontimber forest products, and when possible also project their future quality and quantity in response to proposed treatments.

Research Objectives

Four questions make up the primary focus of the INLAS utilization analysis:

1. What is the product potential[3] for materials removed from each stand (polygon) under alternative management scenarios?

2. Will the various management scenarios require financial subsidies?

3. What is the accessibility of timber and nontimber forest products on each polygon?

4. What is the utilization potential[4] for each polygon?

We will address secondary questions indirectly through integration with the other discipline areas covered by the INLAS project. As the project develops, these questions may change in scope and complexity, but they will initially include:

1. What road network is necessary for utilization and what hazards (e.g., fires, sediment, resource damage) are associated with this network? (Links to vegetation, wildlife, and aquatics discipline areas).

2. How does active management affect the amount or duration of smoke associated with planned and unplanned fires? (Links to vegetation and disturbance discipline areas).

3. How does the collection of nontimber forest products contribute to the local economy? (Links to sociocultural and economics discipline areas).

4. How do various management scenarios influence the abundance and accessibility of nontimber forest products? (Links to vegetation and sociocultural discipline areas).

5. How do proposed treatments enhance or degrade production of nontimber forest products? (Links to vegetation and sociocultural discipline areas).

Research Approach

A key objective of the INLAS project is to use existing models as much as possible. The INLAS utilization module will use available models and methodology to evaluate (1) accessibility, (2) product potential, (3) financial return, and (4) utilization potential (composite of 1 through 3) for timber and nontimber forest products for each polygon on the

[3] The suitability of harvested materials for manufacturing a variety of timber and nontimber forest products.

[4] Utilization combines product potential, accessibility, and financial return.

landscape. Models are available to describe the mechanics of timber harvest, the finances of harvesting and processing, the impacts of harvesting on other resources and ecological processes, wood utilization, and the subsequent economic impacts of wood processing industries. Comparable information does not currently exist for most nontimber forest products. This information gap leads to an apparent emphasis on timber over nontimber forest products in this section. Where possible we will incorporate available information on nontimber forest products into the INLAS framework. We hope to highlight those areas where additional research about nontimber forest products is needed and use our analysis of wood utilization to demonstrate how this information could be used for integrated landscape modeling.

Accessibility for Extraction of Forest Products

The potential economic value of all forest products is influenced by road access, the costs associated with harvesting, and transportation to markets. Geographical information system (GIS) layers are available with current road locations, polygon delineation, topographic features, and sensitive areas. We will define the physical accessibility of each polygon as the distance from the centroid of the polygon to the nearest road. Likewise, we will determine the haul distance from each polygon to one of three major exit points from the watershed. The physical access information will point out the need for new roads by indicating where the distance to the nearest road exceeds a predetermined threshold level. For nontimber forest products, travel times will include both the time required to drive to the closest access point for each polygon plus an estimate of the time required to walk from the closest road access to collection sites. Under some policy goals, administrative access to certain polygons is restricted or prohibited. In those cases we will reduce or eliminate accessibility to them accordingly.

We will compile information into an index and display it graphically as a set of maps that indicate access to both timber and nontimber resources. Prescription design and management scenarios can make use of this information, and the implications for utilization potential and product values can also be evaluated during allocation of treatments across the subbasin. Assigning specific polygons to classes of hauling/travel distances or administratively restricted access will provide a simple method to summarize the results of the GIS analysis.

Wood Utilization

Our analyses will include the expected performance of harvested materials in various primary-manufacturing applications. Projections of the volume and characteristics of wood removed under each management scenario will allow evaluation of alternative configurations of industrial facilities that might develop over the coming decades. The wood processing facilities that use materials from the Upper Grande Ronde basin, however, are likely to draw resources from a much broader geographic area, so it will not be possible to estimate the size of the industry that treatments might support.

Tree lists generated by the vegetation simulators (Hemstrom et al. Chapter 2, Bettinger et al. Chapter 4) will identify both the trees selected for removal and those slated for retention under each management scenario. We will use information on the residual stands to evaluate future timber volume and quality. For harvested material we will use existing methods to estimate the harvesting costs (Hartsough et al. 2001), and both the quantity (Wycoff et al. 1982) and characteristics (Barbour and Parry 2001, Barbour et al. 1997, Parry et al. 1996) of wood removed under different management alternatives. Surveys of delivered log prices (e.g., Log Lines 2003) to existing facilities will supply the initial input prices for financial analyses.

We will combine elements of existing models, e.g., FEEMA (Fight and Chmelik 1999), with new programming solutions and tree-level information from the vegetation simulators (Hemstrom et al. Chapter 2, Bettinger et al. Chapter 4) to develop estimates of both potential yields of and financial returns from various wood product options.

The system will pass tree lists from the vegetation simulators included in the INLAS framework to a tool for characterizing wood product potential and conducting financial analyses. Storage of results in a database will allow production of customized tabular outputs. Combining these results with GIS data on road systems and land allocation will result in maps illustrating where different types of wood material are located, the financial costs associated with removing it, and the biophysical or sociopolitical constraints on removing it (fig. 34).

Output tables will include information on the means and variability of initial and residual stand conditions, size and volume of merchantable and submerchantable trees removed during treatments, log diameter, species distribution, and financial return. The tremendous amount of data generated from each scenario evaluated by using the INLAS process makes the creation of a succinct set of tables essential. Final formats will reflect user needs, with one possible format shown in figure 35. This format was used for a recent analysis of current and projected future conditions in the state of Montana (Barbour et al., 2004).

A set of idealized maps (fig. 36) provides an example of spatially explicit graphical results for a hypothetical landscape with four polygons. These four simple maps provide estimates of (1) accessibility, (2) wood product potential, (3) financial return, and (4) utilization potential (an index arrived at by combining 1 through 3). Accessibility is a function of road density or road proximity, physical characteristics of the land, and land use designation. Wood product potential is derived from cut-tree lists and a set of rules describing the types of material that the local industry can process. Financial return is the difference between the estimated dollar costs of harvesting, hauling, handling, and processing the raw material and the selling price of the end products. The utilization potential is a composite measure calculated from the other three that provides a visual display of the current status of the landscape in terms of the potential for wood utilization.

In the example shown here, the northwest (upper left) polygon on this landscape has low accessibility, moderate wood product potential, and a low financial return. Perhaps it is a steep unroaded area where trees are of moderate size. Financial return is low because expensive logging systems—helicopters or long-span skyline systems—are required, and the material removed is not particularly valuable. As a result, the utilization potential of this polygon is low. Managers might want to consider strategies that would not require removal of wood from this polygon. The northeast polygon might represent a different flat part of the unroaded area where there are many large shade-tolerant trees that are slated for removal because of disease concerns or a desire to enhance regeneration of seral species. Even though this is an unroaded area, the trees are large enough to justify their removal with helicopters, which lowers financial return. As a result, the utilization potential for wood products is moderate. The southwest polygon is a flat roaded area with sensitive soils, where fuel reduction treatments are desired and trees are small. Financial return is moderate because the cost of removing trees is low, but soil mitigation adds to total harvesting costs. As a result, utilization potential is low. Finally, the southeast quadrant is a flat roaded area with no operational restrictions, so the harvesting

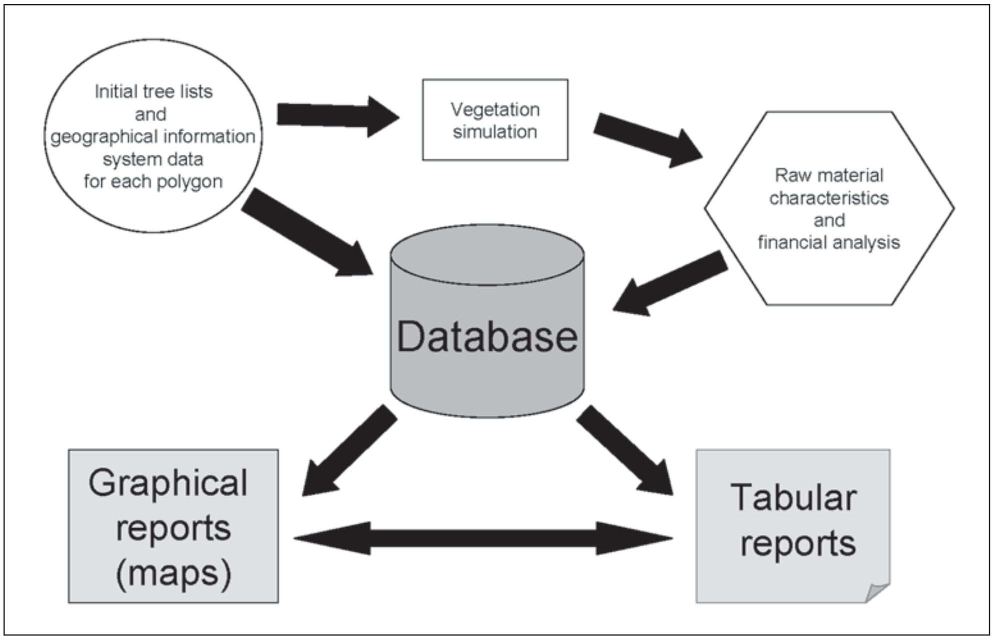

Figure 34—Steps in analytical process for the utilization module (adapted from Christensen et al. 2002 fig. 1).

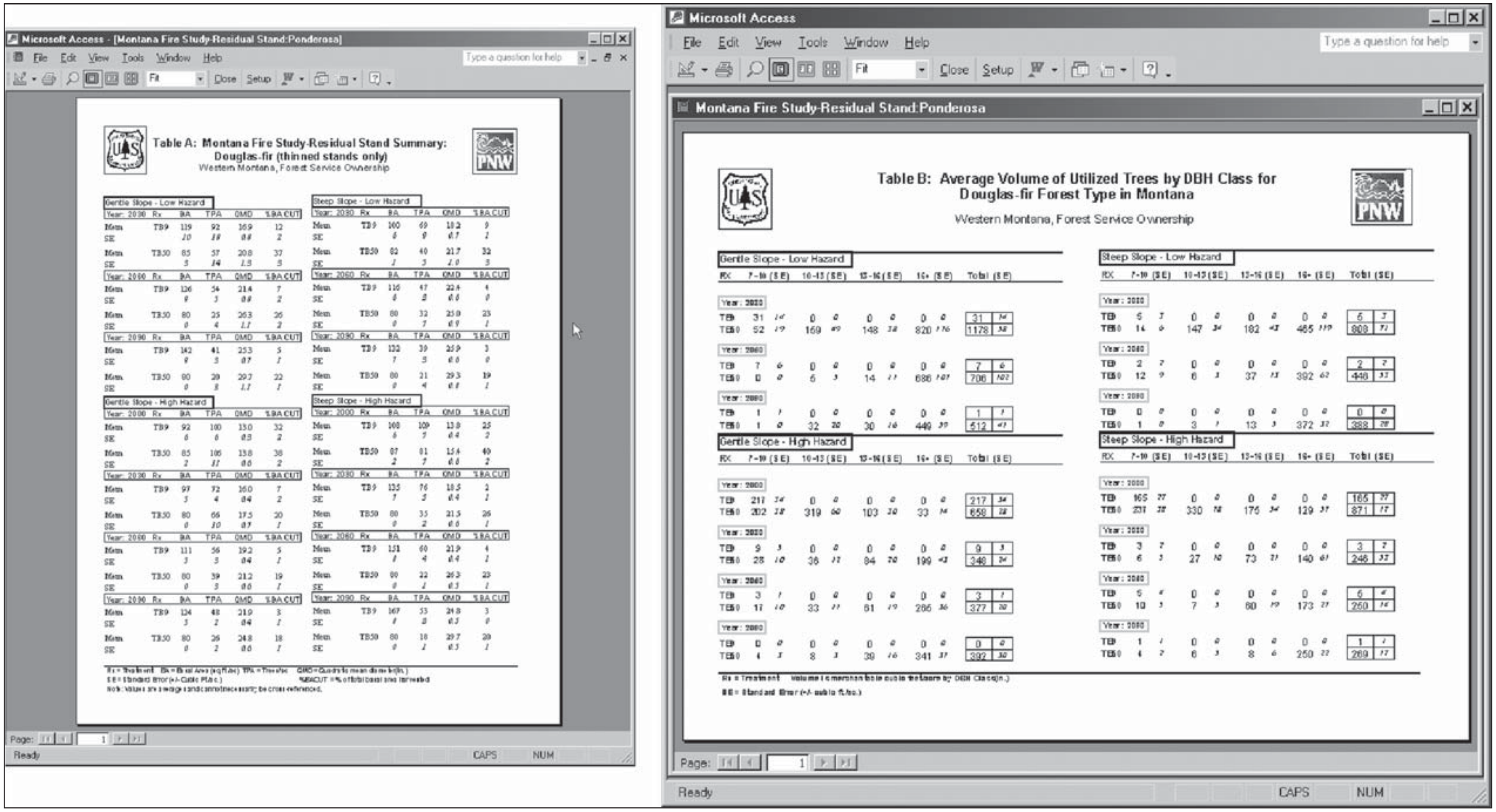

Figure 35—Potential formats for tabular reports (adapted from Christensen et al. 2002 figs. 2 and 3).

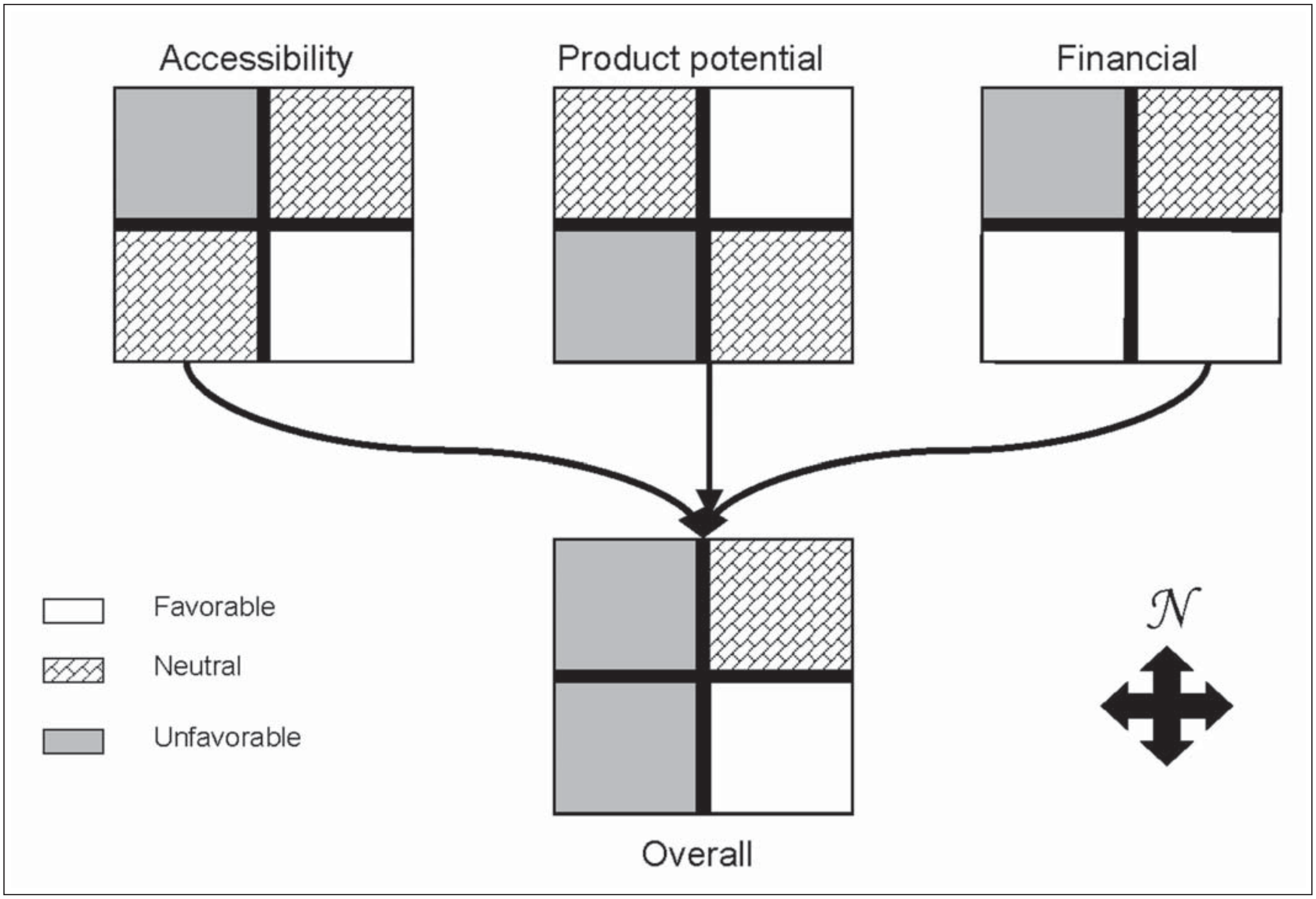

Figure 36—Example of geographic information system output for a highly simplified landscape with four polygons.

costs are low; the trees are moderate in size, so the financial return is good. The utilization potential of this polygon is good. This might be the type of area where wood removals would prove most successful.

In practice, this system will account for many different constraints on operations, product characteristics, and land or stand conditions. At a glance it will provide an idea of the suitability of different parts of the landscape for treatments that involve removal of wood products at different points in time. It will also provide a visual method for diagnosing why particular polygons or groups of polygons are either desirable or undesirable in terms of wood removals. In many instances, such qualitative visual displays will produce sufficient detail. In others, they will help analysts identify places where quantitative information is needed. Tabular reports can then be used to provide that detail.

Utilization of Nontimber Forest Products

Current information on nontimber forest products is sparse. An initial task is to identify the set of potentially important nontimber forest products found in the Upper Grande Ronde watershed. Alternative products may be added or substituted as the project develops. The analyses will supply information on current demand for each of the targeted nontimber forest products. We also want to understand the contribution of different stand structures to providing a given quantity and quality of each nontimber forest product. The information will be summarized as the amount of material available by type, and where possible, its estimated economic value.

We will project nontimber forest product presence and abundance from known relations with stand structure and site or habitat type. Information to establish predictive models will be collected from the literature, and the models will be developed or refined from published and unpublished data that have not yet been incorporated into models. To the degree that existing information allows, the nontimber forest products module will provide tabular and graphical outputs similar to those for timber.

Products and Audience

The primary outputs from this analysis will be sets of tables and maps that are suitable for evaluating different management scenarios. Maps will graphically display the product potential, net financial return, relative accessibility, and overall utilization potential of timber and nontimber forest products for individual polygons or groups of polygons in a more qualitative fashion. Maps that illustrate outcomes will allow us to graphically display results more concisely, although less precisely, than the tabular format. These will be useful to groups who want a general picture of utilization potential and how it changes over time but do not need quantitative information. Often the same groups who are interested in tabular outputs will first look to maps to gain a general understanding of where the commodities they care about are most abundant. Some examples of these users are members of the public interested in utilization of wood, gathering of nontimber forest products, or forest conditions after treatments; policymakers who evaluate broad policy goals and want information on the materials generated by treatments or the costs of implementing treatments; and others interested in wood utilization or collection of nontimber forest products.

Tabular displays of data are intended to provide information to a variety of user groups who need quantitative information. These groups might include managers or planners who want information about wood or nontimber product outputs generated under different management scenarios; forest operators who bid on contracts to implement treatments; and wood processors or purchasers of nontimber forest products who need estimates of characteristics and volumes of materials available.

We anticipate that the nature of the outputs developed to describe utilization potential will evolve as we work with users and clients to implement the ideas presented in this paper. Our goal is to develop an easily understandable and useful method for evaluating the potential for use of timber and nontimber forest products that can be integrated with other resource outputs from subbasins in the interior Northwest, and to do that, collaboration with users is essential.

Literature Cited

Barbour, R.J.; Ager, A.A.; Hayes, J.L. 2004. A framework for the development and application of INLAS: the Interior Northwest Landscape Analysis System. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrated modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1-16. Chapter 1.

Barbour, R.J.; Fight, R.D.; Christensen, G.A.; Pinjuv, G.L.; Nagubadi, V. 2004. Thinning and prescribed fire and projected trends in wood product potential, financial return, and fire hazard in Montana. Gen. Tech. Rep. PNW-GTR-606. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 78 p.

Barbour, R.J.; Johnston, S.; Hayes, J.P.; Tucker, G.F. 1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. Forest Ecology and Management. 91: 205-219.

Barbour, R.J.; Parry, D.L. 2001. Log and lumber grades as indicators of wood quality in 20- to 100-year-old Douglas-fir trees from thinned and unthinned stands. Gen. Tech. Rep. PNW-GTR-510. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Bettinger, P.; Graetz, D.; Ager, A.A.; Sessions, J. 2004. The SafeD forest landscape planning model. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrated modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 41-63. Chapter 4.

Christensen, G.A.; Fight, R.D.; Barbour, R.J. 2002. Simulating fire hazard reduction, wood flow and economics of fuel treatments with FVS, FEEMA, and FIA data. In: Crookston, N.L.; Havies, R.N., comps. Second Forest Vegetation Simulator conference. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 91-103.

Fight, R.D.; Chmelik, J.T. 1999. Analysts guide to FEEMA for financial analysis of ecosystem management activities. Gen. Tech. Rep. FPL-GTR-111. Madison, WI: U.S Department of Agriculture, Forest Service, Forest Products Laboratory. 5 p.

Hartsough, B.R.; Zhang, X.; Fight, R.D. 2001. Harvesting cost model for small trees in natural stands in the interior Northwest. Forest Products Journal. 51(4): 54-61.

Hemstrom, M.; Ager, A.A.; Vavra, M. [et al.]. 2004. State and transition approach for integrating landscape models. In: Hayes, J.L.; Ager, A.A.; Barbour, R.J., tech. eds. Methods for integrated modeling of landscape change: Interior Northwest Landscape Analysis System. Gen. Tech. Rep. PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 17-32. Chapter 2.

Log Lines. 2003. Monthly price reports. Mount Vernon, WA: Log Lines Price Reporting Service. 10 p.

Parry, D.L.; Filip, G.M.; Willits, S.A.; Parks, C.G. 1996. Lumber recovery and deterioration of beetle-killed Douglas-fir and grand fir in the Blue Mountains of eastern Oregon. Gen. Tech. Rep. PNW-GTR-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Vance, N.C.; Borsting, M.; Pilz, D.; Freed, J. 2001. Special forest products: species information guide for the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-513. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 169 p.

von Hagen, B.; Fight, R.D. 1999. Opportunities for conservation-based development of nontimber forest products in the Pacific Northwest. Gen. Tech Rep. PNW-GTR-473. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 18 p.

Wycoff, W.R.; Crookston, N.L.; Stage, A.R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Chapter 14: Bibliography

Marti Aitken and Alan A. Ager[1]

Introduction

This chapter consists of a bibliography listing and index to recently published literature relating to the Interior Northwest Landscape Analysis System (INLAS) project area. The bibliography is intended to provide background information about the natural and socio-economic research that has been conducted in the project area. It is not a complete compendium of literature cited within the chapters of this general technical report.

The bibliography was developed by searching public and academic library databases in Oregon, Washington, and Idaho for literature specifically related to the INLAS study area. We also used DigiTop, the digital desktop library for the U.S. Department of Agriculture. The library emphasizes products focused on scientific research and provides access to databases, journals, newspapers, statistics, and other important digital information resources. The Thomson Institute for Scientific Information (ISI) Web of Knowledge was the primary platform used.

The INLAS study area is located in the Upper Grande Ronde watershed, in the Blue Mountains of northeast Oregon (fig. 37). The Upper Grande Ronde watershed is one of three hydrologic unit codes (HUC4) subwatersheds in the Grande Ronde basin and is approximately 178 000 ha. Because authors seldom reference the Upper Grande Ronde in their keywords, broader geographic references were used. These terms included Blue Mountains, Wallowa-Whitman National Forest, Umatilla National Forest, and Union County. Even broader-scale geographic references such as northeastern Oregon, or eastern Oregon were found to be too broad to be useful. Additional citation information was gathered through the Grande Ronde Model Watershed Program (GRMWP)

---

[1] **Marti Aitken** is a resource information manager, and **Alan A. Ager** is an operations research analyst, U.S. Department of Agriculture, Forest Service, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, OR 97850.

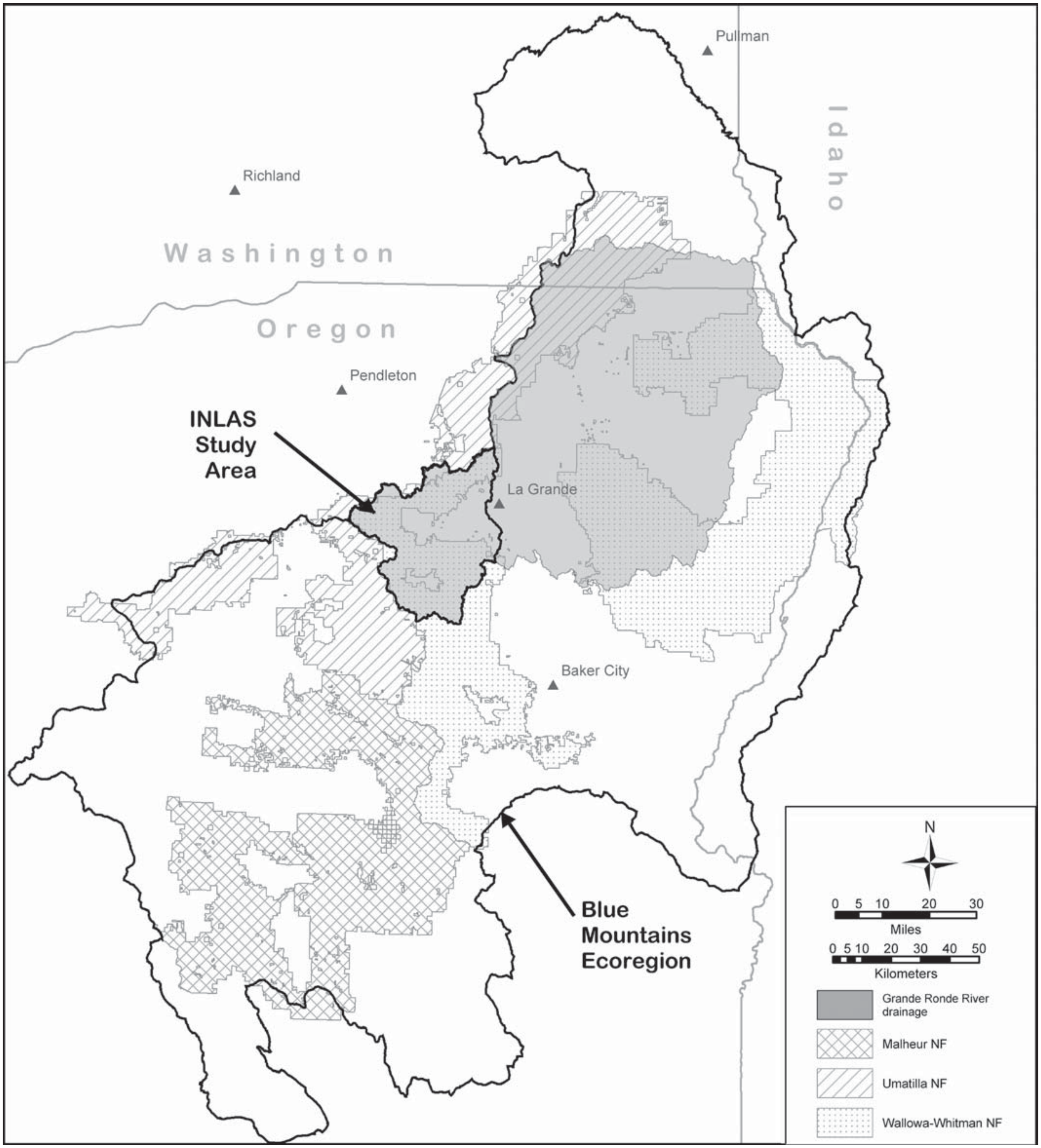

Figure 37—The INLAS study area in relation to the Grande Ronde watershed and the Blue Mountains.

and from direct contact with local researchers and specialists. The GRMWP is composed of local representatives and agency personnel involved with the multiple uses of natural resources within the basin, and coordinates policy for the development, implementation, monitoring, and maintenance of the model watershed for the Grande Ronde River basin.

The complete search turned up more than 500 references. This bibliography contains the highlights of the search and consists of 358 citations dated from 1960 through April 2003. These citations cover a broad range of topics and have been grouped into the following 10 disciplines addressed in the INLAS project: aquatics, fire, grazing, herbivory, insects/disease, modeling, socioeconomics, utilization, vegetation, wildlife, and general. Citations addressing multiple disciplines (e.g., environmental impact analysis) can be found under the general grouping. Citations also have been grouped into three geographic categories: Upper Grande Ronde, Grande Ronde, and Blue Mountains. Geographic groupings are based on the best available information about the research locations. The intent was to reference as many citations as possible to the Upper Grande Ronde watershed. Citations that could not be georeferenced to the Upper Grande Ronde watershed were georeferenced either to the Grande Ronde watershed, or to the Blue Mountains, depending on the information available.

Publications include journal articles, government publications, reports, theses, and books. Although the study area includes the Starkey Experimental Forest and Range, we avoided duplicating references available through the Starkey Experimental Forest and Range Web site (http://www.fs.fed.us/pnw/starkey/publications/index.shtml). The Web site lists numerous publications related to ungulate behavior, habitat, and management. This bibliography also does not contain hydrologic and water quality references available through the Oregon Department of Water Resources Web site (http://www.wrd.state.or.us/surface_water/index.shtml) or the Oregon Department of Environmental Quality (http://www.deq.state.or.us/wq/TMDLs/TMDLs.htm).

Unfortunately, publications listed below are not on file or available for use at any central location. Libraries, especially those serving as federal depositories, are the first and best source for information. Listed theses and dissertations are available from the individual schools.

Citations are listed alphabetically by author, date, and title. The [brackets] around a date means the approximate year (exact date was not found on the publication).

Aquatics

Anderson et al. 1993
Bach 1995
Ballard 1998a
Ballard 1998b
Ballard 1999
Baxter 2002
Benner 1999
Beschta et al. 1991
Betts and Wisseman 1995
Bohle 1994
Bryant 1982
Bryce and Clarke 1996
Bryson 1993
Buckhouse and Gaither 1982
Bull and Carter 1996
Carlson 1989
Carmichael 1993
Carmichael and Boyce 1986
Chen 1996
Chen et al. 1998a
Chen et al. 1998b
Clifton et al. 1999
Cordova 1995
Corrarino and Brusven 1983
Diebel 1997
Dwire 2001
Ebersole 1994
Ebersole et al. 2002
Filip et al. 1989a
Fowler et al. 1979
Gill 1994
Helvey and Tiedemann 1978
Higgins et al. 1988
Higgins et al. 1989
Howell 2001
Huntington 1994
James 1984
Keefe et al. 1994
Keefe et al. 1995
Knight 1977
Lytjen 1998
Maloney et al. 1999
Marcot et al. 1994
McHugh 2003
McIntosh 1992
McIntosh 1995
McIntosh et al. 1994a
McIntosh et al. 1994b

McIntosh et al. 1995
McIver and Starr 2001
McLemore and Meehan 1988
Meays 2000
Mobrand et al. 1995
Moffat et al. 1990
Neitzel and Frest 1992
Noll et al. 1987
Northwest Power Planning Council 1990
Oregon Department of Fish and Wildlife [1988]
Oregon Department of Fish and Wildlife [1990]
Oregon Department of Fish and Wildlife [1993-1996]
Oregon Department of Fish and Wildlife [1994]
Oregon Department of Fish and Wildlife [1999]
Oregon Department of Transportation 1984
Parker et al. [1995]
Porath et al. 2002
Price 1998
Rieman et al. 2001
Robichaud and Brown 1999
Smith 1975a
Steel 1999
Tiedemann et al. 1988
Torgersen et al. 1999
U.S. Army Corps of Engineers 1999
U.S. Department of Agriculture, Forest Service 1992a
U.S. Department of Agriculture, Forest Service 1992b
U.S. Department of Agriculture, Forest Service 1994c
U.S. Department of Agriculture, Natural Resources Conservation Service and U.S. Department of Agriculture, Forest Service 1996
U.S. Department of Energy, Bonneville Power Administration 1997
U.S. Department of the Interior, Bureau of Land Management, Baker Resource Area Office 1993
U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region 1982
U.S. Department of the Interior, Geological Survey 1989
Van Cleve and Ting 1960
Walters et al. 1994
Watershed Sciences, LLC 2000
Wellman et al. 1993
Wells 1975
White et al. 1981
Widner 1991
Wissmar et al. 1994a
Wissmar et al. 1994b
Wondzell 2001

Fire and fuels

Agee 1994
Diaz-Avalos 1998
Diaz-Avalos et al. 2001

Filip and Yang-Erve 1997
Hall 1976
Hall 1977
Hall 1980
Heyerdahl 1997
Heyerdahl et al. 1996
Heyerdahl et al. 2001
Huff et al. 1995
Johnson [1998]
Langston 1995
Lehmkuhl et al. 1994
Maruka 1994
McIver and Starr 2000
McIver and Starr 2001
Mohr and Both 1996
Mutch et al. 1993
Olson 2000
Ottmar and Sandberg 2001
Petersen and Mohr 1984
Reed 1998
Robichaud and Brown 1999
Shindler and Reed 1996
Skovlin 1996
Skovlin and Thomas 1995
Thies and Niwa 2001
Tiedemann et al. 2000
Wickman 1992
Williamson 1999
Wissmar et al. 1994b

General

Anderson et al. 1993
Bauer 2000
Berggren 1983
Bormann et al. 1994
Clarke and Bryce 1997
Clarke et al. 1997
Everett 1994
Everett et al. 1994
Gast et al. 1991
Harvey et al. 1994
Jensen and Bourgeron 1994
Hessburg et al. 1994
Jaindl and Quigley 1996
Johnson et al. 1994
Keith 1991
Langston 1994
Langston 1995
Langston 2000
Marcot et al. 1994

Mutch et al. 1993
Oliver et al. 1994
Robbins and Wolf 1994
Starr et al. 2001
Tanaka et al. 1995
Thomas et al. 1976
U.S. Department of Agriculture, Forest Service 1992a
U.S. Department of Agriculture, Forest Service 1994b
U.S. Department of Agriculture, Forest Service 1998
U.S. Department of Agriculture, Forest Service 2002
U.S. Department of the Interior, Bureau of Land Management and U.S. Department of Agriculture, Forest Service 1990
Union Soil and Water Conservation District 1995
Whitney 1999
Williams 2000
Wissmar et al. 1994b

Grazing

Bryant 1982
Bull and Hayes 2000
Clark 1996
Cook et al. 1996
Edgerton and Smith 1971
Gebauer 1998
Gillen et al. 1985
Heyerdahl et al. 2001
Holechek et al. 1980
Holechek et al. 1981
Holechek et al. 1982a
Holechek et al. 1982b
Holechek et al. 1983
Holechek et al. 1987
Holechek and Vavra 1983
Irwin et al. 1994
Knight 1977
Maloney et al. 1999
McInnis et al. 1990
McIntosh et al. 1994a
McIntosh et al. 1994b
Moser and Witmer 2000
Porath et al. 2002
Quigley et al. 1991
Riggs et al. 2000
Roath and Krueger 1982
Sanderson et al. 1988
Sheehy 1987
Skovlin 1967
Skovlin et al. 1976
Sneva and Hyder 1962
Svejcar and Vavra 1985a

Svejcar and Vavra 1985b
Vavra and Phillips 1979
Vavra and Phillips 1980

Herbivory

Bryant 1993
Clark 1996
Cook et al. 1996
Gebauer 1998
Irwin et al. 1994
Moser and Witmer 2000
Parks et al. 1998
Riggs et al. 2000
Sheehy 1987
Skovlin 1967

Insects and disease

Aho 1974
Aho and Hadfield 1975
Beckwith and Stelzer 1979
Bull et al. 1992a
Bull et al. 1995
Delucchi 1976
Downing et al. 1977
Ferguson 1994
Filip et al. 1987
Filip et al. 1989b
Filip et al. 1989c
Filip et al. 1992
Filip et al. 1996
Filip and Parks 1987
Filip and Parks 1991
Filip and Yang-Erve 1997
Grimble and Beckwith 1992-1994
Grimble et al. 1993
Hayes and Daterman 2001
Hayes and Ragenovich 2001
Helvey and Tiedemann 1978
Hessburg et al. 1994
Kemp et al. 1986
LaBonte et al. 2001
Langston 1995
Lehmkuhl et al. 1994
Lundquist et al. 1996
Mason 1996
Mason and Paul 1988
Mason and Paul 1996
Mason and Wickman [1988]
McIver et al. 1997

Murphy and Croft 1990
Parks and Bull 1997
Parks and Flanagan 2001
Parks and Hoffman 1991
Parks et al. 1999
Parry et al. 1996
Powell 1994
Roush 1978
Ryan 1983
Ryan 1985
Ryan 1997
Swetnam et al. 1995
Thies 2001
Thies and Niwa 2001
Tiedemann et al. 2000
Torgersen 2001
Torgersen and Bull 1995
Wickman 1976
Wickman 1988
Wickman 1992
Wickman et al. 1980
Youngblood and Wickman 2002
Zack et al. 1979

Modeling

Baxter 1993
Bettinger et al. 1996a
Bettinger et al. 1996b
Chen 1996
Chen et al. 1998a
Chen et al. 1998b
Diaz-Avalos 1998
Diaz-Avalos et al. 2001
Hemstrom et al. 2002
Higgins et al. 1988
Hitchcock and Ager 1992
Kemp et al. 1986
Lundquist and Beatty 1999
Lundquist and Beatty 2002
McHugh 2003
McInnis et al. 1990
Sneva and Hyder 1962
Wells 1975
White et al. 1981

Social and economic

Applegate and O’Donnell 1994
Barklow 1987
Bormann et al. 1994
Braun 1991

Buan and Lewis 1991
Davis et al. 1991
Delucchi 1976
Downing et al. 1977
Duncan 1998
Ebert 1987
Evans 1991
Gildemeister 1998
Hall 1977
Hall and Bigler-Cole 2001
Haynes et al. 2001
Hermens and Turner 1985
Johnson [1997]
Keith 1991
Langston 1995
Langston 2000
Quigley 1992
Reed 1998
Shindler et al. [2002]
Shindler and Reed 1996
Starr and Quigley 1992
U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region 1982
Wells 1975
Williams 1976
Wissmar et al. 1994a
Womack 1982

Utilization

Aho 1974
Aho and Hadfield 1975
Bull and Carter 1996
Bull et al. 1997
Clausnitzer [1993]
Cochran and Barrett 1993
Cochran and Barrett 1995
Cochran and Dahms [1998]
Cochran and Seidel 1995
Coulter 1999
Filip et al. 1987
Filip et al. 1989c
Geist et al. 1989
Gill 1994
Haynes et al. 2001
Ince 1982
Klock and Lopushinsky 1980
Lennette 1999
Lundquist and Beatty 1999
Lundquist et al. 1996
McIntosh et al. 1994a
McIntosh et al. 1994b

McIver and Starr 2000
McIver and Starr 2001
Oester et al. 1995
Parry et al. 1996
Peterson and Hibbs 1989
Quigley 1992
Quigley et al. 2001
Reed 1998
Seidel 1982
Seidel and Head 1983
Shindler and Reed 1996
Skovlin et al. 1989
Tiedemann et al. 1988
Wickman 1978
Wickman 1986
Wickman et al. 1980
Williams 1988
Wilson et al. 2001
Wissmar et al. 1994a
Youngblood 2000

Vegetation

Beck 1996
Bohle 1994
Brady 2001
Brookshire 2000
Buckhouse and Gaither 1982
Bull et al. 2001b
Case 1995
Chen et al. 1998b
Clausnitzer 1979
Clausnitzer [1993]
Crowe and Clausnitzer 1997
Diaz-Avalos 1998
Diaz-Avalos et al. 2001
Dwire 2001
Ferguson 1994
Filip et al. 1989a
Filip and Yang-Erve 1997
Franklin and Dyrness 1973
Ganskopp 1978
Gebauer 1998
Hall 1973
Hall 1974
Hall 1976
Hall 1977
Hall 1980
Harrod 2001
Hemstrom 2001
Hemstrom et al. 2002

Hines 1998
Hines and Bradshaw 1997
Huntington 1994
Irwin et al. 1994
Johnson 1981
Johnson [1993]
Johnson [1998]
Johnson and Clausnitzer 1992
Lehmkuhl et al. 1994
Lennette 1999
Lundquist and Beatty 1999
Lundquist et al. 1996
Lytjen 1998
Mannan 1982
Maruka 1994
Moser and Witmer 2000
Oester et al. 1995
Olson 2000
Otting 1998
Parks et al. 1998
Parks and Schmitt 1997
Powell 1999
Reed 1998
Riegel 1989
Riggs et al. 2000
Shirley and Erickson 2001
Skovlin 1996
Skovlin et al. 1976
Skovlin and Thomas 1995
Smergut 1991
Tiedemann et al. 2000
Wissmar et al. 1994a
Wissmar et al. 1994b
Wood 1971
Youngblood 2001

Wildlife

Bolon 1994
Bryant 1993
Bull 1980
Bull 1984
Bull 1987
Bull 2000
Bull 2001
Bull [In press]
Bull and Anderson 1978
Bull and Beckwith 1993
Bull and Blumton 1997
Bull and Blumton 1999
Bull and Carter 1996

Bull and Collins 1993
Bull and Collins 1996
Bull and Hayes 2000
Bull and Hayes 2001
Bull and Hayes 2002
Bull and Heater 1995
Bull and Heater 2000
Bull and Heater 2001
Bull and Henjum 1990
Bull and Holthausen 1993
Bull et al. 1987
Bull et al. 1989
Bull et al. 1990
Bull et al. 1992a
Bull et al. 1992b
Bull et al. 1995
Bull et al. 1997
Bull et al. 2000
Bull et al. 2001a
Bull et al. 2001b
Bull and Meslow 1988
Bull and Shepherd 2003
Bull and Skovlin 1982
Bull and Wales 2001a
Bull and Wales 2001b
Cook et al. 1996
Cook et al. 1999
Ebert 1987
Edgerton and Smith 1971
Goggans 1985
Hitchcock and Ager 1992
Irwin et al. 1994
Korfhage et al. 1980
Leckenby 1984
Mannan 1982
Marcot et al. 1994
McCluskey 1976
Moore and Henny 1984
Moser and Witmer 2000
Nowak 1999
Noyes et al. 1996
Parks and Bull 1997
Parks et al. 1998
Parks et al. 1999
Pelren 1996
Pelren and Crawford 1999
Riggs et al. 2000
Sallabanks et al. 2002
Sheehy 1987
Sheehy and Slater 1998

Skovlin et al. 1989
Skovlin and Vavra 1979
Smith 1975a
Smith 1975b
Smith 1982
Snyder 2001
Thomas et al. 1976
Thomas et al. 1979
Thomas et al. 1986
Torgersen and Bull 1995
Wales 2001

Upper Grande Ronde

Anderson et al. 1993
Bach 1995
Ballard [1998a]
Bettinger et al. 1996b
Bohle 1994
Brookshire 2000
Bryce and Clarke 1996
Bull 1980
Bull 1984
Bull 1987
Bull 2000
Bull 2001
Bull [In press]
Bull and Anderson 1978
Bull and Beckwith 1993
Bull and Blumton 1997
Bull and Blumton 1999
Bull and Carter 1996
Bull and Collins 1993
Bull and Collins 1996
Bull and Hayes 2000
Bull and Hayes 2001
Bull and Hayes 2002
Bull and Heater 1995
Bull and Heater 2000
Bull and Heater 2001
Bull and Henjum 1990
Bull and Holthausen 1993
Bull and Meslow 1988
Bull et al. 1987
Bull et al. 1989
Bull et al. 1990
Bull et al. 1992a
Bull et al. 1992b
Bull et al. 1995
Bull et al. 1997
Bull et al. 2000

Bull et al. 2001b
Bull and Shepherd 2003
Bull and Skovlin 1982
Case 1995
Chen 1996
Chen et al. 1998a
Chen et al. 1998b
Clark 1996
Delucchi 1976
Dwire 2001
Edgerton and Smith 1971
Filip et al. 1987
Filip et al. 1989a
Filip et al. 1992
Filip and Parks 1987
Filip and Parks 1991
Ganskopp 1978
Gildemeister 1998
Gill 1994
Hemstrom et al. 2002
Hines 1998
Holechek et al. 1980
Holechek et al. 1981
Holechek et al. 1982a
Holechek et al. 1982b
Holechek et al. 1983
Holechek et al. 1987
Holechek and Vavra 1983
Knight 1977
Lytjen 1998
Mason and Paul 1988
Mason and Wickman [1988]
McHugh 2003
McIntosh 1992
McLemore and Meehan 1988
Otting 1998
Parks and Bull 1997
Parks et al. 1999
Parks and Schmitt 1997
Skovlin et al. 1976
Svejcar and Vavra 1985a
Swetnam et al. 1995
Torgersen and Bull 1995
U.S. Department of Agriculture, Forest Service 1992a
U.S. Department of Agriculture, Forest Service 1992b
U.S. Department of Agriculture, Forest Service 1994a
U.S. Department of Agriculture, Forest Service 1994b
U.S. Department of Agriculture, Forest Service 1994c
U.S. Department of Agriculture, Forest Service 1998
U.S. Department of Agriculture, Forest Service 2002

Union Soil and Water Conservation District 1999
Wickman 1976
Wickman 1978
Wickman 1986
Wickman 1988
Wickman et al. 1980
Youngblood 2000
Youngblood and Wickman 2002

Grande Ronde

Ballard 1998b
Ballard 1999
Bauer 2000
Baxter 2002
Beschta et al. 1991
Bryson 1993
Carmichael 1993
Carmichael and Boyce 1986
Cook et al. 1999
Corrarino and Brusven 1983
Diebel 1997
Duncan 1998
Filip et al. 1989b
Filip et al. 1989c
Hermens and Turner 1985
Hines and Bradshaw 1997
Huff et al. 1995
Huntington 1994
James 1984
Keefe et al. 1994
Keefe et al. 1995
Lennette 1999
Maruka 1994
McIntosh et al. 1994b
McIntosh et al. 1995
Mobrand et al. 1995
Neitzel and Frest 1992
Noll et al. 1987
Northwest Power Planning Council 1990
Oregon Department of Fish and Wildlife [1988]
Oregon Department of Fish and Wildlife [1990]
Oregon Department of Fish and Wildlife [1994]
Oregon Department of Fish and Wildlife [1999]
Oregon Department of Transportation 1984
Parker et al. [1995]
Ryan 1983
Ryan 1985
Ryan 1997
Sheehy and Slater 1998
Smergut 1991

Smith 1975a
Steel 1999
U.S. Army Corps of Engineers 1999
U.S. Department of Agriculture, Natural Resources Conservation Service and U.S. Department of Agriculture 1996
U.S. Department of Energy, Bonneville Power Administration 1997
U.S. Department of the Interior, Bureau of Land Management 1993
U.S. Department of the Interior, Bureau of Land Management and U.S. Department of Agriculture, Forest Service 1990
U.S. Department of the Interior, Geological Survey 1989
Union Soil and Water Conservation District 1995
Van Cleve and Ting 1960
Walters et al. 1994
Watershed Sciences, LLC 2000
Wells 1975
White et al. 1981
Whitney 1999
Wissmar et al. 1994a
Wissmar et al. 1994b

Blue Mountains

Agee 1994
Aho 1974
Aho and Hadfield 1975
Applegate and O'Donnell 1994
Barklow 1987
Baxter 1993
Beck 1996
Beckwith and Stelzer 1979
Benner 1999
Bettinger et al. 1996a
Betts and Wisseman 1995
Bolon 1994
Brady 2001
Braun 1991
Bryant 1982
Bryant 1993
Buan and Lewis 1991
Buckhouse and Gaither 1982
Bull et al. 2001a
Bull and Wales 2001a
Bull and Wales 2001b
Clarke and Bryce 1997
Clarke et al. 1997
Clausnitzer [1993]
Clausnitzer 1979
Clifton et al. 1999
Cochran and Barrett 1993
Cochran and Barrett 1995
Cochran and Dahms [1998]

Cochran and Seidel 1995
Cook et al. 1996
Cordova 1995
Coulter 1999
Crowe and Clausnitzer 1997
Diaz-Avalos 1998
Diaz-Avalos et al. 2001
Downing et al. 1977
Ebersole 1994
Ebersole et al. 2002
Ebert 1987
Evans 1991
Everett 1994
Everett et al. 1994
Ferguson 1994
Ferguson 2001
Filip et al. 1996
Filip and Yang-Erve 1997
Fowler et al. 1979
Franklin and Dyrness 1973
Gast et al. 1991
Gebauer 1998
Geist 1977
Geist et al. 1989
Geist and Strickler 1978
Gillen et al. 1985
Goggans 1985
Grimble and Beckwith 1992-1994
Grimble et al. 1993
Hall 1973
Hall 1974
Hall 1976
Hall 1977
Hall 1980
Hall and Bigler-Cole 2001
Harrod 2001
Harvey et al. 1994
Hayes and Daterman 2001
Hayes and Ragenovich 2001
Haynes et al. 2001
Helvey and Tiedemann 1978
Hemstrom 2001
Hessburg et al. 1994
Heyerdahl 1997
Heyerdahl et al. 1996
Heyerdahl et al. 2001
Higgins et al. 1988
Higgins et al. 1989
Hitchcock and Ager 1992
Howell 2001

Ince 1982
Irwin et al. 1994
Jaindl and Quigley 1996
Jensen and Bourgeron 1994
Johnson 1994
Johnson 1981
Johnson [1997]
Johnson [1998]
Johnson and Clausnitzer 1992
Johnson et al. 1994
Keith 1991
Klock and Lopushinsky 1980
Korfhage et al. 1980
Kreger and Roschke 1991
LaBonte et al. 2001
Langston 1994
Langston 1995
Langston 2000
Leckenby 1984
Lehmkuhl et al. 1994
Lundquist and Beatty 1999
Lundquist and Beatty 2002
Lundquist et al. 1996
Mannan 1982
Marcot et al. 1994
Mason 1996
Mason and Paul 1996
McInnis et al. 1990
McIver et al. 1997
McIver and Starr 2000
Mohr and Both 1996
Moore and Henny 1984
Moser and Witmer 2000
Murphy and Croft 1990
Mutch et al. 1993
Nowak 1999
Oester et al. 1995
Oliver et al. 1994
Olson 2000
Ottmar and Sandberg 2001
Parks and Hoffman 1991
Parks and Flanagan 2001
Parks et al. 1998
Parry et al. 1996
Pelren and Crawford 1999
Petersen and Mohr 1984
Peterson and Hibbs 1989
Porath et al. 2002
Powell 1994
Powell 1999

Price 1998
Quigley 1992
Quigley et al. 1991
Quigley et al. 2001
Reed 1998
Riegel 1989
Riggs et al. 2000
Roath and Krueger 1982
Robbins and Wolf 1994
Robichaud and Brown 1999
Sallabanks et al. 2002
Seidel 1982
Seidel and Head 1983
Sheehy 1987
Shindler and Reed 1996
Shirley and Erickson 2001
Skovlin 1967
Skovlin 1996
Skovlin and Thomas 1995
Skovlin and Vavra 1979
Skovlin et al. 1989
Smith 1975b
Smith 1982
Sneva and Hyder 1962
Starr and Quigley 1992
Starr et al. 2001
Svejcar and Vavra 1985b
Tanaka et al. 1995
Thies and Niwa 2001
Thies 2001
Thomas et al. 1976
Thomas et al. 1979
Thomas et al. 1986
Tiedemann et al. 1988
Tiedemann et al. 2000
Torgersen 2001
Trauba 1975
U.S. Department of Agriculture, Soil Conservation Service and Oregon State University Agricultural Experiment Station 1985
U.S. Department of the Interior, Bureau of Reclamation, Pacific Northwest Region 1982
U.S. Department of the Interior, Geological Survey 1996
Vavra and Phillips 1979
Vavra and Phillips 1980
Wales 2001
Wickman 1992
Widner 1991
Williams 1976
Williams 1988
Williams 2000
Williamson 1999

Wilson et al. 2001
Womack 1982
Wondzell 2001
Wood 1971
Youngblood 2001
Zack et al. 1979

Agee, J.K. 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. Gen. Tech. Rep. PNW-GTR-320. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 52 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Aho, P.E. 1974. Defect estimation for grand fir in the Blue Mountains of Oregon and Washington. Res. Pap. PNW-175. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Aho, P.E.; Hadfield, J.S. 1975. How to estimate defect in grand fir in the Blue Mountains of Oregon and Washington. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

Anderson, J.W.; Beschta, R.L.; Boehne, P.L. [et al.]. 1993. A comprehensive approach to restoring habitat conditions needed to protect threatened salmon species in a severely degraded river—the Upper Grande Ronde River anadromous fish habitat protection, restoration and monitoring plan. In: Tellman, B.; Cortner, H.J.; Wallace, M.G. [et al.], tech. coords. Riparian management: common threads and shared interests. A western regional conference on river management strategies: Proceedings of a western regional conference on river management strategies. Gen. Tech. Rep. RM-226. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 175-179.

Applegate, S.; O'Donnell, T., eds. 1994. Talking on paper: an anthology of Oregon letters and diaries. Corvallis, OR: Oregon State University Press. 324 p.

Bach, L. 1995. River basin assessment—Upper/Middle Grande Ronde River and Catherine Creek. Portland, OR: Oregon Department of Environmental Quality. [Pages unknown].

Ballard, T. [1998a]. 1994-1998 Grande Ronde River basin water quality monitoring report for the Upper Grande Ronde, Lower Grande Ronde, Wallowa and Imnaha subbasins. Unpublished report. On file with: Grande Ronde Model Watershed, 10901 Island Avenue, La Grande, OR 97850.

Ballard, T. 1998b. Grande Ronde basin water quality monitoring report for six key subwatersheds. Portland, OR: U.S. Department of Energy, Bonneville Power Administration. Unpublished report. On file with: Grande Ronde Model Watershed, 10901 Island Avenue, La Grande, OR 97850.

Ballard, T. 1999. Grande Ronde River Basin, 1994-1998, water quality monitoring report. La Grande, OR: Union and Wallowa Soil and Water Conservation Districts and Grande Ronde Model Watershed Program. 211 p.

Barklow, I. 1987. From trails to rail: the post offices, stage stops, and wagon roads of Union County, Oregon. Enterprise, OR: Enchantments Publication of Oregon. 300 p.

Bauer, S.B. 2000. Grande Ronde River basin monitoring program review. Boise, ID: Pocket Water, Inc. Unpublished report. Submitted to Grande Ronde Basin Partnership. On file with: Grande Ronde Model Watershed, 10901 Island Ave., La Grande, OR 97850.

Baun, C.M.; Lewis, R. 1991. The first Oregonians: an illustrated collection of essays on traditional lifeways, federal-Indian relations, and the state's native people today. Portland, OR: Oregon Council for the Humanities. 128 p.

Baxter, C.V. 2002. Fish movement and assemblage dynamics in a Pacific Northwest riverscape. Corvallis, OR: Oregon State University. 174 p. Ph.D. dissertation.

Baxter, P.A. 1993. Utilizing GIS to analyze collections of the Eagle Cap Wilderness flora of northeastern Oregon. Pullman, WA: Washington State University. 60 p. M.S. thesis.

Beck, A.P. 1996. 4,400 years of vegetation change at Twin Lakes, Wallowa Mountains, northeastern Oregon. Pullman, WA: Washington State University. 51 p. M.A. thesis.

Beckwith, R.C.; Stelzer, M.J. 1979. The duration of cold storage and eclosion of the Douglas-fir tussock moth. Annals of the Entomological Society of America. 72(1): 158-161.

Benner, D.A. 1999. Evaporative heat loss of the upper Middle Fork of the John Day River, northeastern Oregon. Corvallis, OR: Oregon State University. 142 p. M.S. thesis.

Berggren, B.J. 1983. The minerology and morphology of loess derived soils along a traverse in northeastern Oregon. Corvallis, OR: Oregon State University. 147 p. M.S. thesis.

Beschta, R.L.; Platts, W.S.; Kauffman, J.B. [et al.]. 1991. Field review of fish habitat improvement projects in the Grande Ronde and John Day River basins in eastern Oregon. Portland, OR: U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. 53 p.

Bettinger, P.; Bradshaw, G.A.; Weaver, G.W. 1996a. Effects of geographic information system vector-raster-vector data conversion on landscape indices. Canadian Journal of Forest Research. 26(8): 1416-1425.

Bettinger, P.; Johnson, K.; Sessions, J. 1996b. Forest planning in an Oregon case study: defining the problem and attempting to meet goals with a spatial analysis technique. Environmental Management. 20(4): 565-577.

Betts, B.J.; Wisseman, R.W. 1995. Geographic range and habitat characteristics of the caddisfly *Cryptochia neosa*. Northwest Science. 69(1): 46-51.

Bohle, T.S. 1994. Stream temperatures, riparian vegetation, and channel morphology in the Upper Grande Ronde River watershed, Oregon. Corvallis, OR: Oregon State University. 116 p. M.S. thesis.

Bolon, N.A. 1994. Estimates of the values of elk in the Blue Mountains of Oregon and Washington. Gen. Tech. Rep. PNW-GTR-316. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 38 p.

Bormann, B.T.; Brookes, M.H.; Ford, E.D. [et al.]. 1994. Volume V: a framework for sustainable-ecosystem management. Gen. Tech. Rep. PNW-GTR-331. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 61 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment).

Brady, T.J. 2001. The significance of population successional status to the evolution of seedling morphology in *Pinus contorta* var. *latifolia* (Pinaceae). Madroño. 48(3): 138-151.

Brookshire, E.N.J. 2000. Forests to floodplain meadows: detrital dynamics on two headwater streams. Corvallis, OR: Oregon State University. 112 p. M.S. thesis.

Bryant, L.D. 1982. Response of livestock to riparian zone exclusion. Journal of Range Management. 35(6): 780-785.

Bryant, L.D. 1993. Quality of bluebunch wheatgrass (*Agropyron spicatum*) as a winter range forage for Rocky Mountain elk (*Cervus elaphus nelsoni*) in the Blue Mountains of Oregon. Corvallis, OR: Oregon State University. 147 p. Ph.D. dissertation.

Bryce, S.A.; Clarke, S.E. 1996. Landscape-level ecological regions: linking state-level ecoregion frameworks with stream habitat classifications. Environmental Management. 20(3): 297-311 .

Bryson, D. 1993. Northeast Oregon hatchery Grande Ronde River management plan. Portland, OR: U.S. Department of Energy, Bonneville Power Administration; final report. [Pages unknown].

Buckhouse, J.C.; Gaither, R.E. 1982. Potential sediment production within vegetative communities in Oregon's Blue Mountains. Journal of Soil and Water Conservation. 37(2): 120-122.

Bull, E.L. 1980. Resource partitioning among woodpeckers in northeastern Oregon. Moscow, ID: University of Idaho. 109 p. Ph.D. dissertation.

Bull, E.L. 1984. Bird response to beetle-killed lodgepole pine. Murrelet. 64(3): 94-96.

Bull, E.L. 1987. Ecology of the pileated woodpecker in northeastern Oregon, USA. Journal of Wildlife Management. 51(2): 472-481.

Bull, E.L. 2000. Seasonal and sexual differences in American marten diet in northeastern Oregon. Northwest Science. 74(3): 186-191.

Bull, E.L. 2001. Survivorship of pileated woodpeckers in northeastern Oregon. Journal of Field Ornithology. 72(1): 131-135.

Bull, E.L. [In press]. Use of nest box use by Vaux's swifts. Journal of Field Ornithology.

Bull, E.L.; Akenson, J.J.; Henjum, M.G. 2000. Characteristics of black bear dens in trees and logs in northeastern Oregon. Northwestern Naturalist. 81: 148-153.

Bull, E.L.; Anderson, R.G. 1978. Notes on flammulated owls in northeastern Oregon. Murrelet. 59: 26-27.

Bull, E.L.; Aubry, K.B.; Wales, B.C. 2001a. Effects of disturbance on forest carnivores of conservation concern in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 180-184.

Bull, E.L.; Beckwith, R.C. 1993. Diet and foraging behavior of Vaux's swifts in northeastern Oregon. Condor. 95: 1016-1023.

Bull, E.L.; Blumton, A.K. 1997. Roosting behavior of postfledgling Vaux's swifts in northeastern Oregon. Journal of Field Ornithology. 8: 302-305.

Bull, E.L.; Blumton, A.K. 1999. Effect of fuels reduction on American martens and their prey. Res. Pap. PNW-RP-539. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 9 p.

Bull, E.L.; Carter, B.E. 1996. Tailed frogs: distribution, ecology, and association with timber harvest in northeastern Oregon. Res. Pap. PNW-RP-497. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Bull, E.L.; Collins, C.T. 1993. Nesting chronology, molt, and ectoparasites of Vaux's swifts in northeastern Oregon. Avocetta. 17: 203-207.

Bull, E.L.; Collins, C.T. 1996. Nest site fidelity, breeding age, and adult longevity in the Vaux's swift. North American Bird Bander. 21: 49-51.

Bull, E.L.; Hayes, M.P. 2000. Livestock effects on reproduction of the Columbia spotted frog. Journal of Range Management. 53(3): 291-294.

Bull, E.L.; Hayes, M.P. 2001. Post-breeding season movements of Columbia spotted frogs (*Rana luteiventris*) in northeastern Oregon. Western North American Naturalist. 6: 119-121.

Bull, E.L.; Hayes, M.P. 2002. Overwintering of Columbia spotted frogs in northeastern Oregon. Northwest Science. 76: 141-147.

Bull, E.L.; Heater, T.W. 1995. Intraspecific predation on American marten. Northwestern Naturalist. 76: 132-134.

Bull, E.L.; Heater, T.W. 2000. Resting and denning sites of American martens in northeastern Oregon. Northwest Science. 74(3): 179-185.

Bull, E.L.; Heater, T.W. 2001. Home range and dispersal of the American marten in northeastern Oregon. Northwestern Naturalist. 82: 7-11.

Bull, E.L.; Henjum, M.G. 1990. Ecology of the great gray owl. Gen. Tech. Rep. PNW-GTR-265. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 39 p.

Bull, E.L.; Hohmann, J.E.; Henjum, M.G. 1987. Northern pygmy-owl nests in northeastern Oregon. Journal of Raptor Research. 21(2): 77-78.

Bull, E.L.; Holthausen, R.S. 1993. Habitat use and management of pileated woodpeckers in northeastern Oregon. Journal of Wildlife Management. 57: 335-345.

Bull, E.L.; Holthausen, R.S.; Beckwith, R.C. 1992a. Arthropod diet of pileated woodpeckers in northeastern Oregon. Northwestern Naturalist. 73: 42-45.

Bull, E.L.; Holthausen, R.S.; Henjum, M.G. 1992b. Roost trees used by pileated woodpeckers in northeastern Oregon. Journal of Wildlife Management. 56: 786-793.

Bull, E.L.; Meslow, E.C. 1988. Breeding biology of the pileated woodpecker—management implications. Res. Note PNW-RN-474. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 8 p.

Bull, E.L.; Parks, C.G.; Torgersen, T.R. 1997. Trees and logs important to wildlife in the interior Columbia basin. Gen. Tech. Rep. PNW-GTR-391. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p.

Bull, E.L.; Shepherd, J.F. 2003. Water temperature at oviposition sites of *Rana lueteiventris* in northeastern Oregon. Western North American Naturalist. 63(1): 108-113.

Bull, E.L.; Skovlin, J.M. 1982. Relationships between avifauna and streamside vegetation. Transactions of the 47th North American Wildlife and Natural Resources Conference: 496-506.

Bull, E.L.; Torgersen, T.R.; Blumton, A.K. [et al.]. 1995. Treatment of an old-growth stand and its effects on birds, ants, and large woody debris: a case study. Gen. Tech. Rep. PNW-GTR-353. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Bull, E.L.; Torgersen, T.R.; Wertz, T.L. 2001b. The importance of vegetation, insects, and neonate ungulates in black bear diet in northeast Oregon. Northwest Science. 75: 244-253.

Bull, E.L.; Wales, B.C. 2001a. Effects of disturbance on amphibians of conservation concern in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 174-179.

Bull, E.L.; Wales, B.C. 2001b. Effects of disturbance on birds of conservation concern in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 166-173.

Bull, E.L.; Wright, A.L.; Henjum, M.G. 1989. Nesting and diet of long-eared owls in conifer forests, Oregon. Condor. 91(4): 908-912.

Bull, E.L.; Wright, A.L.; Henjum, M.G. 1990. Nesting habitat of flammulated owls in Oregon. Journal of Raptor Research. 24: 52-55.

Carlson, J.Y. 1989. Effects of forest management on fish habitat and macroinvertebrates in northeast Oregon. Corvallis, OR: Oregon State University. 127 p. M.S. thesis.

Carmichael, R.W. 1993. Preliminary results of habitat patient-template analysis for Grande Ronde basin stocks of spring chinook. Tech. Memorandum. La Grande, OR: Oregon Department of Fish and Wildlife, Fish Research and Development. [Pages unknown].

Carmichael, R.W.; Boyce, R.R. 1986. U.S. v. Oregon, Grande Ronde River spring chinook production report**.** In: U.S. v. Oregon Subbasin Production Reports. Portland, OR: Oregon Department of Fish and Wildlife. [Irregular pagination].

Case, R.L. 1995. The ecology of riparian ecosystems of northeast Oregon: a shrub recovery at Meadow Creek and the structure and biomass of headwater Upper Grande Ronde ecosystems. Corvallis, OR: Oregon State University. 137 p. M.S. thesis.

Chen, Y.D. 1996. Hydrologic and water quality modeling for aquatic ecosystem protection and restoration in forest watersheds: a case study of stream temperature in the Upper Grande Ronde River, Oregon. Athens, GA: University of Georgia. 268 p. Ph.D. dissertation.

Chen, Y.D.; Carsel, R.F.; McCutcheon, S.C. [et al.]. 1998a. Stream temperature simulation of forested riparian areas: I. Watershed-scale model development. Journal of Environmental Engineering. 124(4): 304-315.

Chen, Y.D.; McCutcheon, S.C.; Norton, D.J. [et al.]. 1998b. Stream temperature simulation of forested riparian areas: II. Model application. Journal of Environmental Engineering. 124(4): 316-328.

Clark, P.E. 1996. Use of livestock to improve the quality of elk winter range forage in northeastern Oregon. Corvallis, OR: Oregon State University. 179 p. Ph.D. dissertation.

Clarke, S.E.; Bryce, S.A., eds. 1997. Hierarchical subdivisions of the Columbia Plateau and Blue Mountains ecoregions, Oregon, and Washington. Gen. Tech. Rep. PNW-GTR-395. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 114 p.

Clarke, S.E.; Garner, M.W.; McIntosh, B.A. [et al.]. 1997. Landscape-level ecoregions for seven contiguous watersheds, northeast Oregon and southeast Washington. In: Clarke, S.E.; Bryce, S.A., eds. Hierarchical subdivisions of the Columbia Plateau and Blue Mountains ecoregions, Oregon and Washington. Gen. Tech. Rep. PNW-GTR-395. Portland, OR: [U.S. Department of Agriculture], Forest Service, Pacific Northwest Research Station: 53-113.

Clausnitzer, R.R. 1979. Annual understory production as a function of overstory structure and successional status in the *Abies grandis*/*Pachistima myrsinites* habitat type in the Blue Mountains of southeastern Washington and northeastern Oregon. Pullman, WA: Washington State University. 58 p. M.S. thesis.

Clausnitzer, R.R. 1993. The grand fir series of northeastern Oregon and southeastern Washington [microform]: successional stages and management guide. R6-ECO-TP 050-93. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 193 p.

Clifton, C.F.; **Harris, R.M.**; **Fitzgerald, J.K. 1999**. Flood effects and watershed response in the northern Blue Mountains, Oregon and Washington. In: Olsen, D.S.; Potyondy, J.P., eds. Wildland hydrology proceedings. Herdon, VA: American Water Resources Association: 175-182.

Cochran, P.H.; Barrett, J.W. 1993. Long-term response of planted ponderosa pine to thinning in Oregon's Blue Mountains. Western Journal of Applied Forestry. 8(4): 126-132.

Cochran, P.H.; Barrett, J.W. 1995. Growth and mortality of ponderosa pine poles thinned to various densities in the Blue Mountains of Oregon. Res. Pap. PNW-RP-483. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 27 p.

Cochran, P.H.; Dahms, W.G. [1998]. Lodgepole pine development after early spacing in the Blue Mountains of Oregon. Res. Pap. PNW-RP-503. [Portland, OR]: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Cochran, P.H.; Seidel, K.W. 1995. Growth of western larch under controlled levels of stocking. In: Schmidt, W.C.; McDonald, K.J., comps. Ecology and management of *Larix* forests: a look ahead. Proceedings of an international symposium. Gen. Tech. Rep. INT-319. [Ogden, UT]: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 285-292.

Cook, J.G.; Irwin, L.L.; Bryant, L.D. [et al.]. 1999. Relations of forest cover and condition of elk: a test of the thermal cover hypothesis in summer and winter. Wildlife Monographs 141: 1-61.

Cook, J.G.; Riggs, R.A.; Tiedemann, A.R.; Irwin, L.L.; Bryant, L.D. 1996. Ungulate relationships on rangelands. In: Edge, W.D.; Olsen-Edge, S.L., eds. Proceedings of a symposium on sustaining rangeland ecosystems. [Corvallis, OR]: Oregon State University Extension Service: 155-159.

Cordova, J.J. 1995. Streamside forests, channel constraint, large woody debris characteristics, and pool morphology in low order streams, Blue Mountains, Oregon. Corvallis, OR: Oregon State University. 143 p. M.S. thesis.

Corrarino, C.A.; Brusven, M.A. 1983. The effects of reduced stream discharge on insect drift and stranding of insects. Freshwater Invertebrate Biology. 2(2): 88-98.

Coulter, E.D. 1999. Hungry Bob harvest production study: mechanical thinning for fuel reduction in the Blue Mountains of northeast Oregon. Corvallis, OR: Oregon State University. 96 p. M.S. thesis.

Crowe, E.A.; Clausnitzer, R.R. 1997. Mid-montane wetland plant associations of the Malheur, Umatilla, and Wallowa-Whitman National Forests. Tech. Pap. R6-NR-ECOL-TP-22-97. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 299 p.

Davis, L.S.; Ruth, L.W.; Teeguarden, D. [et al.]. 1991. Ballot box forestry. Journal of Forestry. 89(12): 10-18.

Delucchi, P.B. 1976. Effects of Douglas-fir tussock moth infestation on outdoor recreationists in the Blue Mountains, Oregon. Corvallis, OR: Oregon State University. 124 p. M.S. thesis.

Diaz-Avalos, C. 1998. Space-time analysis of forest fires. Seattle, WA: University of Washington. 120 p. Ph.D. dissertation.

Diaz-Avalos, C.; Peterson, D.L.; Alvarado, E. [et al.]. 2001. Space-time modelling of lightning-caused ignitions in the Blue Mountains, Oregon. Canadian Journal of Forest Research. 31(9): 1579-1593.

Diebel, K. 1997. Grande Ronde Basin Water Quality Monitoring: plans for six key subwatersheds. [La Grande, OR]. Unpublished document. On file with: Grande Ronde Model Watershed, 10901 Island Ave, La Grande, OR. Prepared for Union Soil and Water Conservation District, Wallowa Soil and Water Conservation District, and Grande Ronde Model Watershed Program. [Irregular pagination].

Downing, K.B.; Delucchi, P.B.; Williams, W.R. 1977. Impact of the Douglas-fir tussock moth on forest recreation in the Blue Mountains. Res. Pap. PNW-RP-224. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Duncan, A. 1998. History, science, the law, and watershed recovery in the Grande Ronde: a case study. ORESU-G-97-001. Corvallis, OR: Oregon Sea Grant. 82 p.

Dwire, K.A. 2001. Relations among hydrology, soils, and vegetation in riparian meadows: influence on organic matter distribution and storage. Corvallis, OR: Oregon State University. 168 p. Ph.D. dissertation.

Ebersole, J.L. 1994. Stream habitat classification and restoration in the Blue Mountains of northeast Oregon. Corvallis, OR: Oregon State University. 59 p. M.S. thesis.

Ebersole, J.L.; Liss, W.J.; Frissell, C.A. 2002. Heterogeneous thermal habitat for a stream fish assemblage. Ecological Society of America Annual Meeting Abstracts. 87: 120.

Ebert, K.M. 1987. The effects of wilderness recreation on avian species richness and distribution in the Eagle Cap Wilderness Area. Pullman, WA: Washington State University. 52 p. M.S. thesis.

Edgerton, P.J.; Smith, J.G. 1971. Seasonal forage use by deer and elk on the Starkey Experimental Forest and Range, Oregon. Res. Pap. PNW-112. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Evans, J.W. 1991. Powerful rockey: the Blue Mountains and the Oregon Trail, 1811-1883. La Grande, OR: Eastern Oregon State College and Pika Press. 374 p.

Everett, R.L., comp. 1994. Volume IV: restoration of stressed sites and processes. Gen. Tech. Rep. PNW-GTR-330. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; volume IV).

Everett, R.; Hessburg, P.; Jensen, M.; Bormann, B. 1994. Volume I: executive summary. Gen. Tech. Rep. PNW-GTR-317. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 61 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment).

Ferguson, B.A. 1994. Fungal root pathogen interactions in a mixed conifer forest in the Blue Mountains of northeastern Oregon. Corvallis, OR: Oregon State University. 128 p. M.S. thesis.

Ferguson, S. 2001. Climatic variability in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 62-69.

Filip, G.M.; Bryant, L.D.; Parks, C.A. 1989a. Mass movement of river ice causes severe tree wounds along the Grande Ronde River in northeastern Oregon. Northwest Science. 63(5): 211-213.

Filip, G.M.; Christiansen, E.; Parks, C.A. 1989b. Secondary resin production increases with vigor of *Abies grandis* inoculated with *Trichosporium symbioticum* in northeastern Oregon. Res. Note PNW-RN-489. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Filip, G.M.; Colbert, J.J.; Parks, C.A. [et al.]. 1989c. Effects of thinning on volume growth of western larch infected with dwarf mistletoe in northeastern Oregon. Western Journal of Applied Forestry. 4(4): 143-144.

Filip, G.M.; Parks, C.A. 1987. Simultaneous infestation by dwarf mistletoe and western spruce budworm decreases growth of Douglas-fir in the Blue Mountains of Oregon. Forest Science. 33(3): 767-773.

Filip, G.M.; Parks, C.A. 1991. First report of stem cankers caused by *Cytospora* species on *Alnus incana* in Oregon. Plant Disease. 75(12): 1286.

Filip, G.M.; Parks, C.A.; Seidel, K.W. [et al.]. 1987. Incidence of decay fungi in stumps of two thinned western larch stands in northeastern Oregon. Res. Note PNW-RN-468. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 5 p.

Filip, G.M.; Parks, C.A.; Starr, G.L. 1992. Incidence of wound-associated infection by *Cytospora* sp. in mountain alder, red-osier dogwood, and black hawthorn in Oregon. Northwest Science. 66(3): 194-198.

Filip, G.M.; Torgersen, T.R.; Parks, C.A. [et al.]. 1996. Insect and disease factors in the Blue Mountains. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests: 169-202.

Filip, G.M.; Yang-Erve, L. 1997. Effects of prescribed burning on the viability of *Armillaria ostoyae* in mixed-conifer forest soils in the Blue Mountains of Oregon. Northwest Science. 71(2): 137-144.

Fowler, W.B.; Helvey, J.D.; Johnson, C. 1979. Baseline climatic and hydrologic relationships for the High Ridge evaluation area in the Blue Mountains of Oregon. Gen. Tech. Rep. PNW-GTR-91. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Franklin, J.F.; Dyrness, C.T. 1973. Natural vegetation in Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

Ganskopp, D.C. 1978. Plant communities and habitat types of the Meadow Creek experimental watershed. Corvallis, OR: Oregon State University. 162 p. M.S. thesis.

Gast, W.R., Jr.; Scott, D.W.; Schmitt, D. [et al.]. 1991. Blue Mountains forest health report: new perspectives in forest health. [Portland, OR]: U.S. Department of Agriculture, Forest Service, Malheur, Umatilla, and Wallowa-Whitman National Forests. [Irregular pagination].

Gebauer, C.E. 1998 . Forest grazing and site quality: influences of cattle, big game and tree species on soil nutrients, soil compaction and vegetation of a seral forest in northeastern Oregon. Pullman, WA: Washington State University. 109 p. M.S. thesis.

Geist, J.M. 1977. Nitrogen response relationships of some volcanic ash soils. Soil Science Society of America. 41(5): 996-1000.

Geist, J.M.; Hazard, J.W.; Seidel, K.W. 1989. Assessing physical conditions of some Pacific Northwest volcanic ash soils after forest harvest. Soil Science Society of America. 53(3): 946-950.

Geist, J.M.; Strickler, G.S. 1978. Physical and chemical properties of some Blue Mountain soils in eastern Oregon. Res. Pap. PNW-236. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 19 p.

Gildemeister, J. 1998. Watershed history: Middle and Upper Grande Ronde River subbasins. La Grande, OR: [Publisher unknown]. [Irregular pagination].

Gill, R.E. 1994. Sediment delivery to headwater stream channels following road construction and timber harvest in the Blue Mountains, Oregon. Corvallis, OR: Oregon State University. 59 p. M.S. thesis.

Gillen, R.L.; Krueger, W.C.; Miller, R.F. 1985. Cattle use of riparian meadows in the Blue Mountains of northeastern Oregon. Journal of Range Management. 38(3): 205-209.

Goggans, R. 1985. Habitat use by flammulated owls in northeastern Oregon. Corvallis, OR: Oregon State University. 54 p. M.S. thesis.

Grimble, D.G.; Beckwith, R.C. 1992-1994. A survey of the Lepidoptera fauna from the Blue Mountains of eastern Oregon. Journal of Research on the Lepidoptera. 31(1-2): 83-102.

Grimble, D.G.; Beckwith, R.C.; Hammond, P.C. 1993. New Lepidoptera records for the Blue Mountains of eastern Oregon. Res. Pap. PNW-RP-469. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 6 p.

Hall, F.C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. R-6 Area Guide. [Portland, OR]: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 62 p.

Hall, F.C. 1974. Key to environmental indicator plants of the Blue Mountains in eastern Oregon and southeastern Washington. R6 Area Guide 3-2. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 51 p.

Hall, F.C. 1976. Fire and vegetation in the Blue Mountains—implications for land managers. In: Komareck, E.V., ed. Tall Timbers Research Station. Proceedings of the 15th annual Tall Timbers fire ecology conference. Tallahassee, FL: Tall Timbers Research Station: 155-170.

Hall, F.C. 1977. Ecology of natural underburning in the Blue Mountains of Oregon. R6-Ecol. 79-001. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 11 p.

Hall, F.C. 1980. Fire history—Blue Mountains, Oregon. In: Stokes, M.A.; Dietrich, J.H., eds. Proceedings of fire history workshop. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 75-81.

Hall, T.; Bigler-Cole, H. 2001. Sociocultural factors and forest health management. Northwest Science. 75(Spec. issue): 208-233.

Harrod, R.J. 2001. The effect of invasive and noxious plants on land management in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 85-90.

Harvey, A.E.; Geist, J.M.; McDonald, G.I. [et al.]. 1994. Biota and abiotic processes in eastside ecosystems: the effects of management on soil properties, processes, and productivity. Gen. Tech. Rep. PNW-GTR-323. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Hayes, J.L.; Daterman, G.E. 2001. Bark beetles in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 21-30.

Hayes, J.L.; Ragenovich, I. 2001. Non-native invasive forest insects of eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 77-84.

Haynes, R.; Fight, R.; Lowell, E. [et al.]. 2001. Economic aspects of thinning and harvest for forest health improvement in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 199-207.

Helvey, J.D.; Tiedemann, A.R. 1978. Effects of defoliation by Douglas-fir tussock moth on timing and quantity of streamflow. Res. Note PNW-326. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Hemstrom, M. 2001. Vegetative patterns, disturbances, and forest health in eastern Oregon. Northwest Science. 75(Spec. issue): 91-109.

Hemstrom, M.; Smith, T.; Evans, T. [et al.]. 2002. Midscale analysis of streamside characteristics in the Upper Grande Ronde subbasin, northeastern Oregon. Res. Note PNW-RN-534. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 16 p.

Hermens, R.A.; Turner, J.E. 1985. La Grande, 1885-1985. La Grande, OR: Grande Ronde Publishing Co. 156 p.

Hessburg, P.F.; Mitchell, G.R.; Filip, G.M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW-GTR-327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Heyerdahl, E.K. 1997. Spatial and temporal variation in historical fire regimes of the Blue Mountains, Oregon and Washington: the influence of climate. Seattle, WA: University of Washington. 224 p. Ph.D. dissertation.

Heyerdahl, E.K.; Agee, J.K.; Brubaker, L.B. 1996. Historical size and seasonality of low severity fires in the Blue Mountains, Oregon, from tree rings. Bulletin of the Ecological Society of America. 77(3 Suppl. Part 2): 195.

Heyerdahl, E.K.; Brubaker, L.B.; Agee, J.K. 2001. Spatial controls of historical fire regimes: a multiscale example from the interior West, USA. Ecology. 82(3): 660-678.

Higgins, D.A.; Maloney, S.B.; Tiedemann, A.R. [et al.]. 1988. Calibration of water-balance model for small watersheds in eastern Oregon. Water Resources Bulletin. 24(2): 347-360 .

Higgins, D.A.; Tiedemann, A.R.; Quigley, T.M. [et al.]. 1989. Streamflow characteristics of small watersheds in the Blue Mountains of Oregon. Water Resources Bulletin. 25(6): 1131-1149.

Hines, C.; Bradshaw, G.A. 1997. Landscape analysis of black cottonwood community dynamics, Grande Ronde River, Oregon, USA: assessing restoration potential and long-term viability. Bulletin of the Ecological Society of America. 78(4 Suppl): 109.

Hines, C.A. 1998. Evaluating the restoration potential of potential black cottonwood (*Populus trichocarpa*) from multiple scales of observation, Grande Ronde River basin, Oregon, USA. Corvallis, OR: Oregon State University. 149 p. M.S. thesis.

Hitchcock, M.; Ager, A. 1992. Microcomputer software for calculating an elk habitat effectiveness index on Blue Mountain winter range. Gen. Tech. Rep. PNW-GTR-301. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 p.

Holechek, J.; Vavra, M.; Skovlin, J. [et al.]. 1982a. Cattle diets in the Blue Mountains of Oregon, USA 1. Forests. Journal of Range Management. 35(2): 239-242.

Holechek, J.; Vavra, M.; Skovlin, J. [et al.]. 1982b. Cattle diets in the Blue Mountains of Oregon, USA 2. Grasslands. Journal of Range Management. 35(1): 109-112.

Holechek, J.L.; Berry, T.J.; Vavra, M. 1987. Grazing system influences on cattle performance on mountain range. Journal of Range Management. 40(1): 55-59.

Holechek, J.L.; Vavra, M. 1983. Fistula sample numbers required to determine cattle diets on forest and grassland ranges. Journal of Range Management. 36(3): 323-326.

Holechek, J.L.; Vavra, M.; Skovlin, J. 1980. Performance, diet and intake of yearling heifers under rest-rotation and season-long grazing systems. In: Society for Range Management 33rd annual meeting. [Place of publication unknown]: Society for Range Management: [Pages unknown].

Holechek, J.L.; Vavra, M.; Skovlin, J. 1981. Diet quality and performance of cattle on forest and grassland range. Journal of Animal Science. 53(2): 291-298.

Holechek, J.L.; Vavra, M.; Skovlin, J. 1983. Cattle diets and daily gains on a mountain riparian meadow in northeastern Oregon, USA. Journal of Range Management. 35(6): 745-757.

Howell, P.J. 2001. Effects of disturbance and management of forest health on fish and fish habitat in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 157-165.

Huff, M.H.; Ottmar, R.D.; Alvarado, E. [et al.]. 1995. Historical and current landscapes in eastern Oregon and Washington. Part II: Linking vegetation characteristics to potential fire behavior and related smoke production. Gen. Tech. Rep. PNW-GTR-355. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 43 p.

Huntington, C.W. 1994. Stream and riparian conditions in the Grande Ronde basin 1993. Canby, OR: Clearwater Biostudies, Inc. [Pages unknown]. Unpublished document. On file with: Grande Ronde Model Watershed, 10901 Island Ave., La Grande, OR 97850.

Ince, P.J. 1982. Economic perspective on harvesting and physical constraints on utilizing small, dead lodgepole pine. Forest Products Journal. 32(11/12): 61-66.

Irwin, L.L.; Cook, J.G.; Riggs, R.A.; Skovlin, J.M. 1994. Effects of long-term grazing by big game and livestock in the Blue Mountains forest ecosystems. Gen. Tech. Rep. PNW-GTR-325. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 49 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Jaindl, R.G.; Quigley, T.M., eds. 1996. Search for a solution: sustaining land, people, and the economy of the Blue Mountains. Washington, DC: American Forests. 316 p.

James, G. 1984. Grande Ronde River basin—recommended salmon and steelhead habitat improvement measures. Working Rep. [Place of publication unknown]: Confederated Tribes of the Umatilla Indian Reservation. 58 p. [plus appendices].

Jensen, M.E.; Bourgeron, P.S., tech. eds. 1994. Volume II: Ecosystem management: principles and applications. Gen. Tech. Rep. PNW-GTR-318. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 376 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment).

Johnson, C.G., Jr. 1981. An interpretation of synecologic relationships in the Billy Meadows Area of the Wallowa-Whitman National Forest. Corvallis, OR: Oregon State University. 342 p. Ph.D. dissertation.

Johnson, C.G., **Jr. 1994.** Forest health in the Blue Mountains: a plant ecologist's perspective on ecosystem processes and biological diversity. Gen. Tech. Rep. PNW-GTR-339. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p.

Johnson, C.G., Jr. [1998]. Vegetation response after wildfires in national forests of northeastern Oregon. Tech. Pap. R6-NR-ECOL-TP-06-98. [Portland, OR]: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 157 p.

Johnson, C.G. Jr.; Clausnitzer, R.R. 1992. Plant associations of the Blue and Ochoco Mountains. Tech. Pap. R6-ERW-TP-036-92. [Portland, OR]: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 164 p.

Johnson, C.G. Jr.; Clausnitzer, R.R.; Mehringer, P.J.; Oliver, C.D. 1994. Biota and abiotic processes of eastside ecosystems: the effects of management on plant and community ecology, and on stand and landscape vegetation dynamics. Gen. Tech. Rep. PNW-GTR-322. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 66 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Johnson, L.C. [1997]. A brief history of Union County, Oregon. La Grande, OR: Grande Ronde Publishing Company. 76 p.

Keefe, M.; Anderson, D.J.; Carmichael, R.W. [et al.]. 1995. Early life history study of Grande Ronde River basin chinook salmon: annual progress report. Portland, OR: U.S. Department of Energy, Bonneville Power Administration. [Pages unknown].

Keefe, M.L.; Carmichael, R.W.; Jonasson, B.C. [et al.]. 1994. Fish research project Oregon: investigations into the life history of spring chinook salmon in the Grande Ronde River basin. La Grande, OR: Oregon Department of Fish and Wildlife. Annual report prepared for U.S. Department of Energy, Bonneville Power Administration, Environment, Fish and Wildlife; project number 92-026-01; contract 94BI33299. [Pages unknown]. On file with: Grande Ronde Model Watershed, 10901 Island Avenue, La Grande, OR 97850.

Keith, T. 1991. Restoring forest health in the Blue Mountains: a strategy and action plan for state and private lands. Salem, OR: Oregon Department of Forestry, Public Affairs Office. 7 p.

Kemp, W.P.; Dennis, B.; Beckwith, R.C. 1986. Stochastic phenology model for the western spruce budworm (Lepidoptera, Tortiricidae). Environmental Entomology. 15(3): 547-554.

Klock, G.O.; Lopushinsky, W. 1980. Soil water trends after clearcutting in the Blue Mountains of Oregon. Res. Note PNW-RN-361. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Knight, R.W. 1977. Streamside erosional response to animal grazing practices on Meadow Creek in northeastern Oregon. Corvallis, OR: Oregon State University. 68 p. M.S. thesis.

Korfhage, R.C.; Nelson, J.R.; Skovlin, J.M. 1980. Summer diets of Rocky Mountain elk in northeastern Oregon. Journal of Wildlife Management. 44(3): 746-750.

Kreger, A.E.; Roschke, D.J. 1991. Wallowa-Whitman National Forest soils database. Soil Survey Horizons. 32(4): 91-96.

LaBonte, J.R.; Scott, D.W.; McIver, J.D. [et al.]. 2001. Threatened, endangered, and sensitive insects in eastern Oregon and Washington forests and adjacent lands. Northwest Science. 75(Spec. issue): 185-198.

Langston, N. 1994. The general riot of the forest: landscape in the Blue Mountains. Seattle, WA: University of Washington. 324 p. Ph.D. dissertation.

Langston, N. 1995. Forest dreams, forest nightmares: the paradox of old growth in the inland West. Seattle, WA: University of Washington Press. 368 p.

Langston, N. 2000. When sound science is not enough: regulating the Blues. Journal of Forestry. 98(11): 31-35.

Leckenby, D.A. 1984. Elk use and availability of cover and forage habitat components in the Blue Mountains, northeast Oregon, 1976-1982. Wildlife Res. Rep. 14. Portland, OR: Oregon Department of Fish and Wildlife, Research and Development. 40 p.

Lehmkuhl, J.F.; Hessburg, P.F.; Everett, R.L. [et al.]. 1994. Historical and current forest landscapes of eastern Oregon and Washington. Part I: Vegetation pattern and insect and disease hazards. Gen. Tech. Rep. PNW-GTR-328. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 88 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Lennette, A.P. 1999. Twenty-five year response of *Larix occidentalis* stem forms to five stand density regimes in the Blue Mountains of eastern Oregon. Corvallis, OR: Oregon State University. 59 p. M.S. thesis.

Lundquist, J.E.; Beatty, J.S. 1999. A conceptual model for defining and assessing condition of forest stands. Environmental Management. 23(4): 519-525.

Lundquist, J.E.; Beatty, J.S. 2002. A method for characterizing and mimicking forest canopy gaps caused by different disturbances. Forest Science. 48(3): 582-594.

Lundquist, J.E.; King, R.M.; Beatty, J.S. 1996. Assessing the relative influence of disease in forest ecosystems in the Blue Mountains. Phytopathology. 86(11 Supplement): S38.

Lytjen, D.J. 1998. Ecology of woody riparian vegetation in tributaries of the Upper Grande Ronde River basin, Oregon. Corvallis, OR: Oregon State University. 76 p. M.S. thesis.

Maloney, S.B.; Tiedemann, A.R.; Higgins, D.A. [et al.]. 1999. Influence of stream characteristics and grazing intensity on stream temperatures in eastern Oregon. Gen. Tech. Rep. PNW-GTR-459. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 19 p.

Mannan, R.W. 1982. Bird populations and vegetation characteristics in managed and old-growth forests, northeastern Oregon. Corvallis, OR: Oregon State University. 67 p. Ph.D dissertation.

Marcot, B.G.; Wisdom, M.J.; Li, H.W.; Castillo, G.C. 1994. Managing for featured, threatened, endangered, and sensitive species and unique habitats for ecosystem sustainability. Gen. Tech. Rep. PNW-GTR-329. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 39 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Maruka, K.R. 1994. Fire history of *Pseudotsuga menziesii* and *Abies grandis* stands in the Blue Mountains of Oregon and Washington. Seattle, WA: University of Washington. 73 p. M.S. thesis.

Mason, R.R. 1996. Dynamic behavior of Douglas-fir tussock moth populations in the Pacific Northwest. Forest Science. 42(2): 182-191.

Mason, R.R.; Paul, H.G. 1988. Predation on larvae of Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae), by *Metaphidippus aeneolus* (Araneae: Salticidae). Pan-Pacific Entomologist. 64(3): 258-260.

Mason, R.R.; Paul, H.G. 1996. Case history of population change in a *Bacillus thuringiensis*-treated vs. an untreated outbreak of the western spruce budworm. Res. Note PNW-RN-521. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Mason, R.R.; Wickman, B.E. [1988]. The Douglas-fir tussock moth in the interior Pacific Northwest. In: Berryman, A.A., ed. Dynamics of forest insect populations: patterns, causes, implications. New York: Plenum Press: 179-209.

McCluskey, D.C. 1976. DDT and reproductive success of bluebirds and house wrens in northeastern Oregon. Corvallis, OR: Oregon State University. 44 p. M.S. thesis.

McHugh, P. 2003. A model-based approach to assessing the potential response of chinook salmon to habitat improvements. Logan, UT: Utah State University. 183 p. M.S. thesis.

McInnis, M.L.; Quigley, T.M.; Vavra, M. [et al.]. 1990. Predicting beef cattle stocking rates and live weight gains on eastern Oregon rangelands: description of a model. Simulation: 137-145.

McIntosh, B.A. 1992. Historical changes in anadromous fish habitats in the Upper Grande Ronde River, Oregon. Corvallis, OR: Oregon State University. 88 p. M.S. thesis.

McIntosh, B.A. 1995. Historical changes in stream habitats in the Columbia River basin. Corvallis, OR: Oregon State University. 175 p. Ph.D. dissertation.

McIntosh, B.A.; Price, D.M.; Torgersen, C.E. [et al.]. 1995. Distribution, habitat utilization, movement patterns, and the use of thermal refugia by spring chinook in the Grande Ronde, Imnaha, and John Day basins. Progress Rep. Project 93-700. Portland, OR: U.S. Department of Energy, Bonneville Power Administration. 16 p.

McIntosh, B.A.; Sedell, J.R.; Smith, J.E. [et al.]. 1994a. Historical changes in fish habitat for select river basins of eastern Oregon and Washington. Northwest Science. 68(Spec. issue): 36-53.

McIntosh, B.A.; Sedell, J.R.; Smith, J.E. [et al.]. 1994b. Management history of eastside ecosystems: changes in fish habitat over 50 years, 1935 to 1992. Gen. Tech. Rep. PNW-GTR-321. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

McIver, J.D.; Starr, L. 2000. Environmental effects of postfire logging: literature review and annotated bibliography. Gen. Tech. Rep. PNW-GTR-486. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p.

McIver, J.D.; Starr, L. 2001. A literature review on the environmental effects of postfire logging. Western Journal of Applied Forestry. 16(4): 159-168.

McIver, J.D.; Torgersen, T.R.; Cimon, N.J. 1997. A supercolony of the thatch ant *Formica obscuripes* Forel (Hymenoptera: Formicidae) from the Blue Mountains of Oregon. Northwest Science. 71(7): 18-29.

McLemore, C.E.; Meehan, W.R. 1988. Invertebrates of Meadow Creek, Union County, Oregon, and their use as food by trout. Res. Pap. PNW-RP-394. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 p.

Meays, C.L. 2000. Elevation, thermal environment, and stream temperatures on headwater streams in northeastern Oregon. Corvallis, OR: Oregon State University. 140 p. M.S. thesis.

Mobrand, L.; Lestell, L.; Gilbertson, L. [et al.]. 1995. Grande Ronde model watershed ecosystem diagnosis and treatment: template for planning status report for Grande Ronde Model Watershed project and progress report on the application of an ecosystem analysis method to the Grande Ronde watershed using spring chinook salmon as a diagnostic species. Portland, OR: U.S. Department of Energy, Bonneville Power Administration; final report; project 94-030. [Pages unknown]. On file with: Grande Ronde Model Watershed, 10901 Island Avenue, La Grande, OR 97850.

Moffat, R.; Wellman R.; Gordon, J. 1990. Statistical summaries of streamflow data in Oregon: monthly and annual streamflow, and flow-duration curves; open-file report 90-118. Portland, OR: U.S. Department of the Interior, Geological Survey. [Pages unknown]. Vol. 1.

Mohr, F.; Both, B. 1996. Confinement—a suppression response for the future? Fire Management Notes. 56(2): 17-22.

Moore, K.R.; Henny, C.J. 1984. Age-specific productivity and nest characteristics of Coopers hawks. Northwest Science. 58(4): 290-299.

Moser, B.W.; Witmer, G.W. 2000. The effects of elk and cattle foraging on the vegetation, birds, and small mammals of the Bridge Creek Wildlife Area, Oregon. International Biodeterioration and Biodegradation. 45(3-4): 151-157.

Murphy, C.F.; Croft, B.A. 1990. Forest ant composition and foraging following aerial spraying of carbaryl to suppress western spruce budworm. Canadian Entomologist. 122(7-8): 595-606.

Mutch, R.W.; Arno, S.F.; Brown, J.K. [et al.]. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. Gen. Tech. Rep. PNW-GTR-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p.

Neitzel, D.A.; Frest, T.J. 1992. Survey of Columbia River basin streams for Columbia pebblesnail (*Fluminicola columbiana*) and shortface lanx (*Fisherola nuttalli*). Tech. Rep. PNL-8229. Richland, WA: Battelle Pacific Northwest Labs. 83 p.

Noll, W.; Williams, S.; Boyce, R. 1987. Grande Ronde River basin fish habitat improvement implementation plan. Portland, OR: Oregon Department of Fish and Wildlife. [Pages unknown].

Northwest Power Planning Council. 1990. Grande Ronde River subbasin salmon and steelhead production plan. Columbia basin system planning. Portland, OR: Northwest Power Planning Council, and the agencies and Indian tribes of the Columbia Basin Fish and Wildlife Authority. [Pages unknown].

Nowak, M.C. 1999. Predation rates and foraging ecology of adult female mountain lions in northeastern Oregon. Pullman, WA: Washington State University. 75 p. M.S. thesis.

Noyes, J.H.; Johnson, B.K.; Bryant, L.D. [et al.]. 1996. Effects of bull age on conception dates and pregnancy rates of cow elk. The Journal of Wildlife Management. 60(3): 508-517 .

Oester, P.T.; Emmingham, W.; Larson, P. [et al.]. 1995. Performance of ponderosa pine seedlings under four herbicide regimes in northeast Oregon. New Forests. 10(2): 123-131.

Oliver, C.D.; Irwin, L.L.; Knapp, W.H. 1994. Eastside forest management practices: historical overview, extent of their applications, and their effects on sustainability of ecosystems. Gen. Tech. Rep. PNW-GTR-324. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Olson, D.L. 2000. Fire in riparian zones: a comparison of historical fire occurrence in riparian and upslope forests in the Blue Mountains and southern Cascades of Oregon. Seattle, WA: University of Washington. 274 p. M.S. thesis.

Oregon Department of Fish and Wildlife. [1988]. Summer steelhead creel surveys in the Grande Ronde, Wallowa, and Imnaha Rivers for the 1987-88 run year; progress report. Portland, OR: Oregon Department of Fish and Wildlife, Fish Division. [Pages unknown].

Oregon Department of Fish and Wildlife. [1990]. Grande Ronde River subbasin: salmon and steelhead production plan. [Portland, OR]. 163 p.

Oregon Department of Fish and Wildlife. [1993-1996]. Residual hatchery steelhead: characteristics and potential interactions with spring chinook salmon in northeast Oregon; progress report. Portland, OR: [Pages unknown].

Oregon Department of Fish and Wildlife. [1994]. Smolt migration characteristics and mainstem Snake and Columbia River detection rates of Grande Ronde and Imnaha River naturally produced spring chinook salmon; progress report. Portland, OR: [Pages unknown].

Oregon Department of Fish and Wildlife. [1999]. Summer steelhead creel surveys in the Grande Ronde, Wallowa, and Imnaha Rivers for the 1998-99 run year; progress report. Portland, OR: Oregon Department of Fish and Wildlife, Fish Division. [Pages unknown].

Oregon Department of Transportation. 1984. Grande Ronde and Wallowa River scenic waterway study, Union and Wallowa Counties. [Place of publication unknown]: State Parks and Recreation Division, Scenic Waterways Program. [Pages unknown].

Otting, N.J. 1998. Ecological characteristics of montane floodplain plant communities in the Upper Grande Ronde basin, Oregon. Corvallis, OR: Oregon State University. 71 p. M.S. thesis.

Ottmar, R.D.; Sandberg, D.V. 2001. Wildland fire in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 46-54.

Parker, S.J.; Keefe, M.; Carmichael, R.W. [1995]. Natural escapement monitoring of spring chinook salmon in the Imnaha and Grande Ronde River basins; progress report. Portland, OR: Oregon Department of Fish and Wildlife. 15 p.

Parks, C.A.; Hoffman, J.T. 1991. Control of western dwarf mistletoe with the plant-growth regulator ethephon. Res. Note PNW-RN-506. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 p.

Parks, C.G.; Bednar, L.; Tiedemann, A.R. 1998. Browsing ungulates—an important consideration in dieback and mortality of Pacific yew (*Taxus brevifolia*) in a northeastern Oregon stand. Northwest Science. 72(3): 190-197.

Parks, C.G.; Bull, E.L. 1997. American marten use of rust and dwarf mistletoe brooms in northeastern Oregon. Western Journal of Applied Forestry. 12: 131-133.

Parks, C.G.; Bull, E.L.; Tinnin, R.O. [et al.]. 1999. Wildlife use of dwarf mistletoe brooms in Douglas-fir in northeastern Oregon. Western Journal of Applied Forestry. 14(2): 100-105.

Parks, C.G.; Flanagan, P.T. 2001. Dwarf mistletoes, rust disease, and stem decays in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 31-37.

Parks, C.G.; Schmitt, C.L. 1997. Wild edible mushrooms in the Blue Mountains: resource and issues. Gen. Tech. Rep. PNW-GTR-393. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Parry, D.L.; Filip, G.M.; Willits, S.A. [et al.]. 1996. Lumber recovery and deterioration of beetle-killed Douglas-fir and grand fir in the Blue Mountains of eastern Oregon. Gen. Tech. Rep. PNW-GTR-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Pelren, E.C. 1996. Blue grouse winter ecology in northeastern Oregon. Corvallis, OR: Oregon State University. 67 p. Ph.D. dissertation.

Pelren, E.C.; Crawford, J.A. 1999. Blue grouse nesting parameters and habitat associations in northeastern Oregon. Great Basin Naturalist. 59(4): 368-373.

Petersen, G.J.; Mohr, F.R. 1984. Underburning on white fir sites to induce natural regeneration and sanitation. Fire Management Notes. 45(2): 17-20.

Peterson, W.C.; Hibbs, D.E. 1989. Adjusting stand density management guides for sites with low stocking potential. Western Journal of Applied Forestry. 4(2): 62-65.

Porath, M.L.; Momont, P.A.; DelCurto, T. [et al.]. 2002. Offstream water and trace mineral salt as management strategies for improved cattle distribution. Journal of Animal Science. 80(2): 346-356.

Powell, D.C. 1994. Effects of the 1980s western spruce budworm outbreak on the Malheur National Forest in northeastern Oregon. Tech. Pap. R6-FI&D-TP-12-94. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Insects and Diseases Group. 176 p.

Powell, D.C. 1999. Historical references about vegetation conditions: a bibliography with abstracts. Tech. Pap. F14-SO-TP-05-99. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 310 p.

Price, D.M. 1998. Multiscale habitat electivity and movement patterns by adult spring chinook salmon in seven river basins of northeast Oregon. Corvallis, OR: Oregon State University. 77 p. M.S. thesis.

Quigley, T.M. 1992. Forest health in the Blue Mountains: social and economic perspectives: science perspectives. Gen. Tech. Rep. PNW-GTR-296. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 9 p.

Quigley, T.M.; Hayes, J.L.; Starr, G.L. [et al.]. 2001. Improving forest health and productivity in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 234-251.

Quigley, T.M.; Tanaka, J.A.; Sanderson, H.R. [et al.]. 1991. Economically optimal private land grazing strategies for the Blue Mountains of eastern Oregon. Journal of Range Management. 44(1): 38-42.

Reed, M.A. 1998. On-site public evaluations on the use of prescribed fire and mechanical thinning. Corvallis, OR: Oregon State University. 102 p. M.S. thesis.

Riegel, G.M. 1989. Understory competition for resources in *Pinus ponderosa* forests of northeastern Oregon. Corvallis, OR: Oregon State University. 189 p. Ph.D. dissertation.

Rieman, B.; Peterson, J.T.; Clayton, J. [et al.]. 2001. Evaluations 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.

Riggs, R.A.; Tiedemann, A.R.; Cook, J.G. [et al.]. 2000. Modification of mixed-conifer forests by ruminant herbivores in the Blue Mountains ecological provinces. Res. Pap. PNW-RP-527. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 77 p.

Roath, L.R.; Krueger, W.C. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management. 33(3): 332-338.

Robbins, W.G.; Wolf, D.W. 1994. Landscape and the intermontane Northwest: an environment history. Gen. Tech. Rep. PNW-GTR-319. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Robichaud, P.R.; Brown, R.E. 1999. What happened after the smoke cleared: onsite erosion rates after a wildfire in eastern Oregon. Wildland Hydrology Proceedings: 419-426.

Roush, C.F. 1978. Nesting biologies and seasonal occurrence of yellowjackets in northeastern Oregon forests (Hymenoptera: Vespidae). Pullman, WA: Washington State University. 80 p. M.S. thesis.

Ryan, R.B. 1983. Population density and dynamics of the larch casebearer (Lepidoptera: Coleophoridae) in the Blue Mountains of Oregon and Washington before the build-up of exotic parasites. Canadian Entomologist. 115(19): 1095-1102.

Ryan, R.B. 1985. Relationship between parasitism of larch casebearer (Lepidoptera: Coleophoridae) and dead hosts in the Blue Mountains, 1973-1983. Canadian Entomologist. 117(8): 935-939.

Ryan, R.B. 1997. Before and after evaluation of biological control of the larch casebearer (Lepidoptera: Coleophoridae) in the Blue Mountains of Oregon and Washington 1972-1995. Environmental Entomology. 26(3): 703-715.

Sallabanks, R.; Riggs, R.A.; Cobb, L.E. 2002. Bird use of forest structural classes in grand fir forests of the Blue Mountains, Oregon. Forest Science. 48(2): 311-321.

Sanderson, H.R.; Quigley, T.M.; Spink, L.R. 1988. Defining, implementing and evaluating grazing management strategies. Journal of Soil and Water Conservation. 43(4): 345-348.

Seidel, K.W. 1982. Growth and yield of western larch: 15-year results of a levels-of-growing-stock study *Larix occidentalis*, Wallowa-Whitman National Forest, northeastern Oregon. Res. Note PNW-398. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Seidel, K.W.; Head, S.C. 1983. Regeneration in mixed-conifer partial cuttings in the Blue Mountains of Oregon and Washington. Res. Pap. PNW-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Sheehy, D.P. 1987. Grazing relationships of elk, deer, and cattle on seasonal rangelands in northeastern Oregon. Corvallis, OR: Oregon State University. 269 p. Ph.D. dissertation.

Sheehy, D.P.; Slater, R. 1998. Improvement of elk habitat in the North Grande Ronde Valley. Annual Report. [Place of publication unknown]: Eastern Oregon Agricultural Research Center. 125 p.

Shindler, B.A.; Brunson, M.; Stankey, G.H. 2002. Social acceptability of forest conditions and management practices: a problem analysis. Gen. Tech. Rep. PNW-GTR-537. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 68 p.

Shindler, B.A.; Reed, M. 1996. Forest management in the Blue Mountains: public perspectives on prescribed fire and mechanical thinning. Corvallis, OR: Oregon State University, Department of Forest Resources. 57 p.

Shirley, D.M.; Erickson, V. 2001. Aspen restoration in the Blue Mountains of northeast Oregon. In: Shepperd, W.D.; Binkley, D.; Bartos, D.L. [et al.], eds. Sustaining aspen in Western landscapes: symposium proceedings. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 101-115.

Skovlin, J.M. 1967. Fluctuation in forage quality on summer range in the Blue Mountains. Res. Pap. PNW-44. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 20 p.

Skovlin, J.M. 1996. Interpreting landscape changes in the Blue Mountains of western North America through repeat photography. In: West, N.E., ed. Rangelands in a sustainable biosphere. Proceedings of the 5th international rangeland congress. Denver, CO: Society for Range Management: 521-522.

Skovlin, J.M.; Bryant, L.D.; Edgerton, P.J. 1989. Timber harvest affects elk distribution in the Blue Mountains of Oregon. Res. Pap. PNW-RP-415. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

Skovlin, J.M.; Harris, R.W.; Strickler, G.S. [et al.]. 1976. Effects of cattle grazing methods on the ponderosa pine-bunchgrass range in the Pacific Northwest. Tech. Bull. 1531. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service. 40 p.

Skovlin, J.M.; Thomas, J.W. 1995. Interpreting long-term trends in Blue Mountain ecosystems from repeat photography. Gen. Tech. Rep. PNW-GTR-315. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 102 p.

Skovlin, J.M.; Vavra, M. 1979. Winter diets of elk and deer in the Blue Mountains, Oregon. Res. Pap. PNW-260. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 21 p.

Smergut, T.A. 1991. *Cardaria draba* (L.) in the sagebrush ecosystem of northeastern Oregon. Corvallis, OR: Oregon State University. 42 p. M.S. thesis.

Smith, A.K. 1975a. Fish and wildlife resources of the Grande Ronde basin, Oregon, and their water requirements; federal aid to fish restoration project completion report. Portland, OR: Oregon Department of Fish and Wildlife. 51 p.

Smith, G.W. 1975b. An ecological study of the porcupine (*Erethizon dorsatum*) in the Umatilla National Forest, northeastern Oregon. Pullman, WA: Washington State University. 101 p. M.A. thesis.

Smith, G.W. 1982. Habitat use by porcupines in a ponderosa pine/Douglas-fir forest in northeastern Oregon. Northwest Science. 56(3): 236-240.

Sneva, F.A.; Hyder, D.N. 1962. Forecasting range herbage production in eastern Oregon. Station Bull. 588. Portland, OR: Oregon State University, Agricultural Experiment Station. 11 p.

Snyder, J.W. 2001. Restoration of Columbian sharp-tailed grouse into northeastern Oregon. Corvallis, OR: Oregon State University. 131 p. Ph.D. dissertation.

Starr, L.; Hayes, J.L.; Quigley, T.M. [et al.]. 2001. A framework for addressing forest health and productivity in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 1-10.

Starr, L.; Quigley, T.M., eds. 1992. Forest health in the Blue Mountains public forums, April-June 1991. B 62/2. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Blue Mountains Natural Resources Institute. 84 p.

Steel, E.A. 1999. In-stream factors affecting juvenile chinook salmon migration. Seattle, WA: University of Washington. 111 p. Ph.D. dissertation.

Svejcar, T.; Vavra, M. 1985a. Seasonal forage production and quality on four native and improved plant communities in eastern Oregon. Tech. Bull. 149. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 24 p.

Svejcar, T.; Vavra, M. 1985b. The influence of several range improvements on estimated carrying capacity and potential beef production. Journal of Range Management. 38(5): 395-399.

Swetnam, T.W.; Wickman, B.E.; Paul, H.G. [et al.]. 1995. Historical patterns of western spruce budworm and Douglas-fir tussock moth outbreaks in the northern Blue Mountains, Oregon since A.D. 1700. Res. Pap. PNW-RP-484. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 27 p.

Tanaka, J.A.; Starr, L.; Quigley, T.M. 1995. Strategies and recommendations for addressing forest health issues in the Blue Mountains of Oregon and Washington. Gen. Tech. Rep. PNW-GTR-350. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 18 p.

Thies, W.G. 2001. Root diseases in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 38-45.

Thies, W.; Niwa, C. 2001. Interaction of various ecosystem components with prescribed fires in ponderosa pine stands in the southern Blue Mountains. Phytopathology. 91(6 Supplement): S155-S156.

Thomas, J.W., tech. ed. 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Handb. 553. Washington, DC: Wildlife Management Institute and U.S. Department of Agriculture, Forest Service. 512 p.

Thomas, J.W.; Leckenby, D.A.; Erickson, L.J. [et al.]. 1986. Wildlife habitat by design: national forests in the Blue Mountains of Oregon and Washington. In: Wildlife Management Institute, ed. Transactions of the 51st North American Wildlife and Natural Resources Conference. Washington, DC: Wildlife Management Institute: 203-214.

Thomas, J.W.; Miller, R.J.; Black, H. [et al.]. 1976. Guidelines for maintaining and enhancing wildlife habitat in forest management in the Blue Mountains of Oregon and Washington. In: Proceedings: Transactions of the 41st North American wildlife and natural resources conference. Washington, DC: Wildlife Management Institute: 452-476.

Tiedemann, A.R.; Klemmedson, J.O.; Bull, E.L. 2000. Solution of forest health problems with prescribed fire: Are forest productivity and wildlife at risk? Forest Ecology and Management. 127(1-3): 1-18.

Tiedemann, A.R.; Quigley, T.M.; Anderson, T.D. 1988. Effects of timber harvest on stream chemistry and dissolved nutrient losses in northeast Oregon. Forest Science. 34(2): 344-358.

Torgersen, C.E.; Price, D.M.; Li, H.W. [et al.]. 1999. Multiscale thermal refugia and stream habitat associates of chinook salmon in northeastern Oregon. Ecological Applications. 9(1): 301-319.

Torgersen, T.R. 2001. Defoliators in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 11-20.

Torgersen, T.R.; Bull, E.L. 1995. Down logs as habitat for forest dwelling ants—the primary prey of pileated woodpeckers in northeastern Oregon. Northwest Science. 69 (4): 294-303.

Trauba, W.C. 1975. Petrography of pre-tertiary rocks of the Blue Mountains, Umatilla County, northeast Oregon. Corvallis, OR: Oregon State University. 171 p. M.S. thesis.

U.S. Army Corps of Engineers. 1999. Grande Ronde River stream restoration, La Grande, Oregon: Grande Ronde Section 1135. Ecosystem restoration report and environmental assessment. La Grande, OR. [Pages unknown].

U.S. Department of Agriculture, Forest Service. 1992a. Monitoring strategy plan, appendix N- biological assessment. La Grande, OR: Wallowa-Whitman National Forest, La Grande Ranger District. [Pages unknown].

U.S. Department of Agriculture, Forest Service. 1992b. Upper Grande Ronde River anadromous fish habitat restoration and monitoring plan. Baker, OR: Wallowa-Whitman National Forest. [Pages unknown].

U.S. Department of Agriculture, Forest Service. 1994a. Biological assessment: Upper Grande Ronde River (section 7). [Place of publication unknown]: Wallowa-Whitman National Forest, La Grande Ranger District; Umatilla National Forest, North Fork John Day Ranger District; final report. [Irregular pagination].

U.S. Department of Agriculture, Forest Service. 1994b. Upper Grande Ronde watershed analysis report. La Grande, OR: Wallowa-Whitman National Forest. [Irregular pagination].

U.S. Department of Agriculture, Forest Service. 1994c. Upper Grande Ronde conservation strategy for endangered Snake River spring/summer chinook salmon. La Grande, OR: Wallowa-Whitman National Forest, La Grande Ranger District. [Irregular pagination].

U.S. Department of Agriculture, Forest Service. 1998. Beaver Creek watershed analysis. La Grande, OR: Wallowa-Whitman National Forest. [Irregular pagination].

U.S. Department of Agriculture, Forest Service. 2002. Meadow Creek watershed analysis. La Grande, OR: Wallowa-Whitman National Forest, La Grande Ranger District. [Irregular pagination].

U.S. Department of Agriculture, Natural Resources Conservation Service; U.S. Department of Agriculture, Forest Service. 1996. Grande Ronde cooperative river basin study for Union County. [La Grande, OR]. [Pages unknown]. Unpublished report. On file with: Grande Ronde Model Watershed, 10901 Island City Ave., La Grande, OR 97850.

U.S. Department of Agriculture, Soil Conservation Service; Oregon State University Agricultural Experiment Station. 1985. Soil survey of Union County area, Oregon. Washington, DC. 194 p.

U.S. Department of Energy, Bonneville Power Administration. 1997. Fish research project—Oregon investigations into the early life history of naturally produced spring chinook salmon in the Grande Ronde River basin: Bonneville Power Administration annual report 1996. [Place of publication unknown]: [Pages unknown].

U.S. Department of the Interior, Bureau of Land Management, Baker Resource Area Office. 1993. Wallowa and Grande Ronde Rivers: final management plan/environmental assessment. Washington, DC. [196 p.].

U.S. Department of the Interior, Bureau of Land Management; U.S. Department of Agriculture, Forest Service. 1990. Resource assessment: Grande Ronde River, National Wild and Scenic River. [Baker, OR]: BLM, Vale District and Wallowa-Whitman National Forest. 47 p.

U.S. Department of the Interior, Bureau of Reclamation. 1982. Baker project: Oregon, Baker and Union Counties. [Washington, DC]: [The Pacific Northwest Region]. 6 p.

U.S. Department of the Interior, Geological Survey. 1989. Water resources data, Oregon, water year 1988. Vol. 1. Eastern Oregon. [Place of publication unknown]. [Pages unknown].

U.S. Department of the Interior, Geological Survey. 1996. Geology of the Blue Mountains region of Oregon, Idaho, and Washington: petrology and tectonic evolution of pre-tertiary rocks of the Blue Mountains Region. [Place of publication unknown]. [Pages unknown].

Union Soil and Water Conservation District. 1995. Grande Ronde River basin study: abstracts. La Grande, OR. [Pages unknown].

Union Soil and Water Conservation District. 1999. Upper Grande Ronde River subbasin local agricultural water quality advisory committee—Upper Grande Ronde River subbasin agricultural water quality management area plan. La Grande, OR. [Pages unknown].

Van Cleve, R.; Ting, R. 1960. The condition of salmon stocks in the John Day, Umatilla, Walla Walla, Grande Ronde and Imnaha Rivers as reported by various fisheries agencies. Seattle, WA: University of Washington. 83 p.

Vavra, M.; Phillips, R.L. 1979. Diet quality and cattle performance on forested rangeland in northeastern Oregon. Proceedings, Western Section, American Society of Animal Science. 30: 170-173.

Vavra, M.; Phillips, R.L. 1980. Drought effects on cattle performance, diet quality and intake. Proceedings,Western Section, American Society of Animal Science. 31: 157-160 .

Wales, B.C. 2001. The management of insects, diseases, fire, and grazing and implications for terrestrial vertebrates using riparian habitats in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 119-127.

Walters, T.R.; Carmicheal, R.W.; Keefe, M. 1994. Smolt migration characteristics and mainstem Snake and Columbia River detection rates of PIT-tagged Grande Ronde and Imnaha River naturally produced spring chinook salmon: annual progress report. Portland, OR: Oregon Department of Fish and Wildlife. [Pages unknown].

Watershed Sciences, LLC. 2000. Remote sensing survey of the Grande Ronde River basin, thermal infrared and color videography; final report prepared for Oregon Department of Environmental Quality. Corvallis, OR. 49 p.

Wellman, R.E.; Gordon, J.M.; Moffat, R.L. 1993. Statistical summaries of streamflow data in Oregon: Vol. 2—Annual low and high flow, and instantaneous peak flow. Open File Report 93-63. Portland, OR: U.S. Department of the Interior, Geological Survey. [Pages unknown].

Wells, G.R. 1975. A sensitivity analysis of simulated river basin planning for capital budgeting decsions. Computer Operations and Research. 2(1): 49-54.

White, R.G.; Milligan, J.H.; Bingham, A.E. [et al.]. 1981. Effects of reduced stream discharge on fish and aquatic macroinvertebrate populations. OWRT B-045-IDA(1) 14-34-0001-8080. Springfield, VA: National Technical Information Service. 283 p.

Whitney, L. 1999. Grande Ronde Section 319 national monitoring program project, temperature monitoring summary report, 1993-1998. Portland, OR: Oregon Department of Environmental Quality. [Pages unknown].

Wickman, B.E. 1976 . Douglas-fir tussock moth egg hatch and larval development in relation to phenology of grand fir and Douglas-fir in northeastern Oregon. Res. Pap. PNW-206. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Wickman, B.E. 1978. Tree mortality and top kill related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. Res. Pap. PNW-233. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 47 p.

Wickman, B.E. 1986. Radial growth of grand fir and Douglas-fir 10 years after defoliation by the Douglas-fir tussock moth in the Blue Mountain outbreak. Res. Pap. PNW-367. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Wickman, B.E. 1988. Seasonal variation of degree-day accumulation in relation to phenology of western spruce budworm, Douglas-fir tussock moth, and host trees in northeastern Oregon. Res. Note PNW-RN-482. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Wickman, B.E. 1992. Forest health in the Blue Mountains: the influence of insects and diseases. Forest health in the Blue Mountains: science perspectives. Gen. Tech. Rep. PNW-GTR-295. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p. (Quigley, T.M., ed.; Forest health in the Blue Mountains: the influence of insects and disease).

Wickman, B.E.; Henshaw, D.L.; Gollob, S.K. 1980. Radial growth in grand fir and Douglas-fir related to defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. Res. Pap. PNW-269. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 23 p.

Widner, G.L. 1991. Summer low flow characteristics of forest streams in northeast Oregon. Corvallis, OR: Oregon State University. 93 p. M.S. thesis.

Williams, J.D. 1988. Overland flow and sediment production potentials in logged and nonlogged sites of a ponderosa pine forest in northeastern Oregon. Corvallis, OR: Oregon State University. 108 p. M.S. thesis.

Williams, M. 2000. Putting ‘flesh on the carbon-based bones’ of forest history. In: Agnoletti, M.; Anderson, S., eds. Methods and approaches in forest history. Wallingford, United Kingdom: CABI Publishing: 35-46.

Williams, W.R. 1976. The economic impact of Douglas-fir tussock moth on private recreation businesses in northeastern Oregon. Corvallis, OR: Oregon State University. 73 p. M.S. thesis.

Williamson, N.M. 1999. Crown fuel characteristics, stand structure, and fire hazard in riparian forests of the Blue Mountains, Oregon. Seattle, WA: University of Washington. 98 p. M.S. thesis.

Wilson, D.; Maguire, D.; Ager, A. 2001. Effects of forest planning regulations on potential small diameter timber harvest from overstocked stands on the Umatillla National Forest. Misc. Rep. Pendleton, OR: U.S. Department of Agriculture, Forest Service, Umatilla National Forest. [Pages unknown].

Wissmar, R.C.; Smith, J.E.; McIntosh, B.A. [et al.]. 1994a. A history of resource use and disturbance in riverine basins of eastern Oregon and Washington (early 1800s-1900s). Northwest Science. 68(Spec. issue): 1-35.

Wissmar, R.C.; Smith, J.E.; McIntosh, B.A. [et al.]. 1994b. Ecological health of river basins in forested regions of eastern Washington and Oregon. Gen. Tech. Rep. PNW-GTR-326. [Portland, OR]: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 p. (Everett, R.L., assessment team leader, Eastside forest ecosystem health assessment; Hessburg, P.F., science team leader and tech. ed., Volume III: assessment).

Womack, B. 1982. Prehistoric settlement patterns in the Crow and Elk Creek drainages Wallowa-Whitman National Forest, northeastern Oregon, USA. Northwest Anthropological Research Notes. 15(2): 220.

Wondzell, S. 2001. The influence of forest health and protection treatments on erosion and stream sedimentation in forested watersheds of eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 128-140.

Wood, B.W. 1971. Response of Canada milkvetch (*Astragalus canadensis* var. *mortonii* (Nutt.) Wats.) to range and forest improvement practices in northeastern Oregon. Corvallis, OR: Oregon State University. 166 p. Ph.D. dissertation.

Youngblood, A. 2000. Damage to residual trees and advance regeneration from skyline and forwarder yarding in mixed-conifer stands of northeastern Oregon. Western Journal of Applied Forestry. 15(2): 101-107.

Youngblood, A. 2001. Old-growth forest structure in eastern Oregon and Washington. Northwest Science. 75(Spec. issue): 110-118.

Youngblood, A.; Wickman, B.E. 2002. The role of disturbance in creating dead wood: insect defoliation and tree mortality in northeastern Oregon. In: Laudenslayer, W.F., Jr.; Shea, P.J.; Valentine, B.E. [et al.], tech. coords. Proceedings of the symposium on the ecology and management of dead wood in Western forests. Gen. Tech. Rep. PSW-GTR-181. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 155-168.

Zack, R.S.; Davis, E.J.; Raffa, K. 1979. A new host record and notes on *Nosodendron californicum* Horn (Coleoptera: Nosodendridae). Coleopterists Bulletin. 33(1): 74.

Pacific Northwest Research Station

Web site	http://www.fs.fed.us/pnw
Telephone	(503) 808-2592
Publication requests	(503) 808-2138
FAX	(503) 808-2130
E-mail	pnw_pnwpubs@fs.fed.us
Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, OR 97208-3890