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An environmental narrative of Inland Northwest United States forests, 1800–2000

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Abstract

Fire was arguably the most important forest and rangeland disturbance process in the Inland Northwest United States for millennia. Prior to the Lewis and Clark expedition, fire regimes ranged from high severity with return intervals of one to five centuries, to low severity with fire-free periods lasting three decades or less. Indoamerican burning contributed to the fire ecology of grasslands and lower and mid-montane dry forests, especially where ponderosa pine was the dominant overstory species, but the extent of this contribution is difficult to quantify. Two centuries of settlement, exploitation, management, and climate variation have transformed the fire regimes, vegetation and fuel patterns, and overall functionality of these forests. We present a narrative that portrays conditions beginning at the first contact of Euro-American settlers with Indoamericans of the region and extending to the present. Due in part to its geographic isolation, the Inland Northwest was among the last regions to be discovered by Euro-Americans. In 200 years the region has undergone fur trapping and trading, sheep, cattle, and horse grazing, timber harvesting, mining, road construction, native grassland conversion to agricultural production, urban and rural area development, fire prevention, and fire suppression. We highlight key changes to forest landscape patterns and processes that occurred under these combined influences, discuss implications of the changes, and progress towards restoring sustainability. An adaptive ecosystem management model has been adopted by public land management agencies to remedy current conditions. Ecosystem management is a relatively new concept that emphasizes the integrity and sustainability of land systems rather than outputs from the land. Adaptive management emphasizes the twin notions that incomplete knowledge and high degrees of risk and uncertainty about earth and climate systems will always limit land and resource planning and management decisions, and that management is chiefly a learning and adapting process. We discuss current issues and future options associated with ecosystem management, including the low likelihood of social consensus concerning desired outcomes, the lack of integrated planning, analysis, and decision support tools, and mismatches between existing land management planning processes, Congressional appropriations, and complex management and restoration problems.
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Keywords: Landscape change; Human settlement; Management history; Environmental narrative; Inland northwest; Fire regimes; Vegetation patterns; Adaptive ecosystem management

1. Introduction

> “*The intruders who came to dominate the region by the mid-19th century carried with them powerful cultural prescriptions about the proper ordering of their new surroundings. Those mostly white new-*

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> *comers imposed on their adopted homelands a new language, a discourse steeped in the politics of power: that defined the intruders favorably against the native residents, that vested landscapes with special meaning and purpose, that carried with it heavy suggestions about transforming the land itself. The collective force of that new cultural vision led to new definitions, new bounds of reckoning, and new perceptions about place. These were manifested in changes to the landscape and in the development of a literary tradition that emphasized optimism and the prospects of human betterment*".
> Robbins (1997)

At the heart of the American ethos is an unspoken belief that early explorers and surveyors of the American west discovered a pristine world of noble savages, unspoiled vistas, and untouched forests, rivers, and prairies. But historical writings and scholarly research of the 19th and 20th centuries suggest that another narrative is more likely. In this paper, we summarize the environmental history of the Inland Northwest United States (hereafter, Inland Northwest) beginning at the time of the first contact of Euro-American explorers and settlers with Indoamericans and extending to the present. We summarize historical and environmental research characterizing the landscape at that time and changes occurring over the period of settlement and industrialization. We discuss the implications of landscape-scale changes in forests, fuels, and fire regimes in the light of current and emerging social issues, and suggest some approaches that may be useful for addressing the changes.

1.1. The region

The Inland Northwest landscape has many faces owing to great variety in climate, geology, landforms and topography, plants and animals, and ecological processes. Fires, glaciers, great floods, volcanoes, earthquakes, and temporal variation in climate have repeatedly shaped the region's forests, woodlands, shrub steppes, and prairies. Over many millennia, these disturbances favored species, conditions, and ecosystem processes that were attuned to these events and their spatial and temporal dynamics. Many of these same disturbances, which occur on time scales ranging from days to millennia, remain essential today to maintain this diverse array of forest and rangeland habitats, species, and processes.

For this paper, we consider the Inland Northwest the catchment area of the Interior Columbia River Basin in the coterminous US (Fig. 1). The Basin includes all of Washington and much of Oregon east of the crest of the Cascade Mountain Range, excluding the Northern Great Basin and Owyhee River Uplands; nearly all of Idaho north of the Owyhee Uplands and Snake River Plains and portions of northwestern and southwestern Montana extending to the Continental Divide. This large area consists of nearly all of the Northern Rocky Mountain Province (M333, Bailey, 1995), which includes the Okanogan Highlands of northeastern Washington, eastern portions of the Cascade Province (M242), northern portions of the Intermountain Semi-desert Province (342), which includes the Columbia River Plateau of Oregon and Washington, extreme western portions of the Great Plains and Palouse Dry Steppe Province (331), and portions of the Middle Rocky Mountains Province (M332), which includes the Blue Mountains of northeastern Oregon and southeastern Washington, and the Central Idaho Batholith (Fig. 1). Refer to Bailey (1989, 1995), Bailey et al. (1994) and Hessburg et al. (1999a, 2000a) for more detailed descriptions of the biogeoclimatic conditions of each province.

The span of historical fire regimes of the Inland Northwest included a full spectrum of low (nonlethal), moderate (mixed), and high-severity (lethal) regimes (Agee, 1993, 1994; Quigley et al., 1996; Fig. 2A). Low-severity regimes displayed frequent fire return intervals, low fire intensity, small patch size, and little edge. Mixed-severity regimes exhibited less frequent fire return, a mix of fire intensities that included underburning and stand-replacement fires, intermediate patch sizes, and significant edge between patches. High-severity regimes displayed infrequent fire, generally high fire intensity, large patch sizes, and intermediate edge (Agee, 1998).

Prior to Euro-American settlement, fire regimes ranged from low to high severity in the Northern Rocky Mountains (Table 1, Fig. 2A). High-elevation forests normally displayed high-severity regimes, which transitioned to mixed and low severity in the middle and lower montane forests. Although detailed fire history information for the grasslands and shrub steppe areas are lacking, they likely burned frequently (see Section 2.1).

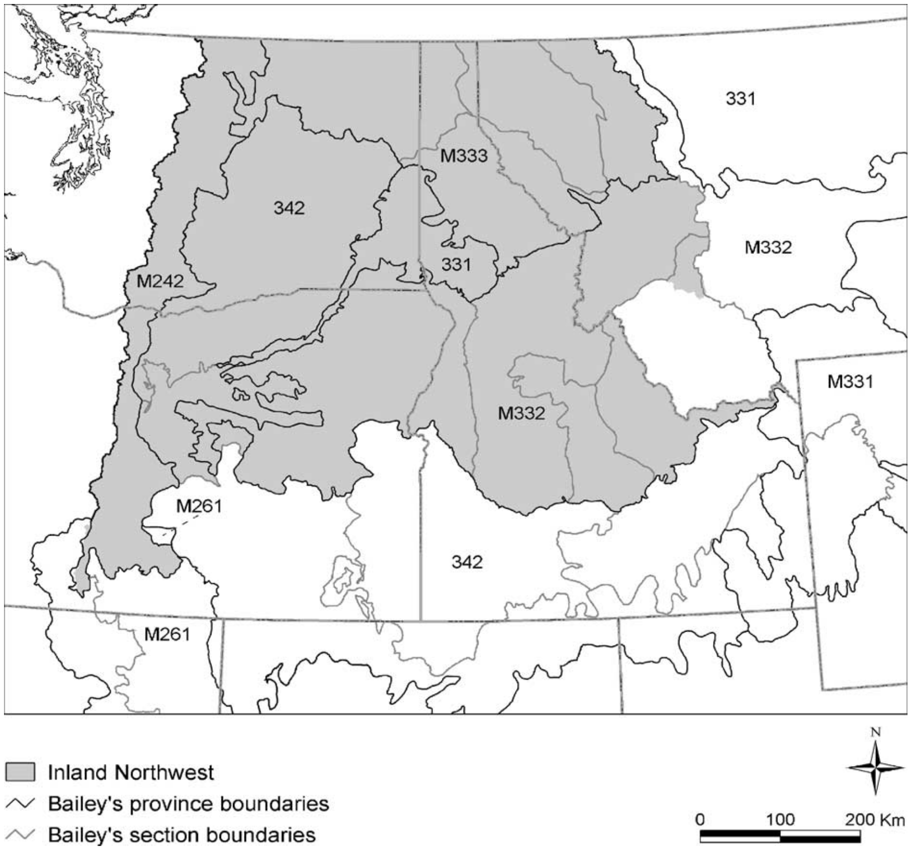

Fig. 1. A map of the Inland Northwest, which is essentially the lower portion of the Interior Columbia River Basin that resides in the coterminous United States east of the crest of the Cascade Mountain Range. The associated Bailey's province boundaries are also shown (Bailey, 1995). Provinces are: M242—Cascade; 331—Great Plains-Palouse Dry Steppe; 342—Intermountain Semi-desert; M332—Middle Rocky Mountain; M333—Northern Rocky Mountain; M261—Sierran; M331—Southern Rocky Mountain.

Fire regimes differed from north to south in the eastern portion of the Cascade Province (Fig. 2A). A gradient of fire regimes similar to that for the Northern Rockies existed to the north: high severity at high elevation, including those maritime subalpine forests of mountain hemlock (*Tsuga mertensiana*) and Pacific silver fir (*Abies amabilis*), transitioning to low severity in the forests bordering the shrub steppe landscapes. To the south, a higher proportion of mixed-severity fire was found in the high-elevation forests, particularly those dominated by red fir (*A. magnifica*; Agee, 1993). On the pumice flats of south-central Oregon are climax lodgepole pine (*Pinus contorta*) forests, where cold air ponding limits productivity and fuel buildup, and therefore, fire spread and effects.

The Middle Rocky Mountains Province is comprised of the Blue Mountains, Salmon River Mountains, and basins and ranges of southwestern Montana (Bailey, 1995). Historical fire regimes of the Middle Rockies included a typical gradient from high-severity fire at upper elevations to low severity in the lower-elevation forests. However, substantial variability existed within a given forest type, representing not only regional (top-down) variability due to climate, but also local (bottom-up) variability due to slope and aspect (Heyerdahl et al., 2001).

The grasses that dominated the historical Intermountain semi-desert were well adapted to burning, such that the year following fire little effect on the grasslands would be noticed. Woody plants were less

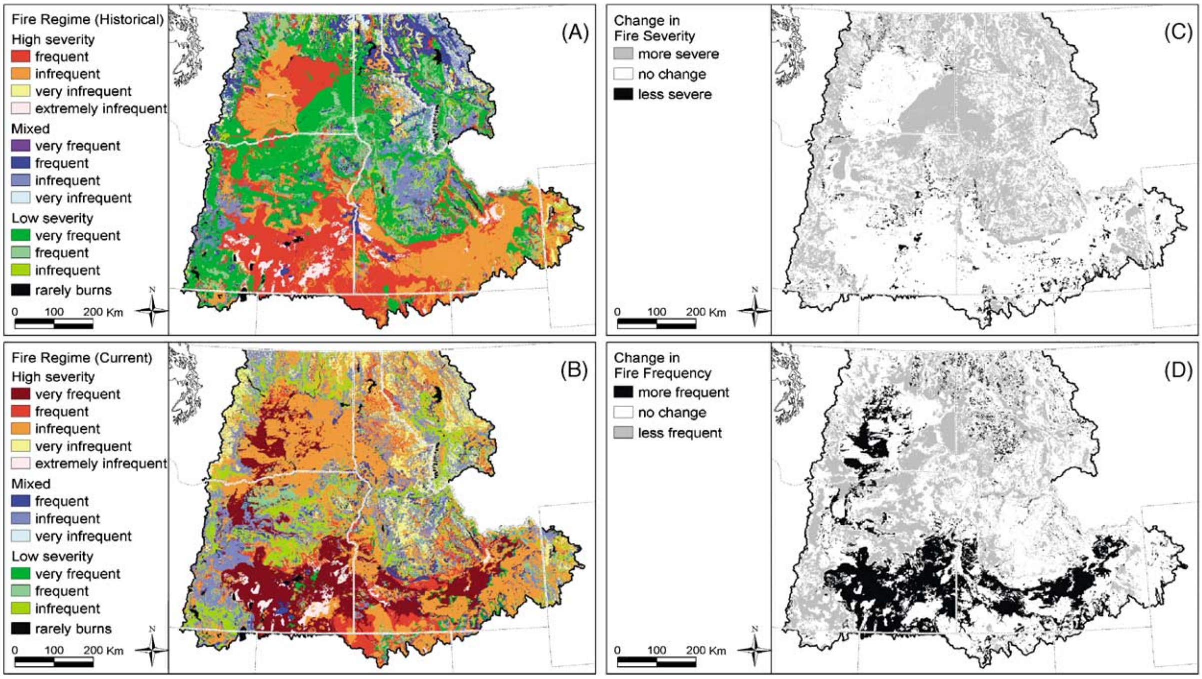

Fig. 2. Broadscale (1 km^2 pixels) maps of (A) historical (circa. 1800) and (B) current fire regimes of the Interior Columbia Basin and vicinity (from Hann et al., 1997), and changes in (C) fire severity and (D) fire frequency between 1800 and 2000 A.D. High severity = stand-replacing fire that kills $> 70\%$ of the overstory tree basal area; low severity = fire that kills $< 20\%$ of the overstory tree basal area; mixed severity = fire that kills 20–70% of the overstory tree basal area, and rarely burns = fire seldom occurs. Very frequent = 0–25 year mean fire-return interval; frequent = 26–75 year mean fire-return interval; infrequent = 76–150 year mean fire-return interval; very infrequent = 151–300 year mean fire-return interval; extremely infrequent > 300 year mean fire-return interval.

resilient, such that sagebrush (*Artemisia* spp.) or western juniper (*Juniperus occidentalis*) was more than likely killed, leaving woody skeletons that puzzled some early travelers (Evans, 1991). Likewise, grasslands of the Palouse steppe region also burned frequently, and kept woody vegetation largely confined to canyon bottoms and riparian areas (Agee, 1994).

2. Accounts of Indoamerican burning

Historical research of the 20th century tells us that Native American Indians (hereafter, Indoamericans) used fire over a long period of time to intentionally burn Inland Northwest landscapes (Pyne, 1982; Robbins, 1997; Robbins and Wolf, 1994; Sauer, 1971; White, 1991). Dobyns (1981) contended that fire was "the principal technology that Indoamericans possessed for modifying natural environments in order to augment their food supplies". Barrett (1980a,b) proposed that Indoamerican use of fire to improve subsistence gathering was technically advanced because fire chronologies from tree-rings show that fires were intentionally set when seasonal and fuel conditions favored low-intensity burns and their effects. According to Barrett (1980a,b), natives used fire to: (1) stimulate new growth of grasses, herbs, and shrubs for browsing ungulates, upland birds, and waterfowl; (2) enhance the development, fruiting, and distribution of a variety of food plants; (3) improve forage for and hunting access to wild game animals; (4) open and maintain clearings for easier foot and horse travel; (5) improve forage for their horse herds, once Spanish horses had been introduced. After reading the 17th century literature, Sauer (1971) was convinced that intentional burning was widely employed across North America, except where wet or humid climates prevailed or where aridity prevented fuel accumulation.

White (1983, 1999) contended that Indoamericans on Puget Sound's Whidbey Island used fire to improve

Table 1
Fire regime data for major vegetation types of the Inland Northwest[a]

Vegetation type	Severity of fire regime	Range of fire return intervals from various studies (years)
Western juniper series[b]	Mixed	15–20, 7–17, 25
Ponderosa pine series[c]	Low	16–38, 7–20, 11–16, 3–36
Douglas-fir series[d]	Low to Mixed	7–11, 10, 10–24, 14, 8–18
White fir series[e]	Low to Mixed	9–42, 9–25, 9–18
Grand fir series[f]	Low to Mixed	16, 47, 33–100, 17, 100–200
Lodgepole pine series[g]	Mixed	60
Western hemlock/western redcedar series[h]	High	50–200$^+$, 50–100, 150–500
Subalpine fir series[i]	High	25–75, 109–137, 140–340, 250, 50–300

[a] Summary data are taken from studies cited in Agee (1993) and some newer studies. Data were collected using a wide variety of fire history methods, which influences the fire return intervals cited. Some of the variability is therefore methodological, and some is inherent within the fire regime.

[b] Young and Evans (1981), Martin and Johnson (1979), Burkhardt and Tisdale (1976).

[c] Bork (1985), Weaver (1959), Soeriaatmadja (1966), Heyerdahl et al. (2001).

[d] Wischnofske and Anderson (1983), Hall (1976), Finch (1984), Everett et al. (2000).

[e] McNeil and Zobel (1980), Bork (1985), Kilgore and Taylor (1979).

[f] Weaver (1959), Wischnofske and Anderson (1983), Arno (1976), Antos and Habeck (1981).

[g] Agee (1981), Stuart (1984).

[h] Arno and Davis (1980), Davis et al. (1980).

[i] Barrett et al. (1991), Agee et al. (1990), Fahnestock (1976), Arno (1980), Morgan and Bunting (1990).

growing conditions for camas (*Camassia quamash*) and bracken fern (*Pteridium aquilinum*), vegetables essential to their diet. In fact, White concluded that camas and bracken dominated the prairies *because* they were primary food sources, suggesting that Indoamerican use of fire to enhance vegetable production had dramatically altered their distribution and abundance. Boyd (1986, 1999) and Boag (1992) made a similar case for Indoamerican burning in Oregon's Willamette Valley to improve food plant abundance and forage for game. Today, one can see the progressive conifer recolonization of former grasslands and oak woodlands that were once apparently maintained by burning.

Intentional Indoamerican burning east of the Willamette Valley and Puget Lowlands was also common (Barrett and Arno, 1982, 1999, and references therein; Pyne, 1982, and references therein; Agee, 1993, and references therein; Ross, 1999, and references therein). In the eastern Cascades of Oregon and Washington, on the Columbia Plateau, and east to the Bitterroot Range and Continental Divide, Indoamericans apparently fired the landscape to enhance food production locally and improve browse for deer, elk, and bear that were important sources of protein in the native diet.

Exactly when fire became a significant tool for actively manipulating landscapes is unknown. Archaeological finds in Oregon reveal that modern humans apparently appeared on the scene in the Inland Northwest 11,000–13,000 B.P., as the Pleistocene waned (Cressman, 1962; Grayson, 1993). By this time, alpine and continental glaciers had receded from their maximum (18,000 B.P.), and a period of retreating continental ice sheets was imminent. In the late Pleistocene, much of the northern half of what is now the Inland Northwest was blanketed by snow and ice, including middle, upper montane, and subalpine forests of the northern Cascades, Okanogan Highlands, and northern Rockies. Continental glaciers also covered vast low-lying areas of the Okanogan Highlands and northern Rockies. Warming associated with an early Holocene (10,000–5000 B.P.) climate would encourage the expansion of temperate forests and prairies (Roberts, 1998).

The spatial extent of areas influenced by intentional Indoamerican burning and resulting variation in patterns of forest and prairie vegetation has not been clearly shown, and cannot be shown from historical narratives. Much of the available evidence for the extent of burning comes from descriptive writings of early white explorers, surveyors, and fur traders who first encountered the region and its native people. Observations, though numerous, were colored by the values of the observers because the effects of burning on vegetation and wildlife were seen as destructive and wasteful of commodities of significant value to the observers (White, 1992; Baker, 2002). Journal entries of Lewis and Clark (Thwaites, 1959; Moulton, 1983–1993), Ogden (Davies, 1961), and others (Evans, 1991; Robbins and Wolf, 1994; Robbins, 1997) bemoan frequent encounters of charred prairie and forest landscapes, burned-over river bottoms, smoke-filled vistas, vast grass swards regrown after fires, and extensive, park-like pine forests. As Robbins and Wolf (1994) put it, "The widespread practice of burning created an artificial forest environment of open glades and park-like settings, a descriptive refrain that runs through virtually all of the 19th century travel and survey literature".

While the solid evidential record of Indoamerican burning in prehistory is thin and mostly inseparable from other burning in the dendroecological fire records, it is probable that Indoamericans had been burning portions of the North American landscape well before the Columbian encounter. Hence, there is no pretreatment period upon which to base estimates of the contribution of Indoamerican burning. As one forest historian (Cronon, 1989; also see Christensen, 1989) noted "humankind has influenced the composition and structure of nearly all North American ecosystems for nearly 10,000 years". But only via reconstructed evidence (sensu Swetnam et al., 1999) can we observe the fire record and quantify any potential contribution of Indoamerican burning to spatial patterns of forest and prairie vegetation.

2.1. Fire regimes and Indoamerican burning

The influence of Indoamerican burning on fire regimes is an ecology of place. That is, Indoamericans burned those places where it was to their advantage and where they could successfully burn. Before 1960, Indoamericans were thought to have been passive aboriginals with little landscape effect (Clar, 1959). After 1970, they suddenly were perceived as master gardeners, affecting every acre of the western US (Pyne, 1982). Neither view is supported by our current knowledge (Baker, 2002; Whitlock and Knox, 2002). Indoamericans more than likely had some effect on the historical low-severity fire regimes characteristic of grasslands, and low-elevation, dry montane forests (compare Figs. 2A and 3), but it is nearly impossible to sort out the extent of their contribution. The many accounts by early explorers of Indoamericans firing the land almost always were in grassland, savanna, woodland, and dry forest types, where they used fire to protect their villages (the original urban–wildland interface) and for a variety of resource-related products (Whitney, 1994; Vale, 2002, and references therein).

These low-severity fire regime areas are naturally fire-prone, fuel—rather than ignition-limited environments, so it is not altogether clear whether Indoamericans supplemented or simply substituted for lightning fires (e.g., Baker, 2002). Barrett and Arno (1982) made the case that Indoamerican burning may have halved the fire return interval in dry Montana forests (18–9 years), but they combined fire records over different-sized study units so there is an area bias inherent in their results (Agee, 1993). Nevertheless, the influence of Indoamerican burning likely did influence fire return in some low-severity regime areas, and some prairies were likely burned annually to biennially if the accounts of burned prairies by early explorers are pieced together.

The Indoamerican influence is less clear in the mixed-severity and high-severity fire regime areas (Agee, 1993; Sea and Whitlock, 1995; Baker, 2002, and references therein; Whitlock and Knox, 2002, and references therein). There is evidence suggesting that reduced fire return intervals along travel corridors may have been a result of Indoamerican burning (e.g., see Barrett, 1980a,b, 1981; Barrett and Arno, 1982; Olson, 1999), but the longer fire return intervals for mixed-severity regime areas (25–75 years; Agee, 1993) suggest that if Indoamericans were burning in these areas, it was a once-in-a-generation event. It is even less likely that Indoamericans widely burned the landscape in high-severity regime areas with fire return intervals of 100–300 years (Agee, 1993). There are several areas where Indoamericans did regularly burn subalpine glade and bordering forest environments to maintain huckleberry fields (e.g., the slopes of Mount Adams, Washington Cascades), but these appear to be localized and mostly well known (French, 1999). Lightning-caused fires also occurred in subalpine areas, and because of the relatively slow recoloniza-

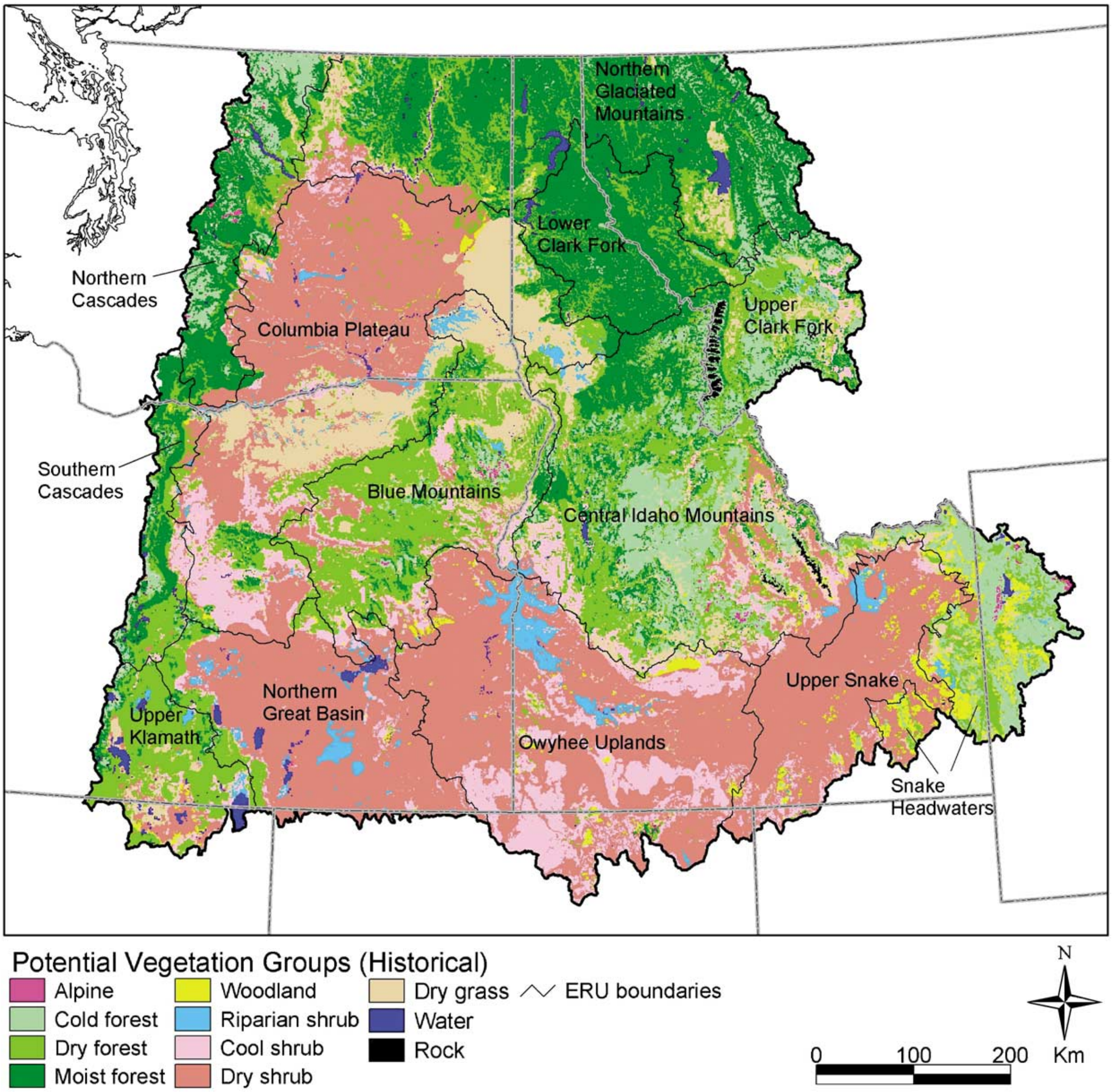

Fig. 3. Broad-scale (1 km^2 pixels) map of historical (circa 1800) potential vegetation groups and ERUs (ERUs ≈ provinces) within the Interior Columbia Basin and vicinity (from Hann et al., 1997).

tion by trees after fires, some may have remained good berry fields for years to decades (Little and Peterson, 1991; Agee, 1993).

Overall, by consciously burning dry forest and prairie landscapes, Indoamericans actively practiced an early form of agriculture by extensive plant culture; burning encouraged the development, fruiting, and increased abundance of certain species while discouraging others. Burning also made food gathering and hunting more convenient and efficient because it encouraged increased food plant and game distribution and abundance in the neighborhood of their encampments. At a landscape scale, such burning may or may not have influenced spatial patterns and temporal variation of forest, woodland, steppe, and prairie vegetation.

2.2. Landscape evidence for the influence of pre-settlement fire

To gain additional insights into the magnitude of effects associated with the loss of fire by all mechanisms, we revisit two recent bioregional assessments that evaluated changes to Inland Northwest forests and prairies under the influence of settlement and industrialization (Hann et al., 1997; Hessburg et al., 1999a, 2000a). In those studies, vegetation changes were thought to be primarily the result of late 19th and 20th century management activities including selective tree cutting, road construction, livestock grazing, and fire prevention and suppression.

2.2.1. Changes in physiognomic conditions

The historical potential vegetation map of the Interior Columbia River Basin and vicinity (Fig. 3) in Hann et al. (1997) showed that most of the grassland and dry forest area occurred in a handful of ecological reporting units (ERUs, ≈provinces, Bailey, 1995). Since historical ecology research and narrative accounts tell us that frequent surface fires were typically concentrated in grasslands adjoining dry forest or woodland environments, we re-examined changes to these areas to determine whether the empirical evidence supported both the research and narrative records. Before Euro-American settlement, the Columbia Plateau and Blue Mountains provinces contained the largest expanses of native grasslands in the Interior Columbia Basin. By the 1930s, sample-based estimates showed that 26% of the land area of the Columbia Plateau was forested, almost half was composed of shrublands (32%) and grasslands (13%), and 7% was composed of oak (*Quercus* spp.) or juniper (*Juniperus* spp.) woodland (Hessburg et al., 1999a). By the 1990s, forests had increased to 29% of the province, and woodlands had expanded to 12% (Fig. 4). Transition analysis showed that both increased at the expense of shrubland area, which fell to 23% of the province area. By the 1930s, most of the native grasslands were converted to agricultural uses (Hann et al., 1997), so no change there was noted. An example of one Columbia Plateau subwatershed exhibiting increased woodland and forest area is shown (Fig. 5A).

The coincidence between the start of juniper woodland expansion and the introduction of large livestock herds into the Inland Northwest (both in the late 19th century) argues that grazing and associated reduction in fire frequency (due to the grazing induced loss of fine fuels) are the primary causes of woodland expansion (Ellison, 1960; Burkhardt and Tisdale, 1976; Young and Evans, 1981; Eddleman, 1987; Neilson, 1987; Miller and Wigand, 1994). But amidst some disagreement (Smith et al., 1987; Archer, 1994; Belsky, 1996) climate change and increased

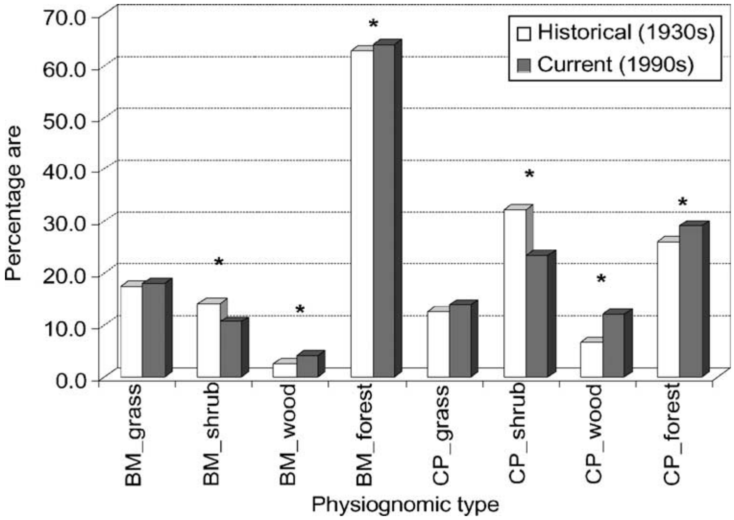

Fig. 4. Percentage of historical (1930s) and current (1990s) province area in grassland (grass), shrubland (shrub), woodland (wood), and forest physiognomic types in the Blue Mountains (BM) and Columbia Plateau provinces (from Hessburg et al., 1999a).

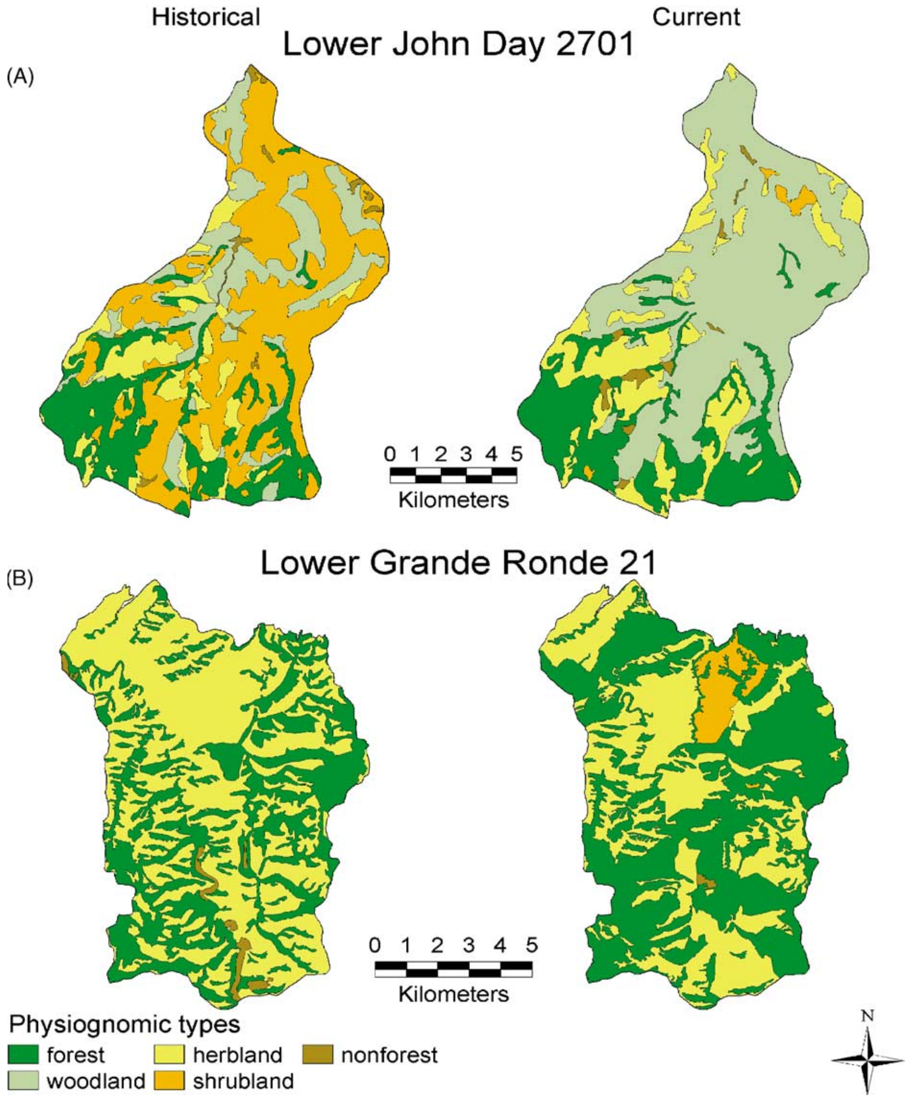

Fig. 5. Historical (1930s) and current (1990s) patterns of physiognomic types in (A) subwatershed 2701 in the Lower John Day subbasin of the Columbia Plateau province, and (B) subwatershed 21 in the Lower Grande Ronde subbasin of the Blue Mountains province (from Hessburg et al., 1999a).

atmospheric CO_2 have also been suggested as contributing factors (Miller and Wigand, 1994; Miller et al., 1994).

In the 1930s, sample-based estimates showed that 63% of the land area of the Blue Mountains province was forested, nearly one-third was composed of grasslands (17%) and shrublands (14%), and 3% was in woodland. By the 1990s, forest area had increased to 64%, woodlands had increased to 4%, and shrublands, declined to 11% of the province area (Fig. 4). All changes were significant. An example of a Blue Mountains subwatershed showing increased forest area over a span of about 60 years is shown (Fig. 5B). Noteworthy in this example is the decline in grassland area with expanding forest. Absent frequent fires in lower montane forests and grasslands, ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) forest cover expanded.

Examples from the Columbia Plateau and Blue Mountains represent significant and ecologically important changes (outside of broad natural ranges, sensu Hessburg et al., 1999b) in the area of physiognomic types. This evidence suggests that fire frequency occurring prior to the early 20th century was sufficient to constrain forests and woodlands to a smaller area than they would have otherwise occupied.

2.2.2. Cover type changes

Another effect that would logically be associated with the loss of fire would be increased overstory cover and dominance of conifers, especially shade-tolerant and fire-intolerant conifers in dry forests. Regular burning would have maintained fire-tolerant, early seral species such as ponderosa pine and western larch (*Larix occidentalis*) and discouraged establishment and dominance of shade-tolerant species such as Douglas-fir, grand fir (*Abies grandis*), and white fir (*Abies concolor*). In their analysis, Hessburg et al. (1999a, 2000b) noted this effect in several provinces and attributed changes to fire exclusion by fire suppression and livestock grazing, and early selective timber harvesting.

Conspicuous cover type changes occurred in the Blue Mountains, Columbia Plateau, Northern Cascades, Northern Glaciated Mountains, Northern Great Basin, Owyhee Uplands, and Upper Klamath provinces. In the Northern Great Basin, Owyhee Uplands, and Upper Klamath, the principal type change was expanding juniper land cover. From the historical (1930s) to the current (1990s) condition, juniper cover rose from 14 to 22% of the Northern Great Basin province area, from 5 to 7% of the Owyhee Uplands province area, and from 8 to 13% of the Upper Klamath province area (Fig. 3).

In the Blue Mountains, Douglas-fir cover composed 12% of the historical forest of the 1930s. By the 1990s, Douglas-fir cover had increased from 8 to 17% of the province (e.g., Fig. 6A). Over the same period in the Columbia Plateau, ponderosa pine cover increased from 19 to 21%, and juniper cover increased from 6 to 12% (e.g., Fig. 6B). In the Northern Cascades province, Douglas-fir cover composed 30% of the historical forest. By the 1990s, it increased from 24 to 26% of the province area (e.g., Fig. 7A).

In the Northern Glaciated Mountains province, forests constituted about 81% of the total land cover in both the historical (1930s) and current (1990s) conditions. Of the historical forest, approximately 47% was composed of early seral species such as western larch, ponderosa pine, western white pine (*Pinus monticola*), whitebark pine (*Pinus albicaulus*), lodgepole pine, aspen (*Populus tremuloides*), cottonwood (*Populus* spp.), and willow (*Salix* spp.). The balance (53%) consisted of a mix of Douglas-fir, western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja occidentalis*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and mountain hemlock cover types. By the 1990s, 59% of the forest area was dominated by fire-intolerant, shade-tolerant conifers (e.g., Fig. 7B).

Twentieth century changes in physiognomic and cover type conditions are consistent with both historical ecology and narrative records of frequent fire return in grasslands and dry forests. Because the influences of lost Indoamerican burning, fire suppression, livestock grazing, and selection cutting each favor similar successional trajectories and outcomes, it is impossible to separate their effects on cover type change. Absence of fire primarily favored expansion of juniper woodland and ponderosa pine forest. We speculate that the primary effect of fire exclusion in habitats where ponderosa pine was the early seral dominant was increased evenness or reduced clumpiness of trees, and increased overall tree density within patches (e.g., Harrod et al., 1999).

3. Spanish horses

Three hundred years ago, at the beginning of the 18th century, the Interior Columbia River Basin from the Cascade Crest to the Continental Divide and from the Salmon River in the south to the upper Fraser River in the north remained relatively isolated from the modern world. More than a dozen tribal groups inhabited the area, but most groups shared certain cultural fundamentals. Salmon was a plentiful and chief food resource and it joined many Interior Columbia Basin tribes in Oregon, Washington, and Idaho with the cycles of salmon and rivers, either in encampments along salmon-bearing streams, or by drawing them seasonally back to streams to replenish their supplies. Many tribal groups were riverine fishing economies that supplemented their fish diets with

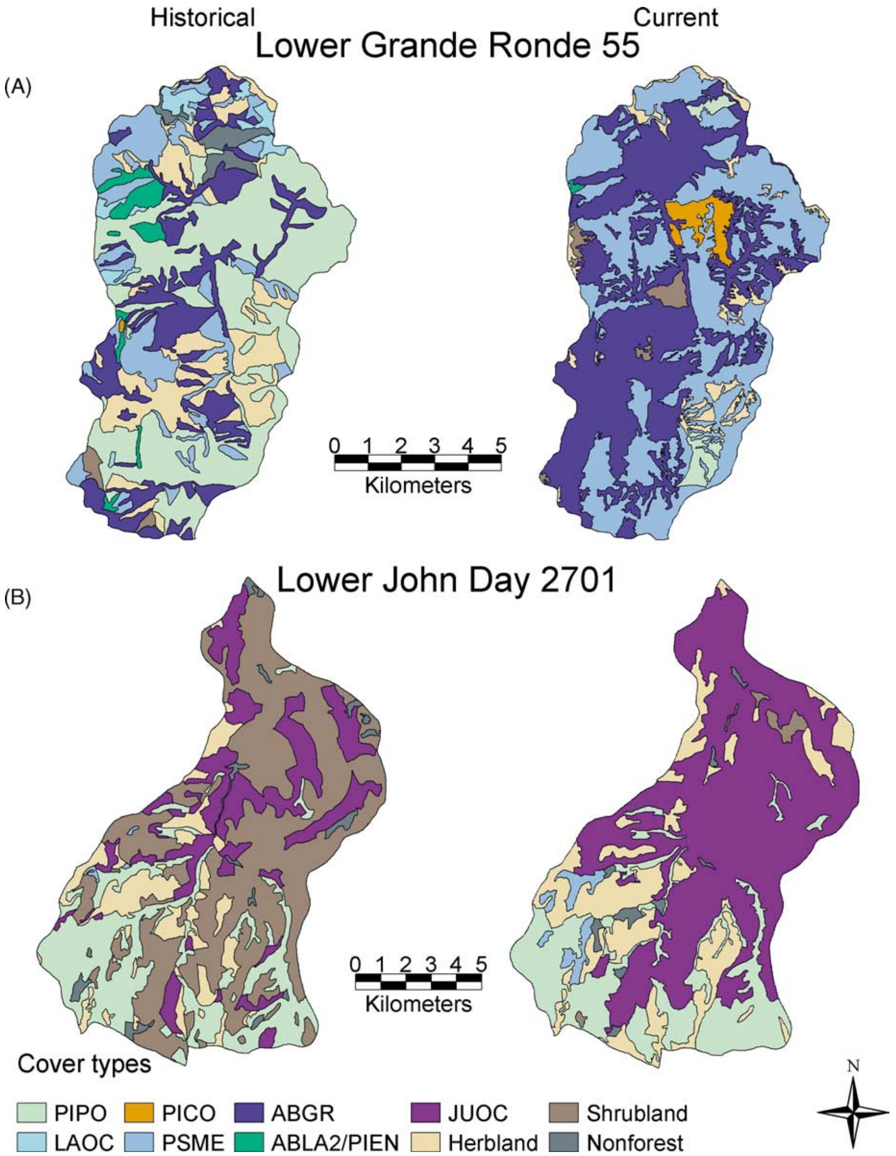

Fig. 6. Historical (1930s) and current (1990s) maps of forest and woodland cover type changes in (A) subwatershed 55 in the Lower Grande Ronde subbasin of the Blue Mountains province, and (B) subwatershed 2701 in the Lower John Day subbasin of the Columbia Plateau province (from Hessburg et al., 1999a). Cover types are PIPO: ponderosa pine; LAOC: western larch; PICO: lodgepole pine; PSME: Douglas-fir; ABGR: grand fir; ABLA2/PIEN: subalpine fir and Engelmann spruce; JUOC: western juniper.

elk, deer, bear, rabbit, and grouse, and berries, bulbs, nuts, seeds, and eggs of waterfowl (Barrett and Arno, 1999; Boyd, 1999; French, 1999; Leopold and Boyd, 1999; Norton et al., 1999; Robbins, 1997, 1999; Turner, 1999; White, 1999). Among other tribes native salmonids were less important. Much of this changed with the coming of Spanish horses.

The horses that spread throughout the American West originated in the Spanish colonies of what is now New Mexico. Pueblo Indians living in the vicinity of the Rio Grande River rose up against the Spaniards in 1680, drove them off their lands and liberated their horses, some of which made their way north along either side of the Rocky Mountains (Robbins and

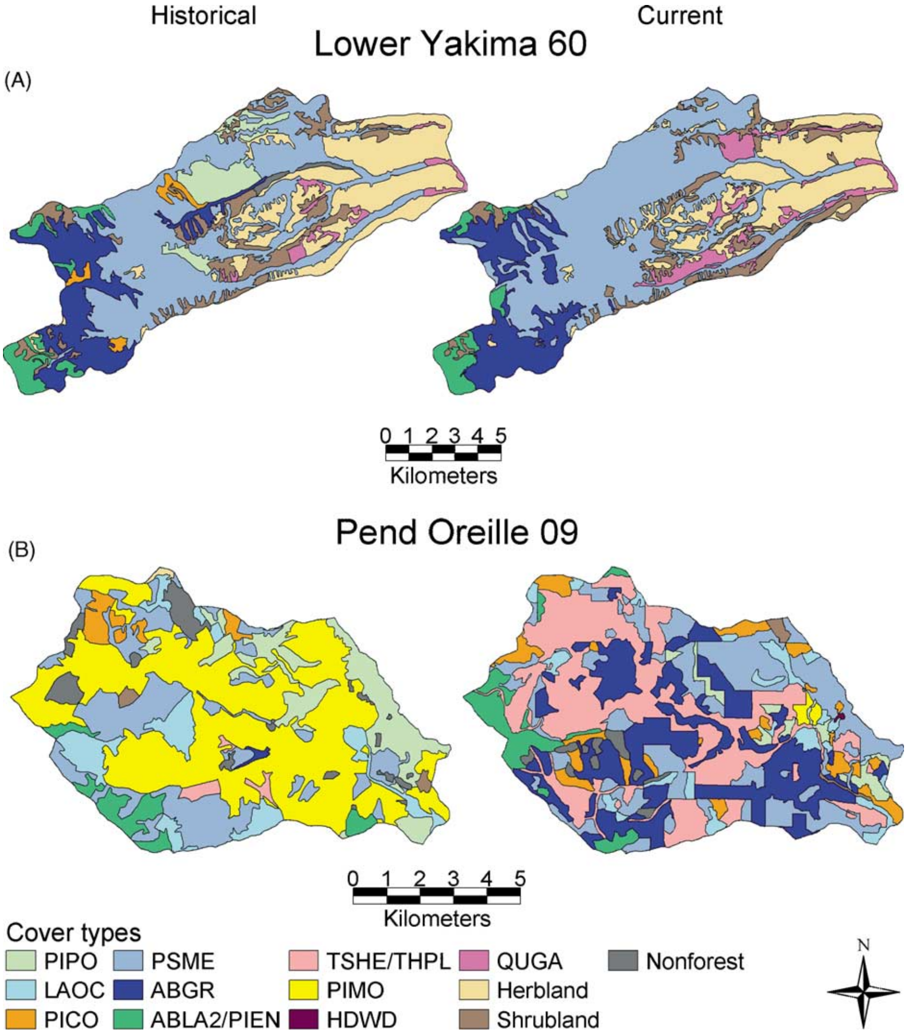

Fig. 7. Historical (1930s) and current (1990s) maps of forest and woodland cover type changes in (A) subwatershed 60 in the Lower Yakima subbasin of the Northern Cascades province, and (B) subwatershed 09 in the Pend Oreille subbasin of the Northern Glaciated Mountains province (from Hessburg et al., 1999a). Cover types are PIPO: ponderosa pine; LAOC: western larch; PICO: lodgepole pine; PSME: Douglas-fir; ABGR: grand fir; ABLA2/PIEN: subalpine fir and Engelmann spruce; TSHE/THPL: western hemlock and western redcedar; PIMO: western white pine; HDWD: hardwoods; QUGA: Oregon white oak.

Wolf, 1994; Robbins, 1999). Through trading and raiding, Spanish horses were spread northward from one Indoamerican culture to another. At the close of the 17th century, the Shoshone in the upper Snake River Plain had acquired horses, and within a few decades, parties of Salish and Kootenai, Nez Perce, and Cayuse had obtained horses. By the 1730s, Utes, Shoshones, Salish and Kootenai, Nez Perce, and Cayuse Indians had all acquired horses (Haines, 1938).

By the early 19th century the Yakama, Cayuse, and Nez Perce had amassed substantial horse herds (Haines, 1938). The effects of horse acquisition were immense on the tribal groups that were once tied to salmon and salmon-bearing streams. New-found mobility improved hunting efficiency, enlarged economic territories, extended trading contacts, and intensified warfare among traditional enemies to the south and east. Expeditions to bison (*Bison bison*) ranges to the southeast became an annual affair. Fighting between Columbia Basin and Plains Indians often marked bison expeditions, and Indoamericans of the Interior Columbia Basin began to adopt elements of Plains horse culture, especially fighting techniques and rituals associated with horse warfare. Wealth and prestige became associated with great herds of horses and success in battle. Access to bison and increased range and hunting efficiency favored improved economic security and expanding Indian populations.

The effects of these large horse herds on forest and prairie ecosystems and any associated practice of Indoamerican burning are poorly understood. Some scholars argue that grasslands promoted by Indoamerican burning were underutilized in the wake of Pleistocene extinctions. However, Robbins (1997) presented evidence that the introduction of horses and the expansion of horse herds may have intensified Indoamerican burning. He cited as evidence numerous journal references of early explorers, settlers, and surveyors of the region to vast recently fired areas, extensive lush prairies, numerous horse trails used by Indoamericans, and large bands of well-fed horses. For example, he cites the story of the Astorian Wilson Price Hunt, who when visiting an Indian encampment along the Umatilla River during the winter of 1811–1812 counted 34 lodges that presumably housed about 34 families. Grazing in the vicinity of the camp were an estimated 2000 horses (Hunt, 1935). If Indoamerican burning practices were locally intensified in support of large horse herds, and herds were concentrated in the vicinity of Indoamerican encampments, we speculate that localized livestock overgrazing may have begun in certain grasslands early in the 1800s, well before Euro-Americans arrived with their large cattle and sheep herds.

4. Market driven capitalism

4.1. Fur trapping and trading

The expansion of market capitalism was the great motivating force behind the transformation of the Inland Northwest (White, 1991; Robbins, 1997). It was fashion—the American and British appetite for felt hats and fur coats—that drove capitalists, markets, and fur traders to ultimately plunder the beaver (*Castor canadensis*) and river otter (*Lutra canadensis*) resources of Inland Northwest streams. Beaver and otter trapping began on a fairly benign basis, but fear of competition from other traders and immigrants drove several prominent companies, including Hudson's Bay, Astor's Pacific Fur, and the Northwest Company to policies of rapid overtrapping. To illustrate the sentiment of the period, George Simpson of the Hudson's Bay Company wrote, ''... we have convincing proof that the country is a rich preserve of Beaver ... which for political reasons we should endeavor to destroy as fast as possible''. British and American trappers and traders from Canada and the eastern and midwestern US trapped throughout the Willamette and Columbia river regions, often deliberately creating ''fur deserts'' to discourage competitors from entering the region (Langston, 1995).

While trafficking furs and combing the river valleys in search of their quarry, trappers and traders of the 1770s and 1780s unwittingly introduced an astonishing variety of contagious and lethal human diseases. Since Indoamericans of the region carried no resistance or immunity to the diseases, the loss of human life was staggering. According to the anthropologist Hunn (1990), the story of Indoamerican-white trader and settler relations in the middle Columbia region was ''first and foremost a history of the ravages of disease ... which drastically reduced aboriginal populations''. Included among the introduced diseases were both localized epidemics and pandemic outbreaks of typhus, cholera, smallpox, chicken pox, measles, and whooping cough. Before ditching, draining, and flood control measures were put in place, major malarial pandemics also occurred throughout the Willamette, Rogue, and Lower Columbia Valleys during the 1830s, which proved extremely lethal to the native population (Robbins, 1997, and references therein). Of the introduced diseases, smallpox epidemics were the worst of all. The end of a smallpox epidemic was often accompanied by nearly 100% mortality of Indoamerican people in the affected area. Boyd (1990) estimated that in 1770 the Indoamerican population in the Pacific Northwest was approximately 300,000. By the late 1860s that number had fallen by 80% to only about 60,000 people. The mortality rate west of the Cascades in the lower Columbia region and Willamette Valley was estimated at a much higher 92% (Robbins, 1997). Robbins (1997) reported that recent evidence suggests that smallpox and perhaps other diseases may have been initially spread to the Lower Columbia and Northwest Coast regions from Plains tribes via the horse (Boyd, 1990; Moulton, 1990).

The relatively complete removal of beaver from the Inland Northwest landscape represents an incalculable loss to fish and fish habitat, as well as riverine and riparian biotic diversity and productivity. Beaver dams located on small and mid-sized streams slowed the flow of water, dramatically enhanced stream braiding and wetland area, buffered streams against floods, prolonged late summer flows, trapped sediment and organic matter loads behind dams, increased aquatic ecosystem and riparian zone productivity, and directed riparian zone succession. Naiman et al. (1986, 1988) estimated that in North America prior to trapping, there may have been 60–400 million beaver distributed over 15.5 million km^2. Over much of that area, beaver and their influences were virtually eliminated in less than five decades.

4.2. Missionaries and settlers

While a number of the early trappers, explorers, and traders eventually settled in the northwest late in the 18th and early in the 19th centuries, Protestant missionaries of the 1830s and their entourages represented the first wave of Christianity into the region. Langston (1995) claimed that there were two things that "transformed the Inland West more thoroughly than had the British fur desert . . . missionary zeal and cows". To the east in Missouri, politicians like Thomas Hart Benton and Lewis Flinn were extolling the virtues of the agrarian Utopia to be found in the west in the Willamette Valley and Lower Columbia regions (Robbins, 1997). Within a short time, the propaganda of the 1820s had motivated a small but determined Euro-American immigrant population to come to Inland Northwest.

In contrast to Indoamericans who cultured landscapes with fire, Euro-American immigrants set about to "husband the familiar" (White, 1991). That is, they brought with them a profusion of nonnative plant and animal species such as sheep, goats, cattle, and pigs, wheat, barley, rye and corn. Indigenous plants and animals were successively eliminated from areas brought under cultivation because their apparent lack of utility to Euro-Americans made them "weed" and "pest" species. One of the ramifications of this husbandry was the often purposeful damage it did to Indoamerican subsistence living because many of the unwanted or competing plant and animal species were important to the diet of the native people.

Protestant missionaries of the day were not only intent on redeeming Indoamerican souls; they felt obligated to overhaul their subsistence way of life. The motivating ideals behind the almost religious fervor of missionaries to get natives to adopt the American model of farming were apparently 2-fold. First, Euro-Americans believed that in order to honorably lay claim to land ownership, one must work it with their own hands; Indoamericans on the other hand hunted, fished, and gathered, which were considered by Euro-Americans of the day to be leisure pastimes. Second, missionaries believed it would be difficult to convert Indoamericans to Christianity if they nomadic. The Protestant missionary, Spalding, wrote that "while we point them with one hand to the Lamb of God which taketh away the sins of the world, we believe it to be equally our duty to point with the other to the hoe" (Hurlbert and Hurlbert, 1941; Miller, 1985).

From the 1830s to 1860s, missionaries had converted few Indoamericans, but they were much more successful in encouraging Euro-American settlers to occupy the Inland Northwest. Accordingly, more than 300,000 newly immigrated Euro-American settlers streamed west on overland trails between 1840 and 1860 (Robbins, 1997). Settlers were looking for parcels that were suitable for supporting a small farm. Such parcels were best found where grass grew plentifully and where pine forests were sparsely treed and interspersed with prairies and meadows.

Despite repeated gold discoveries during the 1840s and 1850s across the region of the interior Columbia River and California, it was the moist and fertile agricultural lands of the river valleys that beckoned most Euro-American settlers. The focus of settler ambitions was to gain valid title to land. Under increasing pressure of settlement, settlers pressed the federal government to terminate otherwise valid Indoamerican title to the land. This step was necessary to legitimize the removal of Indoamericans from their lands because constitutional law under a clause of "prior occupancy" protected the rights of native people as legal tenants. Indoamerican tenancy could only be extinguished under existing US laws if Indoamerican title to land was formally ceded to the US under a treaty. Well aware of the constitutional requirements, Congress over a period of three decades (1845–1875) empowered the US Army via new laws, manpower, and provisions to reduce, subdue, and defeat Indoamerican tribes throughout the western US and drive the survivors onto reservations (White, 1991; Robbins, 1997). Indoamerican burning probably declined during this period.

4.3. Miners

The discovery of precious metals and ensuing gold and silver rushes in the 1850s and 1860s were added motivating factors for hastily removing Indoamericans from their lands. Miners wanted access to precious metals and minerals, and they wanted license to remove their quarry in any manner that they chose. Large-scale industrial mining was an environmental disaster. For a short time, placer miners benignly panned for gold, but the modest quantities of gold that could be captured in a pan soon played out. Reservoirs, canals, ditches, and steam-powered dredges replaced panning. Riparian zones to be dredged were burned off, streambeds were gobbled up and processed by the dredges, and waste rock and soil was spewed out to the side of the channel (Langston, 1995; Wilkinson, 1992). A complete tally of affected streams and the toll on fish and fish habitats has never been quantified (Wissmar et al., 1994a,b).

With the discovery of gold or precious minerals in montane forest environments, miners injudiciously burned the timbered slopes, and fires would often spread far and wide (Langston, 1995). Under the particularly destructive methods of hydraulic mining, veins exposed near the surface were blasted with high-pressure water hoses and entire hillsides were eroded to remove the gold. Veins buried deeply within bedrock were mined via elaborate networks of tunnels and shafts. Removed rock and waste were indiscriminately cast aside below the mines. Adjacent streams and lakes were often poisoned with leached arsenic, mercury, and other heavy metals; some have yet to recover (Wilkinson, 1992).

4.4. Roads and rails

To improve access to the western US, Congress in the 1850s authorized four railroad survey expeditions to explore potential rail routes. Railroad access was essential to move cargo that could be grown or extracted in the western US (e.g., gold, silver, copper, sheep, cattle, furs, hides, timber, and wheat) to national and international markets. One expedition led by Stevens explored the country between the 47th and 49th parallels. Another lead by Gunnison explored a route along the 38th parallel. Whipple led an expedition along the 35th parallel, and Davis followed a route to the south along the 32nd parallel. Likewise, in the 1850s and 1860s, Congress through the Department of the Interior funded a constellation of road surveys and 34 separate road-building projects across the western territories (White, 1991). Road builders found the most feasible routes west, leveled steep grades, ditched the roads to prevent their erosion, and bridged the largest rivers and streams that could not be driven across. So began the process of forest and rangeland fragmentation at a broad regional-scale.

Between 1862 and 1872, Congress extended its system of land grants west of the Mississippi by granting more than 50.5 million ha of land to railroad companies to encourage them to construct railroad lines to the west. Grants initially went to two of the largest companies, the Union Pacific and Central Pacific railroads, who completed the first transcontinental route. These companies received 20 odd-numbered sections of land for every 1.6 km of track laid. But the largest grant, one of about 16 million ha, went to the Northern Pacific Railroad Company who received 20 odd-numbered sections for each 1.6 km of track laid across the states, and 40 sections per 1.6 km for laying tracks across the western territories. By granting lands to railroads, Congress hoped to serve the twin goals of removing lands from free entry by settlers under the Homestead Act, and encouraging the railroad companies to turn around and sell the land to farmers, ranchers, and settlers to pay the cost of railroad construction. Railroad land grants promoted rapid settlement and development of the western US, and by the 1870s a significant rail network existed (White, 1991). Broad-scale landscape fragmentation was further hastened by this system of land grants because adjacent landowners treated the land and its

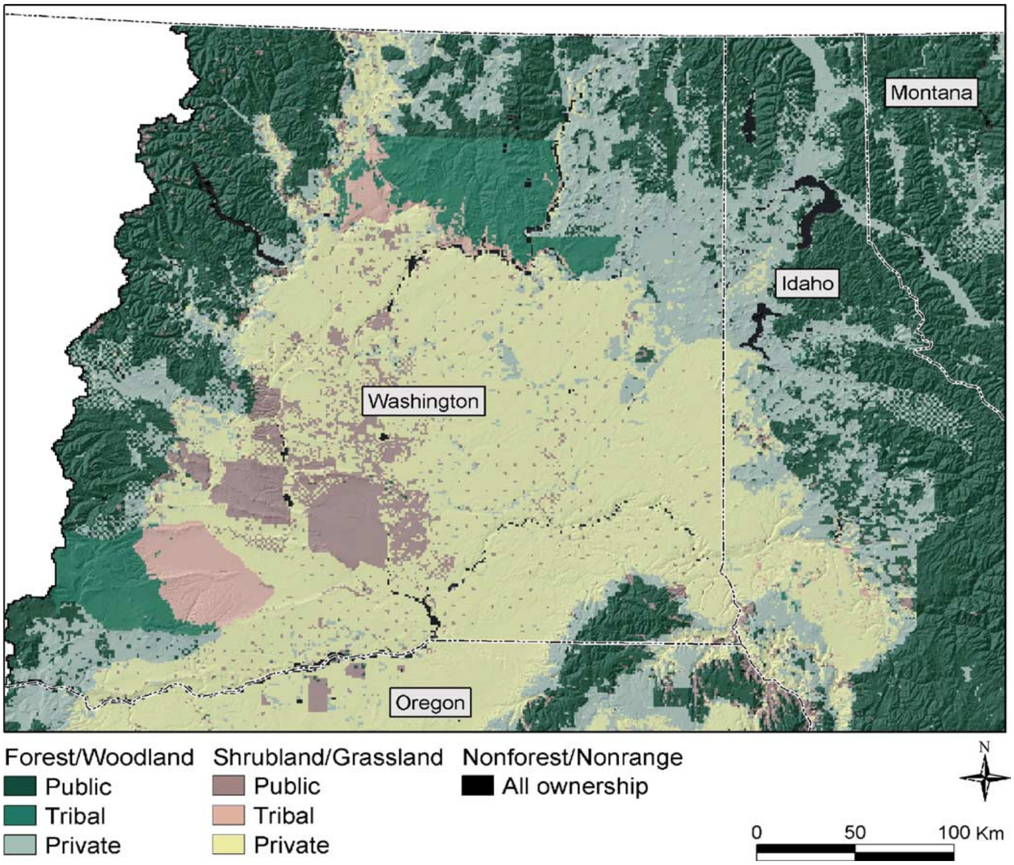

Fig. 8. Map of eastern Washington, northern Idaho, and northwestern Montana showing broad-scale forest and woodland, shrubland, and grassland fragmentation associated with land ownership.

vegetation quite differently. This was especially true in the areas of checkerboard ownership (Fig. 8).

Between the 1860s and 1900s, the building of the transcontinental railroads and feeder lines consumed large quantities of wood for ties, bridges, fencing, and stations (20–25% of annual US production; White, 1991). This spurred economic growth within the fledgling timber industry. Rail lines also became supply lines to eastern US markets, further stimulating mining, timber, farming, and cattle ranching industries in the western US.

Hunting had eliminated bison east of the Mississippi River in the late 1700s and market hunting of western bison herds began in the early 1830s and 1840s. But the coming of the railroads provided an efficient means of hauling hides to eastern tanneries. In the early 1870s, professional bison hunters arrived to kill bison to feed railroad crews, but trade in hides, tongue, and pemmican accelerated the harvest, and by the early 1880s, bison were all but eliminated from the Inland Northwest.

From the 1770s to 1870s, human disease epidemics wiped out at least 80% of the resident Indoamerican population present at the time of first contact. Survivors were eventually subjugated and moved to reservations. During this period, Indoamerican hunting pressure on deer (*Odocoileus* spp.) and elk (*Cervus elaphus*) abruptly declined, and game populations rose sharply (Broughton, 1994; Langston, 1995). Over the short three-decade period that followed (1870–1900), market hunting for deer and elk hides seriously depleted their numbers. Market hunters were many of the same men who had extinguished the vast Plains buffalo herds.

4.5. Cattle and sheep

With the subjugation of Indoamericans completed, cattleman and sheepherders stocked the region with great livestock herds over the period of the 1860s–1890s. Cattle and sheep had long since entered the region with the first settlers, but the early settlers focused on agriculture, and their livestock herds typically included just enough dairy cows, goats, oxen, sheep, horses, and beef cattle to work and support the family farms. Cattlemen initially believed that cattle could survive the harsh winters, and the prairies appeared to be lush, endless, renewable, and ripe for the taking. By 1860, there were 200,000 cattle in the region, but a severe winter in 1861–1862 killed many stock (Galbraith and Anderson, 1991). They note that a Walla Walla newspaper stated, about 1000 m from town, one could almost step from one dead cow to another throughout the whole valley. This was repeated in 1880–1881 and again in 1889–1890, after which most cattlemen recognized that shelter and feed were required for a sustainable cattle operation.

Large cattle herds were brought west and north and by the late 1880s, overgrazing by cattle left the rangelands in a weakened condition. Cattle in large numbers also wrought havoc on dry forest and grassland riparian zones. Since cattle require a considerable amount of water compared to other livestock, they preferred to graze riparian zones, creek bottoms, and wet meadows that supported lush grasses through the dry summers, and provided a steady supply of water. Riparian zones constitute 1–4% of the land area of eastern Oregon and Washington national forests (Kauffman, 1988), yet supply more than 80% of the herbaceous material removed by livestock (Roath and Krueger, 1982). More than 70% of that riparian area continues (early 1990s) to be within grazing allotments (Wissmar et al., 1994b). It is likely that in addition to the intentional burning of riparian zones by placer miners, cattle began to harm fish habitat and riparian vegetation more than 100 years ago, and that effect continues today.

Because sheep require less water and can graze more successfully on rangelands than cattle (because of wider forage selection and a mouth capable of higher utilization), introductions of sheep boomed in the mid- to late 1880s with the decline of cattle. Eventually sheep numbers outstripped cattle and often-violent conflicts arose between Basque and Mormon sheepherders and resident cattlemen. The battles were the fiercest in Crook, Lake, Wheeler, and Deschutes counties in south central Oregon, and 8000–10,000 sheep were killed per year for several years (Galbraith and Anderson, 1991). Overgrazing by sheep left native bunchgrasses and forbs in worse condition than that caused by cattle overgrazing. By the late 19th century, numerous exotic plants such as the bull and Canada thistles (*Cirsium vulgare,* and *C. arvense*), cheatgrass (*Bromus tectorum*), Dalmation and yellow toadflax (*Linaria dalmatica* and *L. vulgaris*), diffuse and spotted knapweeds (*Centaurea diffusa* and *C. maculosa*), and leafy spurge (*Euphorbia esula*) had already become established (Wissmar et al., 1994a,b; Langston, 1995; Hann et al., 1997).

Grazing permits and fees were required on what are now National Forest lands beginning in 1906, although grazing intensity increased until the 1920s (Wilkinson, 1992). In the 1930s Congress approved the Taylor Grazing Act of 1934, which regulated grazing on the public domain (later, lands of the Bureau of Land Management) through the use of permits. Subsequently, cattle and sheep numbers dropped. Recent assessments of grassland condition suggest that grasslands are slowly recovering from some of the effects of historical overgrazing, and current conditions are perhaps the best they have been in 100 years (Harvey et al., 1994; Johnson et al., 1994; Skovlin and Thomas, 1995). Unfortunately, because of countless non-native species introductions, some changes in native plant community structure, organization, and productivity may be permanent. On Bureau of Land Management lands across the western US, rangelands classed as "excellent" condition increased from 1.5 to only 5% from the period 1936–1984, due to these losses (Holechek et al., 1995). Changes in rangelands classed as "good" condition were substantially higher. Even at this writing, there is public debate over whether livestock grazing on public lands should be continued under the Taylor Grazing Act (e.g., see Belsky et al., 1999, and references therein).

4.6. Exotic species introduced

4.6.1. Non-native plants

Euro-American settlement in the mid- to late 1800s facilitated the invasion and expansion of many non-native or exotic plants (Hann et al., 1997, and references therein). Most successfully introduced plant species originated in similar climatic regions (Trewartha and Horn, 1980; Mack, 1986). Change from wildland to agricultural uses promoted many initial invasions of non-native species; agricultural practices of land conversion, tilling, and seeding were primary avenues for non-native plant introduction and spread. Rapid and severe depletion of native bunchgrasses by livestock grazing and trampling was often the impetus for deliberately introducing exotic forage species (Mack, 1981, 1986). Non-native plant seeds became regular contaminants of crop seeds.

Today there are more than 850 introduced plant species in the Inland Northwest, and distributions of non-native species are increasing (Baker, 1986; Hann et al., 1997). This is due in part to an often-shared life history strategy. Some species are opportunistic pioneers, capable of prolific seed or other disseminule production. These species frequently colonize sites that have been recently disturbed and are lacking in plant cover (Bazzaz, 1986). Colonizers are often well adapted to long-distance dispersal, can germinate seeds under a wide variety of conditions, establish quickly, grow fast as seedlings, and out-compete native plant species for water and nutrients. Other non-native plants (invaders) can establish within intact vegetation cover and displace native species without the aid of soil disturbance. Some non-native plants can colonize or invade depending on the habitat type.

Ecologists are concerned about non-native plant species introductions because invasions can alter natural disturbance regimes, net primary production, decomposition, hydrology, and nutrient cycling. To date, non-native plant introductions have altered the structure, organization, and succession pathways of rangeland and dry forest ecosystems at landscape to regional scales (Belsky and Blumenthal, 1997, and references therein).

4.6.2. Non-native insects and pathogens

At the present time, there are nearly 400 non-native insects and diseases established throughout North America. Many of the most damaging species entered North America on imported plant materials or in infested planting stock (Gibbs and Wainhouse, 1986; Liebhold et al., 1995; Tainter and Baker, 1996, and references therein). Perhaps the most important non-native insect or pathogen introduced to the Inland Northwest was the white pine blister rust. The blister rust fungus *Cronartium ribicola* was introduced separately to eastern and western North America early in the 20th century. In the western US, it was initially introduced to a nursery in Vancouver, British Columbia in about 1910, and then it spread south through the Cascade Range and Sierra Nevada through the 1920s and 1930s, and east to the Northern Rocky Mountains in the 1920s. Today in the Inland Northwest, blister rust is widely distributed throughout the ranges of all native five-needle pines (most notably, western white pine, sugar pine (*Pinus lambertiana*), and whitebark pine), and mortality losses in high-risk areas exceed 70–90% (Monnig and Byler, 1992; Maloy, 1997).

4.7. Industrial logging

The industrial transformation of Inland Northwest forests came about later and somewhat more slowly than other changes. By the 1860s, old forests of the Great Lakes region had not yet been cut over and mills of that region were still relatively well supplied. The condition of relative plenty in the midwestern US had the effect of limiting capital available from eastern investors to build new mills or engage in the expensive business of expanding road and rail networks in the northwest (Robbins, 1982; Robbins and Wolf, 1994).

Timber harvesting during the decades of the 1860s–1880s was linked to completing the transcontinental railroads and feeder lines of the Northern Pacific (1883), Oregon Short Line (1884), Great Northern (1893), and the Milwaukee Road (1909), and supplying the local construction uses of developing communities. Logging supplied timbers for railroad bridges, trestles, and ties, and building materials to meet the local demands of burgeoning natural resource-based mining, farming, and logging communities. But the rate of industrial transformation in the Inland Northwest was governed by progress in developing rail and road transportation networks. This was true because long-distance transport of logs to mills via waterways was limited to a handful of major rivers. An alternate transportation network was needed to supply regional distribution centers and national and international markets. The transcontinental railroads would fill this gap.

With the completion of several transcontinental rail lines between the 1880s and 1900s, large-scale lumber production in the northwest had its beginning. Movement of significant quantities of lumber to distant markets both in the eastern US and abroad began in the early 20th century after World War I (Robbins and Wolf, 1994). Before 1910, the federal government had transferred to the private sector virtually all lands that were not later removed from the public domain as Forest Reserves (which became National Forests in 1907). By this time, virgin stands of timber in the Great Lakes region had been logged, and lumber capitalists began looking to harvest the virgin stands of timber in the northwest (Robbins, 1982). The transfer of land led to immense and often highly speculative land purchases in the northwest by Great Lakes timber magnates. At the same time, brisk regional growth in the northwest was slowing in the decade before World War I, and the national economy had turned sluggish. To pay off creditors, lumbermen were under a great deal of pressure to liquidate their newly acquired stumpage. Because of the sluggish economy, regional and national markets were quickly saturated and many who had speculated lost fortunes. The lumber economy remained sluggish and unstable until the outbreak of World War II.

The most important ecological fall-out of these political and economic circumstances in the Inland Northwest was the market driven "high-grade" logging. The combination of glutted lumber markets and production-driven business practices drove northwest lumbermen to only remove trees containing logs of the highest grade. Mills could only saw large logs; there was no market for small, knotty logs. Left behind after logging were the limbs, foliage, and tops of the largest trees, and many small trees fallen and cleared aside to improve access. High-grade logging not only removed many of the largest, oldest, and most sound trees (usually old growth ponderosa pine), it left high fuel loads in the wake of logging, leading to some of Oregon and Washington's most destructive and extensive human-caused forest fires during the 1920s and 1930s (Pyne, 1982).

Some of the most far-reaching impacts of high-grade logging occurred in the Klamath and Deschutes River basins in Oregon (Fig. 9). Nearby regional hubs and distribution centers were Klamath Falls and Bend, respectively. The combination of predominantly private timberland ownership, proximity to California lumber markets, and vast tracts of old growth ponderosa pine forest (~0.6 million ha) focused a tremendous burst of logging activity in the lower and middle sections of these two basins. From 1925 to 1946, sawmills in Bend, Oregon produced an average of 0.5 million m^3 of lumber each year. Harvest soon outstripped growth; lumber production by 1950 was 20% of that in the two prior decades (Robbins and Wolf, 1994).

The short period immediately on either side of World War II was one of great political and technological change. During the war, gasoline-powered crawler-tractors had been improved to such an extent that they were becoming more widely applied in ground-based logging operations. This greatly increased the economy and efficiency of yarding sawlogs from the woods. By the close of the war, the gas-powered chainsaw had also become available, and this small innovation would prove to be a great enhancement to lumbering productivity. Shortly thereafter, improvements in automobiles enabled lumber producers to replace steam-driven locomotives with trucks for transporting logs to sawmills.

By the 1960s, there was evidence throughout the Interior Columbia region that more than a half-century of selection cutting had removed much of the readily accessible ponderosa pine (Robbins and Wolf, 1994; Langston, 1995; Robbins, 1997). From the end of World War II to the early 1960s, markets for lumber other than ponderosa pine were expanded and improved. Timber production statistics in the years following 1960 reflect a steady rise in the harvest of Douglas-fir, western larch, and other species. Improving markets and utilization of Douglas-fir and western larch after World War II dramatically increased harvest levels in the eastern Cascades of Oregon and Washington. Concurrently, large private timberland holders like the Weyerhaeuser Corporation began to scale back selective and salvage cutting for more efficient and lucrative clearcutting. Management of resulting even-aged stands was economically and technically more efficient at all stand development stages. Movement by private and public land managers to clearcutting regeneration methods and the subsequent development of plantation forestry signified the end of extensive mixed-age forest management and the beginning of intensive, stand-based, even-aged agroforestry. Weyerhaeuser foresters would go on in the 1970s and 1980s to refine and further distribute

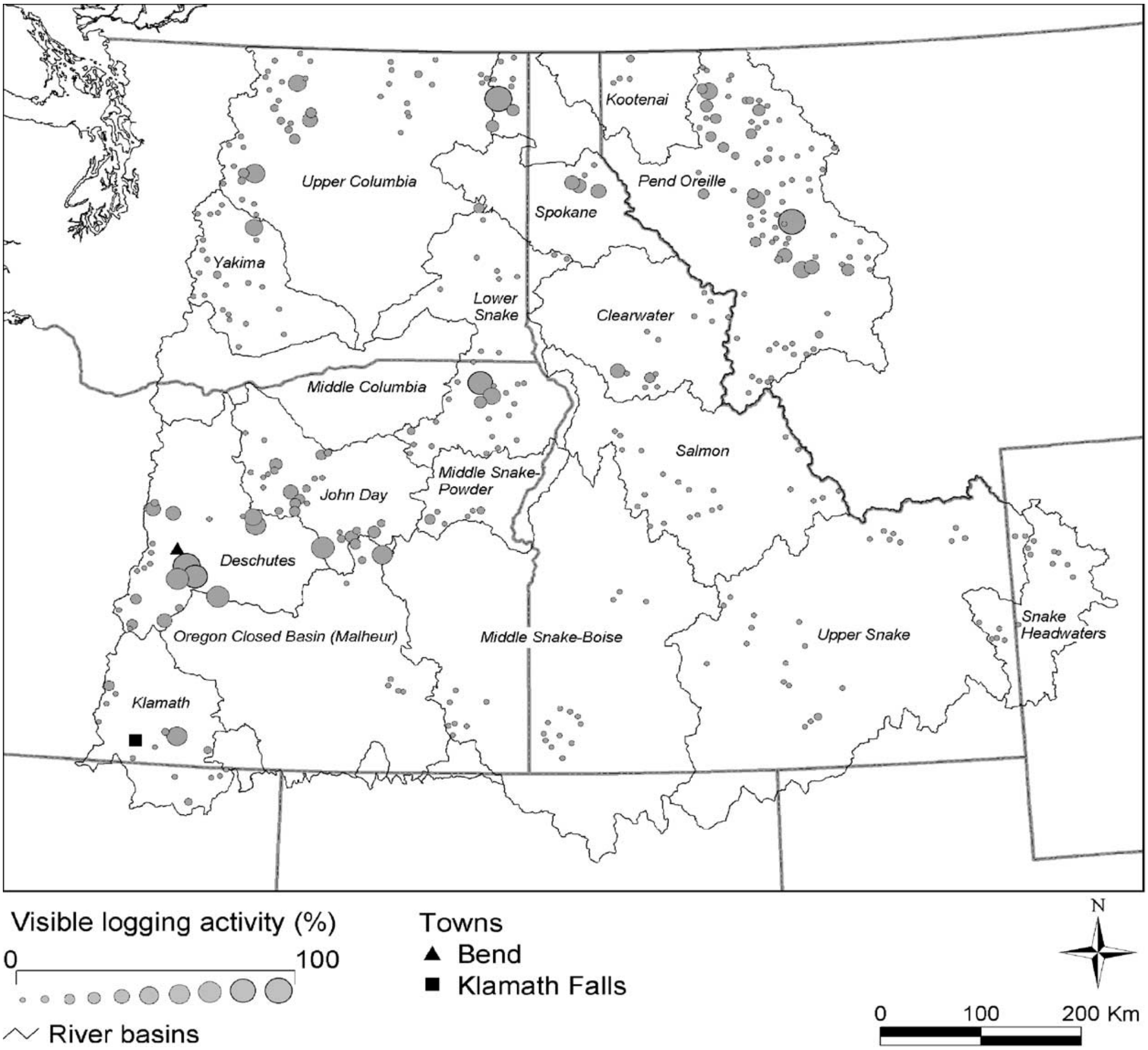

Fig. 9. Map showing the percentage of historical (1930s–1940s) subwatershed area selectively logged as interpreted from B&W aerial photographs by Hessburg et al. (1999a).

these methods on company lands under the aegis of high yield forestry.

5. The environmental movement

Throughout the first half of the 20th century, public forestlands were managed under a custodial philosophy. After World War II, timber demand at levels needed during the war were sustained by housing demand and post-war economic growth, encouraging the development of an industrial forest model for management of public lands. At the time, 40% of the national timber inventory was on public lands that produced only 9% of the national yield (Steen, 1976). Faced by increasing demands on multiple fronts, Congress enacted the Multiple Use-Sustained Yield Act in 1960. It stated that the national forests " . . . are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes''. This act placed into law a multiple-use philosophy that the agency had been operating under throughout the early history of National Forests, but it did not provide a blueprint for how decisions concerning these sometimes competing uses would be made.

Environmental awareness expanded on a large scale in 1962 with publication of Rachel Carson's *Silent Spring* (Carson, 1962). Her book on the scope and magnitude of the pesticide issue both energized and accelerated the environmental movement in the US, the spirit of which was quickly captured by growing organizations such as the Sierra Club. Within 2 years of the book publication, the Wilderness Act (1964) passed into law. Congress then reauthorized the Public Land Law Review Commission in 1964 (the fourth since 1880; Steen, 1976), which reported in 1970 that a dominant-use philosophy should replace that of multiple-use, a reaction to the single-use perception that was enacted by the Wilderness Act. Clearly, controversy over public land management was not resolved.

At the same time the Wilderness Act passed, the Secretary of the Interior received a controversial report from a wildlife management committee established to provide advice on national park wildlife problems (Leopold et al., 1963). The Leopold report suggested that in national parks (and by inference, wilderness), fire was a natural process and was as important as flood, hurricanes, and glaciers to maintain natural processes in these areas. With a modest goal to recreate a ''vignette of primitive America, at least on a local scale'', the report was adopted as policy by 1968, recognizing the use of prescribed and natural fire across all Department of the Interior lands. The Forest Service followed up with a repeal of its 10 AM fire suppression policy in 1973, fostering a shift from fire control to fire management at the federal level.

The environmental movement resulted in three additional laws that have had a significant impact on western wildlands: The 1969 National Environmental Policy Act (NEPA), the 1970 Clean Air Act, and the 1973 Endangered Species Act (ESA), which began to formalize planning and provide single-resource protection. Revision of state forest practices acts and regulations had also begun during this period. Regulations pertaining to the management of forests have increased considerably since the 1970s. For example, riparian regulations for forest operations in Washington State, which were almost non-existent before 1970, increased from about three to over 30 pages in length in 30 years (unpublished regulations, Washington Department of Natural Resources).

Continuing strife over public land management led to the 1974 Resources Planning Act (RPA), the 1976 National Forest Management Act (NFMA), and a related law pertinent to the Bureau of Land Management, the 1976 Federal Land Planning Management Act (FLPMA). The idea behind these acts was that by conducting local resource management planning, controversies could be resolved, and the budgets necessary to implement the plans could be easily collated at a national level for Congressional action (Committee of Scientists, 1999). This ideal failed because individual plans were not spatially explicit, they relied on so-called ''black box'' linear programming models that focused on outputs rather than outcomes for the land, and Congress never recognized the planning process in budget allocations, instead funding timber harvest and road construction at occasionally more than 100% of requested amounts and recreation at much less (Committee of Scientists, 1999). Regulations under NFMA have been promulgated and revised twice, with further revisions underway at this writing. Clearly, a social consensus on public land management has never existed.

An emerging principle in ecology is that scale matters, i.e., the spatial and temporal scales of ecological phenomena such as bird habitats and fire disturbance regimes can best be observed and planned for at specific scales. Likewise, some notion of the scale dependence of ecological, economic, and social phenomena is also emerging in public policy and land management planning contexts. Scale is a relatively new frontier in ecology (Peterson and Parker, 1998) and economics (e.g., Costanza, 1991). Wildland ecosystems are complex, such that processes and patterns, as well as ecosystem management are dependent on information and understanding at several spatial and temporal scales. Even a facile treatment of scale has practical implications (Allen and Roberts, 1998), so that complex applied ecological problems can be more successfully addressed.

Notions of the scale of treatments and effects, of patterns and processes, and of context have begun to permeate a wide range of recent ecosystem planning efforts (Johnson et al., 1999a). Although some scale issues transcend specific ecological or climatological regions (e.g., neotropical migrant birds, global warming), discrete ecological issues with implications for the Inland Northwest have been successfully addressed through bioregional assessments: the Northwest Forest Plan and its precursor assessment FEMAT (Johnson et al., 1999b), the Sierra Nevada Ecosystem Project (Erman, 1999) and its successor the Sierra Framework, and the Interior Columbia Basin Ecosystem Management Project (Quigley et al., 1999). The principles of ecosystem management planning will be further treated in the concluding section.

6. Inland Northwest landscapes—key changes

Thus far, we have described many of important political, social, and economic forces and interactions that shaped the regions' forests and rangelands over the last 200 years. One way to gauge the human influences that shape an environment is to tease them apart and examine each one separately. But to understand the combined effects of human influences on environments, one must study changes to the environments themselves. Here, we recount the human influence on important landscape-scale changes. To do so, we draw on bioregional assessments completed by Huff et al. (1995), Lehmkuhl et al. (1994), Hessburg et al. (1999a, 2000b), and Ottmar et al. (in press), and the studies of Camp (1995) and Camp et al. (1997).

The loss of forest burning by all mechanisms during the last half of the 19th century set in motion dramatic changes in physiognomic conditions. Successful fire prevention and suppression programs of the 20th century further reinforced these changes. The most widespread change in physiognomic conditions was the reduction of native grasslands and shrublands. Hann et al. (1997, 1998) showed that most of the expansive grasslands of the Interior Columbia region (Fig. 3), especially those of the Columbia Plateau, Blue Mountains, Upper Clark Fork, Central Idaho Batholith, and Northern Glaciated Mountains were converted to agricultural uses by the late 19th and early 20th centuries. As with the native prairies of the Great Plains, the demise of Inland Northwest grasslands represented a loss of one of the most biologically diverse biomes on the continent, and a significant reduction of native habitats for native and migrant birds (Samson and Knopf, 1994, 1996). The loss of native shrublands resulted from the expansion of dry forests and woodlands, and the development of croplands including both annual field crops and extensive hayland and pastures (Hessburg et al., 1999a).

In several provinces, there were important shifts in land cover from early to late-seral coniferous species. Reduced area and connectivity of ponderosa pine, western larch, and Douglas-fir cover types was associated with the extensive selective harvesting of medium (40.5–63.5 cm dbh) and large (>63.5 cm dbh) trees of these species from forest overstories (Hessburg et al., 1999a). The periods of high-grade logging and selection cutting and fire suppression that followed not only reduced the dominance of early seral species, but increased the dominance the shade-tolerant conifers like Douglas-fir, grand fir, and white fir (*A. concolor*) in multiple, often dense understory layers. The overall effect of these changes was to make dry forest landscapes structurally and compositionally more homogeneous; forest patches became vertically more complex, and that complexity was widely distributed (Hessburg et al., 1999a). In contrast, historical fire regimes, which included Indoamerican burning, resulted in fairly simple patterns of differing structure and composition.

Historical dry forest composition was more tolerant of fire, favoring damage avoidance in the face of frequent fires. Frequent firing of the landscape not only favored regeneration of conifers like ponderosa pine and western larch by exposing mineral soils, but these species and others, like Douglas-fir, resisted damage by fires because they produce a thick, insulating bark as they aged. Ponderosa pine and western larch tended to torch less often than other species during low- or mixed-severity fires because their crowns are self-pruned and the density and geometry of their crowns favor heat release rather than trapping, making ignition temperatures harder to reach (Agee, 1993).

Shade-tolerant conifers, especially the highly adaptable Douglas-fir, now dominate Interior Columbia Basin dry forests, particularly in the understory. Dry forest landscapes of the Euro-American settlement era formed a relatively simple cover type mosaic. The composition of the forest mosaic was largely determined by topography, especially elevation and aspect, and closely related fire regimes. Ponderosa pine cover dominated southerly aspects, and a mixed coniferous cover including ponderosa pine, Douglas-fir, and grand or white fir dominated the northerly aspects. Patches of shade-tolerant but fire-intolerant conifers displayed a much higher degree of spatial isolation than exists today. Today, regardless of aspect, dense patches of multi-layered shade-tolerant conifers are now most often found directly adjacent to patches of a similar kind.

Changes in dry forest composition do not exist in isolation. They are the favorite of a variety of forest insects and pathogens that have the ability to spread across the landscape either quickly or slowly, reducing tree growth and causing mortality, and further modifying forest structure and composition (Hagle and Schmitz, 1993). In essence, the accrued changes to the structure and composition of forest patches coupled with fire management practices have altered forest disturbance dynamics, directly affecting the spatial and temporal scales at which vegetation patterns and disturbance processes may now interact. Settlement and management have collectively brought about an increase in the overall spatial scale of many dry forest pattern and disturbance process interactions (i.e., larger landscapes are typically affected). This is because the spatial scales of land cover and structural patchiness with respect to their vulnerability to stand replacing disturbance (e.g., fires and defoliator outbreaks) are larger. Similarly, by actively suppressing wildfires for three-quarters of a century, periods between fires are considerably longer than they would ordinarily be. This has resulted in substantial ground fuel accumulation and the development of live fuel ladders. For example, in the dry forests of the eastern Washington Cascades, fire returned to the forest on average every 5–20 years. In some forests, at least 10 low-severity fires have been missed over the period of suppression (Agee, 1993, 1994, 1998; Everett et al., 1997, 2000). And recovery of burned forests after fires may take longer in the future because fire intensity has markedly increased in the absence of frequent burning. It remains to be seen whether new succession and disturbance trajectories will arise from these highly altered fire regimes.

Settlement and management activities have significantly modified the structure of forests in particular. The area that would ordinarily be occupied by old forest structures (both multi-story and single-story park-like stands, sensu O'Hara et al., 1996) declined in most provinces of the Interior Columbia region, but the most significant declines were in the Blue Mountains, Northern Cascades, Snake River Headwaters, and the Upper Klamath provinces (Hessburg et al., 1999a). Important reductions in the landscape area in stand initiation structures (newly regenerated forest) also occurred in the Central Idaho Mountains, Lower Clark Fork, Northern Glaciated Mountains, Upper Clark Fork, and Upper Snake River provinces where high- and mixed-severity fires historically affected much of the landscape (compare Fig. 3 and Fig. 2A–D).

The most widely distributed change in forest structure across the Interior Columbia Basin was sharply increased area and connectivity of intermediate (not new and not old) forest structures (including stem exclusion, understory reinitiation, and young multistory forest structures). Moreover, the environmental settings (∼locations) of remaining late-successional and old forest patches are an artifact of the management history of the landscapes in which they reside. In low-severity fire regime areas, there were few if any refugia: even riparian areas burned frequently (Camp, 1995; Olson, 1999). However, in mixed- and high-severity fire regime areas prior to settlement, old forest patches occurred in semi-predictable locations, i.e., fire refugia (Camp et al., 1997) with combinations of physiography and topography that tended to improve the likelihood that patches would successfully avoid being burned up by fires. Today, late-successional and old forest patches no longer occupy these refugial settings. As a result, long-term plans to reserve remaining late-successional and old forests are probably ill fated because these forests are susceptible to burning (Everett and Lehmkuhl, 1996).

Hessburg et al. (1999a, 2000b) refer to four supplementary findings related to forest structural change that are worth repeating here. First, they found that large (>63.5 cm dbh) and medium (40.5–63.5 cm dbh) trees historically enjoyed wide distribution in structures other than old forest, as a conspicuous remnant after high-severity fires. Over the past century, medium and large trees were targeted for harvest via selection cutting regardless of their structural affiliation. In many cases, this change was more widespread than the loss of old forest. Second, they estimated change in dead tree and snag abundance in each forest patch and found that abundance had increased in most forested provinces, but primarily in the pole and small tree (12.7–40.4 cm dbh) size classes, because the medium and large trees were already depleted by timber harvest. This change in dead tree and snag abundance mirrored the increases observed by Huff et al. (1995) and Ottmar et al. (in press) in the expanded abundance, area, and connectivity of ground fuels. Third, current forest patches have more canopy layers than were displayed in the historical condition, and understory layers are typically composed of late seral species. Fourth, in the historical condition, forest understories were often absent or composed of shrub and herbaceous species. Current forest understories are less often grass or shrub and mostly coniferous. These last three observations provide valuable insight into the mechanisms of increased forest fuels and increased wildfire severity.

7. Management implications

7.1. Forest fuels and fire behavior

Throughout the Interior Columbia region there are currently many large, contiguous areas that display elevated ground fuels and increasingly severe wildfire behavior (Fig. 2C). Across the US, there are over 49 million ha of historical low- and mixed-severity fire regimes that are now classed as having a ‘‘high departure from the natural fire regime’’ (Condition class 3, Fire Modeling Institute, 2001). In Forest Service Regions 1, 4, and 6 (~Inland Northwest), the total ‘‘high departure’’ area is over 6 million ha, and if state and private lands are added in, the total is well over 8 million ha. Another 12–14 million ha are in the ‘‘moderate departure’’ class from the natural fire regime across this same area.

Most of the increase in fuel loadings and severe fire behavior has occurred in the dry forests, where ponderosa pine was historically abundant in the overstory (e.g., compare Fig. 6A and B and Fig. 10A–H). In contrast, fuel loads and the potential for severe fire behavior have been modestly reduced relative to historical conditions in some cool and moist forests of the Basin. This is especially true where large, old Douglas-fir occurred in the overstory over shade-tolerant western hemlock, western redcedar, grand fir, and Pacific silver fir understories. The primary mechanism for reduced fuel loads and severe fire behavior in these instances was clearcutting followed by slash disposal (e.g., Fig. 11A–H).

Prior to the mid-19th century, there were many areas that were normally influenced by mixed- and high-severity fires. These areas displayed relatively high fuel loads and crown fire potential, and wildfire rate of spread, flame length, and fireline intensity. Settlement and management have not made the entire landscape wildfire-prone, but they have removed the degree of spatial isolation that patches prone to high-severity fire once enjoyed (Fig. 10A–H). A reasonable target of restoration would be to restore more natural patterns of forest structure and composition, fuels, and fire behavior attributes to the dry forests. This would restore the synchrony that once existed between patterns of forest vegetation and fire regimes prior to settlement.

Priorities can indeed be identified for altering fire behavior in western US forests. For example, the stylized concept of managing by fire regime areas can be adopted (Cissel et al., 1998, 1999), with local alterations for overlapping regime areas as is appropriate. High-severity fire regime areas are a low priority for restoration for two reasons. First, these are ecosystems that have always burned with high-severity fires that often occur as weather-driven rather than fuel-driven events (Bessie and Johnson, 1995; Agee, 1997). The dominant tree species in high-severity fire regime areas of the Inland Northwest are commonly thin-barked, so a change in fire behavior (for example, from 3 to 2 m flame lengths) will increase chances of control, but have little effect on fire severity within the burned area. Fires will still be high severity because the trees will be girdled at the base by intense heating and burning.

Low-severity fire regime areas, on the other hand, had dominant vegetation that was fire-resistant (thick bark) so that investments in creating fire-tolerant or ‘‘firesafe’’ forests (Agee et al., 2000; Agee, 2002) will pay off in increased control efficiency and decreased fire severity. The principles of firesafe forests (Table 2) can be applied through prescribed fire and low thinning at the stand or patch level, and these are relatively well-accepted principles. As one scales up from indi-

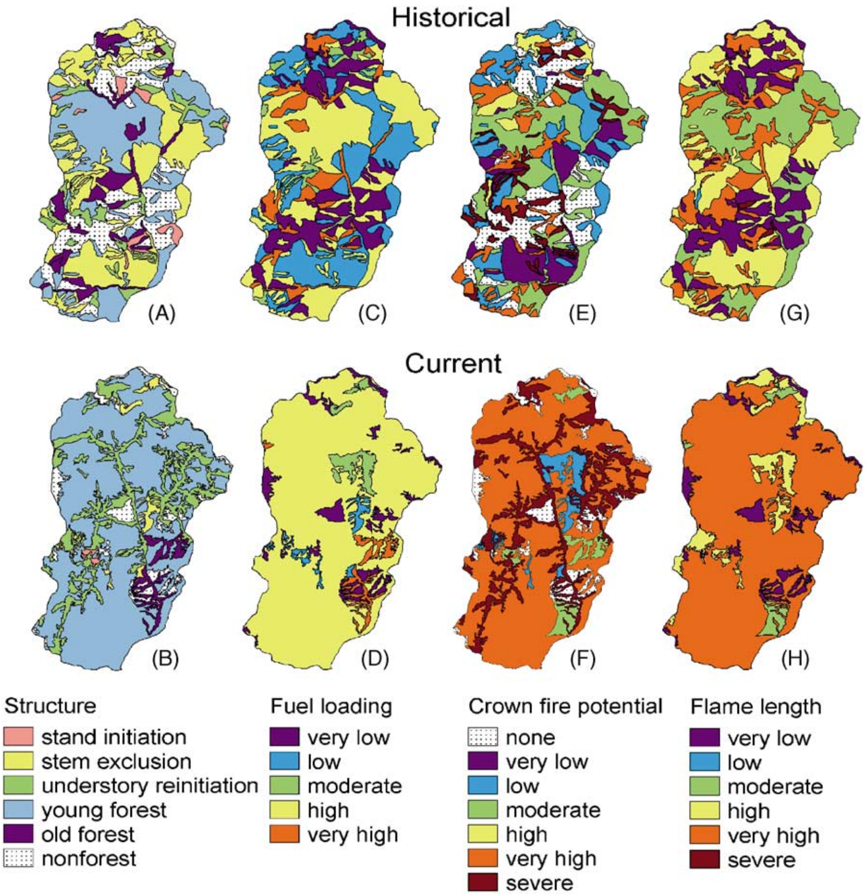

Fig. 10. Maps of the Peavine Creek drainage, a dry forest subwatershed of Lower Grand Ronde subbasin in Blue Mountains province displaying historical and current structural classes (A and B), fuel loading (C and D), crown fire potential under wildfire conditions (E and F), and flame length under wildfire conditions (G and H). Structural class abbreviations are: si: stand initiation; se: stem exclusion (both open and closed canopy conditions); ur: understory reinitiation; yfms: young multi-story forest; of: old multi-story and single story forest; nf: nonforest. Fuel loading classes are: very low < 22.5 Mg/ha; low $= 22.5-44.9$ Mg/ha; moderate $= 45-56.1$ Mg/ha; high $= 56.2-67.3$ Mg/ha; very high > 67.3 Mg/ha. Crown fire potential classes were a relativized index. Flame length classes were: very low < 0.6 m; low $= 0.7-1.2$ m; moderate $= 1.3-1.8$ m; high $= 1.9-2.4$ m; very high $= 2.5-3.4$ m; severe > 3.4 m.

vidual patches to landscapes, the priority of what and how much to treat becomes much less clear, but will be essential to define in ecosystem management decisions. One of the challenges faced by research is to quantify the patterns and amounts of vegetation and fuel treatments that are needed to make current landscapes more fire resilient. Modeling efforts are underway to begin to address this need (e.g., see Finney, 2001), but practical landscape experiments are needed on the ground to validate models and understand controlling factors and variation.

7.2. People, dwellings, and wildfires

Most people who live adjacent to public lands of the Basin live on or adjacent to dry woodlands, or dry forests. These specific settings have been most altered by 19th- and 20th century settlement and management activities. Surface fire regimes that once affected lands of the current wildland–urban interface have become mixed- or high-severity regimes, and forest residents are at risk at each outbreak of fire. Public land managers might consider as a first priority restoring

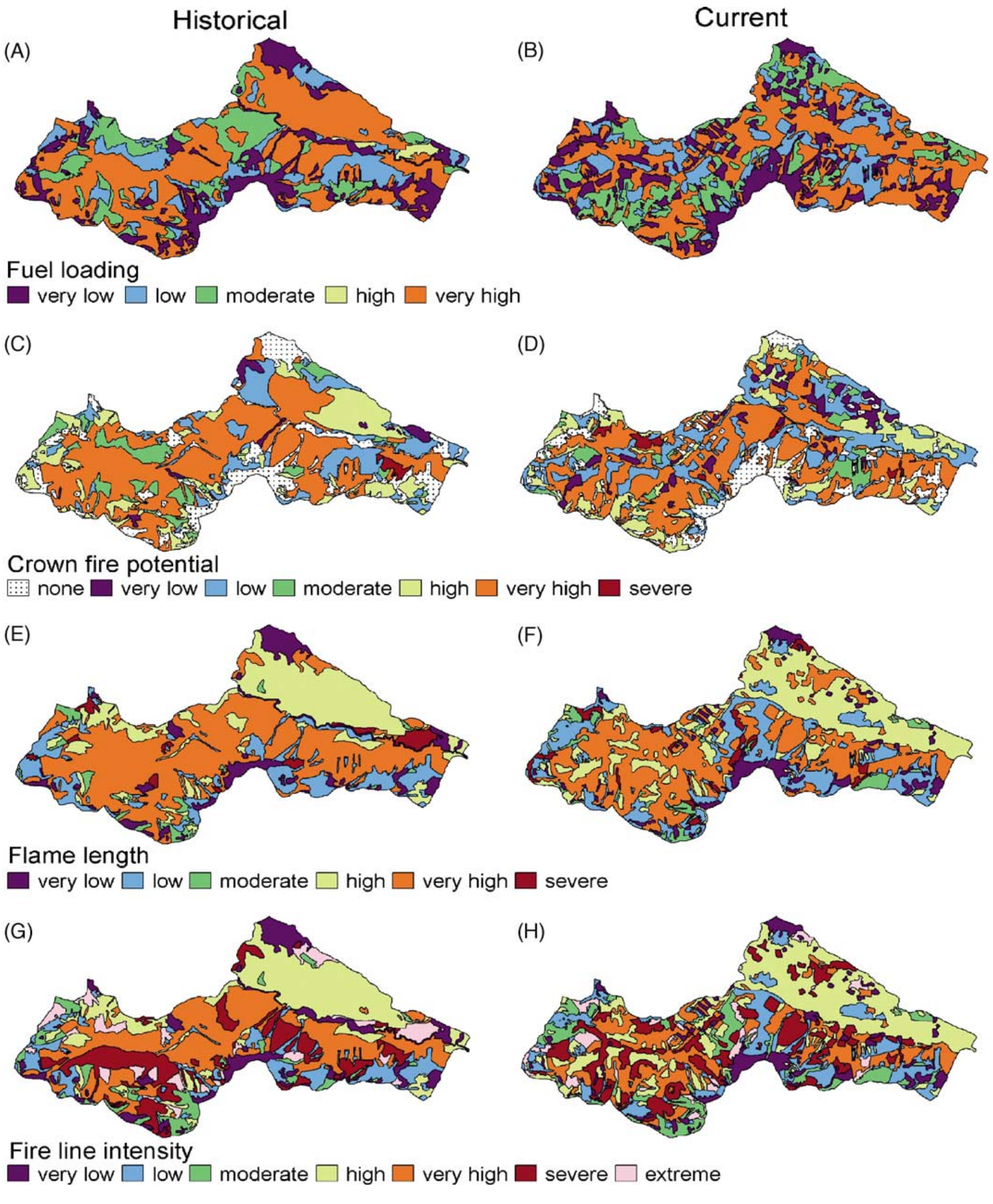

Fig. 11. Maps of the Rainy Creek-Little Wenatchee River drainage, a moist forest subwatershed of Wenatchee River subbasin in Northern Cascades province displaying historical and current fuel loading (A and B), crown fire potential (C and D), flame length (E and F), and fireline intensity (G and H) under an average wildfire burn scenario. Fuel loading classes are: very low < 22.5 Mg/ha; low $= 22.5-44.9$ Mg/ha; moderate $= 45-56.1$ Mg/ha; high $= 56.2-67.3$ Mg/ha; very high > 67.3 Mg/ha. Crown fire potential classes were a relativized index. Flame length classes were: very low < 0.6 m; low $= 0.7-1.2$ m; moderate $= 1.3-1.8$ m; high $= 1.9-2.4$ m; very high $= 2.5-3.4$ m; severe > 3.4 m. Fireline intensity classes were: very low ≤ 173.0 Kw/m; low $= 173.0-345.9$ Kw/m; moderate $= 346.0-1037.8$ Kw/m; high $= 1037.9-1729.6$ Kw/m; very high $= 1729.7-2594.4$ Kw/m; severe $= 2594.5-3459.2$ Kw/m; extreme > 3459.2 Kw/m.

Table 2
Principles of fire tolerant or "firesafe" forests

Principle	Effect	Advantage	Concerns
Reduce surface fuels	Reduces potential flame length	Fire control is easier, less torching of individual trees	Surface disturbance: less with fire; more with other mechanical techniques
Increase height to live crown	Requires longer flame length to begin torching	Less torching of individual trees	Opens understory, may allow surface winds to increase
Decrease crown density	Makes tree-to-tree crown fire spread less probable	Reduces crown fire potential	Surface winds may increase, surface fuels may become drier
Favor fire-tolerant tree species	Reduces potential tree mortality	Improves vegetation tolerance of low- and mixed-severity fires	May be too broadly applied, resulting in simplified landscape patterns of composition and structure

more natural vegetation and fuels patterns in the wildland–urban interface. In addition, land managers might consider working with local citizens and communities to better manage the progress of a rapidly expanding zone of interface. The tacit assumption of citizens who take up private residence in the forest is that public land managers will be able to protect them at the outbreak of fire. As recent events have shown, there is no certainty of this provision.

7.3. Smoke production: wild vs. prescribed fires

The question before public land managers and citizens is not whether there will be fire and smoke in their future, but how they might want their fire and smoke. The air quality and smoke emission tradeoffs between wild and prescribed fires (in particular, 2.5 and 10 μm diameter smoke particles are of concern to human health) are highly significant (Huff et al., 1995; Ottmar et al., in press). Prescribed burning can eliminate at least 50% of the particulate emissions generated by wildfires that are of concern to human health, and the timing, movement, and disposal of smoke in the airshed can be managed. Smoke emissions are reduced during prescribed burning because burns are managed as surface fires and live tree torching is minimized.

According to Hann et al. (1997) and Agee (1997), it is unlikely that fire suppression efficacy will improve given current vegetation and fuel conditions. Provided there is sufficient latitude, it will be up to resource managers and policy-makers to restore forest and fuel patterns to conditions that are more attuned with natural fire regimes and environmental conditions. During the transition time needed to significantly fragment existing fuel beds, prescribed fire smoke will likely add to, rather than substitute for, wildfire emissions.

7.4. Dynamic systems

The most important ecological fallout associated with 20th century management and extraction activities has been the effect on biological diversity and ecosystem dynamics. Among the ecosystems most altered by past exploitation have been late-successional and old forests. In some areas old forests have been depleted by past timber harvests to a level that is well below any known natural range of abundance (Hessburg et al., 1999b,c, 2000b). In the Inland Northwest of the presettlement era, there was apparently a natural ebb and flow of late-successional and old forest abundance that corresponded with the natural range and variation in climate and disturbance processes. Planning, restoration, and management scenarios for the Interior Northwest should be informed by that insight, including scenarios to conserve old forests and associated species (Keane et al., 2002; Swetnam et al., 1999).

Patterns of structure and composition within existing late-successional and old forest reserve networks will change as a result of wildfires, insect outbreaks, and other processes. What may be needed is an approach that marries a short-term system of reserves with a long-term strategy to convert to a continuous network of landscapes with dynamic properties. In such a system, late-successional and old forest elements would be continuously recruited, but would shift semi-predictably in landscape position across space and time. Such an approach would represent a planning paradigm shift from NEPA-like desired future conditions, to planning for landscape-scale desired future dynamics.

7.5. *Fish and forests*

Because disturbance regimes and succession processes of terrestrial and aquatic environments are intertwined (Hann et al., 1997; Lee et al., 1997), it is doubtful that there can be a workable aquatic conservation strategy that is separate from a forest landscape pattern restoration strategy. For example, hydrologic regimes are influenced by spatial and temporal patterns of forest vegetation and disturbance, and associated climate variation. Wildfires and harvest activities have a direct bearing on the timing, quality, and flow of water through a catchment. Disturbance in upland settings can result in either positive or negative effects on aquatic conditions and fish. For example, in the natural history of these ecosystems certain kinds, timings, and frequencies of terrestrial disturbance resulted in the renewal and redistribution of essential aquatic habitats and fish. But over the period of settlement and management we have also observed severe and chronic disturbances that have resulted in harm to fish and aquatic habitats.

By specifying standardized buffer zones and custodial management of riparian zones, aquatic conservation strategies have a direct bearing on the spatial and temporal patterns of vegetation in a catchment. Good sense suggests that scientists and managers might pursue strategies that jointly consider long-term spatial and temporal patterns of upland vegetation and disturbance, *and* consequences to hydrologic regimes, aquatic habitats, and fish.

7.6. *All roads are not equally harmful*

As Lee et al. (1997), Quigley et al. (1996), and Rieman et al. (2000) have shown, road networks have fragmented the regional landscape, and the local and regional status of native fish and fish habitats is directly related to existing road density. Existing road density was the single variable that best explained the current status of native fishes and fish networks in the Interior Columbia Basin region (Lee et al., 1997; Rieman et al., 2001). Current areas with healthy fish networks are non-roaded or exhibit low road densities, and the converse is also true. But all roads are not equally influential; a minority of roads (perhaps 20–30% of roads) is responsible for the most of the harm (more than 80% of the adverse effects) to fish and fish habitats.

Road networks are much like stream networks. Because they are built to access land in a drainage area, road networks tend to reflect the topographic complexity and drainage density of the watershed. The largest roads are in valley bottoms, and they collect arteries that branch out to other areas. These valley bottom roads are among those most damaging to native fish habitat because they are placed next to stream reaches, and many were built before it was generally understood that roads harmed fish and their habitats. Valley bottom roads have channelized complexly braided streams; caused streambed scouring and channel down-cutting, and thereby, severed hydrologic and biological relations with associated riparian zones and floodplains, and altered spatial and temporal patterns of adjacent hillside mass failures, and sediment routing and delivery. Some roads continue to cause damage. Evidence suggests that effort could be successfully applied to move and decommission the most offending roads and avoid building similar roads in the future. In the event that additional roads are needed, managers and engineers can learn from past mistakes to avoid harmful road locations and designs.

Roads are also tied to current fire issues. Current debates run the gamut of ‘‘roads are the source of all fire problems’’ to ‘‘roads are the source of all fire solutions’’ (Agee, 2002). Confusion stems from the fact that in the western US there are higher number of wildfires on the more densely roaded state and private lands. But two-thirds of the burned area is on federal land that is less heavily roaded, with many fire ignitions caused by lightning well away from roads. Less-roaded areas tend to be in higher-elevation, high-severity fire regime areas, while areas with high road density tend to be in lower-elevation, former low- and mixed-severity fire regime areas. In these latter areas, selective logging and fire exclusion have increased fire intensity while decreasing the fire tolerance of the forest because the older, most fire-resistant stems have been logged. Fire severity is now more uniform across these lower montane landscapes, biased towards high severity.

Future management need not intensify this trend. If existing roads were used to allow access for restoration actions such as prescribed burning and low thinning, future wildfire intensity and severity would decline, particularly for former low- and mixed-severity fire regime areas (Agee, 2002). Treating portions of landscapes that are most in need of fuel treatment (i.e., former low- and mixed-severity fire regime areas), or that are strategically located to increase fire control efficiency (Finney, 2001) would provide flexibility to leave other portions of the landscape untreated. Reduction of severe fire potential in former low-severity fire regime areas could help reduce fire-associated erosion and sedimentation.

8. Progress towards ecosystem management

Progress towards a fuzzy target is difficult to judge. Ecosystem management is a phrase comprised of two fuzzy concepts: ecosystem and management. It is not surprising that there are many definitions of what ecosystem management is (Grumbine, 1994). An ecosystem can be any part of the universe chosen as an area of interest, with a line around that area being the porous boundary, and anything crossing the line being input or output (Agee and Johnson, 1988). The more controversial aspect is the management, which integrates ecological, social, and economic interactions (Thomas and Huke, 1996). Most people see ecosystem management as an outgrowth of a land ethic that traces back to Leopold (1949). While outputs from the land are valued, it is the sustainability of the land itself that is fundamental to ecosystem management. Sustainable management can be viewed as a stool with ecological, social, and economic legs, but ecological sustainability is the basis for social and economic sustainability (Costanza et al., 1991; Committee of Scientists, 1999). Human welfare and ecological sustainability are inseparable; ecological systems provide many goods and services that humans require for their persistence (Dale et al., 1999).

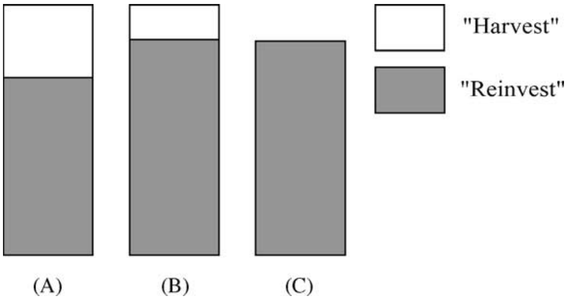

Fig. 12. A conceptual visualization of ecosystem management in action. Total ecosystem productivity broadly defined (trees, fish, etc.) is represented by the total height of the column. The shaded area is the proportion needed as reinvestment back into the ecosystem to maintain genetic potential and ecosystem productivity. In a properly managed ecosystem (A), the proportion of total productivity available for "harvest" may be greatest. Where past management has been more exploitive, more of the productivity needs to be reinvested back into the ecosystem (B). Where productivity has been damaged (C), "harvestable" proportions may be absent, and external investments are needed. Over time, ecosystems may shift from A to C and back again, but some changes in C (such as species losses) may be irreversible.

A sustainable landscape plan maintains two properties: the genetic potential of the land's plants and animals, and its ecological productivity (Franklin, 1993). Where past management has been sustainable, a higher proportion of the total ecosystem productivity may be occasionally captured as output for various types of consumption (Fig. 12A) than where past management has been more exploitive (Fig. 12B). A higher proportion of overall ecosystem productivity needs to be invested back into the system under scenario B. Where past management has damaged productivity (Fig. 12C), perhaps none of an ecosystem's productivity is "harvestable", and the ecosystem may require investments such as forest fertilization, importing large logs to streams, or growing large trees for the purpose of making future old forests, snags, and down wood.

8.1. Ecosystem management: current issues, future options

Ecosystem management planning must acknowledge the central importance of natural processes and pattern–process interactions, the dynamic nature of ecological systems (Attiwill, 1994), the inevitability of uncertainty and variability (Lertzman and Fall, 1998) and cumulative effects (Committee of Scientists, 1999; Dunne et al., 2001). Plans must be scale-appropriate and spatially and temporally explicit at several scales to sufficiently represent ecosystem properties and their dynamics. For example, insect and disease hazards have increased across the Inland

Northwest, but changes are not evident at every landscape or watershed scale. Basin- or province-scale analysis of insect and disease hazards is much less useful than that occurring at a more local watershed or subwatershed scales (Lehmkuhl et al., 1994; Hessburg et al., 1999d, 2000b).

Spatially explicit tools will be required not only to assess ecosystem function but also to show people what the results of future management will look like. Some examples are stand and landscape visualization tools such as UTOOLS/UVIEW (Ager and McGaughey, 1997), the Landscape Management System (LMS, McCarter et al., 1998), the Stand Visualization System (SVS, McGaughey, 1997), and the Environmental Visualization System (EnVision, McGaughey, 2001). Spatially explicit models of watershed change are also being proposed (Dunne et al., 2001). A variety of models that simulate vegetation and disturbance dynamics are now available for landscape planning in the Inland Northwest: FETM—the Fire Emissions Tradeoff Model, LANDSUM—the Landscape Succession Model, SIMPPLLE—Simulating Patterns and Processes at Landscape Scales, and VDDT—the Vegetation Dynamics Development Tool (see Barrett, 2001 for a comparison). A spatially explicit fire spread model, FARSITE—the Fire Area Simulator, simulates both surface and crown fire spread (Finney, 2001), and it can be incorporated with tree mortality models such as FOFEM—the First Order Fire Effects Model (Reinhardt et al., 1997). Most growth and yield models are individual tree or stand-based models, and trees are ordinarily grown on an annual time step. But fire spread is usually simulated over large landscapes, and fire behavior and fire effects can and often must be modeled on hourly or shorter time steps. These spatial and temporal scale issues present formidable hardware and programming challenges when models such as these are linked.

A number of efforts are currently underway in the Inland and Pacific Northwest to apply landscape and decision analysis tools for assessing landscape status, deciphering important ecological changes, and considering the ecological, social, and economic consequences of alternative management strategies, restorative treatments, and landscape pattern configurations. For example, CLAMS (the Coastal Landscape Analysis and Modeling Study), a joint effort of the Pacific Northwest Research Station, Oregon State University, and the Oregon Department of Forestry, is developing and evaluating tools to understand the patterns and dynamics of the Oregon Coast Range provincial ecosystem, and assess the ecological, social, and economic consequences of different forest policies and management strategies across multiple ownerships.

INLAS—the Interior Northwest Landscape Analysis System, a joint effort of the Pacific Northwest Research Station and Forest Service Region 6, Oregon State University, Boise Cascade Corporation, and the Oregon Department of Forestry is using a toolkit approach to project succession and disturbance dynamics affecting Interior Northwest landscapes. Existing models and analytical tools will be linked to the SafeD landscape simulation model (Graetz, 2000) to evaluate the effects of succession, disturbances, and management goals on such things as terrestrial and aquatic habitats, forest and riparian conditions and functionality, water quality, landscape vulnerability to disturbances, human land use patterns, the availability of timber and non-timber forest products, and the financial feasibility of capturing available forest products.

NOCLAMMS—the Northern Cascades Landscape Analysis, Management, and Monitoring System, a joint effort of the Pacific Northwest Research Station, Gifford Pinchot National Forest, and the Mount Adams Ranger District, uses the ecosystem management decision support (EMDS) software (Reynolds, 1999a,b) to evaluate the effects of alternative landscape management strategies and policy decisions on key ecological patterns and processes, habitat and resource conditions, vulnerability to fire, insect, and pathogen disturbances, and key economic and social values (e.g., Hummel et al., 2001). EMDS is a decision support modeling system for integrated landscape evaluation and planning (Reynolds, 2001a,b).

The Tool for Exploratory Landscape Scenario Analysis (TELSA) is a joint effort of ESSA Technologies, the Rocky Mountain and Pacific Northwest Research Stations, the Alberta Pacific Corporation, and the British Columbia Ministry of Forests (Kurz et al., 2000). The TELSA tool is a spatially explicit model of forest succession, disturbances, and forest management activities. It represents forest succession and the impacts of management and disturbances as changes in the cover types and structural classes of patches.

Successional pathway diagrams developed within Vegetation Dynamics Development Tool (Beukema and Kurz, 1998) define the transition times between various succession classes (combinations of cover types and structural classes) and the probabilities and impacts of disturbance by insects, fire, or other agents. These diagrams also define the impacts of forest management actions on stand structure and composition. In TELSA, the area disturbed annually and the size and types of disturbances respond to landscape changes from succession or management.

9. Conclusions

Management will always be faced with incomplete information. The state of incomplete knowledge is not for a lack of investment, or investment at the wrong scale(s), but is inherent to the management of natural resources (Walters, 1986). In many cases, it appears that active management will be necessary for ecosystem restoration, especially in the dry disturbance-prone ecosystems of the Inland Northwest. While management for optimal commodity production will yield unacceptable tradeoffs in ecosystem condition, it should be possible to manage more successfully for ecosystem structural and functional resiliency with some measure of benefits for people. But active management may not be possible in the near term everywhere it may be needed (Rieman et al., 2000).

An experimental approach will be needed that incorporates learning, one of the key tenets of adaptive management (Walters, 1986). Desired future conditions will only be realized by planning for and creating the desired ecosystem dynamics represented by ranges of conditions, set initially in strategic locations with minimal risks to species and processes. Using concepts such as natural or historical range of variability or reference conditions (Landres et al., 1999) may be a key planning tool as, for example, was used in Augusta Creek in the central Oregon Cascades (Cissel et al., 1998, 1999), and in the eastern Washington Cascades (Hessburg et al., 1999b; Hummel et al., 2001). Adapting management through experimentation, observation, and learning (Bormann et al., 1994, 1999; Holling, 1978; Hilborn, 1992; Gunderson et al., 1995) may be a difficult paradigm to adopt, as it is not consistent with the required methods of decision-making in the NEPA process. The NEPA process is highly problematic to adaptive ecosystem management; the very nature of a good NEPA process encourages fragmentation of decisions because inclusion of a single controversial issue can derail the larger project(s) under consideration (Committee of Scientists, 1999). Congress, although it has supported the development of plans and assessments at multiple scales (e.g., RPA, NFMA) has never supported them at the planned funding levels, and has instead funded individual resources or activities in a piecemeal fashion. Thus, our challenges are not only ecological but also social and economic. All must be dealt with simultaneously if we are to move towards more sustainable landscapes in the Inland Northwest.

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