ASSESSMENT OF TERRESTRIAL ECOSYSTEMS IN EASTERN OREGON AND WASHINGTON: THE EASTSIDE FOREST ECOSYSTEM HEALTH ASSESSMENT

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ABSTRACT

We analyzed historical and current vegetation composition and structure in 49 sample watersheds, primarily on national forests, within six river basins in eastern Oregon and Washington. Vegetal patterns were mapped from aerial photographs taken from 1932 to 1959 (historic), and from 1985 to 1992 (current). We described vegetation attributes, landscape patterns, the range of historical variability, scales of change, and potential fire, insect, and disease disturbance hazards. Forest cover increased 8% in three river basins. Forests became more dense in vertical and horizontal canopy structure as understory cover increased with regeneration of shade-tolerant species. The area of early-seral and old forest stages decreased, while the area in multi-layered canopy young and mature stands increased. Visible dead trees increased in all river basins. Landscape pattern became more diverse and fragmented over time in five of the six river basins largely as a result of timber harvest. Insect and disease hazards at the river basin scale changed little, usually <10%, because there was considerable variation at the watershed scale, where large changes in hazards were common. No differences in fire behavior were detected in any of the six river basins considering ground fuels alone, but rate of spread and flame length increased in ≥ 50% of the sample watersheds in all but two river basins. Rate of spread and flame length generally were positively correlated with the proportion of area logged.

Keywords: landscape characterization, insect and disease hazards, fire behavior, air quality, range of variability, ecosystem health

INTRODUCTION

The health of forested ecosystems in eastern Oregon and Washington has been the subject of concern in recent years (Gast et al. 1991). Land-use practices over the last 100 years have altered natural disturbance regimes, and have reduced ecosystem tolerance of endemic disturbances. Fire suppression, timber harvest, and livestock grazing are among the primary management practices contributing to significant changes in vegetation conditions that are conducive to epidemic disease and insect outbreaks, and severe wildfires (Martin et al. 1976; Gast et al. 1991; Johnson et al. 1994; Agee 1994). Other potentially negative effects of ecosystem change include local extinctions of wildlife and endemic plant populations, and deterioration of ecosystem health (Agee 1994). These conditions are not pervasive, however, and some forest areas remain healthy and productive (Gast et al. 1991).

There are few scientific data describing current vegetation composition, structure, and landscape pattern that can be used to assess the extent of the problem of declining ecosystem health and the associated insect, disease, and fire hazards. Moreover, there are few data that describe the historical scale and range of variation in landscape attributes and disturbance regimes. Scale and range of variation are key reference points for judging the scope and direction of change, and for guiding ecosystem management (Risbrudt 1992).

The objectives of this assessment were: (1) to describe recent historical (35-50 years ago) vegetation composition, structure, and range of variation of these attributes on a representative sample of national forest lands in the forested ecoregions of eastern Oregon and Washington; (2) describe current vegetation composition and pattern in that same sample to describe changes and rates of change from historical conditions; (3) assess the impact of the measured changes in vegetation pattern on a suite of primary insect and disease hazards, the fire fuel complex, fire behavior, potential smoke emissions, and other resources; and (4) examine natural processes and management activities, such as fire suppression and logging, that may be driving observed changes in landscape pattern.

We examined historical and current vegetation composition and pattern, associated insect and disease hazards, potential fire behavior, and potential smoke production in sample watersheds within six river basins. These river basins were representative of the five forested ecoregions of eastern Oregon and Washington. We also discuss the possible relationships between past land use and our results, considerations for future management, and questions that can be answered by further analysis of these and supporting data. This report summarizes the results of our work for the Eastside Forest Ecosystem Health Assessment from November 1992 through April 1993, focusing on the information most urgently needed by land managers. A detailed presentation of research questions, methods, results, and discussion can be found in Lehmkuhl et al. (1994) and Huff et al. (in press).

METHODS

Study Areas

Each of the six river basins we sampled represented conditions in a major forested ecoregion (Omernik and Gallant 1987) of

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eastern Oregon and Washington (Figure 1). The Pend Oreille River basin in northeastern Washington represented the Northern Rocky Mountain ecoregion. The Methow River basin was typical of the Okanogan Highlands described by Franklin and Dyrness (1973), which was not included in the Omernik and Gallant (1987) classification, but which we felt was sufficiently distinct in geology, physiography, climate, and potential vegetation to warrant separate analysis. The Northern Washington Cascades was represented by the Wenatchee River basin and the northern portion of the Yakima River basin. The southern part of the Yakima River basin was indicative of the northern end of the Eastern Cascades and Foothills ecoregion. That ecoregion was primarily represented by the Deschutes River basin south of the Metolius River and within the boundaries of the Deschutes National Forest. The Grande Ronde River basin represented the Blue Mountain ecoregion of eastern Oregon.

A prime consideration in choosing the Methow, Wenatchee, Yakima, and Grande Ronde basins was the desire to complement the aquatic analysis described by McIntosh et al. (1994) for the Eastside Forest Ecosystem Health Assessment. Another criterion was that a large portion of the basin should be managed by the Forest Service, since the assessment would be confined primarily to lands within the boundaries of national forests. Also, comparable resource data were more available from Forest Service lands than from a mosaic of federal and other ownerships. Finally, we calculated that six basins were the most we could analyze with the available time and resources for the project.

Sampling Design

We divided the portion of each river basin within national forest boundaries into sample watersheds of mean 8,875 ha (range 5,100 to 13,500 ha) using existing watershed maps from the national forests, or by drawing our own watershed maps from national forest maps where watershed maps were not available. We used stratified random sampling to select watersheds within river basins for analysis. Each river basin was stratified into two to eight sub-basins, depending on basin area, to distribute samples evenly across the basin. We selected a random 15% area sample of the watersheds within each sub-basins. Forty-nine watersheds were selected for the current 15% sample, and an additional 38 watersheds were selected randomly for later mapping and analysis of a larger 25-30% sample.

Vegetation Mapping

Vegetation mapping required high-quality map data for both current and historical periods. The project assignment dictated using existing data where available, but the data were to be of sufficient quality for a scientific assessment. Current-vegetation maps based on aerial photo interpretation that met our criteria were available for the Colville, Wallowa-Whitman, and Umatilla National Forests. We used those data when assessing current vegetal conditions in portions of the Pend Oreille (Colville National Forest) river basin and all of the Grande Ronde (Umatilla and Wallowa-Whitman National Forests) basin. Current vegetation maps for the other four river basins on the Okanogan, Wenatchee, and Deschutes National Forests either did not exist for the entire Forest, were not current, were not consistent with our mapping or data standards, or were highly variable in vegetation mapping criteria. These sources were not suitable for this assessment, so we assembled mapping teams of national forest personnel to map current vegetation using recent aerial photography and orthophotographs.

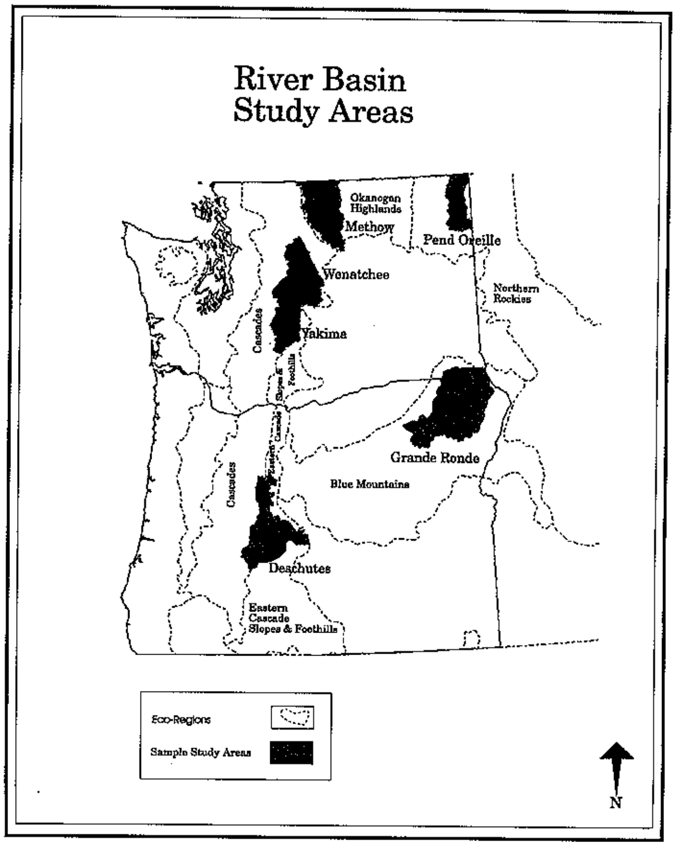

Figure 1.—Forested ecoregions of eastern Oregon and Washington and 6 river basins sampled for ecosystem health assessment during 1993.

We used aerial photographs from the 1930s, 1940s, and 1950s to map historical vegetation. Forest photo-interpretation teams mapped current and historical vegetation, yielding high-quality data that was timely and consistent across the temporal (historic vs. current) and spatial scales of analysis. Lacking the time to field verify maps, photo interpreters were selected that had field experience and knowledge of local conditions. Without field verification, maps were to be used only for research associated with this assessment, and not for management activities such as forest or project planning. Current vegetation maps were reconciled with recent stand examination data, when those data were available, and ocular estimates were adjusted.

Vegetation was mapped as distinct patches, not less than 4 ha, delineated on the basis of homogeneity of vegetation composition or structure. Patches were delineated on aerial photographs with the aid of a mirrored, magnifying stereoscope, and mapped to mylar overlays on geo-referenced 1:24,000 ortho quads.

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Mylar map quads of sample watersheds were digitally scanned, edited and edge-matched using the LT+ software, and entered into the ARC/INFO geographic information system. Composition and structural attributes of vegetation patches (Table 1) were described from stereo-photo interpretations.

Vegetation and Landscape Pattern Analysis

Vegetation maps and patch attributes derived by photo-interpretation formed the basic dataset from which all subsequent analyses were done. Patches were described by attributes of composition and structure, and classed into vegetation types developed from overstory species composition and stand structural classes (Table 1). Structural classes were defined as: **seedling-sapling-pole** (SSP) — one canopy layer, seedling, sapling, or pole trees (< 23 cm diameter at breast height [dbh]); **young** — two canopy layers, overstory pole or young trees (13-40 cm dbh), understory seedlings, saplings, or poles (< 23 cm dbh); **mature** — ≥ two canopy layers, overstory mature trees (41-64 cm dbh), understory trees young or smaller (< 40 cm dbh); **mature park-like** — one or two canopy layers, mature to old overstory trees (> 40 cm dbh), understory trees absent or saplings (<13 cm dbh); **old forest** — ≥ two canopy layers, overstory trees larger than mature (> 64 cm dbh), pole to mature understory (13-64 cm dbh). Pattern analyses were done with a variety of GIS and other computer programs to estimate patch attributes and pattern indices.

Insect and Disease Hazard Analysis

We evaluated major forest insect and disease hazards for historical and current conditions in each watershed. Insect and disease hazard did not equate to actual risk or probability of occurrence because inventories were not done. Rather, hazard indicated presence of susceptible hosts in susceptible arrangements. Insects and diseases were grouped into 12 categories for assessment. The two principal defoliators, the western spruce budworm (*Choristoneura occidentalis* Freeman) and the Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)), were combined to estimate a defoliator hazard rating, although the hazard variables used were most appropriate to the western spruce budworm. Hazard associated with bark beetles was assessed separately for the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), western pine beetle (*Dendroctonus brevicomis* LeConte), mountain pine beetle (*Dendroctonus ponderosae* Hopkins), and fir engraver (*Scolytus ventralis* LeConte). Western pine beetle hazards were separated into two types: Type 1 hazard to mature and overmature ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and Type 2 hazard to immature and overstocked ponderosa pine. Mountain pine beetle hazards were also separated into two types: Type 1 hazard to overstocked lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.), and Type 2 hazard to immature and overstocked ponderosa pine. Dwarf mistletoe hazards were computed for mistletoes of western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine, and lodgepole pine. Root diseases were combined for a group hazard rating for laminated root rot (*Phellinus weirii* (Murr.) Gilb.), Armillaria root disease (*Armillaria ostoyae* (Romag.) Herink), and S-group annosum root diseases (*Heterobasidion annosum* (Fr.) Bref.).

The basic procedure was to rate hazard associated with each insect or pathogen species (or group) for each forest and non-forest stand as the sum of scores for four-six hazard variables. Site quality, a hazard variable used in all calculations, was based on the presence of host species in the overstory and understory. Host abundance was calculated by computing overstory and understory crown cover in host species. Canopy structure was factored into stand ratings by considering the number of canopy layers and their composition. Stand density was estimated qualitatively from total canopy cover. For some beetle species, crown differentiation was a surrogate variable for stand density. Host age was approximated from overstory and understory size class data. Continuity of host species in entire watersheds was estimated from vegetation host-host transition frequencies at the scale of 1 ha. Scores for each variable in a stand were summed by species then weighted by the proportion of watershed area occupied by the stand. A watershed score for each species was computed by summing the weighted stand scores, then adding the host species continuity score, if applicable. (See Lehmkuhl et al. 1994 for an expanded description of hazard variables and hazard rating methods).

Fuel Loading and Fire Behavior

We used published information to calculate ground fuel loadings and surface fire behavior characteristics for each polygon in the sample watersheds. Photo-interpreted attributes of polygons were matched to the closest situation represented in one of several fuel and fire behavior photo series (Fischer 1981; Maxwell and Ward 1976; Maxwell and Ward 1980) by developing a key based on vegetation composition and structure. Of the fuel and fire behavior photo series available, 36 photos were selected or stylized to represent the range of fuel conditions within the six river basins. These photos were applied to fuel complexes representing nonforested conditions, natural forested conditions, and conditions created by timber harvest and other management activities. A more diverse array of fuel photo series could have been selected if information about stand density, applicable understory characteristics, or further details of management activities could be described for each polygon.

For each fuel and fire behavior photo series, we used information on fuel loadings by size class, rate of spread (ROS), flame length (FL), and resistance to suppression (RTS) to develop the fuel loading and fire behavior database. Our evaluation of fire behavior covers surface and understory fires only. Models are yet unavailable that allow evaluation of crown fire behavior scenarios. Resistance to suppression, a subjective assessment of the time it takes to construct firelines under different fuel conditions, was examined to supplement the fire behavior information. RTS is difficult to measure, and is estimated as the time needed to construct a line that holds a fire. Estimates taken from the fuel and fire behavior photo series are based on field experiences but would vary further depending on crew skill and terrain.

Table 1.—Attributes of forest and non-forest stands interpreted from aerial photographs for ecosystem health assessment of eastern Oregon and Washington.

Non-forest type: A vegetation patch was considered non-forested when there was <10% total canopy closure. Categories were: rock, water, wet meadow or marsh, alpine meadow, dry meadow or grassland, grass/forb after logging, shrub, bare ground (burned or logged), bare ground (slumps erosion), agriculture, and urban.

Overstory and understory species: Dominant overstory and understory species were recorded. Species were later grouped to maximize reliability of photo interpretation and to minimize the number of codes by grouping uncommon species or species with similar shade-tolerance.

The primary *overstory species* or species groups were ponderosa pine, western larch, lodgepole pine, Douglas-fir, grand fir/white fir, Pacific silver fir, subalpine fir/Engelmann spruce, western hemlock/western red cedar, mountain hemlock, whitebark pine/subalpine larch, western white pine/sugar pine, hardwoods, or juniper.

Primary *understory species* and groups were ponderosa pine, western larch/ lodgepole pine, Douglas-fir/grand fir/white fir/Pacific silver fir, western hemlock/western red cedar, mountain hemlock, subalpine fir/Engelmann spruce, whitebark pine/subalpine larch, hardwoods, juniper, grass/forb, shrub, and bare ground.

Overstory and understory tree size classes: Trees sizes were estimated as: seedling and saplings (<13 cm [< 5 in] dbh); poles (13-23 cm [5-8.9 in] dbh); small sawtimber (24-41 cm [9-15.9 in] dbh); medium to large sawtimber (41-64 cm [16-25 in] dbh; and mature to overmature sawtimber (> 64 cm [25 in] dbh).

Total canopy closure and overstory canopy closure: Closure was estimated to the nearest 10%.

Canopy layers: Estimated as 1, 2, or > 2 layers.

Tree density: Density was not estimated from aerial photographs, but was recorded from field data (stocking surveys, timber stand exams, etc.) where available.

Clumpiness: Horizontal patchiness of overstory tree cover. Stands were rated as: (1) Clumpy - yes or no; (2) If clumpy, clump distribution is widely scattered, moderately dense, or dense; and (3) average clump size is < 0.4 ha (1 acre), 0.4-2 ha (1-5 acres), or > 2 ha (5 acres) but < 4 ha (10 acres).

Crown differentiation: Degree of differentiation among overstory tree crowns. Estimated as low (< 30% difference), medium (30-100% difference), or high (>100% difference).

Riparian or wetland: Indicated whether the polygon was a riparian or wetland. This attribute was used with overstory vegetation to estimate forested and non-forest wetland area.

Logging entry: Visible logging was interpreted as no logging apparent, regeneration harvested (clearcut, shelterwood, seedtree), selection harvested (partial cut, selective harvest), thinned (commercial or pre- commercial), or patch clearcut (clearcut patches were < 4 ha (10 acres). If patch clearcut, we estimated the percentage of the stand area in clearcut patches to the nearest 10%.

Dead trees and snags: Dead tree and snag abundance was estimated as none apparent, <10% of trees dead, 10- 39% of trees dead, 40-70% trees dead, and > 70% trees dead.

Smoke Production

Following the emissions inventory approach described by Peterson (1988), we determined fuel loading for sample watersheds by the previously described methods. Past, current, and future areas burned in prescribed fires and wildfires were estimated from smoke management reports, surveys, and wildfire databases. We used estimated fuel moisture value and available fuel consumption models for the Pacific Northwest to calculate fuel consumption. Smoke production was estimated by multiplying fuel consumption by an assigned emission factor. All polygons within a watershed were combined to obtain a mean value for the fire and smoke-related attributes. To compensate for the differences in polygon sizes, a weighted mean was used (Hoshmand 1988).

RESULTS

Vegetation Composition and Pattern

High variability among watersheds made it difficult to detect basin-wide shifts in vegetation, but increasing cover, density, canopy layering, and truncation of patch ages were evident. Forest cover increased in the Deschutes, Grande Ronde, and Pend Oreille river basins by 8% from historical levels, but remained relatively unchanged in the other three river basins (Figure 2). We found some dramatic shifts at the river basin scale in the composition of the forest overstory from early-successional species to more shade tolerant species (Figure 3). Ponderosa pine cover decreased by 30% ($P \leq 0.10$) from historical levels in the Methow basin. The Pend Oreille basin showed a clear shift away from early-successional ponderosa pine, western larch, and western white pine (*Pinus monticola* Dougl. ex D. Don), with 53% increases (P ≤ 0.10) in Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) cover. Basin-scale changes in overstory cover were not significant in the Grande Ronde because large changes in watersheds, both positive and negative, were evident. The Wenatchee River basin showed no significant basin-wide change in overstory composition, but examination of individual watershed data indicated large changes in opposing directions. Changes in the Yakima basin were negligible at the basin scale, but highly variable at the watershed level.

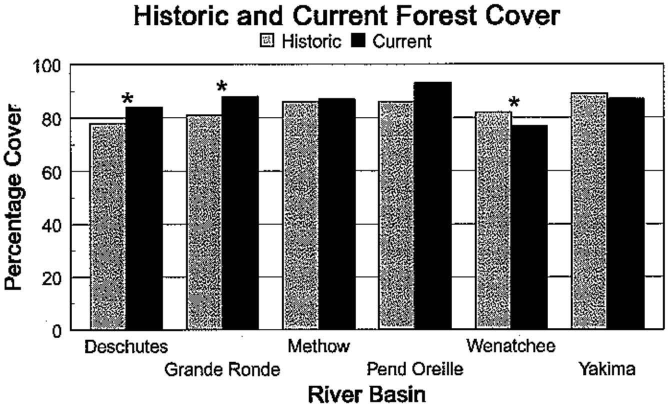

Figure 2.—Historic and current forest cover as the percentage of total area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions.

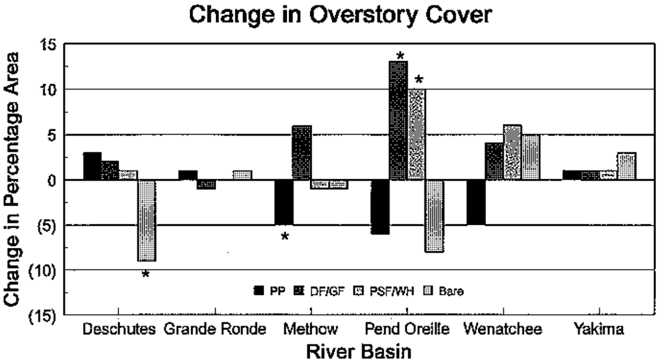

Figure 3.—Changes in some overstory dominant tree species over the last 60 years as the percentage of river basin area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions. Species codes: PP = ponderosa pine; DF/GF = Douglas-fir, grand fir, or white fir; PSF/WH = Pacific silver fir, western hemlock, noble fir, Shasta red fir, or western red.

Forests had become more dense in vertical and horizontal canopy structure. Open bare-ground and grass-forb understories declined in area, as understory cover increased mostly with regeneration of shade-tolerant understory species (Figure 4). The distribution of forest age classes and structure changed as a result of decreases in early-seral and old forest structural stages, and increases in area of multi-layered canopy young and mature patches (Figure 5). Horizontal patch density increased in some areas as shown by increasing size (Figure 6) and density (Figure 7) of tree clumps within patches.

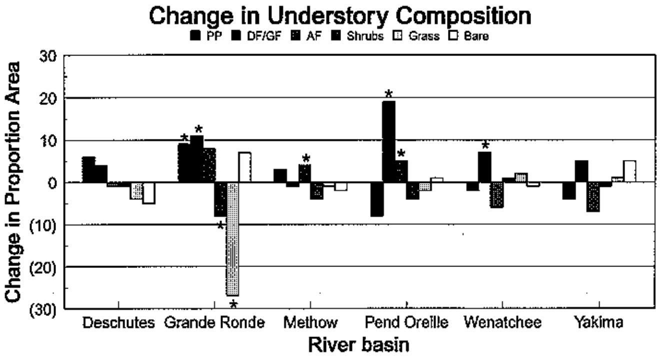

Figure 4.—Changes in understory composition over the last 60 years as the percentage of river basin area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions. Species codes: PP = ponderosa pine; DF/GF = Douglas-fir, grand fir, white fir (or western hemlock and western red cedar in the Pend Oreille); AF = subalpine fir or Engelmann spruce.

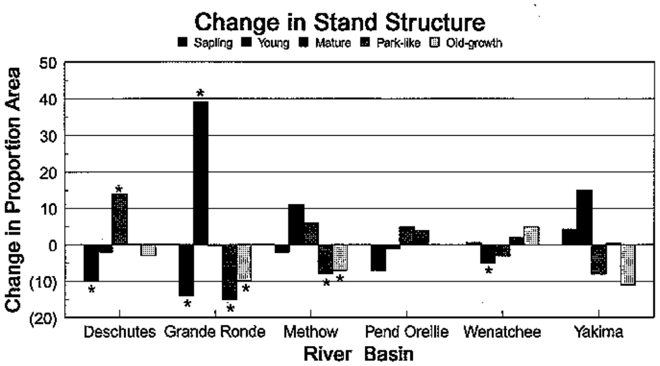

Figure 5.—Changes in stand structure over the last 60 years as the percentage of river basin area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current t basin conditions.

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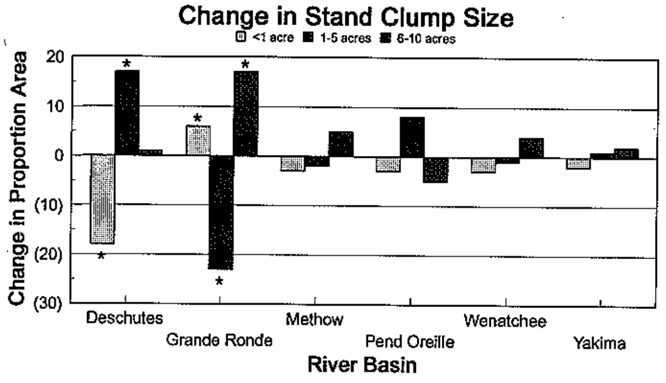

Figure 6.—Changes in clump size within clumpy forest stands over the last 60 years as the percentage of river basin area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions.

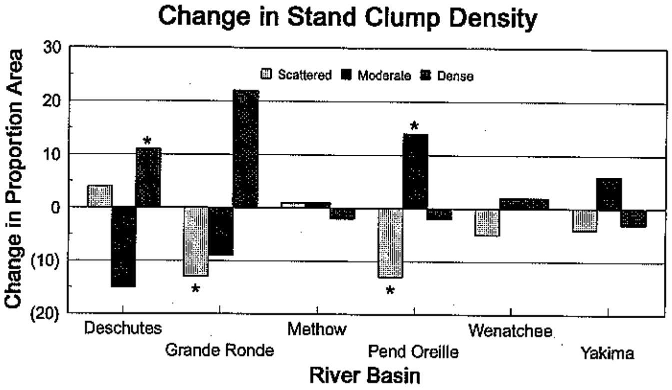

Figure 7.—Changes in clump density within clumpy forest stands over the last 60 years as the percentage of river basin area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions.

The percentage of visible dead trees increased in all river basins in one of two ways (Figure 8). Increases in high concentrations of dead trees (10-70% dead) were most evident in the Deschutes and Grande Ronde basins, but affected areas comprised less than 20% of the basin areas. In the Wenatchee and Yakima basins, however, dead trees were less concentrated within patches, accounting for a smaller percentage of the trees in a patch (< 10% dead), but this condition was more widespread, occurring in 40-50% of the basin areas.

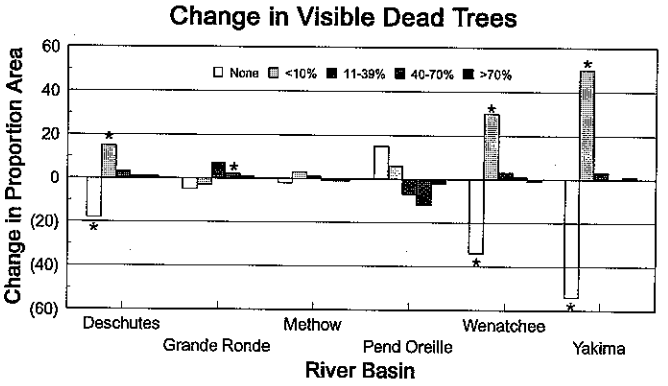

Figure 8.—Changes in the concentration of dead trees over the last 60 years as the percentage of river basin area on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions.

Current landscape pattern in five of the six basins was more diverse and fragmented than in historical times as measured by several attributes (Figure 9). Current patch sizes are smaller, and edge and patch densities are greater than 50 years ago. Mean patch size decreased 30-130% (P ≤ 0.10) and edge density increased 15-40% (P ≤ 0.10) in the Deschutes, Methow, and Pend Oreille basins. As patch size decreased, patch density increased 17- 48% (P ≤ 0.10) in the Deschutes and Methow. Landscape diversity appeared to increase in the Deschutes and Grande Ronde basins, but decline in the other basins. Pattern in the Wenatchee and Yakima basins followed these same trends although differences were not statistically significant.

A comparison between wilderness and managed watersheds in the Grande Ronde basin showed clear differences in patterns of change, and the role that timber harvest and active fire suppression, with a well-developed road system, may have played in pattern development. Wilderness became less diverse and less fragmented than managed watersheds as shown by 24-69% declines in patch density; whereas, patch density in managed watersheds increased 40-100%. Patch size increased 30-225% in wilderness, but declined 30-50% in managed areas. Edge density decreased 30-60% in wilderness, but increased 6-35% in five of six managed watersheds. Diversity decreased and

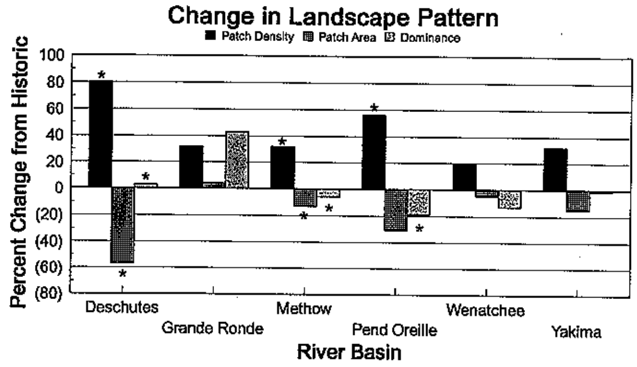

Figure 9.—Percentage changes in patch density (n/km2), mean patch area (ha), and dominance index from historic value over the last 60 years on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences (P ≤ 0.10) between historic and current basin conditions.

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dominance increased, contagion increased, and edge density decreased in wilderness, whereas managed areas followed opposite trends.

Wilderness watersheds in the other five basins were less conspicuously different than managed watersheds, but managed watersheds did show the effects of timber harvest. Examination of change in landscape pattern attributes in all watersheds in the six basins showed considerable variability in the amount of change over time and in the influence of logging activity, and indicated some thresholds of landscape change. Patch density increased with logging up to a threshold of 30% affected area, then did not increase with further increases in logged area (Figure 10). Residual scatter was high, even when very little logging occurred, especially above the fitted line, which indicated other factors made important contributions to overall higher patch densities in current vs. historical times. Logging had a rather steady negative influence on patch size (Figure 11); but, decreases in patch size were evident in the absence of logging, probably as a result of recent increased insect and disease disturbance.

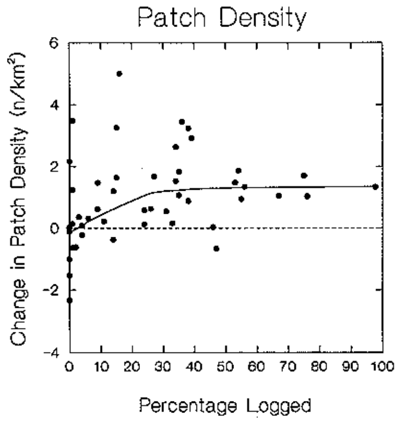

Figure 10.—Percentage changes from historic to current times in patch density vs. the percentage area logged in 49 watersheds in 6 river basins, eastern Oregon and Washington. Curve was fitted by weighted average (Lowess) smoothing

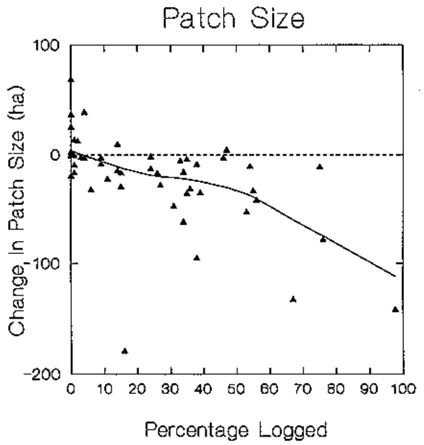

Figure 11.—Percentage changes from historic to current times in patch size vs. the percentage area logged in 49 watersheds in 6 river basins, eastern Oregon and Washington. Curve was fitted by weighted average (Lowess) smoothing.

Insect and Disease Hazard

Insect and disease hazards changed little at the river basin scale because there was considerable variation at the watershed scale. Basin-wide changes were usually <10% different than historical levels (Figures 12, 13). Moreover, changes in hazard among basins were often inconsistent in the direction of change, except perhaps for Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.) hazard, which showed large increases in the Grande Ronde (29%) and Pend Oreille (11%) basins. Large changes in insect and disease hazards were common in individual watersheds, however, which indicated watersheds were the appropriate scale for many insect and disease hazard analyses.

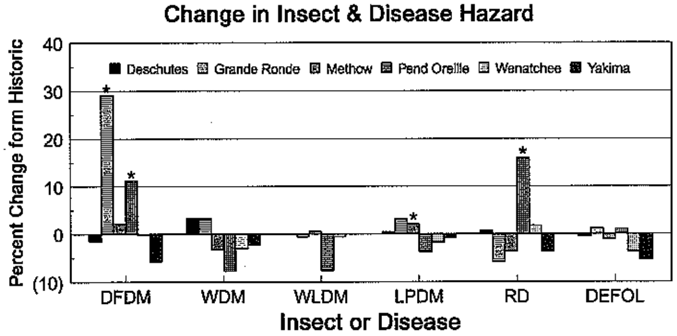

Figure 12.—Percentage changes in dwarf mistletoe, root disease, and defoliator hazards from historical values over the last 60 years on National Forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin condition. Species codes: DFDM = Douglas-fir dwarf mistletoe; WDM = western dwarf mistletoe; WLDM = western larch dwarf mistletoe; LPDM = lodgepole pine dwarf mistletoe; RD = root disease; DEFOL = defoliator

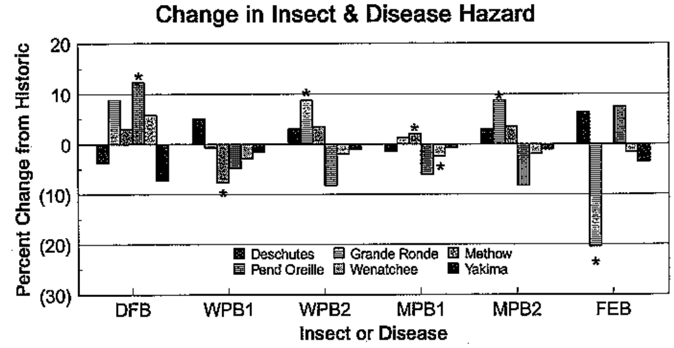

Figure 13.—Percentage changes in bark beetle hazards from historical values over the last 60 years on national forest lands in river basins of eastern Oregon and Washington. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin condition. Species codes: DFB = Douglas-fir beetle; WPB1 = western pine beetle type 1; WPB2 = western pine beetle type 2; MPBI = mountain pine beetle type 1; MPB2 = mountain pine beetle type 2.

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Dwarf mistletoe hazards typically increased when there was a trend in sample watersheds towards increasing dominance of host species in layered canopy arrangements. Dwarf mistletoe hazard decreased in sample watersheds when canopy structure was simplified by harvest, or the dominance of host species in sample watersheds had been reduced. Defoliator hazards increased in sample watersheds with increasing dominance of shade-tolerant species, increased canopy layering, and increased continuity of patches dominated by host species. Defoliator hazards typically decreased with harvest of late-successional and old forest patches, and regeneration to seral species.

Root diseases like laminated root rot, Armillaria root disease, and the spruce and fir type annosum root disease increased in sample watersheds with increasing dominance and density of shade-tolerant species, and decreased with increasing dominance of seral species. Pine bark beetle hazards increased with increasing density, increasing age, or decreasing vigor of pines, and decreased with declining abundance or density of pines.

Of special note, western pine beetle hazard decreased with declining abundance of large ponderosa pine. In many sample watersheds, this hazard was significantly diminished and the consequences of this reduction are potentially quite important. Throughout the ponderosa pine series, and in major portions of the Douglas-fir, grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) series that historically were visited by frequent underburning, or by fires of mixed severity, many of the largest trees were ponderosa pine, and persistent snags were often derived from attacks by the western pine beetle.

Analysis of the distribution of hazard scores for all watersheds shows a preponderance of change within ±10% from historical levels, with some watersheds showing larger changes in both positive and negative directions. Positive and negative changes in hazard for all species were fairly well distributed across all basins. Within sampled watersheds, hazard from defoliators declined in slightly more watersheds than increased. Large increases in defoliator hazard occurred in watersheds of the Grande Ronde, Methow, Deschutes, and Pend Oreille basins. In general, defoliator hazards decreased or stayed the same in watersheds of the Wenatchee and Yakima basins.

Douglas-fir beetle hazard increased more often than they decreased, with seven watersheds in the Grande Ronde, Methow, and Yakima basins showing 30-60% increases in hazard. Western pine beetle Type 1 hazard to overmature ponderosa pine decreased in about 20% of sample watersheds, and increased in 10% of the watersheds. In some Deschutes watersheds, increases of 50-60% were evident. Western pine beetle Type 2 hazard to immature ponderosa pine, followed a trend similar to Type 1 hazard, with most of the large increases occurring in Deschutes and Grande Ronde watersheds.

Mountain pine beetle Type 1 hazard to overstocked lodgepole pine increased by 1-10% or remained unchanged in approximately 50% of the watersheds. Some individual watersheds displayed a 5-10% increase in Type 2 mountain pine beetle hazard, and a few increases in hazard as great as 30-70% have occurred in some Deschutes, Grande Ronde, and Methow watersheds. Change in fir engraver hazards were evenly split, with 45% of the watersheds showing up to a 10 increase in hazard. The greatest decreases (20-38%) in fir engraver hazard occurred in sample watersheds of the Grande Ronde basin.

Mistletoe hazards increased in at least half of all watersheds. Most watersheds that experienced an increase, changed by 5-10% Douglas-fir dwarf mistletoe hazard increased the greatest in Grande Ronde and Pend Oreille watersheds. Douglas-fir dwarf mistletoe hazard increased in nearly every Grande Ronde watershed, with some increases as great as 50-90%. Mistletoe hazard in Douglas-fir decreased in all but one sample watershed in the Yakima basin. The largest increases in hazard associated with western dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) occurred in Deschutes and Grande Ronde watersheds. Western larch dwarf mistletoe (*Arceuthobium laricis* (Piper) St. John) hazards decreased or remained the same in most sample watersheds.

Root disease hazards increased in 50% of the sampled watersheds. The greatest increase in root disease hazard occurred in the Pend Oreille basin where hazard increased in all watersheds. Large increases were also noted in some Grande Ronde and Deschutes watersheds.

Fire Behavior and Smoke Production

Fuel loading averages for the six river basins ranged from 75.3 megagrams/hectare on the Methow River basin (current), to 102.7 megagrams/hectare (metric tons/hectare) on the Yakima River basin (historic) (Table 2). Fuel loading differences between the historic and current periods at the river basin level were very small, ranging from an increase of 7.9 megagrams/hectare on the Deschutes River basin to a decrease of 11.7 megagrams/hectare on the Yakima River basin. Basin differences were not statistically significant (P > 0.10).

No statistically significant differences in fire behavior between current and historic conditions were detected in any of the six river basins (Table 2). Potential rate of spread of fire and flame length were highly variable among sample watersheds in any given river basin. Increases in rate of spread and flame length from historic to current conditions were detected in 50% or more of the sample watersheds in all but the Grande Ronde and Wenatchee River basins, respectively (Table 3). Potential rate of spread in current conditions was above the threshold where initial control would be difficult in more than half the sample watersheds in the Grande Ronde and Deschutes River basins (Table 4). In general, rate of spread and flame length were positively correlated with the proportion of area logged in the sample watersheds. Residues from timber harvesting and vegetation characteristics of plantations appeared to be associated with increased potential surface fire severity.

Prescribed fire fuel consumption averages for the six river basins ranged from 37.3 megagrams/hectare on the Deschutes River basin (current) to 30.9 megagrams/hectare on the Methow River basin (historic) (Table 2). The Grande Ronde River basin

Table 2.—Historic and current fuel loading, fire behavior, fuel consumption, emission factors, and smoke production for six river basins of eastern Oregon and Washington.

		River Basin					
Variable	Period	Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Forest fuels (Mg/ha)	Historic	85.06	84.5	75.33	83.98	98.09	102.65
	Current	92.95	83.27	75.28	85.33	92.89	90.97
	Change	7.89	-1.23	-0.04	1.35	-5.2	-11.68
Fuel consumption Wildfires (Mg/ha)	Historic	56.31	48.39	48.05	53.77	55.16	57.34
	Current	57.34	52.31	49.64	53.7	51.71	54.85
	Change	1.03	3.9 3	1.59	-0.07	-3.45	-2.49
Prescribed fires (Mg/ha)	Historic	37.24	31.43	30.89	36.14	33.92	35.96
	Current	37.32	34.59	32.17	35.08	31.97	35.2
	Change	0.08	3.16	1.28	-1.05	-1.95	-0.76
Fire rate of spread m/min)	Historic	2.08	4.0	2.21	1.72	1.5	1.9
	Current	2.19	3.21	2.11	1.91	1.77	2.27
	Change	0.11	-0.79	-0.1	0.19	0.27	0.37
Flame length (m)	Historic	1.12	1.14	0.95	1.19	0.98	1.09
	Current	1.06	1.25	0.96	1.12	0.96	1.16
	Change	-0.06	0.11	0.02	-0.07	-0.02	0.08
Fire resistance to suppression (m/man-min.)	Historic	0.66	0.64	1.0	0.55	0.73	0.61
	Current	0.62	0.64	0.97	0.6	0.89	0.67
	Change	-0.04	0	0.03	0.05	0.16	0.06
Smoke emission factors PM10 Prescribed fires (g/kg)	Historic	10.96	10.28	10.8	11.31	10.46	10.42
	Current	10.89	10.76	10.87	11.02	10.57	10.53
	Change	-0.06	0.48	0.06	-0.29	0.11	0.11
PM10 Wildfires (g/kg)	Historic	14.09	12.73	13.72	14.56	13.23	13.3
	Current	13.93	13.56	13.85	14.16	13.35	13.47
	Change	-0.15	0.83	0.13	-0.39	0.12	0.17
Smoke production PM10 Prescribed fires (kg/ha)	Historic	409	323.6	332.54	408.34	354.5	375.15
	Current	408	371.93	349.23	386.04	338.04	371.44
	Change	-1	48.33	16.69	-22.3	-16.45	-3.71
Wildfires (kg/ha)	Historic	793.07	622.06	656.87	781.1	730.19	762.93
	Current	799.19	711.71	686.37	759.31	690.94	739.82
	Change	6.12	89.65	29.5	-21.79	-39.25	-23.11

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Table 3.—Ranges and direction of change from historic to current periods in estimates of fire rate of spread (meters/minutes), flame length (meters), and percentage of sample watersheds in Washington and Oregon river basins where rate of spread and flame length increased.

Variable	River Basin Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Change in Rate of Spread						
Maximum (+ change)	1.60	1.24	0.80	1.67	0.99	3.12
Minimum (- change)	-2.61	-2.85	-1.99	-0.66	-0.46	-1.33
Change in Flame Length						
Maximum (+ change)	0.32	0.43	0.12	0.38	0.13	0.30
Minimum (- change)	-0.54	-0.29	-0.16	-0.50	-0.13	-0.02
Percentage Increase						
Rate of spread	50.00	40.00	70.00	66.67	83.33	71.43
Flame length	50.00	70.00	60.00	50.00	16.67	57.14

Table 4.—Percentage of sample watersheds in eastern Washington and Oregon river basins during historic and current periods with rates of spread (ROS) and flame lengths (FL) above thresholds of 2.5 meters/minute (7.6 chains/hour) and 2.3 meters (7.5 feet), respectively, where initial control efforts would be difficult.

Variable	River Basin Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Rate of Spread						
Current	50.0	60.0	20.0	33.0	33.0	28.5
Historic	30.0	70.0	40.0	0.0	0.0	14.3
Flame Length						
Current	0.0	0.0	0.0	0.0	0.0	0.0
Historic	0.0	0.0	0.0	0.0	0.0	0.0
N of sample watersheds	10	10	10	6	6	7

and Methow River basins were the only areas with significant differences in fuel consumption between the historic and current periods. Wildfire fuel consumption averages were approximately double that of prescribed fire, ranging from 57.3 megagrams/hectare on the Deschutes River basin (current) and Yakima basin (historic), to 48.1 megagrams/hectare on the Methow River basin (historic). For wildfire fuel consumption, the Wenatchee River basin was the only one tested that showed a significant decline in wildfire fuel consumption.

Prescribed fire smoke production ranged from 409 kilograms/hectare on the Deschutes River basin (historic) to 323.6 kilograms/hectare on the Grande Ronde River basin (historic). The greatest difference between historical and current conditions for prescribed fires was in the Grande Ronde River basin, which showed an increase of 48.3 kilograms/hectare. The Methow was the only other river basin to show a significant difference in smoke production for prescribed fires. Although two of the six river basins showed significant differences between historical and current wildfire emissions production, the differences were rather small. However, many sample watersheds within a river basin showed large changes from historical times. For example, the Grande Ronde River Basin showed an average increase of 90 kilograms/hectare in smoke production; but, potential smoke production in sample watershed 55 increased 258 kilograms/hectare while a decrease of 98 kilograms/hectare occurred in sample watershed 35. Likewise, in the Yakima River basin potential smoke production decreased slightly by 23 kilograms/hectare; but, watershed 30 within the basin had a 159 kilogram/hectare decrease.

Wildfire smoke production was twice as much as prescribed fire smoke production, ranging from 799.2 kilograms/hectare on the Deschutes River basin (current) to 622.1 kilograms/hectare on the Grande Ronde River basin (historic) (Table 2). The greatest difference between historic and current was an increase of 89.7 kilograms/hectare on the Grande Ronde River basin. The Deschutes and Wenatchee river basins also showed significant differences in wildfire smoke production, but the changes were smaller. If a 20,000-hectare wildfire occurred in the Grande Ronde River basin today, approximately 1.8 million, or 13%, more kilograms of smoke would result than if the fire had occurred 50 years ago.

DISCUSSION

Ecosystem Change

Many factors contributed to the absence of significant change in some landscape attributes over the study period. Detection of significant change within river basins requires that change in a variable be similar among sample watersheds and sample strata. Ecologically diverse systems have high natural variability within and among watersheds and sub-basins. Vegetation, insect and disease hazard, fire behavior, and smoke production data were developed from a population of sample watersheds that have different management and disturbance histories, different vegetative composition and structural characteristics, and, therefore, different trajectories of change. Little change at the basin scale relative to large and variable changes at the watershed scale suggests that the watershed scale is a more meaningful scale at which to analyze landscape change than at the river basin scale.

The data collected in this study was the best available to meet our objectives, and we expected high variation in measured variables. Given the limitations of the dataset, any differences between historic and current conditions are most likely conservative, indicating strong differences. Further analysis of the larger 25% sample of watersheds will yield an even stronger picture of vegetation change.

Insect and Disease Hazard

Insect and disease hazards have changed in response to several management practices. Fire and insect defoliator suppression, and selective harvesting appear to be primary causes of change in vegetation conditions and associated hazards. Management practices have increased or decreased hazards relative to historical baseline conditions depending upon the insect or pathogen, and the watershed. With few exceptions, it is clear that basin-level analysis of insect and disease hazards is less useful than analysis of watershed conditions. Future analyses should focus at that level.

Trends reported here probably are quite conservative when compared with the level of change in vegetation conditions that may have actually occurred since the turn of the century when active fire suppression began. The oldest available aerial photographs used to interpret historical vegetation conditions in any watershed or basin came from the mid-1930s; most photos were from the 1940s and 1950s. It is highly probable that changes in vegetation conditions and associated hazards since 1900 are much greater than we are currently able to show, because we were unable to locate older photography that would show change from 1890.

Fire and Smoke

We assessed the fuel loading for the duff and the dead, woody fuels on the ground, but were not able to address tree crown fuels and live vegetation. Confining the study to dead ground fuels underestimates fuel loading by 5-50% (Snell and Brown 1980; Snell and Anholt 1981; Anderson, 1982). This will result in a lower estimate of fuel consumption and smoke produced than what might actually occur.

No significant differences between historical and current fuel loadings at the river basin level were noted because of the high natural variability within and among watersheds. However, several large differences were evident at the watershed level. In many cases, a decrease in fuel loading from historical to current was related to a natural disturbance (wildfire) or human activity (logging). An increase in fuel loading was often associated with a more homogenous landscape, fewer vegetation types, and less area in early successional species and young stands. This vegetation shift was probably due to natural succession over time and effects of fire suppression activities.

Logged area generally showed a strong association with increased ROS and FL, indicating that tree harvesting is affecting the potential fire behavior within landscapes. Wilson and Dell (1971) described two main reasons why there are fuel and potential fire problems in Pacific Northwest forest and rangelands: (1) fire exclusion has allowed unnatural and hazardous fuels to accumulate and (2) intensive forest management annually produces high loadings of slash fuels. Slash fuels, a by-product of clearcutting, thinning, and other tree removal activities, create both a short- and long-term fire hazard to ecosystems.

Both escaped fires and logging activities, together with fire exclusion, undoubtedly have had substantial effects on ecosystem dynamics. Yet, the interaction of these combined management actions plus other activities such as grazing, which by themselves have distinctly different effects on ecosystems, make landscape patterns difficult to interpret. Fire history prior to the historic time period adds another level of complexity.

The severity of the stresses fire exclusion places on ecosystems is evident, but complex and poorly understood. Interactions of biotic and abiotic factors with fire tend to be circular (Kauffman 1990). Biotic communities, while adapted to specific fire regimes, will influence the pattern and occurrence of fire. Therefore, long-term changes in vegetation composition and structure and in the dead fuel complex, which are often associated with fire exclusion, will likely change the fire regime. Consequently, systems will respond to fire far less predictability, especially if species are poorly adapted to such shifts.

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Changes in fuel loading, fuel consumption, and emission production between the historic and current periods were often less evident at the river basin level than at the watershed level. Wildfires generally produced twice as much smoke as prescribed fires because (1) they occur during drought periods when more fuel is consumed; and (2) the emission factor is 1/3 higher than that of prescribed fire. In areas where wildfires occurred or management activity removed fuels between the historical and current periods, a decrease in fuel loading and a subsequent decrease in emission production was often found. In areas where wildfire did not occur and management activities were not evident, a vegetation shift to high density stands of mixed conifer with an increase in fuel loading and emission production was often noted. Wildfires are not planned, so there is little opportunity to employ emission reduction techniques as is used with prescribed fires.

If there is agreement that earlier, fire-dependent landscapes were more stable and desirable, then prescribed fire will be necessary to restore or maintain these fire adapted ecosystems. However, prescribed fire has the potential to degrade ambient air quality, impair visibility, and expose the public to concentrations of smoke. Scientists will need to describe, and the public will need to understand, the tradeoffs among increased prescribed fires, wildfires, ecosystem health, visibility degradation, and public exposure to smoke.

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CONVERSION FACTORS

Multiply Metric	by	to obtain English
cm	0.3937	inches
hectares	2.471	acres
meters	3.281	feet
meters	0.0497	chains
kilometers	0.6214	miles
grams	0.03527	ounces
kilograms	2.205	pounds
megagrams/hectare	0.4458	tons/acre
grams/kilogram	2.0004	pounds/ton
kilograms/hectare	0.8922	pounds/acre

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