THINNING, FIRE AND FOREST RESTORATION

A SCIENCE-BASED APPROACH FOR NATIONAL FORESTS
IN THE INTERIOR NORTHWEST

by RICK BROWN

DEFENDERS OF WILDLIFE
WASHINGTON D.C. • WEST LINN, OREGON

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ABOUT DEFENDERS OF WILDLIFE

Defenders of Wildlife is a leading nonprofit conservation organization recognized as one of the nation's most progressive advocates for wildlife and biodiversity conservation. The West Coast Office emphasizes alternative approaches to environmental decision-making through partnerships that engage a broad spectrum of participants in processes that help people with divergent interests find common ground and constructive solutions.

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FOREWORD

When we asked Rick Brown in the summer of 2000 to write a paper on the appropriate uses of fire and thinning in forest restoration, we expected the final product to be of interest primarily to Defenders of Wildlife and the small circle of interests involved in the Lakeview Sustainability Initiative in Lake County, Oregon.

Defenders was one of several national conservation organizations involved in the community-based effort to chart a new direction for the Fremont National Forest's Lakeview Sustained Yield Unit. Rick, then an independent consultant, was tracking the process for the Wilderness Society. With forest restoration emerging as the primary focus of the Lakeview initiative, we asked Rick to spend some time exploring the scientific basis for active management techniques such as thinning and prescribed fire.

by BRUCE TAYLOR
Director, Oregon Biodiversity Program
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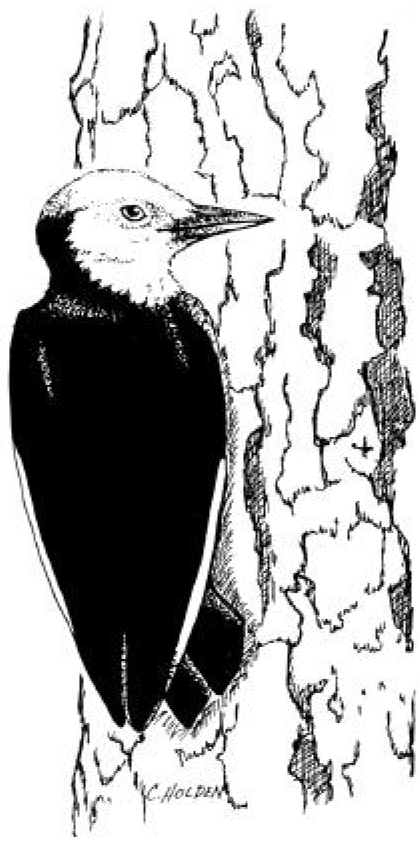
Shortly after we contracted with Rick to write this paper, the summer fire season blew up with an intensity matched only by the inflammatory political rhetoric the fires provoked. As the smoke cleared, we saw a much broader audience for a more thoughtful examination of some of these issues. Coincidentally, we also had the opportunity to recruit Rick to join the staff of Defenders' West Coast Office.

We are pleased to be able to share Rick Brown's timely distillation of these complex issues, and consider ourselves doubly fortunate to have Rick with us. We hope this publication will help set the stage for an ecologically sound approach to forest restoration on the public lands of the interior Northwest.



White-headed woodpecker
by Christine Holden

INTRODUCTION

Much of the National Forest landscape in the interior Northwest has been transformed, especially dry, low-elevation forests dominated by ponderosa pine. These changes began in the second half of the 19th century with the introduction of livestock grazing. Beginning in the late 19th century and accelerating after World War II, selective logging of old fire-resistant trees, extensive road-building to facilitate logging, fire exclusion, and livestock grazing continued trends of forest and watershed degradation. These trends have dramatically altered many forest habitats, especially those supporting species associated with older forests. These management activities have often led to the growth of smaller, less fire-resistant trees in denser stands that can allow the spread of more damaging fires across more of the landscape, to the detriment of habitat, watershed function and the well-being of people whose homes are adjacent to National Forest lands. Roads have severely disrupted hydrologic conditions, and livestock grazing has extensively affected riparian (streamside) ecosystems, degrading water quality and aquatic habitats and contributing to the decline of many species of fish and other aquatic life. Invasive exotic plants (noxious weeds) have invaded extensive areas, degrading both terrestrial habitats and watershed integrity. The Forest Service now needs to reverse these trends if legal requirements to maintain biological diversity and water quality are to be met while maintaining the land's productive capacity (ICBEMP 2000, USDA Forest Service 2000c).

Beginning in the late 19th century and accelerating after World War II, selective logging of old fire-resistant trees, extensive road-building to facilitate logging, fire exclusion, and livestock grazing continued trends of forest and watershed degradation.

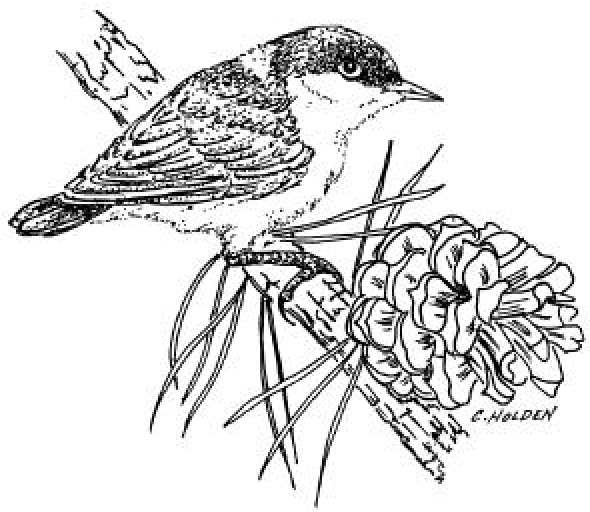
While these problems can appear daunting, methods to address many of them are being developed and refined. Unfortunately, progress lags behind potential for a host of reasons including institutional inertia, commercial pressures, inter-agency conflicts, budgetary limitations, and a lack of political will. One key impediment is the need for a strategic approach that could make more effective use of limited resources. Ecological problems are pervasive, and in one sense, restorative actions taken almost anywhere would provide some benefit. In light of the risk of loss of populations and species of fish and wildlife, the needs of local human communities, and the limited resources available for restoration efforts, what is needed are strategically focused, integrated approaches that will get maximum benefits for a given cost while minimizing unintended adverse effects (Agee 1996a, Finney 2001, Rieman et al. 2000). Focusing treatments in high priority watersheds while integrating aquatic, terrestrial and socio-economic considerations should increase the probability of success of restoration (ICBEMP 2000, Rieman et al. 2000). There will always be some tension between the need to be strategic and the need to act; a good strategy effectively and promptly implemented will be preferable to a perfect one that is never fully developed or put into practice.

Neither haste nor hesitation is acceptable. Millions of acres in the interior Northwest could use some form of treatment (including rest from past and ongoing abuses) if we are to avoid adverse effects on wildlife, fish and human communities. Problems 150 years in the making will take many decades to correct. The needs are great and our knowledge is adequate to begin the task, but the gaps in our knowledge are so substantial that these tasks must be approached with humility and a commitment to learn from both our successes and mistakes.

There is considerable debate about both the extent and nature of human-caused changes in the forest landscape, and the need and means to address those changes. In focusing on issues relating to forest alteration and restoration in the interior Northwest, this paper is a modest attempt to find what Ruggiero and others (2000) describe as the "middle ground between demanding certainty and embracing opinion." I will attempt to explore the scientific basis for what we appear to know, how we might proceed, and what we need to learn. This is neither an exhaustive review of the literature, nor an attempt to address all issues related to forest restoration. Rather, it is an attempt to review the most pertinent scientific literature, merge these findings with policy requirements, and provide recommendations on how best to proceed. Qualitative judgment will inevitably be involved, and what follows should be viewed as general principles, considerations, or rules-of-thumb.

A NOTE ON LANGUAGE

As is often the case, some of the debate over forest restoration is more about language than substance. Apparently simple and straightforward words such as "forest", "thin", and "fire" encompass a wide range of conditions or activities and often connote vastly different things to different people. Forests in the interior Northwest range from dry, low-elevation ponderosa pine to cold, moist, high-elevation forests of subalpine fir and Englemann spruce. Thinning can describe practices ranging from light removal of small understory trees to heavy removal of dominant overstory trees. Fires vary from "cool" surface fires to severe, stand-replacing crown fires. These imperfections of language are compounded by a form of labeling fallacy and a seemingly ineluctable (albeit specious) logic that takes the form of "thinning is logging, and logging means timber sales, and since timber sales have created existing problems, thinning will only make things worse." It is inarguably true that conventional logging practices have contributed (and still do contribute) substantially to degradation of forest habitats and increased risk of destructive fires (Agee 1993, 1997b; Agee et al. 2000; Weatherspoon and Skinner 1995; Weatherspoon 1996; Skinner and Chang 1996; Huff et al. 1995; SNEP 1996; Graham et al. 1999; Stephens 1998, Franklin et al. 2000). Such reasoning, however, does little to shed light on the possible efficacy of understory thinning undertaken to meet explicit restoration objectives.



Pygmy nuthatch
by Christine Holden

THE SETTING

The complexity of the forests of the inland Northwest beggars simple description. Common classifications and descriptions are based on the tree species that comprise the forest (or those that might, given enough time without disturbance) (Agee 1996b); the physical environments forests occupy; or fire regimes, particularly those characteristic of pre-Euro-American-settlement times (Brown 2000, Arno 2000). (Regimes describe the key variables of frequency, predictability, extent, magnitude, synergism, and timing of fire [Agee 1993].) For instance, warm, dry environments are generally dominated by forests of ponderosa pine that historically supported frequent (at average intervals of less than 25 years), low-intensity fires that burned understory vegetation, but seldom burned in tree crowns or killed mature trees. With increasing elevation, where average temperatures are cooler and precipitation greater, tree species such as grand fir and white fir play an increasingly important role, and intervals between fires tended to be longer and more variable. The effects of fire could range from underburns similar to those in ponderosa pine, to stand-replacing crown fires. At still higher elevations, cold, moist environments support forests that are apt to be comprised of subalpine fir and Englemann spruce, where average times between fires might range up to several hundred years, with a high probability of stand-replacing effects.

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These generalizations are complicated by a variety of factors. South and west-facing slopes tend to be warmer and drier and therefore support stands more typical of lower elevations, while forests characteristic of higher elevations tend to extend lower on north and east-facing slopes. Each tree species has a range of environmental circumstances under which it can become established and grow. Species distributions sort out independently, blurring the lines humans would like to apply to delineate clear forest zones and types. While burning by Native Americans interacted with fire patterns resulting from lightning (Agee 1999b), establishing different fire regimes and thus different vegetation, the extent and influence of such burning is difficult to determine (Vale 2002). Climate varies, with a key example being the several hundred-year period of cooler, wetter weather known as the Little Ice Age, which drew to a close around the time of Euro-American settlement in the mid-1800s. Many trees still living were established during the Little Ice Age, but the same species might be unlikely to become established under current conditions (Millar and Woolfenden 1999). Shorter-term fluctuations in climate can lead to sharp variations in fire characteristics or regeneration and survival of trees.

Forest Types and Conditions

Notwithstanding the complexities described in the previous section, and at the risk of over-simplification, there are some useful generalizations that can be applied to forests and the changes they have undergone.

The clearing effects of fire produced the classic "park-like" stands of old-growth pine described by early settlers. These open forests of large old trees provide prime habitat for birds such as the white-headed woodpecker and pygmy nuthatch.

DRY FORESTS

Dry forests of ponderosa pine (occasionally Douglas-fir) were shaped by what is sometimes referred to as a "stand-maintenance" fire regime of low-severity, frequent fires that generally burned grasses, brush, small trees, and fallen needles and branches, but had little effect on older trees with thick insulating bark. Death of lower branches from shading or the effects of fire raised the bottom of the canopy to the point where it was not adversely affected by typical fires.

Periodically, small groups of older trees were killed by bark beetles and, often after falling, would be consumed by fire. This would leave exposed mineral soil and an opening in the canopy, ideal conditions for establishment of a group of young pine trees. This cohort of trees would be thinned by competition, insects, disease, and fire as they grew older, eventually replacing the patch of older trees that previously occupied the site. This dynamic would repeat across the landscape, producing extensive stands of large old trees that appeared even-aged but were actually comprised of many patches of trees of different ages (Weaver 1943). The clearing effects of fire produced the classic "park-like" stands of old-growth pine described by early settlers. These open forests of large old trees provide prime habitat for birds such as the white-headed woodpecker and pygmy nuthatch (Marshall 1997, Wisdom et al 2000). In extremely hot and dry weather, fires would tend to cover a larger area but still were unlikely to kill overstory trees (Agee 1997b).

While some areas still resemble historic conditions, it is these dry-site forests of ponderosa pine that typically have been changed the most by human activities in the last 150 years. Livestock grazing depleted the fine fuels that carried the light, frequent fires, while their hooves exposed mineral soil seedbeds for young ponderosa pine (Swetnam et al. 1999, Belsky and Blumenthal 1997, Miller and Rose 1999). Fire suppression, beginning after 1910 and becoming effective around 1940, allowed far more of these trees to persist, while logging removed most of the large old trees (Biswell et al. 1973). These forests may now have been deprived of ten or more natural fire cycles. The result is forests that, due to continuing fire suppression, tend to burn less frequently, but when they do burn, the fire is much more likely to reach the forest canopy and spread as a crown fire, killing many or all of the overstory trees. A historically low-severity fire regime has turned into a high-severity or mixed-severity fire regime, a change that has occurred over millions of acres in the Interior Columbia River Basin (Morgan et al. 1996, Hann et al. 1997). These higher-severity fires are more apt to have detrimental effects on soils and watersheds, as well as wildlife habitat. They can also have serious implications for humans who have chosen to settle in and around these forests.

MOIST FORESTS

Mid-elevation forests are more difficult to describe in general terms. Cooler, moister conditions allow less drought- and fire-tolerant species such as grand fir and white fir, as well as Douglas-fir, western larch and ponderosa pine, to grow in these areas. In some areas these sites support ponderosa pine-dominated stands that appear similar to the drier forests at lower elevations, although their fire histories may be more complex and variable over long time periods (Shinneman and Baker 1997, Brown et al. 1999, Veblen et al. 2000). With fire exclusion, fir trees can eventually dominate these sites. Where fires were less frequent (up to 200 years or more apart) due to differences in moisture, terrain, lightning or Indian burning practices, more of the other tree species would be present, producing mixed-conifer forests that experienced a fire regime that can also be described as "mixed." Fires could range from low to high severity, depending on the interval between fires (and thus the accumulation of woody fuel), the weather conditions when the fire burned, and topography. Fires of differing severity can occur in close proximity, creating a complex mosaic of forest structures in patches of varying size (Taylor and Skinner 1998).

Fire can damage or kill trees through effects on the cambium (the growing portion of the tree that lies beneath the bark), roots, or foliage (Agee 1993, Ryan and Rheinhart 1988, Peterson and Ryan 1986). Each species of tree has different vulnerabilities to fire, which can vary on different sites (some soils cause roots to be more shallow and thus more at risk of lethal heating), and at different times of year (ponderosa pine roots apparently are more vulnerable to a spring burn than one in the fall) (Swezy and Agee 1991). The interactions of terrain, fire and tree species historically produced a mosaic of stand conditions and wildlife habitat that would shift across the landscape over time. In general, older mixed-conifer forests were structurally complex, with multiple canopy layers and abundant dead standing trees (snags) and logs.

Fire suppression has generally been effective for one to four fire cycles, and has allowed the development of denser, multi-storied forests on more of the landscape. While the fire regime can still be described as mixed, the relative proportion of fire types has shifted, and severe fires are more likely to occur on more of the landscape than they would have historically.

These moist mid-elevation forests, which tend to be the most productive in the interior Northwest, have been heavily altered by logging and road-building. Timber extraction has depleted older forests and generally reduced the presence of large trees, snags and logs, which are key habitat elements for many species of wildlife, such as goshawk, American marten, Vaux's swift and pileated woodpecker (Wisdom et al. 2000, Bull and Hohman 1993, Bull and others 1992, 1997). Fire suppression has generally been effective for one to four fire cycles, and has allowed the development of denser, multi-storied forests on more of the landscape. While the fire regime can still be described as mixed, the relative proportion of fire types has shifted, and severe fires are more likely to occur on more of the landscape than they would have historically (Anonymous 1999).

COLD FORESTS

At still higher elevations, forests of subalpine fir, Englemann spruce, mountain hemlock and lodgepole pine predominated.

These forests are slower growing, but cool, moist conditions generally caused significant fires to be infrequent, allowing development of dense forests of fire-sensitive trees. At periods averaging a few hundred years, extreme drought conditions would prime these forests for large, severe fires that would tend to set the forest back to an early successional stage, with a large carryover of dead trees as a legacy of snags and logs in the regenerating forest. The fire regime for these forests can be described as "weather dominated" in that high fuel loadings are typical and the fire events that determine forest patterns occur under uncommon, extreme weather conditions that can result in stand-replacing fires over large areas (Agee 1997b). While logging and road building have had some detrimental effects on these forests, the fundamental dynamics are relatively little-changed because fire suppression has been effective for less than one natural fire cycle. Fuel levels may suggest a high fire "hazard" under conventional assessments, but what most needs to be considered are the ecological consequences of wildfire, which are apt to be low in these settings.

Restoration Goals and Priorities

The foregoing brief review of the changes that have occurred in forests and watersheds of the inland Northwest leads to the question of what to do about these changes. There appears to be broad agreement that some form and degree of restoration — of habitats, populations of fish and wildlife, productivity of soils, watershed integrity, disturbance patterns — is appropriate (ICBEMP 2000, USDA Forest Service 2000c, Weatherspoon and Skinner in press). However, there is less than full agreement on the objectives of restoration and the best means to achieve those objectives.

While knowledge of historical conditions will be useful, even essential, in guiding restoration efforts, attempts to strictly recreate conditions of the past will often be neither desirable nor feasible.

One commonly suggested approach is to restore landscapes to some semblance of presettlement conditions, or their "historic range of variability." Advocates presume that stands and landscapes like those of the past will provide conditions more likely to support healthy populations of wildlife and fish. Not only would habitats be more like those to which species had adapted over thousands of years, but disturbance processes (fire, insects and disease, floods, landslides) could operate more sustainably in a more resilient landscape. A consensus seems to be emerging that while knowledge of historical conditions will be very useful, or even essential, in guiding restoration efforts, attempts to strictly recreate conditions of the past will often be neither desirable nor feasible (Chang 1996, Christensen 1988, Gregory 1997, Hessburg et al. 1999, Landres et al. 1999, Millar and Woolfenden 1999, Moore et al. 1999, Swanson et al. 1994, Tiedemann et al. 2000).

Knowledge of historic conditions can help clarify the types and extent of changes that have occurred in ecosystems, and help inform the identification of management objectives and restoration priorities (Hessburg et al. 1999). However, climates are now different than at any historic time, and will be different in the future (Millar and Woolfenden 1999). Species have been irrevocably added and subtracted, and the modern human imprint cannot be entirely eliminated. Historical reconstructions can provide good estimates of the large tree component of past forests, but are less reliable for small trees or other ecosystem elements such as herbaceous vegetation or wildlife (Harrod et al. 1999, Fule et al 1997). While past fire regimes may be more accurately estimated than forest structure and composition (Stephenson 1999), as Agee (1998b) points out, "the natural fire regimes of the past are not the regimes of the present, nor will they be the regimes of the future." Nonetheless, careful determinations of past conditions (for example, Harrod et al. 1999, Fule et al. 1997) can be an essential part of deciding what needs to be done. Planning also needs to recognize that conditions other than historic (or "natural") may need to be maintained in order to provide essential habitat for at-risk wildlife until such time as suitable habitat can be restored more broadly on the landscape (Wisdom et al. 2000, ICBEMP 2000).

Determination of restoration goals also needs to recognize potential conflicts or trade-offs among reasonable objectives. Aggressively modifying stands to be highly resistant to severe fire may unintentionally degrade watersheds and habitats for fish and wildlife (Rieman and Clayton 1997, Gresswell 1999). While thinning of co-dominant trees may contribute to restoration of more open stand conditions in some areas, such thinning requires careful consideration of potential unintended consequences. Opening the canopy can exacerbate some fire risks by encouraging the growth of grass and exposing the forest to the drying effects of sun and wind (van Wagtendonk 1996, Weatherspoon 1996, Agee et al. 2000).

Effective communication across traditional disciplinary boundaries will be essential. Too often, discussions are framed in terms of forest health, fire risk and hazard, insect and disease potential, conserving wildlife or fish habitat, or hydrologic condition. The concept that shows the greatest promise for encompassing all these concerns, and more, is ecological integrity.

Higher wind speeds also contribute to more intense fire behavior. Conversely, thinning may increase growth of forbs and shrubs, which can retain moisture until later in the season, reducing fire behavior (Agee 2000). Heavily thinning stands to reduce canopy density and to lower the risk of spreading crown fire may degrade habitat for wildlife needing more closed-forest conditions. Excessive ground disturbance can also degrade soil quality, watershed integrity and aquatic habitats. Notwithstanding these various conflicts and trade-offs, complementary objectives are also possible. Since roads are usually the principal source of degradation of aquatic habitats and are also closely linked to the logging and fire suppression that have degraded terrestrial systems, needs for active management to improve both watershed and forest integrity are apt to coincide (Rieman et al 2000, Lee et al. 1997). Watershed analysis should provide a mechanism for identifying and resolving potential conflicts among objectives.

Effective communication across traditional disciplinary boundaries will be essential. Too often, discussions are framed in terms of forest health, fire risk and hazard, insect and disease potential, conserving wildlife or fish habitat, or hydrologic condition. The concept that shows the greatest promise for encompassing all these concerns, and more, is ecological integrity (Angermeier and Karr 1994). As the Society of American Foresters (1993) put it, "The essence of maintaining ecosystem integrity is to retain the health and resilience of systems so they can accommodate short-term stresses and adapt to long-term change. The key elements include: maintenance of biological diversity and soil fertility; conservation of genetic variation and its dispersal; and through evolution, future biological diversity." The essential components of ecological integrity are the same as those that have been described as basic to ecosystem sustainability: soils, water, species diversity (habitat), resistance to disturbance and evolutionary potential (Perry 1998).

Flammulated owl
by Christine Holden

Restoration Treatments

Ecological restoration efforts are often categorized as either active or passive. While this can be a useful distinction, the term "passive restoration" suffers from potential confusion with "passive management," which some people consider equivalent (at least in some circumstances) to mere neglect or inattention to the needs of the land (Agee 2002). Passive restoration, properly applied, is not at all indifferent or unthinking, but rather should be the result of thoughtful analysis and careful decision-making. Passive restoration is the "cessation of . . . activities that are causing degradation or preventing recovery," (Kauffman et al. 1997) and can be considered the first step in restoration (National Research Council 1996). Passive restoration primarily involves allowing vegetation or other organisms to restore desirable ecological conditions, but can also include allowing wildfires to burn under certain conditions as "prescribed natural fire." One particularly appealing example is the benefits than can quickly accrue if riparian vegetation is allowed to recover sufficiently to support beavers, which can then accomplish a great deal of additional restoration work at no cost (Kauffman et al. 1997).

The primary active restoration techniques considered here are thinning and prescribed fire, although other active treatments, including closure and obliteration of roads, control of off-road vehicles, improved livestock management, in-stream work and noxious weed control, will need to be employed for comprehensive forest and watershed restoration.

The primary active restoration techniques to be considered here are thinning and prescribed fire, although many other active treatments, including closure and obliteration of roads, control of off-road vehicles, improved livestock management, in-stream work, and noxious weed control, will need to be employed for comprehensive forest and watershed restoration. Restoration approaches that focus excessively on thinning will not be considered credible by large portions of the public.

For the purposes of the following discussion, "thinning" refers to "understory thinning," "thinning from below" or "low thinning" to describe the cutting and removal of small trees that may be necessary to meet objectives for restoration of habitat and fire regimes. The majority of these trees will be too small to have commercial value by conventional standards, but efforts are underway around the West to develop processing methods and markets for ever-smaller material. One way or another, some thinned trees may have commercial value that can appropriately be captured as a by-product of restoration activities (Noss 2000). However, removal of large, pre-settlement trees solely to provide a commercial product is apt to undermine credibility of restoration efforts while degrading wildlife habitat and exacerbating fire risk (Weatherspoon and Skinner 1995, Agee 1997b). Restoration thinning may appropriately include the removal of dead trees. However, "salvage" logging, founded on a purely commercial premise, often with truncated environmental considerations and its own peculiar funding imperatives, should not be expected to provide restoration benefits. Through damage to soils and the removal of large trees, snags and logs, salvage is almost certain to degrade ecological integrity, particularly after fire (Beschta et al. 1995, McIver and Starr 2000). Unsalvaged young forests, developing with a full abundance of snags and logs, may be the most depleted forest habitat type in regional landscapes (Lindenmayer and Franklin 2002).

Restoration objectives may be accomplished by prescribed fire alone in some forest types and conditions (Agee and Huff 1986, Biswell 1989, Anonymous 1999, Weatherspoon 1996). Thinning, although it may successfully reduce fire hazard, is very unlikely to meet ecological objectives unless it is combined with prescribed fire (Weatherspoon 1996). Thinning cannot replicate many of the beneficial ecological effects of fire (Weatherspoon and Skinner in press, National Research Council 1999). Thinning can also lead to more severe fires (Agee 1996a, Graham et al. 1999, Weatherspoon 1996), especially if logging slash is not adequately treated. On the other hand, prescribed fire, if applied too broadly and simplistically, can also tend to homogenize the landscape and have detrimental effects on wildlife habitat and nutrient availability (Tiedemann et al. 2000). Widespread prescribed fire can also cause public resistance due to effects on air quality. Neither thinning nor fire will be a panacea; both must be used, but used thoughtfully. Nothing will make forests fireproof, but it appears feasible to make some forests more "fire safe," in that they will have species composition, age structure and fuel levels such that crown fires are unlikely to begin or spread (Agee 1996a).

Prioritizing restoration efforts can make effective use of limited resources and can provide a means to build experience and credibility by focusing on areas that are most likely to provide benefits while presenting low risk of degradation of ecological values. Priorities can be guided by considering watershed and aquatic values, forest characteristics, and human values at risk (Rieman and Clayton 1997, Rieman et al. 2000, Lee et al. 1997).

Neither thinning nor fire will be a panacea; both must be used, but used thoughtfully. Nothing will make forests fireproof, but it appears feasible to make some forests more "fire safe."

The high value of water, the widespread degradation of watersheds, and the prevalence of at-risk populations of fish require that these values receive special consideration in forest management decisions, including forest restoration. Strategies for conserving both aquatic and terrestrial resources at multiple scales are based on similar principles: secure areas with high ecological integrity ("anchor habitats"), extend these areas, and connect them at the landscape level (Lee et al. 1997, Gresswell 1999). An approach that simultaneously considers the condition of a watershed and its associated forests, and the status of aquatic populations (Rieman et al. 2000) appears to offer the best prospects for balancing potentially competing objectives. Simplistic assumptions that what's good for the forest will be good for watersheds and fish will not suffice. Successful forest restoration may help improve watershed resilience and thus aquatic habitats, but active forest restoration carries a risk of further degrading watersheds, especially if it involves road construction or other soil disturbance (Gresswell 1999, Lee et al. 1997). Healthy fish populations can be quite resilient to the effects of wildfire (Gresswell 1999). Most often, healthy populations are associated with roadless or Wilderness areas and cool moist forests that have been relatively little affected by logging and fire suppression (Lee et al. 1997, Rieman et al. 2000). Prescribed fire (ignited either by humans or lightning) may be the best means of managing and restoring these areas (Rieman et al. 2000).

Active restoration involving both thinning and prescribed fire may be more appropriate in heavily roaded, lower elevation forests and in areas adjacent to more intact watersheds (Lee et al. 1997).

Riparian areas provide habitat benefits for wildlife far out of proportion to these streamside areas' relatively limited distribution on the landscape—most notably for migratory birds (Marcot et al. 1997). Riparian areas and the vegetation they support are also essential to the quality of water and aquatic habitats and contribute many functions to ecosystem integrity (Kauffman et al. 1997, Gregory 1997, National Research Council 1996). Logging in riparian areas can cause ground disturbance resulting in sediment delivery to streams, as well as reduce shade and input of large wood to streams, thus degrading aquatic habitat. Riparian areas and their relationship to broader landscapes are highly complex, as are the risks of wildfire, which may be the same, less or greater than in adjacent uplands (Agee 1999a). While pre-commercial thinning may have some application in riparian areas (Gregory 1997), restoration treatments should initially focus on uplands (Johnson et al. 1995, Lee et al. 1997). Commercial thinning can usually be avoided in riparian areas. If commercial-sized trees need to be cut, they can be left on the floodplain or placed in the stream channel (Gregory 1997). Prescribed fire, carefully applied based on site-specific analysis, may be the most appropriate treatment in riparian areas (Agee 1999a, Kauffman et al. 1997).

Decisions about the use of thinning as an element of forest restoration must be based on local conditions and analysis that considers current and historical stand conditions, landscape context, watershed integrity, status of fish and wildlife populations, and many other variables. Nonetheless, some general principles and guidelines can be proposed, based largely on the broad categorization of forest types and fire regimes discussed above. Although anecdotal evidence, computer modeling and common sense provide considerable support for the premise that thinning can reduce fire risk and restore habitat, there is precious little empirical scientific research on the subject (Pollet and Omi 2002, Omi and Martinson 2002, Stephens 1998, van Wagtendonk 1996), and humility and caution should be the order of the day. This

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caveat is especially appropriate when attempting to extrapolate stand-level information to landscape scales (Agee 1997a).

Thinning for restoration does not appear to be appropriate in higher elevation, cold, moist forests (Agee and Huff 1986). These forests have often not yet missed a full fire cycle and the historic dynamic of generally high fuel loadings and a fire regime characterized by weather-dominated, lethal fires has not changed significantly. Efforts to manipulate stand structures to reduce fire risk are apt not only to be futile (Agee 1996a, 1998a), but may also move systems away from presettlement conditions to the detriment of wildlife and watersheds (Johnson et al. 1995, Weatherspoon 1996).

Although anecdotal evidence, computer modeling and common sense provide considerable support for the premise that thinning can reduce fire risk and restore habitat, there is precious little empirical scientific research on the subject and humility and caution should be the order of the day.

Low elevation, dry forests appear to offer the clearest opportunities for thinning — in conjunction with prescribed fire — to contribute to restoration of wildlife habitat while making forests more resistant to uncharacteristically severe fire (Miller and Urban 2000). For reducing fire risk, the priorities are to reduce surface and ladder fuels and raise the bottom of the live canopy (Agee et al. 2000, van Wagtendonk 1996). Thinning is most apt to be appropriate where understory trees are sufficiently large or dense that attempts to kill them with fire would run a high risk of also killing overstory trees (Christensen 1988, Stephenson 1999, Fule et al. 1997, Moore et al. 1999, Arno et al. 1997). Using prescribed fire alone can be desirable in that it provides the full range of ecological effects of fire. However, fire is an imprecise tool and a chainsaw or harvester can provide much more control over which trees are actually killed (Thomas and Agee 1986, Swezy and Agee 1990, Anonymous 1999, Pollet 1999, Fiedler 1996, Sackett et al. 1995). The larger understory trees that are less likely to be safely thinned with fire are more apt to be large enough to have economic value if they are logged. This presents opportunities to defray expenses while providing employment and wood products, as well as risks that economic pressures will bias decisions about which trees to cut and thus undermine the credibility of restoration. Even where understory trees can safely be thinned with fire, consideration will need to be given to potential smoke production and soil heating during subsequent burns that will be necessary to consume the dead understory trees once they fall to the ground (Agee 1997a, Anonymous 1999).

One potential problem with understory thinning operations is that the low value of the wood being removed encourages the use of low-cost logging methods. This typically means ground-based equipment, which can have seriously detrimental effects on soils. As Perry (1994) states, "the importance of soil to forest productivity and health cannot be overstated." Soil is not only the fundamental source of productivity of terrestrial systems, but also strongly influences hydrologic function and water quality. Soil compaction, which can take decades to recover (Harvey et al. 1989), both reduces plant growth and inhibits infiltration of water, increasing erosion, sedimentation and spring run-off. Fire can also adversely affect soils, but these effects are relatively short-lived (Rieman and Clayton 1997), and should not be presumed to give license to unnecessarily degrade soils during thinning operations. To maintain both ecological integrity and management credibility, it will be essential to employ low-impact equipment and use it properly (Johnson et al. 1995). Establishing standards to keep soil compaction, disturbance, and puddling to less than 10% of an activity area, and monitoring to ensure that these standards are met would be a significant, yet feasible, improvement over past practices. Standards should also be applied to protect steep, unstable, or highly erosive slopes.

The adverse ecological effects of roads are legion (Furniss et al. 1991, Noss and Cooperrider 1994, Trombulak and Frissell 2000, Jones et al. 2000, Rieman and Clayton 1997, Ercelawn 1999). Road construction to access thinning sites is highly unlikely to be justified either ecologically or economically. Limitations on road construction and other soil disturbance will also help limit the spread of invasive exotic plants (noxious weeds) (Hann et al. 1997, Parendes and Jones 2000). In the interest of getting necessary work done, most restoration effort can be focused on already roaded portions of the landscape, where controversy is less and there is no shortage of stands appropriate for treatment. However, some undeveloped, roadless or protected areas, if they clearly suffer reduced ecological integrity and risk of uncharacteristically severe fire as a result of fire exclusion, may require active management. Thoughtful, "light touch" restoration practices, generally emphasizing prescribed fire with minimal necessary thinning and no road construction, may be appropriate to maintain these important areas as reservoirs of biological diversity and ecological baselines (Noss 1999).

Within the dry forest zone, high forest integrity will generally be associated with the presence of old-growth trees, especially ponderosa pine. Highest priority should be given to securing high-integrity "anchor habitats" that still closely resemble historic conditions, which can be maintained with prescribed fire alone. Adjacent areas that have developed dense post-settlement understories, especially if they have remnant old trees, are apt to be a priority for restoration treatment with thinning and/or fire to help reduce the likelihood of crown fire spreading into the high integrity stands. Treatment of these areas could help to secure the remnant intact stands from wildfire risks while extending more natural stand conditions across the landscape, eventually connecting high-integrity areas. In general, protection of remnant old-growth pine, from stands to individual trees, should be a top priority, in light of how depleted these trees have become and their importance not only as habitat but also as genetic and scientific resources (Henjum et al. 1994, Wickman 1992). On the other hand, reproduction of ponderosa pine is infrequent and unpredictable (White 1985), and care should be taken, at the landscape scale, to retain some patches of young pine trees in an approximation of historic patterns.

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Mid-seral ponderosa pine stands (roughly 60 to 100 years old) may represent a secondary priority for restoration treatments. These stands are often well on the way to developing old-growth characteristics, and treatments to help ensure that this trend is maintained can increase the probability that old-growth habitats are restored more quickly than they would be otherwise. Thinning to remove smaller trees can reduce the risk of fire spreading into the canopy, while improving the growth rate of remaining trees. Variable density thinning can help mimic the clumped distribution and associated processes found in pre-settlement stands (Harrod et al. 1999, Franklin et al. 1997). Processes other than fire, particularly sources of mortality such as bark beetles, which are a key food source for woodpeckers and influence subsequent decay of snags (George and Zack in press, Samman and Logen 2000), should be provided for at the landscape level.

The mixed conifer zone presents some of the greatest complexities in determining where it will be appropriate to apply thinning and/or fire. Changes following decades of fire exclusion will often mean that reintroduction of fire without thinning will be problematic (Agee and Huff 1986, Swezy and Agee 1990). Given the considerable variability within this zone, local assessment of pre-settlement stand conditions may be particularly important. However, careful consideration must also be given to existing conditions, especially the context of stands at landscape scales. Whereas in dry forest types habitat objectives and fire regime objectives are apt to coincide, they may conflict in portions of the mixed conifer zone, at least in the short term. Past management practices may have led to development of old-growth stands with "unnatural" multiple canopy layers or accumulations of snags and logs, but these areas may provide key habitat that compensates for loss and degradation of these habitat elements elsewhere (Wisdom et al. 2000, ICBEMP 2000). Often, it may be appropriate to attempt to secure such habitats from wildfire by treating adjacent areas (Agee 1996a, 1998a). Attention should be given to protecting large and old trees. For eastern Oregon and Washington, Henjum and others (1994) recommended protecting trees either 20 inches or greater in diameter, or more than 150 years old. Large fir trees, especially those with heartwood decay, provide important habitat for many species (Bull and Hohman 1993; Bull et al. 1992, 1997), and efforts to "cleanse" the landscape of fir should be avoided. Strategic location of fuel treatments may slow the spread of fire across the landscape (Agee 1999a, Finney 2001, Finney et al. in press), but this concept has been explored only in computer models, and will need refinement before being extensively applied. All in all, these complexities appear to recommend a cautious approach to restoration efforts in the mixed-conifer zone. The wildland-urban interface or "intermix zone" is often not very precisely defined

Perhaps the most important consideration regarding efforts to make the interface zone fire safe is that treatment of public forestlands alone will not be enough.

but generally describes areas where human housing intermingles with mostly forested land. The dramatic fires of the 2002 fire season have put the interface zone fully in the national public eye. Growing political attention, although tardy and prone to misdirection, may be appropriate. Not only are human property and lives at risk, but the interface zone most typically occurs in the dry forest types that are most amenable to restoration efforts combining mechanical treatments and prescribed fire. The presence of people, their developments, and their pets mean that habitat values are already somewhat compromised, reducing the severity of some of the unintended consequences that may accompany restoration efforts. On the other hand, the close proximity of people can complicate prescribed burning programs. Perhaps the most important consideration regarding efforts to make the interface zone fire-safe is that treatment of public forestlands alone will not be enough. The crucial area — within 100 or 200 feet of structures — is most apt to be private land, and even here, vegetation treatment alone will not suffice (Cohen 2000). Structures must be built or retrofitted to incorporate fire-safe elements such as non-combustible or fire-resistant roofs and tempered glass windows. Human values at risk may suggest that the interface zone is a priority for attention, but without investment in these structural modifications, public investment in forest treatment is virtually pointless.

In Conclusion

While there is much to be learned about the current status of forested ecosystems on National Forest lands and about the efficacy of thinning and prescribed fire to make these forests more sustainable, it appears clear that action must be taken to reverse trends of degradation, and that thinning and fire can play a role in these restoration efforts. Because thinning is a form of logging, and because prescribed fire can produce excessive smoke, runs the risk of escape, and appears to contradict decades of Smokey Bear's education about the evils of forest fires, both techniques will be controversial with at least some portions of the public. Every effort should be made to apply these tools thoughtfully, in ways and in locations where they will have the highest prospects for success and the lowest likelihood of unintended consequences. Based on current knowledge, it appears that the most credible efforts will:

- **Be part of comprehensive ecosystem and watershed restoration that addresses roads, livestock grazing, invasive exotic species, off-road vehicles, etc.**
- **Consider landscape context, including watershed condition and populations, as well as habitats, of fish and wildlife;**
- **Address causes of degradation, not just symptoms;**
- **Provide timber only as a by-product of primary restoration objectives;**
- **Avoid construction of new roads;**
- **Be based on local assessment of pre-settlement conditions;**
- **Take place in dry forest types;**

- **Use fire as a restoration treatment, either alone or following thinning;**
- **Treat thinning slash and other surface fuels (preferably with fire);**
- **Retain all large, old (pre-settlement) trees and large snags, and provide for their replacement over time;**
- **Have negligible adverse effects on soils;**
- **Address other vegetation in addition to trees, including noxious weeds;**
- **Incorporate monitoring as an essential element and cost of the project;**
- **Learn from monitoring and adapt management accordingly.**

It may not be feasible to fully address all of these considerations for every treatment, but managers who focus their attention on areas where these criteria can be met will have greater prospects for building the experience and credibility that will allow greater discretion in the future. It will also be essential to acknowledge how little empirical scientific study supports assumptions of the efficacy of thinning to restore habitat and reduce fire risk. While additional scientific research is necessary, much can also be learned from routine monitoring, especially if it is structured to reflect a more consistent case studies approach (Shrader-Frechette and McCoy 1993), which could be facilitated by regional guidance from Forest Service research stations. Support within the Forest Service and from the Congress for research, administrative studies and monitoring will be crucial to refining techniques and building public trust. As much as scientific knowledge, that trust must form the basis for successful action.

REFERENCES

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Agee, J.K. 1994. Fire and Weather Disturbances in Terrestrial Ecosystems of the Eastern Cascades. USDA Forest Service PNW Research Station, General Technical Report PNW-GTR-320.

Agee, J.K. 1996a. The influence of forest structure on fire behavior. Presented at the 17th Annual Forest Vegetation Management Conference, Redding CA, January 16-18, 1996.

Agee, J.K. 1996b. Fire in the Blue Mountains: A history, ecology and research agenda, *in* Jaindl, R.G. and T.M. Quigley, eds. *Seach for a Solution.* American Forests, Washington D.C.

Agee, J.K. 1997a. Fire Management for the 21st Century, *in* Kohm, K.A. and J.F. Franklin, eds., Creating a Forestry for the 21st Century. Island Press, Washington, DC.

Agee, J.K. 1997b. The severe weather wildfire - too hot to handle? Northwest Science 71:153-156.

Agee, J.K. 1998a. The landscape ecology of western forest fire regimes. Northwest Science, Vol. 72 Special Issue.

Agee, J.K. 1998b. The ecological role of fire in pine forests. Pages 193-218 *in* Richardson, D. M., ed. Ecology and biogeography of *Pinus*. Cambridge University Press, Cambridge.

Agee, J.K. 1999a. A coarse-filter strategy. Forum for Applied Research and Public Policy 14 (1):15-19.

Agee, J.K. 1999b. Fire Effects on Landscape Fragmentation in Interior West Forests, *in* Rochelle, J., L. Lehman and J. Wisniewski, eds. Forest Fragmentation: Wildlife Management Implications. Brill, Leiden, The Netherlands.

Agee, J. K. 2000. College of Forest Resources, University of Washington. Personal communication.

Agee, J. K. 2002. The fallacy of passive management. Conservation in Practice 3(1): 18-25.

Agee, J.K., B. Bahro, M. A Finney, P. N. Omi, D. B. Sapsis, C. N. Skinner, J. W. van Wagtendonk, C. P. Weatherspoon. 2000. The use of shaded fuelbreaks in landscape fire management. Forest Ecology and Management 127 (2000):55-66.

Agee, J.K. and M.H. Huff. 1986. Structure and process goals for vegetation in wilderness areas. Pages 17-25 *in* Lucas, R.C. compiler. Proceedings -- National wilderness research conference: current research , 23-26 July 1985, Fort Collins, Colorado, USA. USDA Forest Service General Technical

Report INT-212.

Amaranthus, M.P, J.M. Trappe and D.A Perry. 1989. Long-term productivity and the living soil. Pages 36-52 *in* D.A. Perry, R. Meurisse, B. Thomas, R. Miller, J. Boyle, J. Means, C.R. Perry, and R.F. Powers, eds. Maintaining Long-term Productivity of Pacific Northwest Forest Ecosystems. Timber Press, Portland, OR.

Angermeier, P. L. and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives. BioScience 44:690-697.

Anonymous [Fire Ecologist]. 1999. Review of the Wenatchee National Forest's Dry Forest Strategy and Its Application to the Sand EIS. Review facilitated by Hessburg, P.F. and J.F. Lehmkuhl, USDA Forest Service, Pacific Northwest Research Station, Wenatchee, WA.

Arno, S.F., H.Y. Smith and M.A. Krebs. 1997. Old growth ponderosa pine and western larch stand structure: influences of pre-1900 fires and fire exclusion. USDA Forest Service, Intermountain Research Station Research Paper INT-RP-495.

Arno, S.F. 2000. Fire in western forest ecosystems. Chapter 5 *in* Wildland Fire in Ecosystems: Effects of Fire on Flora. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42 volume 2.

Belsky, A. J. and D.M. Blumenthal. 1997. Effects of Livestock Grazing on Stand Dynamics and Soils in Upland Forests of the Interior West. Conservation Biology, Vol. 11, No. 2, pp. 315-327.

Beschta, R.L., C.A. Frissell, R. Gresswell, R. Hauer, J.R. Karr, G.W. Minshall, D.A. Perry, J.J. Rhodes. 1995. Wildfire and salvage logging: recommendations for ecologically sound post-fire salvage logging and other post-fire treatments on federal lands in the West. Pacific Rivers Council, Eugene, OR.

Biswell, H.H. 1989. Prescribed Burning in California Wildlands Vegetation Management. University of California Press, Berkeley.

Biswell, H.H., H.R. Kallander, R. Komarek, R.J. Vogl and H. Weaver. 1973. Ponderosa Fire Management. Tall Timbers Research Station Miscellaneous Publication 2. Tallahassee, Florida: Tall Timbers Research Station.

Brown, J.K. 2000. Introduction and fire regimes in Wildland Fire *in* Ecosystems: Effects of Fire on Flora. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42 volume 2.

Brown, P.M., M.R. Kaufmann, and W.D. Shepperd. 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landscape Ecol. 14:513-532.

Bull, E.L. and J.E. Hohman. 1993. The association between Vaux's swifts and old growth forest in northeastern Oregon. Western Birds. 24(1):38-42.

Bull, E.L., R.S. Holthausen and M.G. Henjum. 1992. Roost trees used by pileated woodpeckers in northeastern Oregon. Journal of Wildlife Management. 56(4):786-793.

Bull, E.L., C.G. Parks and T.R. Torgersen. 1997. Trees and logs important to wildlife in the Interior Columbia River Basin. Gen. Tech. Rep. PNW-391. USDA Forest Service, PNW Research Station. Portland, Oregon.

Chang, Chi-ru. 1996. Ecosystem responses to fire and variations in fire regimes *in* Sierra Nevada Ecosystem Project: Final report to Congress. Vol. II Assessments and Scientific Basis for Management Options. Water Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1071-1099.

Christensen, N. L. 1988. Succession and Natural Disturbance: Paradigms, Problems, and Preservation of Natural Ecosystems *in* Agee, J. K. and D. R. Johnson, eds., Ecosystem Management for Parks and Wilderness. University of Washington Press, Seattle.

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

Ercelawn, A. 1999. End of the Road: The adverse ecological impacts of roads and logging: a compilation of independently reviewed research. Natural Resources Defense Council, San Francisco, CA.

Fiedler, C.E. 1996. Silvicultural Applications: Restoring ecological structure and process in ponderosa pine forests *in* Hardy, C.C. and S.F. Arno, eds. The Use of Fire in Forest Restoration. USDA Forest Service, Intermountain Research Station, General Technical Report INT-GTR-341.

Finney, M.A., D.B. Sapsis, B. Bahro. In Press. Use of FARSITE for simulating fire suppression and analyzing fuel treatment economics, *in* Proceedings of the Fire in California Ecosystems: Integrating Ecology, Prevention and Management, 17-20 November 1997, San Diego.

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

Franklin, J.F., D.R. Berg, D.A. Thornburgh and J.C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems *in* Kohm, K.A. and J.F. Franklin, eds., Creating a Forestry for the 21st Century, Island Press, Washington, DC.

Franklin, J.F., D.A. Perry, R. Noss, D. Montgomery and C. Frissell. 2000. Simplified Forest Management to Achieve Watershed and Forest Health: A Critique. National Wildlife Federation, Seattle, Washington.

Fule, P.Z., W.W. Covington and M.M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications 7(3):895-908.

Furniss, M.J., Roelofs, T.D. and C.S. Yee. 1991. Road Construction and Maintenance *in* Meehan, W.R.. ed. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Pub. 19:297-323. American Fisheries Society, Bethesda, MD.

George, T.L. and S. Zack. In Press. Spatial and Temporal Considerations in Restoring Habitat for Wildlife. Restoration Ecology. (Paper presented at Society for Ecological Restoration annual meeting, The Presidio, San Francisco, CA, September, 1999.)

Graham, Russell T., A. Harvey, T.B. Jain and J.R. Tonn. 1999. The Effects of Thinning and Similar Stand Treatments on Fire Behavior in Western Forests. USDA Forest Service General Technical Report PNW-GTR-463.

Gregory, S.V. 1997. Riparian Management in the 21st Century *in* Kohm, K.A. and J.F. Franklin, eds., Creating a Forestry for the 21st Century, Island Press, Washington, DC.

Gresswell, R.E. 1999. Fire and aquatic ecosystems in forested biomes of North America. Trans. Amer. Fish. Soc. 128:193-221.

Hall, F.C. 1974. Fire and vegetation in the Blue Mountains -- implications for land managers *in* Proceedings Annual Tall Timbers Fire Ecology Conference, October 16-17, 1974. Tall Timbers Research Station, Tallahassee, Florida.

Hann, W.J., J.L. Jones, M.G. Karl, P.F. Hessburg, R.E. Keane, D.G. Long, J.P. Menakis, C.H. McNicoll, S.G. Leonard, R.A. Gravenmier and B.G. Smith. 1997. Landscape Dynamics of the Basin, *in* Quigley, T.M. and S. Arbelbide, tech. eds., An Assessment of Ecosystem Components in the Interior Columbia Basin. Volume II. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-405.

Harrod, R.J., H.M. Bradner, and W.E. Hartl. 1999. Historical stand reconstruction in ponderosa pine forests to guide silvicultural prescriptions. Forest Ecology and Management 114:433-446.

Harvey, A.E., R.T. Meurisse, J.M. Geist, M.F. Jurgensen, G.I. McDonald, R.T. Graham, and N. Stark. 1989. Managing Productivity Processes in the Inland Northwest--Mixed Conifers and Pines *in* Perry and others, eds., Maintaining the Long-Term Productivity of Pacific Northwest Forest Ecosystems. Timber Press, Portland, Oregon.

Henjum, M.G., J.R. Karr, D.L. Bottom, D.A. Perry, J.C. Bednarz, S.G. Wright, S.A. Beckwitt and E. Beckwitt. 1994. Interim protection for late-successional forests, fisheries, and watersheds: National forests east of the Cascades crest, Oregon and Washington. The Wildlife Society Technical Review 94-2, Bethesda, MD. 245 pp.

Hessburg, P.F., G.B. Smith and R.B. Salter. 1999. Detecting change in forest spatial patterns from reference conditions. Ecological Applications 9:1232-1252.

Huff, M.H., R.D. Ottmar, E. Alvarado, R.E. Vihnanek, J.F. Lehmkuhl, P.F. Hessburg, and R.L. Everett. 1995. Historical and current landscapes in eastern Oregon and Washington. Part II: linking vegetation characteristics to potential fire behavior and related smoke production. USDA Forest Service Pacific Northwest Forest and Range Experiment Station, PNW-GTR-355. Portland, Oregon.

Interior Columbia Basin Ecosystem Management Project (ICBEMP). 2000. Interior Columbia Basin Supplemental Draft Environmental Impact Statement. Boise, Idaho.

Johnson, K. N., J. Agee, R. Beschta, J. Beuter, S. Gregory, L. Kellogg, W. McComb, J. Sedell, T. Schowalter and S. Tesch. 1995. Forest Health and Timber Harvest on National Forests in the Blue Mountains of Oregon. A Report to Governor Kitzhaber.

Jones, J.A., F.J. Swanson, B.C. Wemple and K.U. Snyder. 2000. Effects of Roads on Hydrology, Geomorphology, and Disturbance Patches in Stream Networks. Conservation Biology 14 (1):76-85.

Kauffman, J. Boone, R.L. Beschta, N. Otting and D. Lytjen. 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries, vol. 22, no. 5.

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

Lee, D.C., J.R. Sedell, B.E. Rieman, R.F. Thurow and J.E. Williams. 1997. Broadscale Assessment of Aquatic Species and Habitats *in* Quigley, T.M. and S. Arbelbide, tech. eds., An Assessment of Ecosystem Components in the Interior Columbia Basin. Volume III. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-405.

Lindenmayer, D.B. and J.F. Franklin. 2002. Conserving Forest Biodiversity: A comprehensive multi-scaled approach. Island Press, Washington DC.

McIver, J.D. and L. Starr, technical editors. 2000. Environmental effects of postfire logging: literature review and annotated bibliography. USDA Forest Service Pacific Northwest Research Station, General Technical Report PNW-GTR-486, Portland, OR.

Marcot, B.G., M.A. Castellano, J.A. Christy, L.K. Croft, J.F. Lehmkuhl, R.H. Naney, R.E. Rostentreter, R.E. Sandquist and E. Zieroth. 1997. Terrestrial Ecology Assessment *in* Quigley, T.M. and S. Arbelbide, tech. eds., An Assessment of Ecosystem Components in the Interior Columbia Basin. Volume III. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-405.

Marshall, D.B. 1997. Status of the White-Headed Woodpecker in Oregon and Washington. Audubon Society of Portland, Portland, Oregon.

Millar, C.I., and W.B. Woolfenden. 1999. The role of climate change in interpreting historical variability. Ecological Applications 9:1207-1216.

Miller, C. and D.L. Urban. 1999. A model of surface fire, climate and forest pattern in the Sierra Nevada, California. Ecological Modelling 114:113-35.

Miller, C. And D.L. Urban. 2000. Modeling the effects of fire management alternatives on Sierra Nevada mixed conifer forests. Ecological Applications 10(1):85-94.

Miller, R.F. and J.A. Rose. 1999. Fire history and western juniper encroachment in sagebrush-steppe. Journal of Range Management 52:550-559.

Moore, M.M., W.W. Covington and P.Z. Fule. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9:1266-1277.

Morgan, P., S. C. Bunting, A. E. Black, T. Merrill and S. Barrett. 1996. Fire regimes in the interior Columbia River Basin: past and present. Final report for RJVA-INT-94913: Coarse-scale classification and mapping of disturbance regimes in the Columbia River Basin. Interior Columbia Basin Ecosystem Management Project.

National Research Council. 1996. Upstream: Salmon and Society in the Pacific Northwest. Committee on Protection and Management of Pacific Northwest Anadromous Salmonids. National Academy Press. Washington, DC.

National Research Council. 1999. Environmental Issues in Pacific Northwest Forest Management. National Academy Press. Washington, DC.

Noss, R.F. 1999. A Citizen's Guide to Ecosystem Management. Biodiversity Legal Foundation Special Report. Boulder, Colorado. (Distributed as Wild Earth Special Paper #3)

Noss, R.F. 2000. Society for Conservation Biology comment letter on USDA Forest Service Roadless Areas Protection Initiative.

Noss, R.F. and A.Y. Cooperrider. 1994. Saving Nature's Legacy: Protecting and restoring biodiversity. Island Press, Washington, DC.

Omi, P.N. And E.J. Martinson. 2002. Effects of fuels treatment on wildfire severity. Final report, submitted to the Joint Fire Science Program Governing Board.

Perendes, L.A. and J.A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. Conservation Biology 14 (1):64-75.

Perry, D.A. 1994. Forest Ecosystems. The Johns Hopkins University Press, Baltimore, MD.

Perry, D.A. 1998. The Scientific Basis of Forestry. Ann. Rev. Ecol. Syst. 29:435-66.

Peterson, D.L. and K.C. Ryan. 1986. Modeling post-fire conifer mortality for long-range planning. Environmental Management 10:797-808.

Pollet, J. and P.N. Omi. 2000. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire 11(1):1-10.

Rieman, B.E. and J. Clayton. 1997. Wildfire and native fish: issues of forest health of sensitive species. Fisheries 22 (11):6-15.

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

Ruggiero, L. F., K. B. Aubry, S. W. Buskirk [and others]. 2000. Ecology and Conservation of Lynx in the United States. University Press of Colorado, Boulder, CO. 480 pp.

Ryan, K.C. and E.D. Reinhardt. 1988. Predicting postfire mortality of seven western conifers. Canadian Journal of Forest Research 18:1291-7.

Sackett, S.S., S.M. Haase and M.G. Harrington. 1996. Lessons learned from fire use for restoring southwestern ponderosa pine ecosystems *in* Covington, W. and P.K. Wagner, tech. coords. Conference on adaptive ecosystem restoration and management: restoration of cordilleran conifer landscapes of North America. USDA Forest Service, Rocky Mountain Research Station General Technical Report RM-GTR-278.

Samman, S. and J. Logan, tech. eds. 2000. Assessment and response to bark beetle outbreaks in the Rocky Mountain area. Report to Congress from Forest Health Protection, Washington Office, Forest Service, U.S. Department of Agriculture and USDA Forest service, Rocky Mountain research Station, General Technical Report RMRS-GTR-62.

Shinneman, D.J., and W.L. Baker. 1997. Nonequilibrium dynamics between catastrophic disturbances and old-growth forests in ponderosa pine landscapes of the Black Hills. Conserv. Biol. 11:1276-1288.

Shrader-Frechette, K.S. and E.D. McCoy. 1993. Method in Ecology: Strategies for conservation. Cambridge University Press.

Sierra Nevada Ecosystem Project (SNEP). 1996. Status of the Sierra Nevada: Final Report to Congress, Vol. I Assessment Summaries and Management Strategies. Wildland Resources Center Report No. 36. UC Davis: Centers for Water and Wildland Resources, University of California.

Skinner, C. N., and Chi-ru Chang. 1996. Fire regimes, past and present *in* Sierra Nevada Ecosystem Project: Final report to Congress. Chapter 38, Vol. II Assessments and Scientific Basis for Management Options. Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1041-1069.

Society of American Foresters. 1993. Task Force Report on Sustaining Long-Term Forest Health and Productivity.

Stephens, S.L. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behaviour in Sierra Nevada mixed-conifer forests. Forest Ecology and Management 105:21-38.

Stephenson, N. L. 1996. Ecology and management of giant sequoia groves *in* Sierra Nevada Ecosystem Project: final report to Congress, Volume II. Assessments and scientific basis for management options. Wildlands Resources Center Report No. 37, Centers for Water and Wildlands Resources, University of California, Davis, California, USA.

Stephenson, N.L. 1999. Reference conditions for Giant Sequoia forest restoration: structure, process, and precision. Ecological Applications 9: 1253-1265.

Swanson, F.J., J.A. Jones, D.O. Wallin and J.H. Cissel. 1994. Natural Variability--Implications for Ecosystem Management *in* Jensen, M.E. and P.S Bourgeron, eds. Eastside Forest Ecosystem Health Assessment, Vol. II: Ecosystem Management: Principles and Applications. USDA Forest PNW Research Station, General Technical Report PNW-GTR-318.

Swetnam, T.W., C.D. Allen and J.L. Betancourt. 1999. Applied historical ecology: using the past to manage the future. Ecological Applications 9:1189-1206.

Swezy, D.M. and J.K. Agee. 1991. Prescribed-fire effects on fine-root and tree mortality in old-growth ponderosa pine. Canadian Journal of Forest Research 21:626-634.

Taylor, A.H. And C.N. Skinner. 1998. Fire history and landscape dynamics in a late-successional reserve, Klamath Mountains, California, USA. Forest Ecology And Management 111(1998):285-301.

Thomas, T.L. and J.K. Agee. 1986. Prescribed fire effects on mixed conifer forest structure at Crater Lake, Oregon. Canadian Journal of Forest Research 16:1082-7.

Tiedemann, A., J. Klemmedson, and E. Bull. 2000. Solution of Forest Health Problems with Prescribed Fire: Are Forest Productivity and Wildlife at Risk? Forest Ecology and Management 127 (2000):1-18.

Trombulak, S.C and C.A Frissell. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology 14 (1): 18-30.

USDA Forest Service, Washington Office. 2000a. Protecting People and Sustaining Resources in Fire-Adapted Ecosystems: A Cohesive Strategy. The Forest Service management response to the General Accounting Office Report GAO/RCED-99-65, April 13, 2000.

USDA Forest Service, Region 5. 2000b. Sierra Nevada Forest Plan Amendment Project Draft Environmental Impact Statement (DEIS).

USDA Forest Service, Region 5. 2000c. Sierra Nevada Forest Plan Amendment Project Draft Environmental Impact Statement (DEIS): Appendix G Fire and Fuels.

Vale, T.R., editor. 2002. Fire, native peoples, and the natural landscape. Island Press, Washington DC.

van Wagtendonk, J.W. 1996. Use of a Deterministic Fire Growth Model to Test Fuel Treatments. Pages 1155-1165 *in* Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II Assessments and Scientific Basis for Management Options. Centers for Water and Wildland Resources, University of California, Davis.

Veblen, T.T., T. Kitzberger, and J. Donnegan 2000. Climatic and human influences on fire regimes in ponderosa pine forests in the Colorado Front Range. Ecol. Appl. 10:1178-1195.

Weatherspoon, C.P. 1996. Fire-silviculture relationships. Pages 1167-1176 *in* Sierra forests in Sierra Nevada Ecosystem Project, Final Report to Congress. Chapter 44, Vol. II Assessments and Scientific Basis for Management Options. University of California, Centers for Water and Wildland Resources, Davis, California.

Weatherspoon, C.P. and C.N. Skinner. In Press. An ecological comparison of fire and fire surrogates for reducing wildfire hazard and improving forest health. Paper presented to: Fire in California Ecosystems: Integrating ecology, prevention and management. November 17-20, Bahia Hotel, San Diego, CA.

Weatherspoon, C.P. and C.N. Skinner. 1995. An assessment of factors associated with damage to tree crowns from the 1987 wildfire in northern California. Forest Science 41:430-451.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry 41 (1):7-15.

Weaver, H. 1959. Ecological changes in the ponderosa pine forests of the Warm Springs Indian Reservation. Journal of Forestry 57:15-20.

White, A.S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology 66(2):589-594.

Wickman, B.E. 1992. Forest Health in the Blue Mountains: The influence of insects and disease. USDA Forest Service, General Technical Report PNW-GTR-295.

Wisdom, M., R. Holthausen, B. Wales, D. Lee, C. Hargis, V. Saab, W. Hann, T. Rich, M. Rowland, W. Murphy and M. Eames. 2000. Source Habitats for Terrestrial Vertebrates of Focus in the Interior Columbia Basin: Broad-Scale Trends and Management Implications. PNW Research Station General Technical Report, PNW-GTR-485.

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ABOUT THE AUTHOR

Rick Brown joined Defenders of Wildlife's West Coast Office as a senior resource specialist in October 2000. Through his graduate studies, his work for the U.S. Forest Service and the National Wildlife Federation, and most recently as a freelance biologist and conservation advocate, Brown has spent more than 25 years working in and for the forests of the Pacific Northwest.