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Improving Forest Health and Productivity in Eastern Oregon and Washington

Abstract

Forest health and productivity decline in eastern Oregon and Washington has resulted in risks to products, economies, and amenities that are deemed unacceptable to many residents and non-residents. Information and management tools exist that will assist managers in improving conditions, but what is needed is a framework for integrating the available models and information. Steps in developing such a framework include: establishing goals consistent across scales, assessing current conditions and risks, developing management options, describing outcomes of options, selecting an option, establishing priorities for action, implementing those priority activities, and monitoring and evaluating the results of actions. Research projects undertaken by the Forest Health and Productivity Initiative of the Pacific Northwest Research Station include collaboration with managers to develop options for managing insect, disease, and fire disturbances in order to improve ecosystem integrity, to integrate biophysical and socioeconomic considerations, to identify linkages across scales, and to fill significant knowledge gaps at the mid or broad scale. Science can contribute basic understanding of resource conditions and interactions, models to assess risk and opportunities, models that predict future conditions, and options regarding future management actions. The ability to implement actions to achieve improved forest health and productivity depends on the availability of resources to plan and implement actions, the financial feasibility of individual practices on individual sites, the motivation of resource specialists and the public to undertake the actions, and acceptance by the public, interest groups, agencies, and policy makers of the mix of management actions proposed.

Introduction

Forest health and productivity are based on a wide variety of processes that maintain the ecosystem and values that we have come to expect from our forest lands including commodity production, wildlife and fish habitat, air and water quality, human health and safety, property values, and more. As has been established by several assessments (Caraher et al. 1992, Everett et al. 1994, Gast et al. 1991), forest and range conditions in eastern Oregon and Washington are declining. This decrease in forest health and productivity has resulted in risks to products, economies, and amenities that are considered unacceptable by state agencies, county governments, and many residents and non-residents. Many trees are dead or dying, forests are becoming more homogeneous in species and structure, resource-dependent economies of rural communities are depressed, and homes and other structures at the forest interface are at risk from fire. The Research Initiative for Improving Forest Ecosystem Health and Productivity in Oregon and Washington by Managing Ecosystem Disturbance was formed by Pacific Northwest Research Station to focus research on these issues. Its goal was to provide managers with practical information they can readily apply in management decisions at multiple scales and to provide more science information and objectivity for the debate about active versus passive approaches to managing forest health issues. The focus is on natural disturbance processes and consequences of activities intended to manage disturbances, rather than on the consequences of management activities undertaken to achieve other goals. The purpose of this paper, together with others in this issue, is to synthesize what is known about forest health and productivity issues, the tools that are available for managers to address these issues, and to provide an initial answer to the question of what managers might do now to address forest health issues.

Scope of Synthesis

A first step in providing needed information is to gather what is currently known about ecosystem processes, dynamics, historical conditions, and current status. Working with a team of scientists primarily from the Pacific Northwest Research

Station, we focused on inherent disturbance agents that managers may be able to affect (insects, disease, fire, and ungulate grazing). Starr et al. (2001) provide a basic framework for organizing the information, tools, and activities to address the management of disturbance agents. We sought basic information on disturbance processes, ecosystem status, risks to components, and links to key issues. We further sought to identify treatment options to minimize, mitigate, or simulate disturbance agents; to identify the effects (both intended and unintended) of those treatment activities on factors of concern; and to identify monitoring and decision-support tools available to managers.

We recognize that information needed by managers is more helpful if it is at the appropriate scale, integrated across disciplines, focused on regimes rather than events, and is linked to issues that are high priority for managers. We examined the drivers of disturbance (insects, diseases, fire, ungulates, climate) and key issues affected by these agents (invasive species; vegetative patterns; special environments such as old-growth, soil and litter, and riparian areas; threatened, endangered, and rare species; and socioeconomic concerns). We recognize that human actions, such as logging, are also drivers of disturbance, but our focus here is not on the myriad actions that humans undertake.

There is considerable variation in the degree to which literature is available to address the issues, especially at some spatial scales. An indication of the richness of available information at various scales is given in Table 1. Spatial scales chosen are: organism, site/stand (up to 400 ha), subwatershed (3000-8000 ha), watershed (20,000-80,000 ha), and landscape (300,000-400,000 ha).

This collection of synthesis papers briefly touches on what we know about the drivers of disturbance and key issues affected by those drivers. In preparing this synthesis, scientists were asked to focus on general information about the topic assigned, and on both the effects of the topic on forest health and productivity and the effects of forest health and productivity on the topic. They were also asked to consider the effects of treatments designed to improve forest health and productivity. Other issues of focus included spatial scale and any monitoring thresholds identified or decision-support tools available. Information in the brief summaries provided here is expanded in other articles in this issue.

We will first describe the drivers of disturbance with particular attention to the availability of tools to manage the drivers. We then address key issues that receive special focus in management, including key habitats that are at risk in areas of declining forest health, and socioeconomic issues related to forest health and productivity. Next we discuss the common themes that emerge from discussions of disturbance drivers, habitat influences, and socioeconomic concerns. We conclude with a discussion about how science can contribute to the resolution of forest health and productivity issues and point to what might be priorities for moving forward.

Drivers of Disturbance

Insect Pests

Defoliators

Information on the four main defoliators of conifers in eastern Oregon and Washington is abundant (see Torgersen 2001). Because of concerns about growth suppression and mortality of trees during widespread defoliator outbreaks, much research effort has been focused on these species. They are western spruce budworm (*Choristoneura occidentalis*), Douglas-fir tussock moth (*Orgyia pseudotsugata*), pandora moth (*Coloradia pandora*), and larch casebearer (*Coleophora laricella*). Various interactions of defoliators with other system components and natural regulatory processes have been described, as have monitoring and suppression techniques using pheromone-based technologies. Large-scale suppression projects using both chemical and biological materials have been used in attempts to control some defoliator outbreaks. While such suppression projects have prevented some tree mortality and growth loss, they have been largely ineffective in changing the outbreak behavior of these insects. Some suppression materials have undesirable side effects on non-target insects such as sensitive or endangered moths, butterflies, and skippers, or on other ecological processes. Successful control of larch casebearer has been achieved by introduction of parasitic wasps. Because these pests are largely host specific, managing to achieve diversity in structure and species composition can be an effective means of limiting adverse effects for a single insect species. For most defoliators, the recommended strategy is preventative: silvicultural treatment to promote a diversity of tree species, stand structures, and

TABLE 1. The richness of information available in the literature about the drivers of disturbance and key issues affected by those drivers at various spatial scales.[1]

		General	Organism	Stand up to 400 ha	Subwatershed 3000-8000 ha	Watershed 20,000-80,000 ha	Landscape 300,000-400,000 ha
Ecosystem Stressors							
Defoliators	Basic info.	*****	*****	*****	****	****	****
	Effects[2]	*****	*****	*****	****	****	****
	Treatments[3]	*****	*****	*****	*****	*****	*****
	D-S Tools[4]	*****	*****	*****	*****	*****	*****
Beetles	Basic info.	*****	*****	****	***	**	*
	Effects	*****	*****	****	***	**	*
	Treatments	*****	*****	****	***	**	*
	D-S tools	*****	*****	****	***	**	*
Dwarf mistletoe	Basic info.	****	****	****	****	*	*
	Effects	****	***	****	***	**	**
	Treatments	****	****	****	***	***	**
	D-S tools	***	***	***	****	****	****
Root disease	Basic info.	****	****	****	****	**	**
	Effects	****	***	****	***	**	**
	Treatments	****	****	***	***	***	**
	D-S tools	***	***	***	****	****	****
Rusts	Basic info.	***	****	***	***	**	**
	Effects	***	***	***	**	*	*
	Treatments	***	***	***	**	*	*
	D-S tools	****	****	***	****	**	**
Heart rot decay	Basic info.	***	***	****	*	*	*
	Effects	****	***	****	****	**	**
	Treatments	***	***	***	**	**	*
	D-S tools	****	****	****	***	**	**
Wildfire	Basic info.	*****	***	***	***	**	**
	Effects	***	**	**	**	**	**
	Treatments	****	***	***	***	***	**
	D-S tools	****	***	***	***	***	**
Ungulates	Basic info.	*****	*****	*****	**	**	*
	Effects	***	***	***	*	*	*
	Treatments	****	****	****	*	*	*
	D-S tools	**	**	**	*	*	*
Climate	Basic info.	*****	*	**	***	****	*****
	Effects	****	*	*	**	**	***
	Treatments	**	*	*	*	**	**
	D-S tools	***	*	*	**	**	***
Stress chemicals	Basic info.	***	**	*	*	*	*
	Effects	**	**	*	*	*	*
	Treatments	*	*	*	*	*	*
	D-S tools	*	*	*	*	*	*
Invasives							
Invasive fish	Basic info.	**	**	***	*	*	*
	Effects	n/a					
	Treatments	**	*	*	*	*	*
	D-S tools	**	*	*	*	*	*
Invasive insects	Basic info.	****	****	***	***	**	*
	Effects	****	****	***	**	**	**
	Treatments	****	****	***	**	*	*
	D-S tools	***	***	***	**	*	*
Invasive plants	Basic info.	****	***	***	**	**	**
	Effects	**	**	*	*	*	*
	Treatments	*****	*****	****	***	*	*
	D-S tools	****	****	***	*	*	*
Species and Habitats							
TE&Rare fish	Basic info.	***	***	***	**	**	**
	Effects	n/a					
	Treatments	**	**	**	*	*	*
	D-S tools	**	*	*	*	*	*

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Table 1. Continued

		General	Organism	Stand up to 400 ha	Subwatershed 3000-8000 ha	Watershed 20,000-80,000 ha	Landscape 300,000-400,000 ha
TE&Rare birds	Basic info.	***	***	***	**	**	**
	Effects	n/a					
	Treatments	**	***	***	**	*	*
	D-S tools	***	***	**	*	*	*
TE&Rare carnivores	Basic info.	**	***	**	**	**	**
	Effects	n/a					
	Treatments	**	**	**	*	*	*
	D-S tools	**	**	**	*	*	*
TE&Rare amphibians	Basic info.	**	***	**	**	*	*
	Effects	n/a					
	Treatments	**	**	*	*	*	*
	D-S Tools	**	**	*	*	*	*
TE&Rare insects	Basic info.	**	**	**	*	*	*
	Effects	*	*	*	*	*	*
	Treatments	*	*	*	*	*	*
	D-S Tools	*	*	*	*	*	*
TE&Rare plants	Basic info.	***	***	***	**	*	*
	Effects	n/a					
	Treatments	**	**	**	*	*	*
	D-S Tools	**	*	*	*	*	*
Vegetation pattern	Basic info.	*****	*****	*****	****	****	***
	Effects	***	***	*****	****	***	**
	Treatments	*****	*****	*****	****	***	**
	D-S Tools	***	****	*****	***	**	**
Old growth	Basic info.	****	*****	**	**	*	*
	Effects	***	***	**	*	*	*
	Treatments	*****	*****	**	*	*	*
	D-S Tools	**	**	*	*	*	*
Soil and Water-Related							
Riparian Habitat	Basic info.	***	n/a	**	*	*	*
	Effects	n/a					
	Treatments	**	n/a	*	*	*	*
	D-S Tools	*	n/a	*	*	*	*
Riparian Hydrology	Basic info.	**	**	**	*	*	*
	Effects	*	*	*	*	*	*
	Treatments	*	*	*	*	*	*
	D-S Tools	*	*	*	*	*	*
Soil, litter & CWD habitat for arthropods	Basic info.	***	**	**	*	*	*
	Effects	***	*	**	*	*	*
	Treatments	*	*	*	*	*	*
	D-S Tools	*	*	*	*	*	*
Economic and Social							
Economics	Basic info.						
	Markets	***	n/a	**	*	*	*
	Industry structure	**	n/a	*	*	*	*
	Mgmt. Actions	****	n/a	****	**	**	**
	Utilization	***	n/a	****	**	**	**
	Effects	**	*	*	*	*	*
	Treatments	**	n/a	*	*	*	*
	D-S Tools	****	n/a	****	**	**	**
Sociocultural	Basic info.	*	*	*	*	**	**
	Effects	**	*	*	*	*	*
	Treatments	**	*	*	*	*	*
	D-S Tools	**	*	*	*	*	*

[1] Ratings of amount of literature/knowledge on the topic by scale based on expert opinion.
[2] Effects on forest health and productivity
[3] Treatment options for improving factor of interest
[4] Decision-support tools

*= Almost nothing
**= Some coverage
***= Moderate coverage
****= Considerable coverage
*****= Extensive coverage

moderate stocking levels. Decision-support tools, e.g., UPEST and UTOOLS, analyze insect and disease risks, and the Forest Vegetation Simulator models include the ability to model, albeit crudely, the effects of insects and disease on stand growth.

Bark Beetles

Bark beetles are well described in terms of life history and general ecology for the six beetle species of concern in eastern Oregon and Washington: Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), mountain pine beetle (*D. ponderosae* Hopkins), western pine beetle (*D. brevicomis* LeConte), spruce beetle (*D. rufipennis* (Kirby)), fir engraver (*Scolytus ventralis* LeConte), and pine engraver (*Ips pini* (Say)) (see Hayes and Daterman 2001). Many interactions between bark beetles and other agents and resources have been described. Wildfire, windstorms, disease, other insects, and land management practices can weaken trees and attract bark beetles that become locally epidemic. At low population levels, beetles perform useful functions by creating habitat and forage for many organisms, but outbreaks can cause extensive tree mortality and increase risk of wildfire. Natural control agents such as birds, predatory beetles, parasitoids, and parasites, have been studied, but have not been employed operationally in management strategies. While semiochemcial-baited traps provide information about population fluctuations locally, large area monitoring relies primarily on aerial surveillance. Stand susceptibility, hazard, or risk-rating systems exist for most of these species, and infestation growth or damage models are available for a few. In most cases, pesticide sprays, attractants and anti-aggregants, and trap-tree techniques have been useful in specific applications. Anti-aggregants have been proven useful in large-scale operations for Douglas-fir beetle. Salvage or sanitation of infested, wind- or fire-damaged trees can prevent population build-ups if done promptly. Integration of these methods along with prescribed fire and tree thinning has been recommended. Decision-support tools are becoming more prevalent, but each requires validation for different geographic variants.

Diseases

Dwarf Mistletoe

Considerable information is available on the four dwarf mistletoe species of concern in eastern Oregon and Washington: Douglas-fir dwarf mistletoe (*Arceuthobium douglasii*), larch dwarf mistletoe (*A. laricis*), western dwarf mistletoe (*A. campylopodum*), and lodgepole pine dwarf mistletoe (*A. americanum*) (see Parks and Flanagan 2001). Although dwarf mistletoes deplete hosts of water and nutrients and can eventually kill trees, the abnormal branches (witches-brooms) they cause are important habitat for small mammals and birds. Dwarf mistletoe spreads slowly (1 to 2 feet per year) and can be controlled by cutting infected trees and planting non-susceptible tree species. Timely pruning of brooms and use of hormones that cause abcision of dwarf mistletoe plants are feasible only on individual trees in small areas. Models are available for dwarf mistletoe effects and landscape vulnerability.

Rust

Information on ecology and hazard ratings of rust diseases is available (see Parks and Flanagan 2001). Of over 50 species of rusts in the Pacific Northwest, only a few cause significant effects: white pine blister rust (*Cronartium ribicola*) on five-needle pines; western gall rust (*Endocronartium harknessii*), stalactiform rust (*Cronartium coleosporioides*), and comandra rust (*Cronartium comandrae*) on lodgepole pine and ponderosa pine; fir broom rust (*Melampsorella caryophyllacearum*) on true firs; spruce broom rust (*Chrysomyxa arctostaphyli*) on spruces; and incense-cedar rust (*Gymnosporangium libocedri*) on incense-cedar. Rust diseases are spread by airborne spores and may depend on interspersed rangelands harboring the alternate host. Rusts cause deformation, growth loss, tree mortality, and can create infection courts for other pathogens. Resulting brooms also create rest sites for American marten and food for rodents, rabbits, and hares. Genetic resistance and tree species manipulation can be used to control some rusts, and infected branches can be eliminated by pruning. Site hazard ratings based on habitat type and elevation are available.

Heart Rot (Stem) Decay

Timber losses from heart rot (stem) decay are greater than from all other diseases, but infected trees, both living and dead, provide valuable wildlife habitat (see Parks and Flanagan 2001). Species of greatest concern are *Phellinus pini* and *Echinodontium tinctorium* (Indian paint fungus) with *Fomitopsis officinalis* being less common.

Trees younger than 90 years usually have insignificant decay while trees that have experienced more than 50 years of suppressed growth are most vulnerable to infection. Fir on sites previously dominated by ponderosa pine have less decay than those on sites historically dominated by firs. Heart rot fungi are spread by airborne spores to freshly exposed wood at wounds or dead branch stubs. Harvesting trees when they are younger than 90 years old and limiting wounds on remaining trees may decrease infection. On the other hand, because trees with heart rot are valuable habitat and nonexistent in some managed stands, methods are being tested to increase numbers of infected trees where they are absent from the landscape.

Root Disease

Root diseases are important natural disturbance agents affecting all tree species and all forest ecosystems of the Pacific Northwest (see Thies 2001). They influence stand structure, density, composition, function, and yield. The root diseases of greatest concern in eastern Washington and Oregon are annosus root disease, Armillaria root disease, laminated root rot, and black stain root disease. For these diseases some information is available on root disease ecology, population dynamics, biology of the pathogens, and the natural processes that regulate them. Less is known about disease effects at the watershed or landscape level or how diseases interact with other disturbances and how they respond to management strategies. Decision support, such as the Western Root Disease Model, is being developed.

In response to a shift in forest species and structure following a century of fire suppression and partial cutting, root diseases are believed to have spread causing more inoculum on more sites than existed in historical times. Stand management to restore historical vegetation conditions may intensify disease; however, in cases where diseased stands are converted to seral species, incidence and severity of root diseases will likely decline. Treatments that retain high stocking of host species, or allow host regeneration, will likely result in increased levels of root diseases because inoculum remains on the site. Spore infections may increase with partial cutting where stumps are not chemically treated. Disturbance increases activity of some insects, which may act as vectors of root disease pathogens.

Wildfire

Wildland fire is a major disturbance agent that shapes the forest health, productivity, and ecological diversity of eastern Oregon and Washington (see Ottmar and Sandberg 2001). Fire behavior and the effects of fire on flora, fauna, soils, air, and water are in large part driven by the availability of fuels and the meteorological influences during a fire. Fire is both a precursor for and a result of other disturbances such as insects and disease, with complex interactions that can contribute to ecological diversity in some forested systems. Higher ecological diversity may not always be desired; for example, low-elevation ponderosa pine was historically maintained with frequent, low-intensity burns. Historical fire regimes were not homogeneous across broad landscapes, even though substantially more lower-elevation, dry-forest vegetation persisted historically. The result was a complex mosaic of tree structures, compositions, and habitats across landscapes. Natural succession, disturbance processes, and management practices have resulted in increased fuels and vulnerability to extreme fire behavior and crown fires. In some ecosystems, risk to structures is further increased by encroachment of dwellings into forests and rangelands. Prescribed fire, thinning, and mechanical fuel treatment are being used to reduce fire risk, but there is disagreement as to the appropriate balance and efficacy of these actions. New tools to (1) characterize fuelbeds; (2) predict mesoscale meteorology, fire behavior, fire effects, smoke production, and dispersal; and (3) demonstrate tradeoffs between prescribed fire and other fuel treatment methods are continually being improved to assist with wildland fire and prescribed fire decision making.

Wild and Domestic Ungulates

Wild ungulate management is seldom undertaken with a focus on the influences of these animals on forest health and productivity, but rather focusing on populations of the ungulates and their habitat needs (see Kie and Lehmkuhl 2001). Consequently, only limited research has examined grazing and browsing by wild ungulates as a chronic disturbance factor affecting nutrient turnovers, competitive interactions among plant species, and rates and trajectories of successional pathways. Local effects from wild and domestic ungulates, are quite variable and depend on ecosystem productivity. Grazing and browsing can have mixed effects on species richness and exotic plant spread at the landscape scale. Grazing and browsing can also affect nitrogen fixation and rate of nitrogen mineralization. Ungulate density relative to carrying capacity of the site largely determines the effects of herbivory. High populations of ungulates have been shown to change plant composition, tree growth, and to damage tree regeneration. Grazing also reduces fine fuels, which formerly carried low-intensity, high-frequency ground fires. Effects of wild ungulates can be controlled by hunting regulations, and in some cases, by artificial contraception. Effects of grazing by livestock can be controlled through management actions such as changes in livestock numbers; changes in timing and duration of grazing; altering livestock distribution with fencing and placement of water, salt and supplemental feed; and specialized rotational grazing systems.

Climate

Climate is a driving factor in forest health and productivity that limits species survival and affects disturbance processes (see Ferguson 2001). Complex topography and mosaics of land cover compound the variability of climate in eastern Oregon and Washington. The area is a transition zone between marine, arctic, and continental influences with associated extremes in weather. Such extremes affect insect populations, animal migration, streamflow, flooding, and wildfire potential. Additionally, human activities such as deforestation and atmospheric pollution interact with climate, and may cause changes similar in magnitude to the glacial-interglacial epoch in the next 50 to 100 years. Effects of anthropogenic climate changes are ambiguous, however, and could counter-balance each other. For example, tree populations may have more difficulty reestablishing, but growth rates could accelerate. Conversely, management actions can mitigate the effect of climate on fisheries, water resources, wildfire, and floods. Also, management actions can affect climate by modifying carbon exchange and water and energy exchange between land and atmosphere. Models are increasingly able to predict climate variability and trends in climate-related disturbances such as wildfire.

Stress Chemicals

Acute and chronic stresses in forest ecosystems can reduce growth or vigor of trees, and cause changes in their physiology or chemical contents (see Kelsey 2001). Ethanol, acetaldehyde, ethylene, and ethane are volatile compounds often produced in stressed, dying, or recently dead trees. Ethanol accumulation is ecologically important because it attracts insects that attack and damage trees, or spread disease. In addition, other chemicals confer resistance to insects and disease, but they decrease in concentration under stress. Monitoring these compounds can assist in timing the lifting of nursery seedlings, detecting harmful effects from air pollution, confirming the presence of root disease, or identifying trees at risk to insect attack. Chemical indicators of stress have potential to be used in monitoring forest health across various scales, but not enough is yet known about options and techniques.

Key Issues

Invasive Species

Invasive species are a key issue with which managers must be concerned. Some disturbances encourage invasives, and management strategies have been devised to reduce these types of disturbance. Information is available on the species of greatest concern, but integrated decision-support tools are lacking. We focus our discussion on invasive fish, insects, and plants.

Fish

Forest health treatments can potentially influence the composition of aquatic assemblages including exotic species through alteration of stream and riparian habitats (see Howell 2001). Habitat changes (such as temperature) affect interspecific competition among species, differential disease resistance, and predation. Forest health treatments that restore habitats and processes with which native species evolved (such as cold water) should favor native species, but there is little documentation to support this hypothesis.

Insects

An increasing number of non-native insects are reaching our ports and beyond as a result of global travel and trade, but they may also arrive from other regions of the United States (see Hayes and Ragenovich 2001). While historically, the forests east of the Cascade crest have experienced relatively few serious invaders, there is a growing concern over the increased potential for invasion by non-native insect species that may displace native species and/or cause significant economic and ecological damage to east-side forest resources. The threat posed by a non-native invasive species is that the forest may lack natural control mechanisms, and the species may become established, spread, and inflict substantial ecological and economic damage before eradication or mitigation measures can be identified and implemented. In general, treatments and practices that improve forest health reduce the risk or effects of widespread insect outbreaks for indigenous species, and have been prescribed to mitigate the effect of non-native species. However, the most effective management options focus on prevention and suppression efforts, which include investigating potential invaders and pathways of introduction, imposing regulatory restrictions, developing and implementing detection and monitoring strategies, and aggressive eradication efforts. Specific management strategies are likely to differ for each potential invader. Examples of east-side invaders include larch casebearer, which has been successfully controlled by introduced parasitoids, the gypsy moth–both Asian and European strains–which has thus far been prevented from establishing in the Pacific Northwest through diligent surveillance and immediate eradication efforts, and the balsam woolly adelgid, a sap-feeding insect that appears to be an increasing problem in the east side without an immediate solution. An increasing number of introduced woodboring insects that have been discovered in Oregon and Washington, including at least one east-side site, are also of growing concern.

Plants

A key issue for forest and rangeland health and productivity in eastern Oregon and Washington is invasive plant species (see Harrod 2001). Although some exotic plant introductions were accidental, many were intentional for wildlife habitat improvement, ornamental purposes, wood or fiber production, soil conservation, livestock forage production, or other crop uses. Exotic species, or weeds, can be a significant component of global environmental change because of their potential to alter primary productivity, decomposition, hydrology, nutrient cycling, and natural disturbance regimes. At smaller scales, they alter the structure, composition, and successional pathways of ecosystems. They lower diversity by outcompeting native plants. Disturbance caused by forest restoration activities (thinning and prescribed fire) can promote weed spread, but ultimately may improve native plant diversity and productivity, improving ecosystem resistance to weed invasion. Restoration strategies include consideration of weed prevention and control and restoration of natives. Prevention includes restoring ecosystem processes; control includes biological, manual, mechanical, herbicidal, and prescribed burning methods; restoration involves returning native plants to a site. Monitoring is important to provide managers with information that will allow them to evaluate restoration activities and modify ineffective restoration approaches.

Vegetation Patterns

Vegetation patterns in eastern Oregon and Washington are largely a result of environmental conditions, species distributions, plant ecology, and disturbances operating at multiple scales and in different environments (see Hemstrom 2001). In turn, vegetative patterns strongly influence the amount, severity, and distribution of disturbances generated by various agents. We focus on the latter—the relations between vegetation pattern, disturbance, and forest health and productivity. Older forests were historically mosaics of open, park-like stands in frequently underburned areas and more dense, closed stands where less-frequent, mixed-severity fires occurred. At all scales, vulnerability to disturbance appears to increase when vegetation condition and pattern differs from the historical or expected range for a given environment. Generally, forests that are older, composed of larger trees, denser, more homogeneous, or more contiguous than would be expected under natural or historical disturbance regimes are more vulnerable to mortality from insects and diseases. Factors related to vulnerability include site potential, host abundance, canopy structure, host size, patch vigor, patch density, patch connectivity, topography, and logging disturbance. Mortality from insects and diseases contributes to diverse habitat, but current levels of tree mortality from insects and diseases are often outside the historical or expected range of a given site environment. High levels of mortality may continue because many forests have become more contiguous and dominated by shade-tolerant species owing to fire suppression and management. Uncharacteristically severe fires will likely increase in the next 100 years even with restoration management because of changed vegetation conditions, landscape patterns, and, potentially, climate and other factors. Information on vegetation patterns at stand or site scales is relatively abundant in the scientific and management literature. Much broad-scale information is based on models and expert opinion. Research at broad scales is scanty, difficult to replicate, expensive, and time-consuming. However, broad-scale understanding of aggregate finer-scale effects seems necessary for effective landscape restoration.

Key Habitats

There are a few key habitats that any solution to forest health issues must address. These habitats are key for species of concern, but also provide ecosystem services that can be limiting if not specifically managed. We include here old growth, riparian, and soil, litter, and coarse woody debris habitats.

Old-Growth Habitat

Landscapes prone to historical fire, wind, insects, and diseases supported a complex mosaic of old-growth forest structure, and it is difficult to estimate the total proportion of the landscape that historically consisted of old-growth forest structure (see Youngblood 2001). Current old-growth forest structure is estimated to be as little as 3% of presettlement levels; what remains is in isolated patches and is at risk of loss from less frequent but more severe fires. Substantial areas of low-elevation ponderosa pine and Douglas-fir stands are now more densely stocked, contain increased fuel, and often represent compositional shifts to more lodgepole pine and grand fir. The changes are attributed to changes in natural disturbance regimes as a result of management of fire, grazing, timber harvest, wildlife, insects, and diseases. Treatments that can accelerate development of old-growth forest structure include thinning to accelerate growth on residual stems, returning fire to fire-dependent ecosystems, and maintaining large trees and snags. These methods have risks: prescribed fire may not mimic frequency and severity of historical fire, thinning may activate dormant stem decay, increased connectivity may increase susceptibility to stand-replacement fire, insects, and pathogens. Models for multiple species and interactions of treatments, insects, and diseases are not available.

Riparian Habitat

Riparian habitats in eastern Oregon and Washington compose a small percentage of the landscape, and yet these habitats are essential for many species of vertebrates (see Wales 2001). Riparian areas are sensitive to disturbance agents, which can pose a formidable challenge to effective management of these habitats. Moreover, few studies have documented the effects of disturbance agents on riparian habitats and associated fauna. In general, disturbances from insects and diseases likely have strong effects on cavity nesters and insect feeders, and use of Bt (*Bacillus thuringiensis*) to control insect pests may decrease the food supply for insectivores. Most fire effects on terrestrial vertebrates are through changes in habitat, food, and competitors, and responses to fire are variable and species specific. Salvage logging likely has negative effects for species that use dead and dying trees. Livestock grazing in riparian areas can eliminate nesting substrates, alter habitat structure and composition, compact soil, trample banks, encourage cowbird expansion, and increase exotic plants. The magnitude of these effects depends on the timing and intensity of grazing. There are almost no studies on how landscape-level vegetation patterns (including riparian corridors) contribute to the viability of wildlife populations. Managers have usually chosen to buffer riparian areas from harvest, spraying, and prescribed fire, but there are no decision-support tools or guidelines for management of riparian habitat for terrestrial vertebrates.

Treatments for forest health and productivity can affect sediment production in watersheds, channel forming processes, riparian vegetation, and risks posed to riparian zones (see Wondzell 2001). Severe wildfires can affect upland erosion; however, erosion from prescribed fires burning the same area should be much smaller. Dense riparian vegetation might help regulate the amount of sediment that reaches streams, but this effect would be strongly dependent on the geomorphic setting. Forest insects and pathogens are not expected to cause accelerated erosion and stream sedimentation directly, but indirect effects might be substantial if they lead to increased wildfire. The largest risk of accelerated erosion is expected from ground-disturbing activities during fuels reduction treatments, such as construction of roads and firebreaks or salvage logging or thinning. Historical intense grazing has changed composition and cover of riparian vegetation, leading to bank erosion, and in many places, widening or incision of stream channels. Improved grazing prescriptions can result in major changes to riparian vegetation, but response of channel morphology will most likely be slow.

Most of the studies reviewed were conducted at the site or small-watershed scale. Consequently, conclusions at these scales are generally well supported by the available literature. The cumulative effects of forest health and protection treatments imposed across a large region are difficult to assess, however. Given the current state of knowledge, dramatically changing forest land-use practices across eastern Oregon and Washington–including the widespread use of prescribed fires, salvage logging, and mechanical fuel treatments–is a long-term, landscape-scale experiment, the cumulative effects of which are unknown.

Soil, Litter, and Coarse Woody Debris

Arthropods within soil, litter, and coarse woody debris play vital roles in maintaining soil fertility, health, and productivity (see Niwa et al. 2001). Arthropods shred plant material, help mineralize nutrients for plants, act as predators, and serve as food for other wildlife. Some species or groups of species are potentially valuable for monitoring forest health. Natural and human-caused disturbance may immediately kill many arthropods, but changes to habitat structure are likely to cause longer-term effects on their community compositions. Fire effects on arthropods may be minimized if refugia of litter and coarse woody debris are retained. Possible effects of timber harvesting on arthropods include mechanical effects on soil and litter, microclimate changes, and the addition of organic matter, including coarse woody debris, to the forest floor. Soil compaction reduces pore size, which may result in loss of habitat and decreased nutrient retention, and changes the microbial and nematode communities, which can affect nutrient cycling and food resources for microarthropods. Thresholds required for healthy ecosystem function, and predictive and decision-support tools that include these components in relation to disturbances are not available.

Threatened, Endangered, and Rare Species

Managers proposing activities to improve forest health and productivity are mandated by the Endangered Species Act of 1973 to assure that their activities do not jeopardize the existence of any federally listed or candidate species. Much is known about the habitat, ecology, and populations of some species, whereas little is known about others. Natural disturbance events and management actions alike can have both positive and negative effects on various species, and decision-support tools that are integrated with disturbance factors are scarce. For these reasons, a mix of management actions combined with adequate reserves will help serve both uncertain and conflicting needs. Additionally, properly managed activities can be conducted without harm to the ecosystem. Examples include use of new "environmentally-friendly" harvest equipment, species-specific biological insecticides and pheromones, proper preparation and timing of prescribed fire, and modified grazing prescriptions. In general, solutions to forest health issues will need to consider key species and their habitats. Our discussion focuses on plants, salmonids, birds, amphibians, forest carnivores, and insects.

Plants

The floristic diversity of this area reflects the complex biophysical environment (see Croft 2001). There are many endemic vascular plants whose ranges lie entirely within this region; many are restricted to very small geographic areas or highly specialized habitats. A common element is adaptation to natural disturbance; non-natural threats include exotic plant invasion, agricultural conversion, road construction, recreation, fire suppression activities, livestock grazing, herbicide spray that reduces pollinators, and altered fire and hydrological regimes. Because various species are adapted to different successional stages, maintaining a diversity of stages would provide for a variety of these species. Restoration of the natural fire regime and reduction of grazing would benefit upland shrub communities. Mitigation of activities for rare plants is site-specific and may include altering the timing, level of intensity, or methods used.

Fish

Forest fires, insects, and diseases affect fish habitat by their influence on the rate and volume of woody debris recruitment to streams, canopy cover and water temperature, stream flow, channel erosion, sedimentation, nutrients, and residual vegetation (see Howell 2001). Physical effects from fire vary greatly depending on fire severity and extent, geology, soil, topography, and orientation of the site, and subsequent precipitation. Many of the effects moderate within a decade. Post-fire erosion and wood recruitment are also influenced by fire lines, road construction, and timber harvest. Although some disturbances, such as severe fire and subsequent floods, appear catastrophic, and effects may last decades or centuries, natural disturbances help create and maintain diverse, productive aquatic habitats. Recolonization of fish populations following wildfires can be rapid and is related to occurrence of local refugia, life history patterns, access for migratory forms, and distribution of the species. In most livestock studies, grazing negatively affected fish habitat and populations, but results may vary depending on sites and specific grazing management. Effective approaches to grazing management similarly depend on the specific application and the commitment of operators and managers. Restoration of the structure, function, and processes of watersheds more similar to those with which native species evolved may favor those species; however, there is little documentation of the aquatic effects of those activities. Risk from vegetative treatments may be minimized by keeping techniques that are somewhat experimental outside of critical areas (i.e., conserving key habitats and populations, focusing intensive treatments on upland sites). Use of more benign techniques (e.g., lower-impact logging systems) and pulsed treatments consistent with characteristics of natural disturbance regimes are other considerations for achieving both terrestrial and aquatic objectives.

Birds

Those bird species of concern that occur in forested habitats in eastern Oregon and Washington include the bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco peregrinus*), harlequin duck (*Histrionicus histrionicus*), upland sandpiper (*Bartramia longicauda*), northern goshawk (*Accipiter gentilis*), ferruginous hawk (*Buteo regalis*), and black rosy finch (*Leucosticte arctoa*) (see Bull and Wales 2001b). In addition, seven species of woodpeckers and nuthatches were considered because of their rare status. Forest disturbances that create dead trees and logs are critical to cavity-nesting birds because the dead trees with their subsequent decay provide nesting and roosting habitat. The insects associated with outbreaks or other sources of tree mortality provide prey for the woodpeckers and nuthatches. The loss of nest or roost trees as a result of disturbance could be detrimental to bald eagles, goshawks, or ferruginous hawks, while the loss of canopy cover could be detrimental to harlequin ducks and goshawks or to prey of some of the raptors. The more open canopies created by thinning may be beneficial to a species like the black rosy finch, yet detrimental to some woodpeckers due to a decrease in cover. Prescribed burning may be beneficial to those woodpeckers primarily associated with ponderosa pine (*Pinus ponderosa*) stands and detrimental to other woodpeckers because of the loss of coarse woody debris. Removal of roads is likely to benefit most of these species because of the subsequent decrease in human activity. Recovery plans for bald eagles and peregrine falcons are available for managers to use in managing habitat for these species.

Amphibians

Amphibians that occur in forested habitats in eastern Oregon and Washington that are considered of concern include the Oregon spotted frog (*Rana pretiosa*), Columbia spotted frog (*R. luteiventris*), northern leopard frog (*R. pipiens*), Cascades frog (*R. cascadae*), tailed frog (*Ascaphus truei*), Larch Mountain salamander (*Plethodon larselli*), and Cope's giant salamander (*Dicamptodon copei*) (see Bull and Wales 2001a). Little is known regarding the effects of forest health on amphibians, although tree mortality resulting from insects and diseases is unlikely to dramatically affect these species, except for the tailed frog and larch mountain salamander. Both of these species depend on overstory canopy to maintain temperature and moisture conditions; timber harvest in their habitats has rendered them unsuitable. Wildfire, and prescribed burning to a lesser extent, may alter the abundance of prey, coarse woody debris, and vegetation, which could influence movements and survival of dispersing amphibians. Spraying with pesticides could negatively affect these species if the abundance of their prey is decreased. Spraying with biological microbial agents or using pheromones to control insects is unlikely to affect prey abundance. Additional research is needed to determine if disturbances are contributing to the decline of many of these amphibians.

Forest Carnivores

Forest carnivores of conservation concern in eastern Oregon and Washington include the Canada lynx (*Lynx canadensis*), fisher (*Martes pennanti*), and wolverine (*Gulo gulo*) (see Bull et al. 2001). All three species depend to some degree on forest structures, stand conditions, and landscapes created by insects, diseases, and fire. Wildfire and insect outbreaks maintain a mosaic of age classes and structural stages across the landscape that are used by lynx. Thinning of dense lodgepole pine (*Pinus contorta*) stands that result from wildfire and insect outbreaks is detrimental to snowshoe hares (*Lepus americanus*), which are a primary prey of lynx. Fishers use large stands of mature forest and snags, hollow live trees, logs, stumps, witches-brooms, and other structures for rest and den sites. Salvage harvesting, thinning, and conversion from predominantly fir stands to ponderosa pine (*Pinus ponderosa*) may adversely affect habitat conditions for fishers. Use of roads is perhaps most detrimental to wolverines because they are easily trapped.

Insects

Insects play an integral role in the health of forest ecosystems (see LaBonte et al. 2001). While most insect species in eastern Oregon and Washington forests are presumed to be abundant and secure, some may be rare or in decline. Fifteen east-side forest insect species are currently listed as threatened, endangered, or sensitive (TES). These species can be classified according to the reasons for their listing, which include peripheral populations, relict species, species with restricted habitats or hosts, and endemic species.

Whether the needs of currently listed TES east-side forest insects are being met by current management practices can only be ascertained if adequate information is available on their distribution, abundance, habitat requirements, and biologies. However, this information is lacking for many species. For instance, five of the TES species discussed in this paper have poorly known distributions, and better information may change their status. Application of general principles for the conservation of invertebrate diversity and functions may help prevent other east-side forest insects from acquiring federal or state TES classification and could aid species already listed. Many practices already undertaken by federal land managers may help to protect TES populations and habitat. Specific management practices, such as preservation of key habitats at risk of degradation or alteration (e.g., springs and sphagnum bogs), may be necessary to prevent the decline or local extinction of some TES insects. Given the inadequate information available for most non-pest forest insects and their great diversity, a more systematic approach to their conservation and management is needed.

Socioeconomic Issues

In addition to ecological effectiveness, forest health treatments must also be socially acceptable and economically feasible. Such treatments, depending on their scope, can have important social and economic effects beyond the biophysical effects that motivated the treatments.

Economics

Management activities that affect forest health and productivity are driven by social, political, and economic processes (see Haynes et al. 2001). Economic feasibility is important in determining the extent to which various treatments proposed to improve forest health will actually be applied. Three socioeconomic institutions create incentives that are important determinants: markets, land uses, and the processing industry. We have extensive information on timber markets, and land uses have been studied at broad scales. Thinning undertaken for forest health improvement provides mostly small-diameter and dead material, but markets for products from small and dead logs are limited. Harvesting and manufacturing costs, resource characteristics, and lumber prices influence the way timber is processed (i.e., what products are made); design of timber sales (i.e., amount and size of raw materials offered) influences harvest cost. Processing equipment that scans logs and processes them according to shape can greatly improve product yield. Decision tools that incorporate these factors into financial evaluations can assist in harvest and other treatment decisions.

Sociocultural Aspects

Recent research pertaining to the human dimensions of resource management has led to the development of many tools to assess sociocultural factors and techniques to enhance and support decision-making processes (see Hall and Bigler-Cole 2001). Sociocultural factors affected by forest treatments include future timber supply (small-diameter, dead wood, changing species, sustained supply), smoke and hazard to developed areas from prescribed fire, aesthetic acceptability of treated (thinned, burned) areas, effects on valued species (i.e., salmon), and related recreation. Two broad categories used to describe sociocultural factors are social forces (including residence patterns and demographic characteristics) and human values about what is appropriate or desirable (including the roles of science and democracy in decision-making, natural conditions and scenic quality, sense of place, and vestedness). Tools for assessing individual cultural values are mostly at fine scale (community and county) and include questionnaires, hearings, workshops, and focus groups. Tools to weigh values in management decisions include various ranking and analysis techniques, geographic information systems, value-focused thinking, conjoint analysis, Q-methodology, and Delphi studies. Tools to incorporate sociocultural values in decisions include public participation, monitoring and evaluation, and adaptive management.

Solutions to the Forest Health and Productivity Issue—A Work in Progress

The above discussion highlights several common themes that might be used to create a solution to the forest health and productivity issue based on our current level of understanding. Potential solutions to many of the individual issues include returning fire at regular intervals; thinning overstocked stands; pruning; restoring a species mix appropriate to the site under consideration; using harvest methods designed to decrease compaction of soil and wounds on remaining trees; using activities that have pulsed (e.g., focused temporally and spatially) rather than chronic (e.g., widespread and long-lasting) effects; improving grazing management strategies in grassland and forest/grassland areas; retaining coarse woody debris, snags, and riparian vegetation; and maintaining a mosaic of successional stages. Another common theme is managing to restore processes with greater emphasis on the fire regime rather than solely on the individual fire events that are likely to occur.

Some options for improvement of a particular feature conflict with improvement of another feature. For example, thinning or removal of dead material to reduce risk of fire or bark beetle infestation may encourage spread of stem or root diseases. Removal of dwarf mistletoe brooms may decrease habitat for birds and mammals. Prescribed fire cannot be applied with retention of all coarse woody debris. Thus, the need to vary treatments from area to area, to balance competing needs, and to follow site-specific plans is apparent.

The real solution to the forest health and productivity issue for eastern Oregon and Washington is more about setting priorities, determining emphases for individual landscapes, obtaining resources needed to apply treatments, and relying on professional judgments than it is on defining new and unique treatment schemes or searching for treatments that pose no short-term or long-term risk to important resources. This approach assumes that risks are present now and will change whether or not actions are taken. Existing knowledge and tools enable managers and the public to gain some insights into where those risks may be high, where they may be increasing, and how they may change through time under various management strategies.

Much is known about significant pieces of ecosystem function. The Pacific Northwest Research Station has contributed substantially to the existing body of knowledge and is working with its partners toward an improved decision framework. This synthesis reveals areas that may produce the biggest payoff from further research. Basic information still needs to be examined at broader scales. Some monitoring techniques are available for assessing disturbance and recovery, as are thresholds that indicate boundaries for resilient ecosystem functioning, but more can be done in this area, particularly in diseases and the soil food web. Much is known about treatment options for individual problems, but much more interpretation and synthesis is needed in the area of integrated tools that aid decision-making in the real world where problems are compounded. Additionally, the decision-making process needs to more effectively incorporate economic and social factors.

Management options that will improve dysfunctional systems and reduce unacceptable risks are available in the mix of management practices already defined: thinning, prescribed fire, grazing management, and use of insecticides, herbicides, and biocontrol agents. The tools are well known. The challenge remains in deciding when and where to use those tools. Managers need a framework for integrating the available models that includes decision rules for when to use what model, data type, and data source. Further, those models need to (1) incorporate appropriate assumptions and make those assumptions clear, (2) consider all relevant variables, (3) use data compatible with other models, and (4) ensure that model outputs give answers that are relevant and useable.

Scale Considerations

A big part of the decision-making challenge is in scale of focus. Much historical scientific work and most management focuses on the site or stand. It is relatively easy to form a goal and propose activities that will help achieve that goal for a small site. At the site scale, much information is available, fewer people are involved in decisions, and more models and projection tools are available (Table 2). It is much more difficult to form a specific goal for entire watersheds or landscapes, and even harder to form a plan that would achieve that goal over time given the dynamic nature of disturbances and other ecological processes and the changes in funding and human resources to implement actions. Assuming one were able to come up with a plan that allows for an acceptable vegetation pattern, mix of vegetation successional stages, mix of land uses (recreation, timber production, mushroom production, wilderness, etc.), adequate species mix, and a plan to achieve that pattern and mix, it would only be a matter of time before the pattern and mix shifted. In fact, rather than describe a specific desired future condition, which implies a static goal, it may be more useful to think of achieving a dynamic "desired disturbance regime."

Even incorporating all that complexity, it is quite feasible that scientists, managers, and the public working together can come up with an acceptable future vision. But how do we implement that vision? A major difficulty is in deciding exactly which part of the vision a particular piece of land fits into. A visit to the site may suggest immediately what its "best use" might be, but how does that fit into the larger plan? Adding up the "best use" of all the individual sites may not achieve the desired landscape. The decision-support framework should assist with this task of integrating actions across scales.

Steps in developing and implementing such a framework are iterative and include:

- Establish goals at all scales that are consistent across scales.
- Assess current conditions and risks.
- Develop management options.
- Describe outcomes of those options.
- Select an option that is socially acceptable, economically feasible, and ecologically attainable.

TABLE 2. Relative availability of knowledge and modeling tools and typical decision-maker at various scales.

Scale	Who Decides	Level of Understanding Science Offers	Availibility of Models and Projections
Site/stand/project	Landowner or resource manager	High	High
Subwatershed	Landowner or resource manager (sometimes a mix)	Moderate	Moderate
Watershed	Usually a mix of landowners and resource managers	Moderate	Low
Landscape	Usually a mix of landowners and resource managers	Low	Low

- Establish priorities for action.
- Implement those priority activities.
- Monitor and evaluate the results of actions.
- Return to appropriate step for next cycle.

Feedback loops are essential. For example, after examining the outcomes of the options, one may learn that the specific goals are inappropriate or not attainable. Returning to the goal-setting stage would then be appropriate. Similarly, after result evaluation, a return to assessment, option development, prioritizing, or other step may be indicated.

Science Role

Science can help assemble information and tools needed for decisions at various scales once goals are determined. Essential items listed above for improving forest health and productivity include characterization of sites and assessment of risks and opportunities, description of management options and outcomes of those activities, prioritization for where and when to undertake activities, and monitoring and evaluation of outcomes over time. Research contributes basic understanding of resource conditions and interactions, models that can assess risk and opportunities, models that can predict future conditions, and options regarding management actions that can provide probable futures. Necessary steps that are outside the scope of scientific contribution are the choice(s) of desired future landscapes, the decision to achieve specific goals, attention of resource specialists to broadly based forest health and productivity goals, public acceptance of the mix of actions needed to achieve specific goals, and applying resources adequate to carry out the treatments.

Management Challenges

Currently, crises demand considerable energy and resources from managers: widespread wildfires in 2000, western spruce budworm epidemic of the 1980s and 1990s, tussock moth outbreak of 2000, mountain pine beetle outbreaks of the 1970s, ongoing outbreak of Douglas-fir beetle, listing of Snake River Chinook salmon, bull trout, and Canada lynx, and on and on. Although there appears to be broad support for improving forest health and productivity, the cumulative actions of management agencies have been by necessity (given limited money and staff) focused on crises that prevent planning and implementing broadly based strategies that would reduce broadscale risks.

In addition to dealing with the constant crisis environment, managers must respond to a bewildering array of laws that often appear contradictory. For example, the National Forest Management Act (1976) calls for planning that results in a balancing of resource uses, while the Endangered Species Act (1973) appears to mandate actions for a single purpose—the provision of habitat and persistence of a species at risk—as though risks could be reduced to zero or near zero. The Clean Air Act (1970) is unclear in how it interprets smoke that might be generated from fires planned to maintain habitat mandated under the Endangered Species Act. Fire that once naturally maintained an ecosystem and its habitats may now need to be prescribed, forcing debate as to whether there is a natural background level of smoke that should be allowed, even if that level is now from prescribed fire rather than naturally occurring fire.

Although there is much that science can contribute to solutions, the ability to implement actions to achieve improved forest health and productivity depend on the availability of resources to plan and implement actions, the financial feasibility of specific practices on specific sites, the attention of resource specialists and the public to undertake the actions, and acceptance by the public, interest groups, agencies, and policy makers of the mix of management actions proposed.

Broad-Scale Assessments

Several efforts in recent years have attempted to take a whole system view and encompass a wide range of purposes, participants, methods, scope, and success. Results of these efforts range from relatively speedy answers that are narrow in scope (and possibly too narrow to solve the underlying problems) to long-term, broad-based assessments that frustrate needs for immediate policy solutions and management decisions. Johnson and Herring (1999) described broad categories of assessments according to the role scientists play:

1. Scientists assess situation and develop a recommended plan (scientists act as philosopher-kings). For example, Interagency Science Committee plan for conserving northern spotted owls (Thomas et al. 1990) was produced by an inter-agency

team of scientists designated by members of Congress.

2. Scientists develop management alternatives and evaluate them (scientists act as policy analysts and policy makers). The Forest Ecosystem Management and Assessment Team task evolved from proposing a single plan, to proposing alternatives from which the President chose one (FEMAT 1993). South Florida Assessment was conducted by a self-convened group of scientists concerned about drainage and loss of the Everglades (Davis and Ogden 1994, Johnson et al. 1999).
3. Scientists evaluate current conditions and trends and evaluate outcomes of alternatives proposed by managers in response to public goals (scientists act as policy analysts). The Interior Columbia Basin Ecosystem Management Project examined current conditions and future management alternatives for the entire interior Columbia River basin (Quigley et al. 1996).
4. Same as 3 except scientists assist in developing alternatives (scientists act as policy analysts and contributors to policy making). The San Francisco Bay and delta are the focus of CALFED, a group of federal and state agencies focused on solutions to water issues in the bay-delta estuary (see http://calfed.ca.gov).
5. Scientists critique management plans (scientists act as bystanders and critics). The initial National Forest Management plans, developed by managers in response to the National Forest Management Act, were largely critiqued by scientists with little direct involvement during the planning process (Johnson et al. 1999).

A sixth category might be added that recognizes a more traditional role for science in synthesizing/reviewing the existing literature related to a specific set of issues and identifying existing knowledge gaps (scientists act as knowledge brokers). The synthesis of knowledge and conditions related to forest health in the Blue Mountains of eastern Oregon and Washington (Jaindl and Quigley 1996) and the papers in this special issue of Northwest Science represent examples.

The role that an individual scientist or team of scientists plays in addressing resource issues from a policy perspective varies according to their personal interests, their willingness to risk their credibility, their affiliation (i.e., the assignments they receive), and their experience and background. The current trend appears to pull scientists further into the policy process with more assessments at broader scales.

Forest Health and Productivity Initiative

The Forest Health and Productivity Initiative of the Pacific Northwest Research Station seeks solutions to these challenges—treatment options for specific problems, information on tradeoffs of options, and tools to assist in making choices (Hayes et al. 2000). The Initiative emphasizes integration at multiple scales and identification of linkages that will improve predictive capability. Initiative research is organized into four categories:

- Increase basic knowledge of system elements at multiple scales.
- Implement adaptive management by joint efforts of scientists and land managers.
- Apply methods to enhance particular ecosystem values by managing fire, insects, and disease.
- Develop models and decision-support systems to assist with integrated management of fire, insect, and disease disturbances.

Research projects are chosen that develop options for managing insects, diseases, and fire disturbances with managers as collaborators, that integrate biophysical and socioeconomic considerations, that identify linkages across scales, and that fill significant knowledge gaps at the mid or broad scale.

A major new watershed-level effort (category 5 above) that has begun under Initiative leadership is the Interior Northwest Landscape Analysis System (INLAS). In INLAS, a team of scientists and managers plan to develop a suite of models and tools to help landowners and managers characterize conditions and predict future outcomes in a consistent way. They are focusing on a particular watershed (part of the Blue Mountains Demonstration Area, a national watershed restoration area) to keep the work grounded and not just theoretical. They will develop decision rules for when to use what tools and consistent definitions of data type and collection method so that data from various sources are compatible. They will examine assumptions to ensure consistency among components and describe their appropriate application. Such up-front planning will ensure that models yield useable answers to pertinent questions.

Decision-Making Process

The purpose of all of this knowledge, ultimately, is to help people make informed decisions. In recent decades, the process of resource decision-making for federal lands has evolved from one of primarily agency decisions in response to Congressional mandates, to one of interest group involvement and bitterly contested dissension, to broader citizen involvement early in the proposal process. The research role is evolving as well. Court-contested management and emphasis on scientifically based decisions have thrust scientists into the fray. Demands for information where research is incomplete have led to more reliance on expert opinion and development of techniques for gathering it. Science is increasingly focused on clearly defining trade-offs among options. Research has a continuing role to reexamine and update prior conclusions. The model for adaptive management with early and continuing public involvement, scientific input, and regularly adjusted management actions continues to be refined.

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