Management Implications of Recent Changes in Spatial Patterns of Interior Northwest Forests

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Declining health of forest ecosystems in the interior West has been the subject of much study, concern and controversy in recent years (e.g., Everett et al. 1994, Harvey et al. 1995, Lehmkuhl et al. 1994, O'Laughlin et al. 1993, Wickman 1992). Land-use practices of this century have altered disturbance regimes and spatial and temporal patterns of vegetation, and reduced ecosystem resilience to native and human disturbances. Concern for "declining forest health" centers around the human perception that past forest management activities have had a deleterious effect on forest ecosystem structure and functioning. The perception is founded on a widely held social value that forest (and rangeland) ecosystems ought to appear "natural" and be allowed to function "naturally." In that context, significant departure from native conditions in the appearance of forests, in attributes of disturbance regimes (e.g., disturbance frequency, duration, distribution, intensity, and extent), and in other vital ecosystem processes (e.g., succession, species migration, speciation, extinction) indicates anamolous functioning and uncertain outcomes. Hence, by virtue of the perceived deviant functioning and unease with expanding uncertainty, a negative connotation is applied to altered and unprecedented ecosystem states in the notion of "declining ecosystem health."

Fire suppression, fire exclusion, timber harvest and livestock grazing have contributed most to increased forest ecosystem vulnerability to insect, pathogen and wildfire disturbance. These conditions are not pervasive, however, some forests remain in relatively healthy and resilient condition.

This paper summarizes results of a study conducted under the aegis of the Interior Columbia Basin Ecosystem Management Project. We report on a mid-scale scientific assessment of vegetation change in terrestrial landscapes of the interior West, associated change in landscape vulnerability to fire, insect and pathogen disturbances, and management implications of those changes. Our assessment area included the interior Columbia River basin east of the crest of the Cascade Range and portions of the Klamath and Great Basins in Oregon (collectively, the basin). States included in the assessment area were eastern Oregon and Washington, Idaho, western Montana and Wyoming, and northern California, Utah and Nevada (Figure 1).

Our study had four objectives: (1) to characterize current structure and composition of a representative sample of forest and rangeland landscapes; (2) to compare existing conditions to the oldest historical vegetation conditions we could reconstruct at a comparable scale. This was done to better understand the direction and magnitude of vegetation change occurring during the first century of active resource management; (3) to link historical and current vegetation spatial patterns with spatial patterns of vulnerability to insect and pathogen disturbances; and (4) to link historical and current landscape vegetation characteristics throughout the basin with fuel conditions, potential fire behavior and related smoke production. Our rationale was twofold: linkages in objectives 3 and 4 would enable us to better understand causal connections among historical management activities and current conditions, and they would assist us in evaluating current air quality and human health tradeoffs associated with wild and prescribed fires and tradeoffs associated with alternative insect and pathogen vulnerability scenarios.

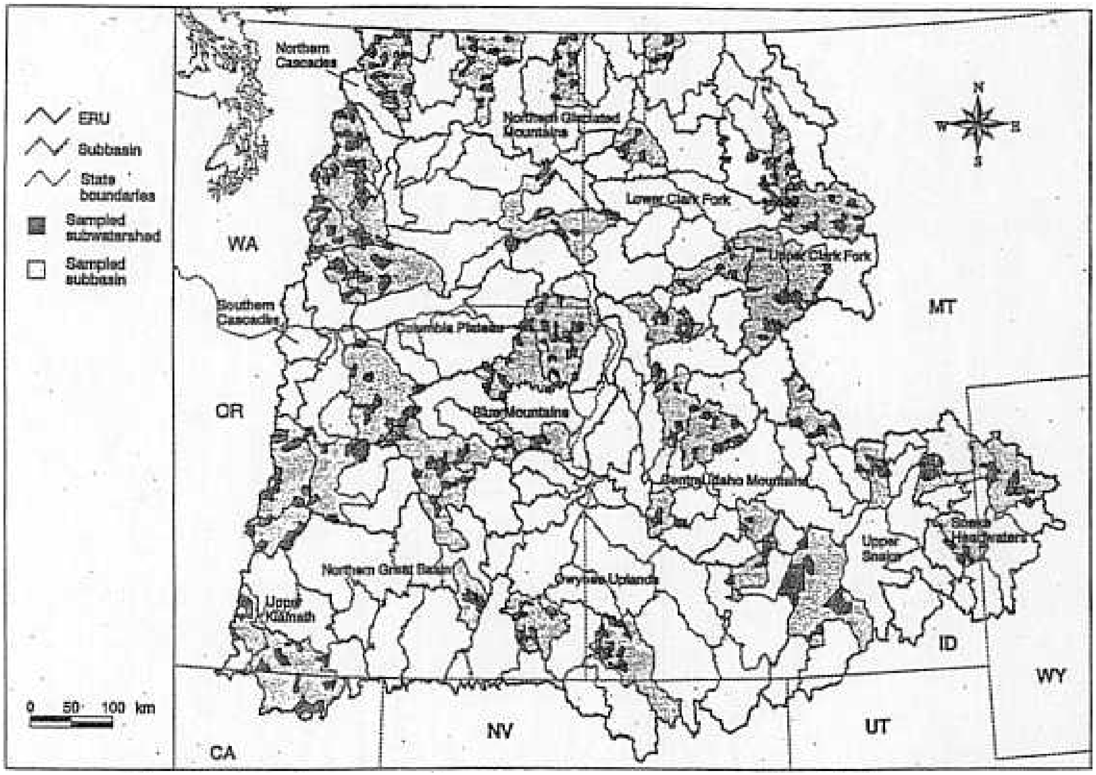

Figure 1. Ecological reporting units (ERUs), subbasins and subwatersheds sampled in the mid-scale assessment of the interior Columbia River basin.

Methods

In the midscale assessment of the interior Columbia basin (Hessburg et al. 1999a), we quantified change in vegetation patterns and landscape vulnerability to fire, insect and pathogen disturbances over the most recent 50 to 60 years. Our sample of historical conditions, although less than 100 years old, corresponded well with the start of the period of most intensive timber harvest, road construction and fire suppression; a period of intermediate and declining intensity in rangeland management; and a period of comparable climate regime. We based our assessment on a stratified random sample of 337 subwatersheds (9,500 hectares average size) distributed in 43 subbasins (404,000 hectares average size), on all public and private ownerships within the basin (Figure 1). Change analysis results were reported by province-scale ecological reporting units (ERUs).

Forest and rangeland vegetation composition and structure were derived from remotely-sensed data developed from resource aerial photographs taken from 1932 to 1966 (historical), and from 1981 to 1993 (current). Historical conditions of most forested settings were represented by photography from the 1930s and 1940s; while historical conditions of most rangelands were represented by 1950s and 1960s vintage photography. Areas with homogeneous vegetation composition and structure were delineated as patches to a minimum size of four hectares. Cover types (composition), structural classes (structure) and potential vegetation types (site potential) were classified for each patch using raw photo-interpreted attributes and either topographic or biophysical data from other digital sources of comparable scale and image resolution.

Each patch was assigned a vulnerability rating for three to seven vulnerability factors associated with each of 21 different potential forest insect and pathogen disturbances: one defoliator disturbance, seven bark beetle disturbances, four dwarf mistletoe disturbances, six root disease disturbances, two rust disturbances, and one stem decay disturbance. Vulnerability factors were unique for each host-pathogen or host-insect interaction modeled and included such items as site quality, host abundance, canopy layers, host age or host size, stand vigor, stand density, connectivity of host patches, topographic setting, and type of visible logging disturbance. Patch vulnerability factors were taken from the published literature or were based on the expert opinions and experience of field pathologists and entomologists with localized expertise in specific geographic areas (Hessburg et al. 1999b).

Similarly, each historical and current patch was assigned ground fuel loading, fuel consumption, crown fire potential, and three fire behavior attributes using published classification procedures (Huff et al. 1995, Ottmar et al. in press). Fuel consumption and fire behavior attributes were classified for both prescribed and wildfire burn scenarios. Fire behavior attributes were fire rate of spread, flame length and fireline intensity.

Vegetation maps, remotely-sensed patch attributes, derived cover type, structural class, and potential vegetation attributes, and other derived attributes formed the basic data set from which all subsequent pattern analyses were accomplished. Individual patch types were described by their composition, structure and potential vegetation. We used percentage of area, mean patch size and patch density metrics to describe change in area and connectivity of patch types in subwatersheds of an ERU. We used 10 additional landscape pattern metrics to describe changes in patch type richness, evenness, diversity, dominance, contagion, dispersion, interspersion, juxtaposition, and edge contrast. Change from historical to current conditions was estimated as the mean difference between historical and current conditions, not as the percentage of change from historical conditions, in order to avoid the bias of establishing the historical condition as an essential reference. For each ERU, means, standard errors and confidence intervals were estimated using methods for simple random samples with subwatersheds as sample units. Significant ($P \leq 0.2$) change was determined by examining the 80 percent confidence interval around the mean difference for the ERU.

We supplemented this significance test with two others that enabled us to evaluate the potential ecological importance of patch type change in area or connectivity of area. First, we estimated a reference variation by calculating for each metric, the 75 percent range around the historical sample median, and we compared the current sample median value with this range. Second, we characterized changes in absolute area of a patch type within a sample using transition analysis to discover the principal transformations. Transition analysis derives the percentage of sampled ERU area of each unique historic to current patch type transition. Significance of change was determined after examining each of the three pieces of information.

Results

Trends in Physiognomic Conditions

Forest cover increased in the Blue Mountains, Columbia Plateau, Southern Cascades, and Upper Snake ERUs, where our results suggested that effective fire prevention, suppressions and exclusion resulted in expansion of forests either into areas that were previously bare ground or shrubland, or into former herbland areas previously maintained by fire or created by early logging (Figure 1, Table 1). Connectivity (spatial aggregation) of forest as a physiognomic condition, increased in the Central Idaho Mountains and Upper Snake ERUs. The Central Idaho Mountains contains large areas of wilderness or roadless areas, and it is likely that increased connectivity occurred as a result of fire exclusion.

Forest cover declined in the Upper Klamath ERU, and analysis indicated that timber harvest activities during the sample period caused the observed depletion of forest area. Connectivity of forests also declined in the Upper Klamath ERU. Upper Klamath forests are naturally quite fragmented; forested slopes are often separated by broad grassy valley bottoms or grasslands on dry southerly aspects. Timber harvest accentuated this characteristic.

Woodland (sparsely wooded rangeland) area increased in the Blue Mountains, Columbia Plateau, Northern Cascades, Northern Great Basin, Owyhee Uplands, Snake Headwaters, and Upper Klamath ERUs and declined in no ERUs, thereby suggesting that fire suppression, fire exclusion, and grazing enabled expansion at the expense of declining herblands and shrublands. Transition analysis confirmed these transformations.

Most dramatic of all changes in physiognomic conditions was the regional decline in area of shrublands (Table 1). Shrubland area declined in all ERUs but the Southern Cascades. Significant reduction was observed in the Blue Mountains, Central Idaho Mountains, Columbia Plateau, Northern Great Basin, Owyhee Uplands, and Snake Headwaters ERUs, and no ERU exhibited increased shrubland area. Transition analyses indicated that losses to native shrublands resulted from various factors, including forest or woodland expansion (Blue Mountains and Northern Great Basin ERUs) cropland expansion (Northern Great Basin ERU), and conversion to seminative or nonnative herbland (Owyhee Uplands and Snake Headwaters ERUs).

Conversely, herblands increased in the Central Idaho Mountains, Northern Great Basin, Owyhee Uplands, Snake Headwaters, and Southern Cascades ERUs and did not decline in any ERU. In the Central Idaho Mountains, herbland increased by about 1 percent, and increases were primarily to colline (those situated in an elevation belt below lower tree line) and montane bunchgrass cover types. But in the Northern Great Basin, herblands increased at the expense of shrublands; historical shrubland area fell by more than 15 percent. Half of the lost shrubland area is currently occupied by juniper woodland, and the balance currently supports montane bunchgrasses or exotic grass and forb cover. Herblands and shrublands followed a similar pattern in the Owyhee Uplands. Across the basin, most of the increase in herblands resulted from expanding colline exotic grass and forb cover with the conversion of shrublands. Here it is important to note that most native herblands were converted from tall and short grass prairies to agricultural production prior to our historical condition. We describe changes to what are essentially relict herblands.

Table 1. Historical (and current) percentage of area of physiognomic types of subwatersheds sampled in Ecological Reporting Units of the mid-scale ecological assessment of the interior Columbia River basin.[a]

Physiognomic types	Blue Mountains	Central Idaho Mountains	Columbia Plateau	Lower Clark Fork	Northern Cascades	Northern Glaciated Mountains
Forest	**62.8**	73.4	**26.1**	91.7	78.8	81.0
	(64.1)	(73.5)	**(29.1)**	(94.5)	(78.2)	(80.8)
Woodland	**2.7**	0.1	**6.7**		**0.3**	
	(4.2)	(0.0)	**(12.2)**		**(0.7)**	
Shrubland	**14.1**	**19.2**	**32.2**	1.9	4.8	3.1
	(10.7)	**(17.1)**	**(23.4)**	(0.6)	(4.1)	(2.5)
Herbland	17.4	**3.2**	12.7	5.4	6.7	7.4
	(18.0)	**(4.5)**	(14.0)	(3.2)	(6.5)	(8.1)
Other[b]	3.0	**4.2**	22.4	0.9	**9.4**	8.5
	(2.9)	**(4.9)**	(21.4)	(1.8)	**(10.6)**	(8.5)

[a] Mean values shown in bold type are significantly different at $P \leq 0.2$.

[b] "Other" includes anthropogenic cover types and other nonforest and nonrange types.

Cover Type Trends

Shifts from early to late seral cover species were evident in most ERUs (Table 2), but in some cases, the shift was at least partially masked by steep climatic gradients. For example, in the Northern Cascades, Douglas-fir is early seral in several mid- to upper montane potential vegetation types, but to the east at lower elevations is climax in the Douglas-fir potential vegetation type. Of all forested ERUs, the most pronounced shifts from early to late seral cover types occurred in the Northern Glaciated Mountains. Western larch cover declined in the Central Idaho Mountains, Columbia Plateau, and Northern Glaciated Mountains ERUs, and ponderosa pine cover decreased in the Northern Cascades, Northern Glaciated Mountains, Upper Clark Fork, and Upper Klamath ERUs. Ponderosa pine cover increased in the Southern Cascades as a result of regrowth of forests that were tractor-logged just before the period of our historical photo coverage. Lodgepole pine cover declined in the Snake Headwaters ERU, and in six other ERUs. Western white pine cover decreased in the Northern Glaciated Mountains ERU as a consequence of white pine blister rust, mountain pine beetle mortality and selective harvesting, and increased slightly in the Northern Cascades as a result of recent reforestation efforts. Whitebark pine-subalpine larch cover declined in the Central Idaho Mountains, Northern Glaciated Mountains, Snake Headwaters, and Upper Clark Fork ERUs and increased in the Blue Mountains and Northern Cascades ERUs.

Table 1. Continued.

Northern Great Basin	Owyhee Uplands	Snake Headwaters	Southern Cascades	Upper Clark Fork	Upper Klamath	Upper Snake
7.2	0.2	74.5	80.5	87.2	**50.5**	**2.4**
(7.3)	(0.2)	(73.8)	(88.3)	(86.2)	**(47.5)**	**(3.2)**
15.3	**5.5**	**0.2**	0.0		**8.4**	3.0
(22.2)	**(7.6)**	**(0.3)**	(0.4)		**(12.8)**	(2.9)
72.8	**88.8**	**16.3**	0.5	2.5	21.4	73.8
(57.6)	**(81.0)**	**(13.9)**	(0.5)	(2.1)	(18.8)	(68.5)
3.9	**1.0**	**6.1**	**0.6**	5.5	10.6	10.6
(12.2)	**(7.4)**	**(8.7)**	**(2.7)**	(5.7)	(9.0)	(9.9)
0.8	4.5	3.0	**18.4**	4.8	**9.1**	10.3
(0.8)	(3.8)	(3.3)	**(18.1)**	(6.0)	**(12.0)**	(15.4)

Decline in whitebark pine cover was the result of ongoing blister rust and mountain pine beetle mortality.

In contrast, Douglas-fir cover increased in the Blue Mountains, Columbia Plateau, and Northern Cascades ERUs; grand fir cover increased in the Northern Cascades and Northern Glaciated Mountains; Pacific silver fir cover increased in the Northern Cascades; Engelmann spruce-subalpine fir cover increased in the Northern Glaciated Mountains, Snake Headwaters, Southern Cascades, and Upper Clark Fork ERUs; and western hemlock-western redcedar cover increased in the Columbia Plateau and the Northern Glaciated Mountains ERUs (Table 2). Engelmann spruce-subalpine fir cover declined in the Blue Mountains, and Engelmann spruce-subalpine fir and western hemlock-western redcedar cover both decreased in the Northern Cascades. Evidence from the mid-scale assessment indicated that the noted increases in shade-tolerant cover types were the direct result of fire suppression and exclusion and selective timber harvest.

In addition to a trend toward expanded area of late-successional species, we noted that average patch sizes of most forest cover species were smaller, and in general, land cover is currently more fragmented. In the historical condition, it was apparent that spatial patterns of biophysical environments and disturbances created patches of land cover that were relatively large. In the current condition, those comparatively simple patterns have been replaced by highly fragmented landscapes comprised of relatively small patches. Evidence clearly suggests that widely applied patterns of small cutting units are responsible for the change.

Table 2. Historical (and current) percentage of area of forest cover types of subwatersheds sampled in Ecological Reporting Units of the mid-scale ecological assessment of the interior Columbia River basin.[a]

Forest cover types	Blue Mountains	Central Idaho Mountains	Columbia Plateau	Lower Clark Fork	Northern Cascades	Northern Glaciated Mountains
	15.3	9.6	1.1	40.4	**1.0**	**0.0**
	(8.4)	(10.2)	(0.4)	(42.5)	**(2.2)**	**(1.2)**
ES/SAF	**6.3**	22.7		2.5	**16.8**	**11.5**
	(4.4)	(24.1)		(2.2)	**(13.6)**	**(13.2)**
ASP/COT	0.1	1.1	0.3	0.1		0.3
	(0.1)	(0.8)	(0.3)	(0.7)		(1.9)
	2.7	0.1	**6.5**			
	(4.2)	(0.0)	**(12.0)**			
	2.6	**0.5**	**1.0**	0.8	1.0	**14.8**
	(2.2)	**(0.3)**	**(0.1)**	(2.6)	(1.0)	**(11.4)**
WBP/SAL	**0.0**	5.1			**3.3**	0.3
	(0.7)	(2.5)			**(4.7)**	(0.2)
	2.4	9.7	1.3	2.1	5.9	8.0
	(2.3)	(9.5)	(0.9)	(1.8)	(5.2)	(8.3)
LP			0.4			
			(0.4)			
PP	28.4	**6.0**	**19.2**	3.0	**16.5**	**13.4**
	(28.9)	**(5.9)**	**(21.4)**	(5.1)	**(13.2)**	**(11.4)**
DF	**7.7**	17.6	**3.0**	26.1	**23.8**	30.3
	(17.1)	(18.5)	**(3.9)**	(21.1)	**(25.8)**	(30.2)
WH/WRC		0.9	**0.4**	14.7	**3.0**	**0.7**
		(1.3)	**(2.2)**	(17.3)	**(2.4)**	**(2.8)**
		0.0		**1.3**	1.3	0.1
		(0.0)		**(0.6)**	(1.2)	(0.0)
SP/WWP					**6.0**	
					(8.3)	
PSF					**0.6**	
					(0.9)	
SRF						
PJ						

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[a] Mean values shown in bold type are significantly different at $P \leq 0.2$.

[b] Forest cover types: GF/WF = grand fir/white fir; ES/SAF = Engelmann spruce/ subalpine fir; ASP/COT = aspen/cottonwood/ willow; JUN = juniper; WL = western larch; WBP/SAL = whitebark pine/subalpine larch; LPP = lodgepole pine; LP = limber pine; PP = ponderosa pine; DF = Douglas fir; WH/WRC = western hemlock/ western redcedar; MH = mountain hemlock; SP/WWP = sugar pine/western white

Table 2. Continued.

Northern Great Basin	Owyhee Uplands	Snake Headwaters	Southern Cascades	Upper Clark Fork	Upper Klamath	Upper Snake
			5.9	0.0	7.8	
			(6.5)	(0.1)	(8.1)	
			24.3	**0.0**	**14.2**	0.1
			(31.4)	**(0.2)**	**(17.3)**	(0.1)
8.4	0.2	**8.8**		0.3	0.0	0.9
(7.7)	(0.2)	**(5.7)**		(0.3)	(0.1)	(1.0)
14.1	**5.5**	**0.2**	0.0		**8.4**	2.6
(21.8)	**(7.5)**	**(0.3)**	(0.4)		**(12.8)**	(2.5)
				2.5	0.0	
				(3.0)	(0.1)	
		6.9	0.0	**4.3**		
		(5.7)	(0.8)	**(3.5)**		
		15.6	19.4	20.9	1.4	0.1
		(11.3)	(20.6)	(19.5)	(1.7)	(0.2)
		0.7		0.0		
		(1.1)		(0.4)		
			22.7	**12.3**	**26.7**	
				(28.1)	**(9.5)**	**(23.5)**
		18.2	1.5	32.7	2.1	1.4
		(18.6)	(1.7)	(32.5)	(1.2)	(2.1)
			30.5	0.0	4.7	
			(29.7)	(0.1)	(4.2)	
			0.3			
			(0.3)			
			0.2		7.8	
			(0.4)		(8.5)	
						0.4
						(0.5)

pine; PSF = Pacific silver fir; OWO = Oregon white oak; SRF = Shasta red fir; and PJ = pinyon/juniper.

Trends Among Structural Classes

In general, the structure of current forest patches was more complex, and the structure of current forest landscapes was generally simpler when compared with historical forests. However, causal links with management were difficult to establish because the amount of fire suppression or total timber harvest, for instance, was not directly measurable. Still, observed structural changes were consistent with management activities implicated as primary factors in the overall simplification of structural complexity of basin forests, namely, timber harvest, fire suppression, fire exclusion, and domestic livestock grazing.

Landscape area in forest stand initiation structures (new forest) declined in five of nine forest-dominated ERUs and increased in one, the Blue Mountains (Table 3). Area in stand-initiation structures declined in the Central Idaho Mountains, Lower Clark Fork, Northern Glaciated Mountains, Upper Clark Fork, and Upper Snake ERUs. Area in old multi-story and old single story forest structures declined in most forested ERUs, but the most significant declines occurred in the Blue Mountains, Northern Cascades, Snake Headwaters, and Upper Klamath ERUs. In general, area in intermediate (neither new nor old forest) structural classes (stem exclusion, understory reinitiation and young multi-story) increased in most forested ERUs. This change toward landscape dominance by intermediate forest structures was the general mechanism of landscape structural pattern simplification. The most notable increases in intermediate structures occurred in the Blue Mountains, Central Idaho Moun-

Table 3. Historical (and current) percentage of area of forest structural classes of subwatersheds sampled in Ecological Reporting Units of the mid-scale ecological assessment of the interior Columbia River basin.[a]

Forest structure classes[b]	Blue Mountains	Central Idaho Mountains	Columbia Plateau	Lower Clark Fork	Northern Cascades	Northern Glaciated Mountains
si	**3.9 (6.5)**	**9.7 (5.9)**	2.3 (2.8)	**32.7 (9.5)**	9.2 (10.4)	**16.9 (19.4)**
seoc	**14.3 (9.6)**	18.4 (17.7)	6.7 (7.8)	**15.7 (9.2)**	13.2 (13.2)	11.8 (11.6)
secc	5.0 (5.0)	7.7 (8.5)	3.8 (3.6)	**10.3 (17.6)**	7.6 (7.9)	**7.2 (12.8)**
ur	**13.6 (11.2)**	**16.0 (21.4)**	3.1 (3.3)	**16.3 (37.7)**	17.5 (19.5)	**18.4 (23.3)**
yfms	**21.3 (29.6)**	18.4 (17.1)	**7.3 (10.0)**	14.3 (17.5)	21.2 (22.0)	**25.5 (22.8)**
ofms	**2.2 (1.0)**	1.4 (1.2)	2.3 (1.3)	0.2 (0.5)	**5.8 (2.7)**	0.5 (0.4)
ofss	**2.7 (0.9)**	1.8 (1.7)	1.1 (1.0)	2.2 (2.5)	**4.3 (2.4)**	0.7 (0.6)

[a] Mean values shown in bold type are significantly different at $P \leq 0.2$.

[b] Forest structure classes: si = stand initiation; seoc = stem exclusion open canopy; secc = stem exclusion closed canopy; ur = understory reinitiation; yfms = young forest multi-story; ofms = old forest multi-story; and ofss = old forest single story.

tains, Columbia Plateau, Lower Clark Fork, Northern Glaciated Mountains, Snake Headwaters, Southern Cascades, and Upper Clark Fork ERUs. Area within intermediate structural classes actually declined in the Upper Klamath ERU, where most evidence suggested extensive past harvesting.

As noted for land cover conditions, we noted across the basin that average sizes of most patches of forest structure were smaller, and in general, landscapes defined in terms of forest structure were more fragmented in the current condition than in the historical condition (Figures 2A and 2B). Patch density and mean patch size analyses indicated that patterns of historical timber harvest were responsible for the change.

Other Significant Findings

Four additional findings are worthy of brief mention. First, in the historical condition, patches with large (>63.5 cm diameter at breast height [dbh]) and medium (40.5-63.5 cm dbh) trees were also once widely distributed in structures other than old forest as a conspicuous remnant after stand-replacing disturbance. Change analysis indicated that timber harvest targeted patches with medium and large trees regardless of their structural affiliation. Today, medium and large trees are no longer as plentiful on the landscape as before. Second, along with other vegetation attributes interpreted from aerial photos, we estimated dead tree and snag abundance in each forest patch using one of five classes: none, less than 10 percent, 10 to 39 percent, 40 to 70 percent, and greater than 70 percent of trees dead or as snags. Results of change analysis using these data indicated that dead tree and snag abundance increased sig-

Table 3. Continued.

Northern Great Basin	Owyhee Uplands	Snake Headwaters	Southern Cascades	Upper Clark Fork	Upper Klamath	Upper Snake
		6.4 (7.0)	9.1 (9.9)	**15.9 (11.1)**	1.9 (3.6)	**0.8 (0.3)**
6.5 (6.0)	0.0 (0.1)	**19.1 (15.3)**	12.3 (14.3)	18.5 (18.2)	11.3 (10.9)	**0.4 (0.1)**
0.7 (1.3)		**7.9 (4.8)**	**0.5 (4.8)**	**16.7 (21.1)**	1.2 (1.6)	0.1 (0.1)
	0.4 (1.1)	13.8 (12.6)	10.3 (8.7)	15.6 (14.0)	5.6 (8.1)	2.5 (1.6)
	0.1 (0.1)	**22.0 (30.9)**	46.0 (45.6)	19.7 (21.1)	**21.1 (16.4)**	0.6 (1.1)
		3.2 (1.8)	0.7 (1.4)	0.6 (0.4)	4.3 (5.5)	
		2.0 (1.3)	1.6 (3.7)	0.2 (0.3)	**7.4 (4.8)**	0.1 (0.0)

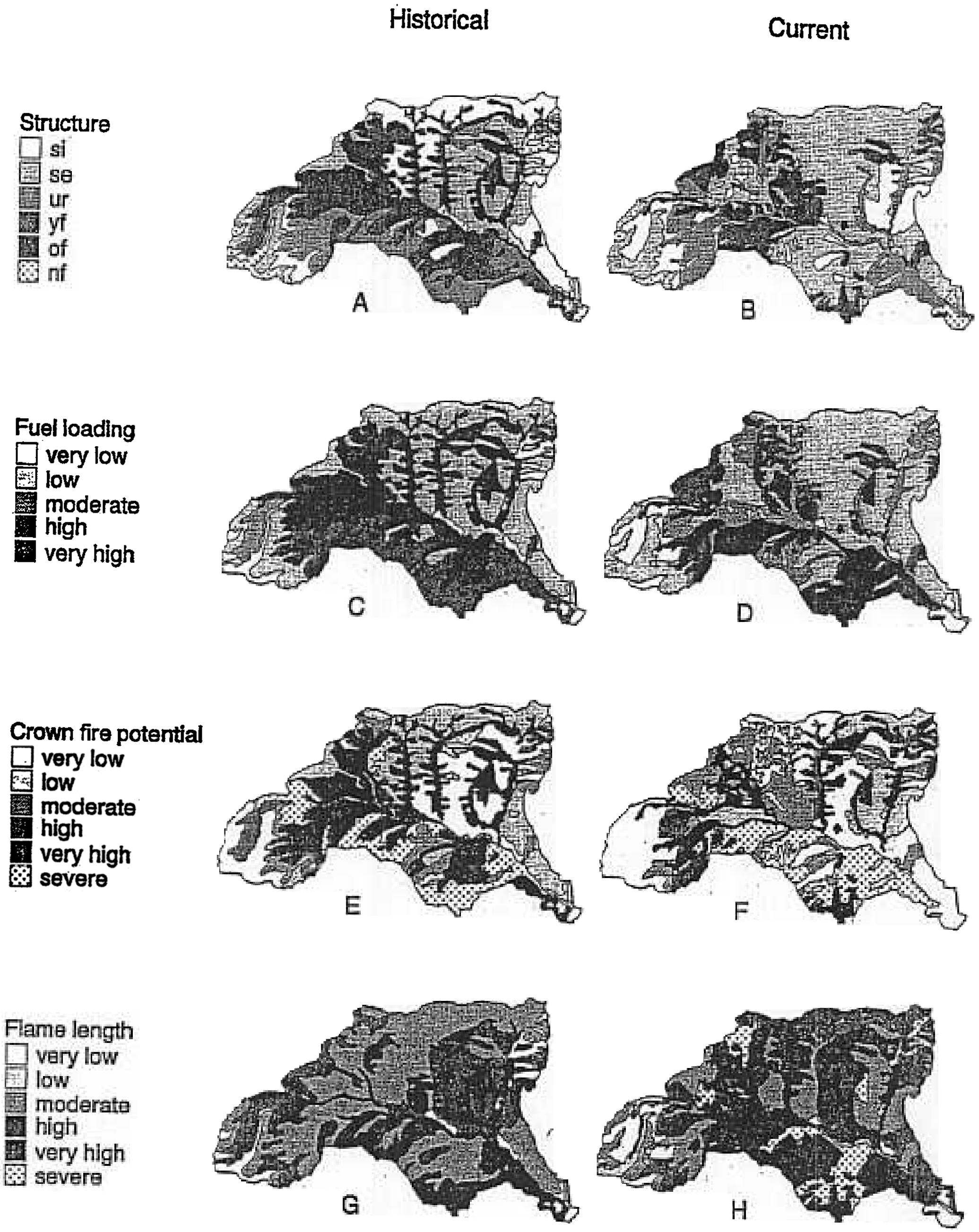

Figure 2. Maps of the Libby Creek sampled subwatershed MET_11 of the Methow subbasin, Northern Cascades ERU, displaying historical (1956) and current (1992) structural classes (A&B), fuel loading (C&D), crown fire potential under wildfire conditions (E&F), and flame length under wildfire conditions (G&H), respectively. Structure classes are: si = stand initiation; se = stem exclusion (both open and closed canopy conditions); ur = understory reinitiation; yf = young forest multi-story; of = old forest (both multi- and single story conditions; nf = nonforest. Fuel loading classes are: very low < 22.5 Mg/ha; low = 22.5-44.9 megagrams per hectare (Mg/ha); moderate = 45-56.1 Mg/ha; high = 56.2-67.3 Mg/ha; and 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; and severe > 3.4 m.

nificantly in most forested ERUs, but primarily in the pole and small tree (12.7-40.4 cm dbh) size classes, because medium and large tree abundance was significantly depleted by timber harvest. Third, forest patches in the current condition have more canopy layers than were displayed in the historical condition, and layers are typically comprised of late successional species. With the exclusion of fire, surface fires were virtually eliminated, and multi-layered understories developed (Hann et al. 1997). And fourth, in the historical condition, forest understories were often absent or were comprised of shrub and herbaceous species. In the current condition, forest understories are less often grass or shrub, and more often coniferous.

Landscape Vulnerability to Disturbances

Insects and pathogens. Forest landscapes have changed significantly in their vulnerability to major insect and pathogen disturbances. In the absence of frequent fires and under the influence of selective harvesting and domestic livestock grazing, overstory and understory cover of Douglas-fir and most other shade-tolerant species expanded, forest structures became more layered, and grass and shrub understories were replaced by coniferous understories. As a consequence, insect and pathogen vulnerabilities that increase with increased dominance and spatial aggregation of shade-tolerant conifers were favored by the changes in vegetation spatial patterns. Conversely, because medium and large trees of early seral species were primarily harvested over the period between the historical and current conditions, insect and pathogen vulnerabilities favored by increasing dominance and spatial aggregation of large trees of early seral species declined. A few highlights follow.

In many ERUs, area vulnerable to western spruce budworm increased, but most changes were not significant at the scale of the ERU, suggesting that ERUs were an inappropriate mid-scale pooling stratum. But such changes were significant at smaller subregional scales. In addition, we noted that the conduciveness of conditions to widespread severe budworm defoliation increased over the sample period. This is largely due to the increased dominance of shade-tolerant conifers, increased dominance of multi-layered host patches, and increased spatial aggregation of host patches reflected in increased average host patch size, and in some cases increased host patch density.

Throughout the basin, area vulnerable to Douglas-fir beetle and Douglas-fir dwarf mistletoe increased because forest landscapes in the existing condition exhibited increased cover and connectivity of Douglas-fir, current stand densities are elevated from historical conditions, and patches today tend to be multi-layered, often with several layers of understory Douglas-fir. Conversely, area vulnerable to western pine beetle disturbance of mature and old ponderosa pine fell because medium and large ponderosa pine were selectively harvested from old forest patches and from other structures. Likewise, area vulnerable to ponderosa pine and western larch dwarf mistletoes declined in many areas of the basin as a result of reduced area of ponderosa pine and western larch overstory cover.

In the Blue Mountains, Snake Headwaters and Southern Cascades ERUs, area vulnerable to mountain pine beetle disturbance of lodgepole pine declined as a result of declining area where lodgepole pine occurred as a major early seral species in mixed cover types. Beetle disturbance and fire exclusion resulted in lodgepole mortality and conversion of some areas to shade-tolerant cover types. These changes were corroborated by transition analysis.

Area highly vulnerable to root pathogens, especially S-group annosum and *Armillaria* root diseases, increased in most ERUs with the expanded cover and connectivity of patches of host species. Conversely, area vulnerable to white pine blister rust disturbance of western white pine declined; decline was the result of white pine blister rust and mountain pine beetle mortality, and extensive selective harvesting of western white pine.

Wildfires. Forest landscapes have been significantly altered in their vulnerability to wildfire disturbance, as well. In general, the risk of stand replacement fire has increased dramatically throughout the forest-dominated portion of the basin, and the likelihood of non-lethal surface fires has declined in equally dramatic fashion. Elevated risk is indicated by increased ground fuel loadings, crown fire potential, flame lengths, fire rates of spread, and fireline intensity, each of which are direct or indirect consequences of changes in spatial patterns of both living and dead forest cover and structure. Changes in vegetation spatial patterns are the result of effective fire prevention and suppression programs, selective timber harvest, and fire exclusion. Key factors responsible for fire exclusion were the widespread elimination of flashy fuels through extensive domestic livestock grazing, especially in the first half of the 20th century (see Hann et al. 1997, Skovlin and Thomas 1995, Wissmar et al. 1994); reduced connectivity of fire-prone landscapes through placement of extensive road networks; settlement of fire-prone interior valleys and subsequent conversion to agriculture by European immigrants; and movement of American Indians, who used fire as a management tool, onto reservations (Robbins and Wolf 1994).

A number of changes in fuel loading, crown fire potential and fire behavior attributes were significant at the ERU scale; a few highlights follow (see Ottmar et al. in press). In the Blue Mountains ERU, area with fuel loading greater than 45 megagrams per hectare (Mg/ha) increased by 4 percent, and area with flame lengths greater than 1.2 meters during wildfires increased by 6 percent. In the event of a wildfire today, it would be difficult to suppress expected flames on roughly two-thirds of the current forest and rangeland area.

In the Central Idaho Mountains, fuel loads (>45 Mg/ha) and flame length

(>1.2 m) increased to high levels or above on more than 5 percent of the area. In the Lower Clark Fork ERU, fuel loads (>45 Mg/ha) and flame lenths great than 1.2 meters during wildfires increased to moderate levels or above on 29 percent of the ERU area. At present, 82 percent of the area of the Lower Clark Fork ERU exhibits moderate to severe crown fire potential. In the event of a wildfire today, it would be difficult to suppress expected flames on 94 percent of the current forest and rangeland area.

In the Northern Glaciated Mountains, fuel loads (>45 Mg/ha) increased on 7 percent of the ERU area, flame lengths greater than 1.2 meters during wildfires increased on 6 percent of the area, and crown fire potential increased to moderate levels and above on 5 percent of the area. At present, 60 percent of the area of the Northern Glaciated Mountain ERU exhibits moderate to extreme crown fire portential, and 76 percent of the forest and rangeland area would experience flame lengths in excess of 1.2 meters during wildfires. Comparable flame length conditions currently exist in the Northern Cascades ERU.

Finally, in the Southern Cascades, fuel loads (>45 Mg/ha) increased on nearly 5 percent of the ERU area, fire rate of spread (2.4 meters per minute) during wildfires increased on more than 11 percent of the area, and extreme fireline intensity (73,459 kilowatts per meter) increased on nearly 8 percent of the area. At present, 56 percent of the ERU area exhibits moderate to extreme crown fire potential, and 82 percent of the forest and rangeland area would experience flame lengths in excess of 1.2 meters during wildfires. In the event of a wildfire today, it would be difficult to suppress expected flames on roughly 8 of every 10 hectares.

Discussion

The primary utility of landscape assessment and change analysis is in understanding the characteristics of ecosystems that we manage (Morgan et al. 1994). Knowledge of landscape-pattern change at regional, provincial and subregional scales provides critical context for regional and forest planning, watershed analysis and project-level planning, and valuable insight for ecological restoration, conservation and monitoring decisions. Landscape change analysis provides an essential empirical basis to evaluate the historical and current rarity of landscape pattern features and is an aid in determining how representative current patterns are in comparison with recent historical conditions.

The basin assessment area is large, and we summarized many changes in vegetation condition and associated vulnerability to disturbance. But here we will focus on some of the most important generalities lest we lose them in a sea of detail. Most dramatic of all changes in physiognomic conditions was the regional decline in shrubland area. Losses of native shrublands resulted from a variety of factors, including forest and woodland expansion, cropland expansion, and conversion to semi- and nonnative herbland. Loss of historical dry herblands to agriculture was equally dramatic but had already been sustained by the start of our historical vegetation coverage (Hann et al. 1997). Forest cover increased substantially in several ERUs at the expense of shrubland and herbland, and woodland cover rose sharply in all ERUs where woodland was more than a minor physiognomic condition. The observed changes in physiognomic conditions are best explained by direct suppression of fire, indirect exclusion of fire, and domestic livestock grazing.

Shifts from early to late seral species were evident in many ERUs. Most of the observed change in ponderosa pine, western larch and Douglas-fir cover were associated with decline in area and connectivity of patches with medium and large trees of these species. We also observed precipitous decline in area and connectivity of western white pine cover in northern Idaho and northwestern Montana, the heart of the historical range. Loss of white pine cover was attributed to early selective harvesting, and mortality associated with white pine blister rust infection and mountain pine beetle infestation.

Overstories and understories comprised of shade-tolerant species were evident in many forested ERUs; across the basin, forests are now more contagiously dominated by shade-tolerant conifers than was true in the historical condition. Lacking significant forest pattern restoration, we can expect that insects and pathogens (e.g., the western spruce budworm, Douglas-fir tussock moth, fir engraver, Douglas-fir dwarf mistletoe, *Armillaria* root disease, and S-group annosum root disease) favored by increased areal extent and contiguity of patches of shade-tolerant conifers, will have an expanding role in shaping forest patterns by their direct disturbance influence, via mortality inputs, and by indirect influence on fire regimes.

Area in old forest-structures declined sharply in all forested ERUs where they historically occupied more than a minor area. The same was true of remnant large trees associated with structural classes other than old forest. But when we evaluated change in area with medium and large trees, regardless of their structural affiliation, we observed what we believe was the most important change in structure in several ERUs. In the Blue Mountains, Northern Cascades and Upper Klamath ERUs, decline in area with medium and large trees both overshadowed and augmented losses to historical old-forest area. Our results suggested that 20th century timber harvest activities targeted medium- and large-sized trees regardless of their structural affiliation. They were most economical to harvest and most accessible, sawmills were tooled to handle them most efficiently and economically, and timber sales were most viable when offered volumes were in the form of medium and large trees. Our results indicate that medium and large trees were harvested wherever they stood; they were often but not always associated with old forest.

There are at least two important ramifications of this observation. First, it has been broadly assumed by forest managers and ecologists alike, that large trees are principally associated with old forest, where they obviously contribute important living and dead structure. Our results indicate that in several ERUs, old forest abundance was historically quite minimal (Table 3), but large (and medium) trees were once widely distributed in other forest structures as a conspicuous remnant after stand-replacing disturbance. In some cases, large trees comprised as much as 24 percent of the crown cover of forest structures that were not old and, although subordinate to other features, contributed important living and dead structure. Hence, many non-old forest structures of historical forest landscapes contributed some measure of late-successional functionality and connectivity with old forest. Second, in those ERUs where old forest area and area with remnant large trees have been depleted, the present and future supply of medium and large dead trees as snags and down logs has been substantially diminished. This is especially true of snags and down logs of early seral species, such as ponderosa pine, western larch, Douglas-fir, western white pine, and sugar pine—all preferred commercial species and the primary focus of 20th century harvest activities. Owing to the magnitude of the depletion, it is likely that terrestrial and aquatic species and ecological processes requiring medium and large dead tree structure may be adversely influenced by this current and future reduction, unless steps are taken to remedy the shortfall through replacement.

Along with reduced area containing large overstory trees, we observed a marked reduction in landscape vulnerability to dwarf mistletoes of early seral species, such as ponderosa pine and western larch. It was apparent from comparisons of historical and current subwatersheds that timber harvest reduced overstory crown cover of large early seral trees, while one or more shade-tolerant understory strata developed.

As expected, we observed that area in stand-initiation structures dramatically declined in several ERUs where stand-replacing fires once were relatively common events. Such reduction was evident, despite widespread timber harvest activity. Along with declining area in stand-initiation and old-forest structures, we observed, across the basin, sharply increased area and connectivity of intermediate forest structures, including stem-exclusion, understory re-initiation and young multi-story conditions.

Results from nearly all forested ERUs indicated that the absence of fire by direct suppression or exclusion has had profound effects on forest and woodland area and connectivity at subwatershed to regional scales. Many direct effects of fire exclusion and fire suppression were observed in our results. For example, we observed increased area and connectivity of forest and woodland physiognomies; total forest and woodland crown cover increased in many forested ERUs, as did area with more than two canopy layers. And area with conifer understories increased, especially area with shade-tolerant conifer understories. The history and legacy of fire suppression and prevention programs is well documented, but the effect of fire exclusion has been more difficult to pin down because many interacting factors played a role in excluding fire from fire-dependent ecosystems. As a result, it is possible and even likely that the efficacy of fire prevention and suppression programs has been overstated, and the role of factors responsible for exclusion of fire has been understated.

Throughout the basin, current forests and rangelands are more fragmented than were landscapes of our historical condition. Whether patch types are cover types, structural classes, or cover type-structural class couplets, patch densities are now higher, mean patch sizes are smaller, the largest patch of any given cover type or structural class is generally smaller, and edge density is greater. These combined outcomes point to landscape fragmentation and reduced patch type connectivity, primarily as a consequence of timber harvest activities and road construction. Landscape pattern metrics, especially contagion, interspersion and juxtaposition metrics, confirmed the presence of highly fragmented landscapes in the current condition and pointed to increased pattern complexity among cover type-structural class patch types in managed landscapes. The converse was true in roadless area and wilderness-dominated subwatersheds, where patch type connectivity generally increased and landscape patterns were simplified.

Management Implications

Important management implications emerge from our assessment of basin conditions and change. We learned that spatial and temporal patterns of historical landscapes were variable, and variation exhibited in historical patterns reflected variation resulting from the dominant disturbance regimes. We learned that ground fuel and fire behavior conditions changed throughout the basin, and landscapes varied considerably in the direction and magnitude of change. We learned that fire, insect and pathogen disturbances were always associated with historical Interior Northwest landscapes and will continue to be. Management may be able to influence to some extent, the timing, magnitude, frequency, location, and characteristics of such disturbances.

Fuels and fire behavior—examining and isolating the risks. Throughout the basin, there are currently many large, spatially continuous areas that display elevated ground fuel conditions and increased severity in fire behavior attributes. Prior to the 20th century period of active resource management, areas that were normally influenced by infrequent lethal fires and those of a mixed lethal-nonlethal type, also displayed relatively high fuel loads, crown fire potential, rate of spread, flame length, and fireline intensity. Active management has not made the entire landscape wildfire prone, rather, it has removed the degree of spatial isolation that patches prone to stand replacement once enjoyed. Now, areas prone to stand replacement are spatially aggregated on the landscape (Figure 2A-H). A reasonable target of restoration would be to restore this more typical pattern of isolation to affected landscapes. To that end, a systematic evaluation of forest susceptibility to stand replacement fire would be helpful. Such an evaluation is now possible using tools and analytical approaches developed during this assessment. The evaluation would identify areas that have changed the most in fuel conditions and fire behavior attributes. From a strategic point of view, such information would be highly useful to allocating scarce monetary and manpower resources to the greatest advantage.

The wildland-urban interface. Most people who live adjacent to National Forest land live on or adjacent to dry woodlands or dry to mesic forests. These specific settings have been most altered by 20th century management activities, and changes in structure, composition, ground fuels, fire behavior attributes, and vulnerability to insect and pathogen disturbance are generally most pronounced in these areas. As a result, surface fire regimes that once affected lands of the current wildland-urban interface have become lethal or at best mixed lethal/nonlethal regimes, and forest residents are at risk at each outbreak of fire. In the context of declining fire suppression efficacy, public land managers might consider restoring vegetation and fuels patterns in the wildland-urban interface as a major priority. In addition, managers might consider working with local citizens to halt what is currently a rapidly expanding zone of interface. The tacit assumption of citizens who take up residence in the forest is that the public land manager will come to their immediate aid at the outbreak of fire. But forest fire fighters are trained to fight wildland fire not protect structures. At some point, the rescue role of public land managers must be clearly enunciated, and the total extent of a wildland-fire interface zone defined. The safety and management implications of not doing so may be large.

Fire and smoke—how much and when. Stated simply, the question before public land managers is not whether there will be fire and smoke in their future, but how do citizens want their fire and smoke. As Ottmar et al. (in press) and Huff et al. (1995) have shown, the air quality and smoke production tradeoffs between wild and prescribed fires are highly significant. Prescribed burning can eliminate 50 percent or more of the particulate emissions generated by wildfires, and the timing, movement and disposal of smoke released to the airshed is managed. According to Hann et al. (1997), it is unlikely that fire suppression efficacy will improve given current vegetation and fuels conditions. Provided there is sufficient management latitude it will be up to resource managers, to reduce fuel loads to manageable levels, and to restore spatial patterns of living and dead vegetation structure and composition to conditions that are more in synchrony with native fire regimes and biophysical environment conditions. Citizens would need to learn to live with some measure of smoke on a regular basis as an alternative to uncertain fire- and smoke-free periods punctuated by periods with extreme levels of fire and smoke of unmanaged distribution, magnitude and effect.

Insects and pathogens—which ones and how much. In the same way that many healthy forests are routinely visited by fires, healthy forests are routinely visited by insects and pathogens. In fact, a good way to think about disturbances caused by native insects and pathogens, is to think of them as succession processes. Insect and pathogen disturbances motivate plant succession. Under native disturbance regimes, these disturbances produced semi-predictable outcomes, and more importantly, insect and pathogen disturbances were usually in synchrony with biophysical environment conditions and native fire regimes. But such is not the case today. Owing to effects of past management activities, current spatial patterns of forest vegetation are out of synchrony with native fire regimes, and current insect and pathogen disturbance regimes are anomalous.

There is no way by active management to eliminate insect and pathogen disturbances from basin landscapes. And we would undoubtedly not wish to do so even if we were able to. The byproduct of most insect and pathogen disturbances is microhabitat of varying quality and residence time, essential to a wide variety of terrestrial and aquatic species. But management, by altering spatial and temporal patterns of vegetation structure and composition, and growing conditions, can have a large impact on the suite of agents operating on a landscape at any given time. Simply stated, management can influence, to some extent, which insect and pathogen disturbances will have prominent and subordinate roles in any given landscape, but it cannot, and from an ecological point of view, should not attempt to eliminate these disturbances.

Dynamic and reserve systems. In the Pacific Northwest, the Northwest Forest Plan (NWFP) defines a network of late-successional reserves throughout the Coast Range of Orĕgon, Washington and California, on both the eastern and western slopes of the Cascade Range in Oregon and Washington, and on the west slope of the Cascade Range in California. While these lands are not explicitly set aside for custodial management, that is how they are currently being managed. It is likely that such an approach is implementable west of the Cascade crest where most fire regimes are lethal, fire return intervals may be as long 250 to 800 years or more, and the most common disturbances which are caused by native insects and pathogens result in canopy gaps. But east of the Cascade crest, the picture is quite different. Wildfires and large-scale insect outbreaks are common, and escaped wildfire frequency is increasing as a consequence of past management (Hann et al. 1997).

Results from both the interior Columbia Basin broad- (Hann et al. 1997) and mid-scale (Hessburg et al. 1999b, Ottmar et al. in press) landscape assessments suggest that in the interior, a two-pronged, dynamic and reserve system management approach may be needed to ensure recovery of the northern spotted owl and associated species. In the short term (e.g., 50-150 years), areas currently functioning as late-sucessional and old forest habitat will be maintained with only limited success. Ground fuel loads are high; risk of stand-replacing fire disturbance is high over abnormally large areas, and risk is spatially aggregated on the landscape; and uncertainty of ecological will be high. During that time frame, some areas will be affected by stand-replacement fires and will cease to function as late-successional habitat. For example, since 1994, 10 of 140 to 180 northern spotted owl nest stands and neighborhoods were lost to uncontrolled wildfires on the Wenatchee National Forest alone. Patterns of structure and composition within the NWFP network of late-successional reserves will continue to change as a result of uncontrolled fires, insect outbreaks and other succession processes. What may be needed is an approach that marries a short-term system of reserves with a long-term strategy to convert from a reserve system to a continuous network of landscapes with dynamic properties. In such a system, late-successional elements with semi-predictable environmental settings (Camp et al. 1997) are continuously recruited, but shifting in landscape position across space and time.

Indeed, the most significant fallout associated with 20th century resource management activities has been the effect of timber extraction and other associated activities on native species biodiversity. Hardest hit have been the late-successional and old forest communities of the Pacific and Interior West. Old forest area,s by all reasonable accounts, has been seriously depleted by past harvest activity, and old forests of the future will be grown from existing conditions. But as we have described, forests of the interior are highly dynamic in their spatial and temporal patterns of vegetation and disturbance. It is ecologically justifiable to posit that adaptive ecosystem management scenarios (*sensu* Walters and Hollings 1990) for the interior should be informed by that insight, including scenarios to conserve old forest-dependent species.

Patches of late-successional and old forest structure are ephemeral landscape elements. They have specific contexts in space and across time. Future old forest will grow from some other condition; current old forests will become something else. Taking hold of this notion enables one to identify the dilemmaof strategies that rely on a system of late-successional reserves without backup. Because of the unfortunate legacy of past management actions, late-successional and old forest reserves must represent a special case for management. But the special case is an unfortunate and unforeseen consequence of past events, and in the interior, the likelihood of success in the long term is low.

Healthy fish and healthy forests. Is their really an aquatic conservation strategy without a landscape pattern restoration strategy? One unavoidable conclusion of reading the interior Columbia basin aquatic (Lee et al. 1997) and landscape assessments (Hann et al. 1997) is the notion that disturbance regimes and succession processes associated with terrestrial and aquatic environments are inexorably intertwined. For example, in forested catchments hydrologic regimes and peak flow events are governed by spatial and temporal patterns of vegetation and disturbance. Wildfires or harvest activities of any significant scale have a direct bearing on the timing and flow of water through a catchment. But disturbance to upland settings can be either good news or bad. The right amount of disturbance across space and time results in the renewal and redistribution of essential aquatic habitats. However, too much or too little disturbance, or the wrong kind, results in deleterious impacts to aquatic systems. It stands to reason that alternative vegetation pattern restoration strategies for uplands will have many and varied effects on hydrologic regimes, sediment production and aquatic habitats. Likewise, aquatic conservation strategies by specifying standardized buffer zones and custodial management of riparian zones of influence have a direct bearing on spatial and temporal patterns of vegetation in the catchment. But in neither case are the effects of either strategy jointly considered. While the tug-of-war between healthy aquatic systems and healthy forests is to be expected initially, reason suggests that as the debate comes of age, scientists and managers would pursue strategies that jointly consider the spatial and temporal patterns of upland vegetation and disturbance, *and* consequences to hydrologic regimes and aquatic habitats.

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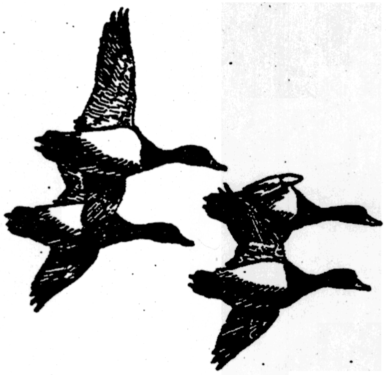

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