Status of Mature and Old-Growth Forests in the Pacific Northwest

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Abstract: *Nearly 10 million ha of federal lands in the Pacific Northwest have been managed under the Northwest Forest Plan since 1994. The plan reduced logging levels by 80%; only recently, however, have inventories on status and condition of mature and old-growth forests become available. Our objectives were to (1) determine the areal extent of old (>150 years) and mature (50–150 years) conifer forests based on 2000 Landsat 7 ETM+ imagery, (2) examine levels of protection, (3) determine the degree of additional protection afforded to old and mature conifer forests if late-successional reserves (LSRs) and inventoried roadless areas (IRAs) were fully protected, and (4) review management options to achieve greater protection of older forests. The historical extent of old-growth forest in the Pacific Northwest was roughly two-thirds (16,672,976 ha) of the total land area. Since the time of European settlement, approximately 72% of the original old-growth conifer forest has been lost, largely through logging and other developments. Of the remaining old growth, the Central and Southern Cascades and Klamath-Siskiyou account for nearly half. Mature conifer area (4,758,596 ha) nearly equaled the amount of old conifer. More than 78% of the old growth and 50% of mature forest were located on public lands. Approximately one-quarter (1,201,622 ha) of the old-growth conifer (or 7% of the historical old-growth area) was classified as GAP status 1 (strictly protected) or GAP status 2 (moderately protected). The total area of LSRs was slightly more than 3 million ha, approximately 36% (1,073,299 ha) of which contained old-growth conifer forest. Combined old and mature conifer within LSRs was approximately 59% of the total LSR area. The total amount of IRA for the Pacific Northwest was approximately 1,563,370 ha; of this, 526,912 ha (34%) was old growth. The combined area of old-growth conifer forest accounted for by protected areas (GAP 1 and 2), LSRs, and IRAs was 2,401,780 ha, which accounts for 66% of the old-growth conifer forests on public land, 51% of the old conifer in the region, and 14% of the amount that occurred historically. Outside these land designations, an additional 1,240,271 ha of old growth are on other public land and another 1,023,392 ha are on private lands throughout the Pacific Northwest. Our results indicate the need to periodically monitor status and condition of older forests and strengthen protections of old growth in the region.*

Key Words: GAP analysis, inventoried roadless areas, Landsat imagery, old growth, protected areas

Estatus de los Bosques Maduros y Viejos en el Pacífico Noroeste

Resumen: *Bajo el Plan Forestal del Noroeste, cerca de 10 millones de ha de terrenos federales en el Pacífico Noroeste (E.U.A.) han sido gestionadas desde 1994. El plan redujo los niveles de cosecha de madera en 80%; sin embargo, los inventarios del estatus y condiciones de los bosques maduros y viejos están disponibles desde hace muy poco. Nuestros objetivos fueron (1) determinar la extensión de bosques de coníferas viejos (>150 años) y maduros (50-150 años) con base en imágenes Landsat 7ETM+ 2000, (2) examinar los niveles de protección, (3) determinar el grado de protección adicional recibido por bosques de coníferas viejos y maduros si las reservas de sucesión avanzada (RSA) y las áreas sin caminos (ASC) estuvieran totalmente protegidas, y (4) revisar opciones de gestión para lograr una mayor protección de los bosques más viejos. La extensión*

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histórica del bosque viejo en el Pacífico Noroeste era casi dos tercios (16,672,976 ha) del total del área. Desde el establecimiento de europeos, se ha perdido aproximadamente 72% de la superficie original de bosques de confieras viejos debido a la tala y otros desarrollos. Del remanente de bosques viejos, casi la mitad se encuentra en los Central y Southern Cascades y Klamath-Siskiyou. El área de bosques maduros (4,758,596 ha) casi era igual a la de bosques viejos. Más de 78% del bosque viejo se localizó en terrenos públicos. Aproximadamente la cuarta parte (1,201,622 ha) de los bosques de coníferas viejos (o 70% del área histórica de bosques viejos) fue clasificada en estatus GAP 1 (protección estricta) o estatus GAP 2 (protección moderada). El área total de RSA fue ligeramente mayor a 3 millones ha, de las cuales aproximadamente 36% (1,073,299 ha) contenían bosques de coníferas viejos. La combinación de bosques de coníferas viejos y maduros dentro de RSA fue aproximadamente 9% de la superficie total de RSA. El total de ASC en el Pacífico Noroeste fue de 1,563,370 ha; de las cuales, 526,912 ha (34%) eran bosques viejos. El área combinada de bosques de coníferas viejos en áreas protegidas (GAP 1 y 2), RSA y ASC comprendió 2,401,780 ha, que a su vez corresponde a 66% de los bosques de coníferas viejos en terrenos públicos, 51% de los bosques viejos de la región y 14% de la cantidad que existió históricamente. En el Pacífico Noroeste, fuera de estas designaciones de tierra, 1,240,271 ha de bosques viejos adicionales se encuentran en otros terrenos públicos y otras 1,023,392 ha se encuentran en terrenos privados. Nuestros resultados indican la necesidad de monitorear periódicamente el estatus y condiciones de los bosques más viejos y de reforzar la protección de los bosques viejos en la región.

Palabras Clave: análisis de discrepancias, áreas protegidas, bosque viejo, catálogo de áreas sin caminos, imágenes Landsat

Introduction

How much old-growth forest remains and how fast it is disappearing are at the center of heated debate among the timber industry, federal land managers, scientists, decision makers, and conservation groups throughout the United States. Such forests have been reduced significantly from historical levels because of agricultural development, urbanization, and industrial-scale logging (Noss et al. 1995; Lindenmayer & Franklin 2002). Thus, older forests are a conservation priority in reserve design, given their unprecedented decline and ecological importance.

The topic of old-growth forests is complex because of numerous description and mapping challenges. Many different forest communities are present in the Pacific Northwest, but Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco), which dominates much of the forested region west of the Cascade Crest, is one of the more heavily studied ones and is usually the forest type most associated with the region. For Douglas-fir forests, the definition of old growth ranges from 150 to 200 years (Haynes 1986). These forests are characterized by high densities of large (>100 cm in diameter) conifers, a broad array of tree sizes, a high percentage of trees with broken and dead tops, high densities of shade-tolerant trees, and high levels of snags and downed wood (Old-Growth Definition Task Group 1986; Spies & Franklin 1991; Wimberly et al. 2000). Other forest types, including subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), white fir/grand fir (*A. concolor* [Gord. & Glend.] Lindl. ex Hildebr./*A. grandis* [Dougl. ex D. Don] Lindl.), and ponderosa pine (*Pinus ponderosa* P. & C. Lawson), have been assigned old growth age thresholds of 150 years, whereas others such as Pacific silver fir (*A. amabilis* [Dougl. ex Loud.]) are not considered old growth until they are 260 to 360 years old (Fierst 1993).

For Douglas-fir, mature forests are defined as being between 80 and 200 years of age, a period between the culmination of maximum growth and the development of old-growth characteristics (Franklin & Spies 1991*b*). These forests are also characterized by lower levels of snags and down wood than young, naturally regenerating forests and older age classes (Spies & Franklin 1991); the mature stage, however, represents an important intermediate age class from which old-growth conditions are likely to develop over time (Spies & Franklin 1991; Franklin et al. 2002). Lower age thresholds have been published for late seral Douglas-fir (e.g., 40 years) based more on how timber management views age rather than on ecological criteria (Sachs et al. 1998). Douglas-fir stands <80 years old are considered ecologically young and are characterized by a period of very rapid conifer growth (Franklin & Spies 1991*b*). Furthermore, young forests originating from natural disturbance typically have much higher levels of structural complexity (e.g., snags and downed logs) and species richness than young forests managed for timber production (Lindenmayer & Franklin 2002).

Decades of research in the Pacific Northwest have documented the many values of old-growth forests, including their importance as wildlife habitat, regulation of hydrologic processes, sequestration of carbon, and maintenance of soil and nutrient processes (Norse 1990; Franklin & Spies 1991*a*; Thomas 1991; NRC 2000; Lindenmayer & Franklin 2002). The Forest Ecosystem Management Assessment Team (FEMAT 1993) responded to concerns about the management of old-growth forests within the

range of the federally threatened Northern Spotted Owl (*Strix occidentalis caurina*) and determined that approximately 1084 species were associated with older forests, including 10 species on the federal endangered species list.

Since 1994, approximately 9.8 million ha of U.S. Department of Agriculture Forest Service (USFS) and Bureau of Land Management (BLM) lands within the range of the Northern Spotted Owl have been managed under the Northwest Forest Plan (USDA Forest Service & BLM 1994). The plan shifted federal lands management from predominantly resource extraction toward an ecosystem management approach (Thomas et al. 2006 [this issue]). Before the plan, logging on both private and federal lands had reduced old-growth forests substantially and would have eliminated most old growth within about four decades outside national parks, wilderness, and remote areas (Franklin et al. 1981; Wimberly et al. 2000). The plan dramatically reduced (~80%) the amount of logging on federal lands through a combination of reserves and management. The allowable cut dropped from an average of about 10.6 million m^3 annually to a probable (but never achieved) level of 2.4 million m^3 annually on federal lands (USDA Forest Service & BLM 1994).

Under the plan, an array of land-use designations was specified, including late-successional reserves (LSRs; 2.97 million ha); congressionally reserved areas (2.93 million ha); matrix (1.59 million ha); riparian reserves (1.05 million ha); adaptive management areas (608,720 ha); administrative withdrawn areas (590,840 ha); and managed late-successional areas (40,880 ha) (USDA Forest Service & BLM 1994). In general, strictest protection was afforded to congressionally reserved and, for at least a period of time, administrative withdrawn areas. Timber management activities were permitted in many of the other designations to achieve "ecological" objectives and commercial logging was emphasized in the matrix. Thus, the plan assumed a continued but diminished decline in older forests region-wide due to logging in the matrix and on private lands but this would eventually (within ~100 years) be offset by forests aging within the reserves and by management designed to accelerate the development of older characteristics of younger forests also within the reserves. Notably, only a portion of the LSRs actually includes older forests (USDA Forest Service & BLM 1994).

Only recently have inventories of old and mature conifer forests become available to help evaluate the impact of the plan established over a decade ago. Such information is needed to guide land-use planning decisions regarding the fate of millions of hectares of older forests and the ability of the plan to deliver its stated ecological objectives. Monitoring is essential in determining whether the LSRs are reaching desired mature and old-growth conditions and, if not, whether the plan can be modified to increase protections by incorporating the remaining unprotected older forests in reserves, adjusting reserve boundaries, or strengthening existing protections. Notably, the Roadless Conservation Rule of 2001 (USDA Forest Service 2001) protected more than 23 million ha of federal lands throughout the nation, many of which overlap with older forests as determined by regional assessments (Strittholt & DellaSala 2001). However, the efficacy of this policy is in jeopardy, as recent administrative changes have greatly weakened the Rule. Further, recent efforts to increase salvage logging within LSRs regenerating from forest fires call into question whether the reserves qualify as protected areas under standardized protected area definitions (e.g., GAP status 1 or GAP status 2, Scott et al. 2001). Therefore, our objectives were to (1) determine the areal extent of old (>150 years) and mature (50–150 years) conifer forests with 2000 Landsat 7 Enhanced Thematic Mapper Plus imagery, (2) examine levels of protection, (3) determine the degree of additional protection that would be afforded to old and mature conifer forests if LSRs and inventoried roadless areas (IRAs) were granted increased protection, and (4) review management options to achieve greater protection for older forests.

Methods

Study Area

The study area covers the Pacific Northwest region of the United States, including parts of Washington, Oregon, and California (Fig. 1, inset), encompassing approximately 25 million ha and the entire Northwest Forest Plan region. Eight ecoregions, defined as relatively large areas that contain geographically distinct assemblages of natural communities (Ricketts et al. 1999), served as one of our primary analytical units (Fig. 1).

Historical Old-Growth Estimates

We generated historical old-growth conifer estimates with a variety of data inputs and existing subregional reconstructions. First, we subtracted all existing land cover classes of rock, ice, and water from the classification of the 2000 imagery from each ecoregion area total. We applied a similar process to a 1930s GIS layer of land cover created by the USFS for the Washington and Oregon portions of the region (USDA Forest Service 2003). We classified all conifer forest classes in the 1930s file as old growth as well as recently disturbed sites (clearcut or burned).

In ecoregions where significant disturbance had already taken place by 1930, we relied on other vegetation reconstructions (maps and descriptions). For example, the Oregon Natural Heritage Program (a cooperative interagency effort) recreated pre-European settlement for

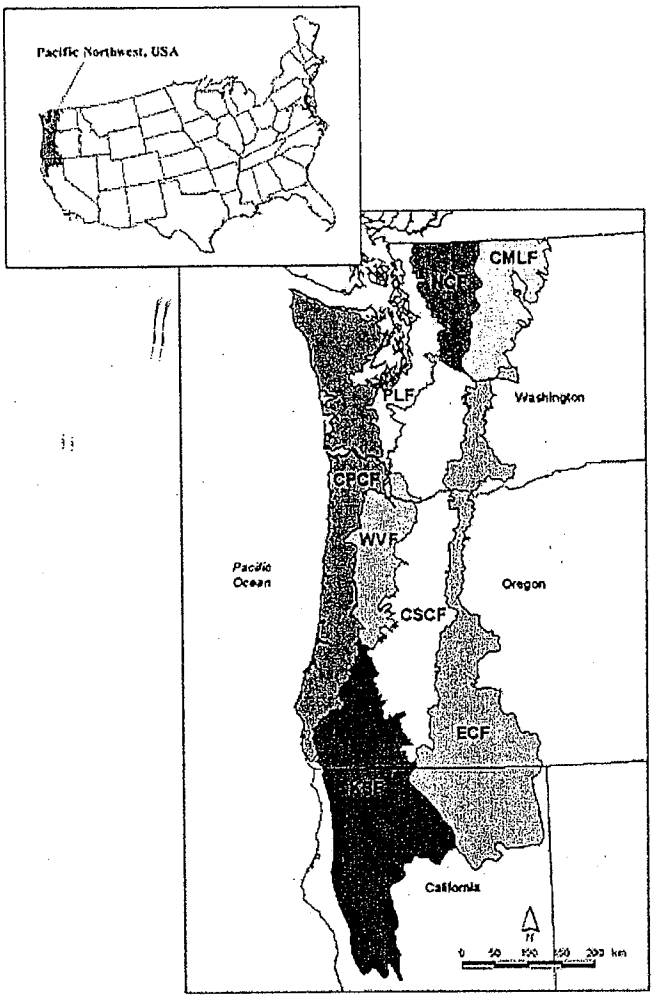

Figure 1. Map of study area showing the World Wildlife Fund ecoregions (CMLF, Cascade Mountains Leeward Forests; NCF, Northern Cascades Forests; PLF, Puget Lowland Forests, CPCF, Central Pacific Coastal Forests; CSCF, Central and Southern Cascades Forests; ECF, Eastern Cascades Forests; KSF, Klamath-Siskiyou Forests; WVF, Willamette Valley Forests).

the Willamette, Rogue, Umpqua, and Illinois valleys of Oregon and the Columbia Basin, Oregon, based on General Land Office plat maps from 1850 to 1870 and on notes from the original land surveyors (unpublished data). We used these maps to estimate the extent of historical old-conifer coverage for these regions within the study area.

Our final adjustment was made based on consideration of natural and aboriginal fires. Both are difficult to account for, especially aboriginal burning practices (Johannessen et al. 1971), but are important considerations nonetheless. Western conifer forests are dynamic systems created and maintained by fire (Agee 1993), and most pre-European settlement forests included diverse mixtures of conifers of different age and size classes, with each class occurring in large patches (Ripple et al. 1991; Spies et al. 1994). Therefore we made individual adjustments to each ecoregion according to their particular fire regimes.

Late-Seral Forest Interpretation

Using an optimal iterative unsupervised classification (OIUC) method, we classified land cover from 23 Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite images acquired from July to September of 2000 (Jiang et al. 2004). Old and mature conifer classes were extracted from the classification and used as the primary base layer for analysis. Overall accuracy for mapping old and mature conifer forest was roughly 90% and 80%, respectively (Jiang et al. 2004). All other cover types generated in the original image classification, including young conifer forests, mixed forests, deciduous forests, woodlands, open forests, and nonforests, were combined into a single cover type and excluded from further consideration.

Old-conifer forests were defined as being >150 years and mature-conifer forest as being 50–150 years. The definition of old conifer was based on the most common old-growth threshold reported in a review of different forest types in the region (Fierst 1993). The starting age for our mature conifer forest class (50 years) falls below the most common age cited for mature Douglas-fir forests (80 years) but is well within the economical mature range for forests in the region. We realize that remote-sensing techniques are not capable of mapping forest age directly—image interpretation is based on spectral signatures driven by canopy structure and chlorophyll content—but the classes derived can be used to approximate relative forest age. Our old-growth conifer category corresponds roughly to the single and multistory medium/large conifer category used by the FEMAT during the formulation of the plan and our mature conifer class corresponds roughly to the small conifer, single story class (FEMAT 1993).

Protected-Areas Classification

Spatially explicit protected-areas data used in this assessment were obtained from a national protected-areas database (CBI 2003). Only GAP status categories of 1 (strictly protected) and 2 (moderately protected) were considered protected. The LSR data (map scale 1:250,000) were obtained from FEMAT (1993). The IRA data were obtained (map scale 1:24,000–1:128,000) from the USFS (USDA Forest Service 2000). Summary statistics were generated for old and mature conifer forests for each ecoregion according to general ownership (public versus private), protection status (GAP status 1 and 2), LSRs, and IRAs.

Results

Historical versus Current Extent of Old and Mature Conifer Forest

Based on individualized estimates for each ecoregion, the approximated historical extent of old-growth forest in the Pacific Northwest was nearly two-thirds (16,133,162 ha) of the total land area. The remaining 36% comprised other natural land cover classes, including wetlands, native prairie/shrublands, oak savannas and other hardwoods, young conifer forests regenerating after disturbance (usually fire), and alpine cover types. The amount of old conifer forest (>150 years) reported for the Pacific Northwest was 4,665,443 ha, based on the classification of satellite imagery obtained in 2000 (Jiang et al. 2004). Therefore, since the time of European settlement, approximately 72% of the original old-growth conifer forest has been lost to conversion or subjected to intensive forestry practices. Two ecoregions, the Puget Lowland and Willamette Valley, were largely converted to urban and agricultural land uses (Table 1). The Central Pacific Coast and Eastern Cascades were also highly affected (loss of original old-growth conifer by approximately 80% in both cases). Intensive forestry activities were the dominant factor, predominantly logging of Douglas-fir forests in the Central Pacific Coast and ponderosa pine forests in the Eastern Cascades. Ecoregions containing high mountains or rugged terrain (e.g., Cascade ecoregions and Klamath-Siskiyou) showed substantial losses of original forest as well, but not to the same degree as the more accessible ecoregions.

Approximately 28% of the Pacific Northwest that was historically old-growth conifer remains in old-conifer forest cover today. The Central and Southern Cascades and Klamath-Siskiyou accounted for nearly half of this amount (Table 1). The Central Pacific Coast and Eastern Cascades, both large ecoregions, contained similar amounts of old conifer forest, 668,281 ha and 687,836 ha, respectively. The two northern Cascades ecoregions contained the highest percent area of old-conifer forest, as high as 67% in the case of the North Cascades. And the Puget Lowland and Willamette Valley combined accounted for only 2% of the total old conifer area.

Mature conifer forest (50–150 years) almost equaled the amount of old conifer forest (4,758,596 ha). The Klamath-Siskiyou contained the greatest area as well as greatest percent area followed closely by the Eastern Cascades and Central and Southern Cascades (Table 1). The Central Pacific Coast contained 683,098 ha of mature forest, just slightly more than old conifer forest for the same region. All the remaining ecoregions contained a fairly narrow range (203,000 to 286,000 ha) of mature conifer forest.

Combining old and mature classes provides an estimate of near-term potential for attaining greater proportions of old-growth conifer forest for each ecoregion (Table 1). Assuming the historical estimates are accurate, a few ecoregions could approach their historical levels of old conifer forest if the existing old and mature conifers were protected from logging and would not be affected by large wildfire losses. For example, 93% of the original extent of the Northern Cascades would be old-growth conifer forest if these areas were protected. Other ecoregions with high potential include the Klamath-Siskiyou and Cascade Mountain Leeward Forests. The amount of old conifer was never high for the Willamette Valley, and historical levels could be met with the maturation of existing mature conifer and retention of remaining old conifer forests. The potential of Central Pacific Coast and Eastern Cascades differs because so much of their original old-growth conifer is currently in fields, shrublands, or young conifers. The Central and Southern Cascades ecoregion

Table 1. Area (ha) of Pacific Northwest ecoregions, estimated historical extent of old-growth conifer forest, and current (2000) extent of old-growth and mature conifer forest.

	Cascade Mountain Leeward Forests	*North Cascades Forests*	*Puget Lowland Forests*	*Central Pacific Coastal Forests*	*Central & Southern Cascades Forests*	*Eastern Cascades Forests*	*Klamath-Siskiyou Forests*	*Willamette Valley Forests*
Ecoregion area	1,600,444	1,278,056	1,719,726	4,267,988	4,481,279	5,398,139	5,033,181	1,487,769
Historical old conifer area	960,279	766,844	1,289,794	3,627,790	3,361,005	3,238,883	2,516,625	371,942
Percentage of ecoregion	60	60	75	85	75	60	50	25
Current old conifer area	420,394	511,396	67,353	668,281	1,328,796	687,836	946,394	34,993
Percentage of historical old conifer	44	67	5	18	39	18	38	9
Percent change	−56	−33	−95	−82	−61	−79	−62	−91
Mature conifer area	285,441	203,994	229,634	683,098	899,266	947,215	1,239,586	270,362
Percentage of historical old conifer	30	27	18	19	27	25	49	73
Combined area	705,835	715,391	296,987	1,351,379	2,228,063	1,635,051	2,185,980	305,355
Percentage of historical old conifer	74	93	23	37	66	43	87	82

Table 2. Area (ha) and percent area of old conifer and mature conifer forests in public ownership in the Pacific Northwest by ecoregion.

	Cascade Mountain Leeward Forests	*North Cascades Forests*	*Puget Lowland Forests*	*Central Pacific Coastal Forests*	*Central & Southern Cascades Forests*	*Eastern Cascades Forests*	*Klamath-Siskiyou Forests*	*Willamette Valley Forests*
Total old conifer area	420,394	511,396	67,353	668,231	1,328,796	687,836	946,394	34,993
Public old conifer area	389,725	446,729	23,003	628,989	1,066,221	400,845	679,669	6,871
Percent old conifer public	93	87	34	94	80	58	72	20
Total mature conifer area	285,441	203,994	229,634	683,098	899,266	947,215	1,239,586	270,362
Public mature conifer area	264,704	151,759	54,132	211,481	605,959	298,973	774,552	26,279
Percent mature conifer public	93	74	22	31	67	31	62	10
Total old/mature conifer area	705,835	715,390	296,987	1,351,379	2,228,062	1,635,051	2,185,980	305,355
Public old/mature conifer area	654,429	598,488	77,135	840,470	1,672,180	699,818	1,454,221	33,150
Percent old/mature conifer public	93	84	26	62	75	43	66	11

falls somewhere between the Klamath-Siskiyou and Central Pacific Coastal situations. Because of the extent of urbanization and agriculture, the Puget Lowland ecoregion can never approach its original natural state.

Landownership Patterns and Levels of Protection

Of the 4,665,443 ha of old-growth conifer forest in the Pacific Northwest, more than 78% (3,642,051 ha) was located on public lands. Percent area of remaining old-growth conifer forest on public land was particularly high in the Central Pacific Coastal Forests (94%) and the Cascade Mountain Leeward Forests ecoregions (93%) (Table 2).

Of the 4,758,596 ha of mature conifer forest in the Pacific Northwest, approximately half was located on public lands (2,387,840 ha). The Central and Southern Cascades and Klamath-Siskiyou contained the largest amounts of mature conifer forest cover, accounting for approximately 58% of the mature conifer forest on public land. The Puget Lowland and Willamette Valley contained relatively low amounts of mature forest on public lands, and the remaining ecoregions fell between 150,000 and 300,000 ha.

One-third (1,201,622 ha) of the old-growth conifer located on public land was classified as GAP status 1 or 2 (Fig. 2). This amounts to one-third of old growth on public lands, 26% of old growth in the Pacific Northwest, and 7% of the original historical extent. The Central and

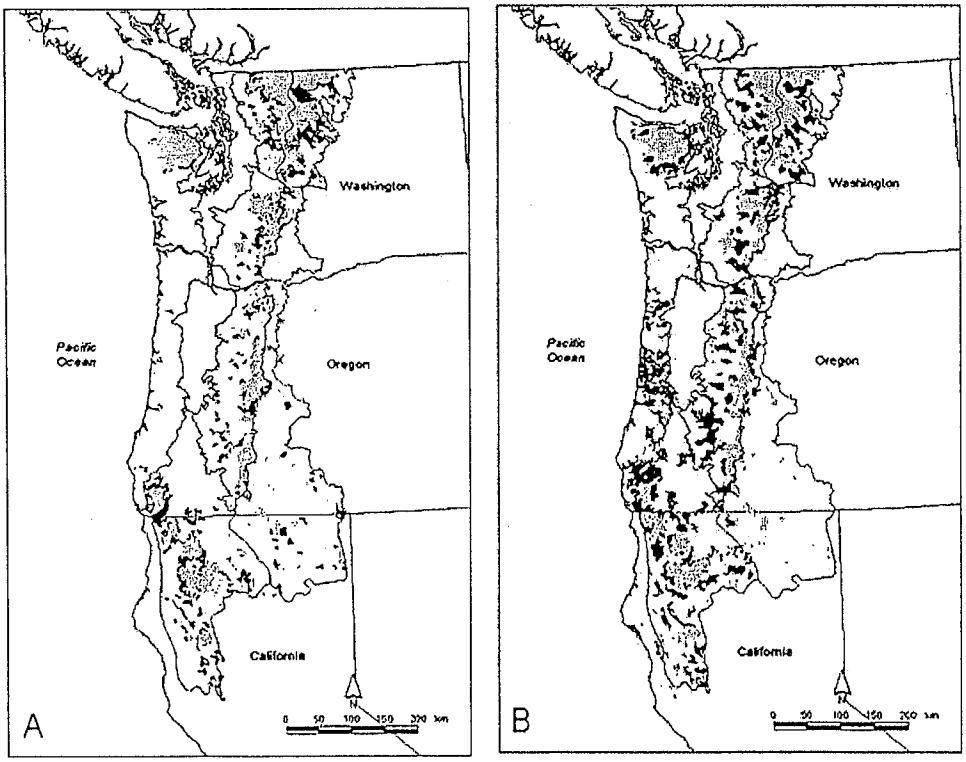

Figure 2. (a) The GAP status 1 (strict protection) and 2 (moderate protection) reserves (light gray) and inventoried roadless areas (black) within the Pacific Northwest and (b) GAP status 1 and 2 reserves (light gray) and late-successional reserves (black) within the Pacific Northwest.

Table 3. Area (ha) and percent area of old conifer and mature conifer forests protected in GAP status 1 & 2 lands, inventoried roadless areas (IRAs) and in late-successional reserves (LSRs) in the Pacific Northwest by ecoregion.

	Cascade Mountain Leeward Forests	*North Cascades Forests*	*Puget Lowland Forests*	*Central Pacific Coastal Forests*	*Central & Southern Cascades Forests*	*Eastern Cascades Forests*	*Klamath-Siskiyou Forests*	*Willamette Valley Forests*
Public old conifer area	389,725	446,729	23,003	628,989	1,066,221	400,845	679,669	6,871
Protected old conifer area	178,762	228,107	283	261,092	302,353	46,659	184,205	162
Percent public old protected	46	51	1	41	28	11	27	2
Public mature conifer area	264,704	151,759	54,132	211,481	605,959	298,973	774,552	26,279
Protected mature conifer area	90,775	48,474	280	31,747	124,903	36,455	183,103	1,246
Percent public mature protected	34	32	<1	15	21	12	24	5
Total IRA area	346,890	159,970	0	63,381	318,750	189,606	484,773	0
IRA old conifer area	98,618	97,905	0	30,574	141,224	41,112	117,479	0
Percent public old in IRA	25	22	0	5	13	10	17	0
IRA mature conifer area	57,133	21,598	0	8,328	66,787	34,502	117,075	0
Percent public mature in IRA	22	14	0	4	11	11	15	0
Total LSR area	279,077	243,409	2,762	589,845	817,888	188,048	873,715	7,658
LSR old conifer area	96,184	139,019	1,102	176,568	347,741	62,070	249,356	1,259
Percent old conifer in LSR	25	31	5	28	33	15	37	18
LSR mature conifer area	54,375	41,008	646	114,289	200,744	34,383	261,958	3,327
Percent mature conifer in LSR	20	27	1	54	33	11	34	13

Southern Cascades had the most area protected (302,353 ha), but it accounted for only 28% of the available public old-conifer forest in that ecoregion (Table 3). Similar percentages of old-conifer forests on public lands occurred for the Klamath-Siskiyou. Additionally, roughly 40 to 50% of old-conifer forest on public lands was classified as either GAP status 1 or 2 in the two northern Cascade ecoregions and in the Central Pacific Coast. Much smaller areas and relative percentages were found in the remaining ecoregions.

The amount and relative percentage of mature conifer forest protected were generally lower across all ecoregions except for the Willamette Valley. Overall, only 22% of the mature-conifer forest on public lands was found in existing protected areas compared with 33% for old-conifer forests. Naturally, the combined old and mature conifer totals lowered the overall protection level to 28% of the available old or mature forest on public lands.

Amount of Old and Mature Conifer Forests in IRAs and LSRs

In our protected areas assessment, special land designations such as IRAs and LSRs were not classified as protected because of logging projects under way or recent administrative changes weakening protections (Fig. 2). Adding the area of old and mature conifer for these two partially overlapping land management designations substantially increased the old- and mature-conifer forest available for future protections.

The total amount of IRAs in the Pacific Northwest is approximately 1,563,370 ha. The largest area of IRAs occurred in the Klamath-Siskiyou, which was followed closely by the Cascades Mountain Leeward Forests and Central and Southern Cascades Forests (Table 3). Total area of old conifer forest in IRAs was 526,912 ha (or 34% of the total IRA area). Approximately half of the old-conifer forest within IRAs occurred in the Central and Southern Cascades (141,224 ha) and the Klamath-Siskiyou (117,479 ha). The IRAs in the two northern Cascade ecoregions contained nearly equal amounts of old conifer (approximately 98,000 ha). The amount of old conifer in IRA was not a factor in the Puget Lowland and Willamette Valley ecoregions, where there were no IRAs. Little old-conifer area occurred in the Central Pacific Coast and Eastern Cascades ecoregions, although the historical estimates for these two regions were among the highest in the PNW.

The area of GAP 1 and 2 status old-conifer forest area (1,201,622 ha) combined with IRA old-conifer area (526,912 ha) resulted in a total potential protected old-conifer area of 1,728,534 ha, which is 47% of current old conifer on public land, 37% of current old conifer region wide, and 10% of the estimated historical extent region wide.

A total of 305,423 ha of mature conifer forest was found in IRAs with 60% in two regions—Klamath-Siskiyou and Central and Southern Cascades (Table 3). Mature conifer forest area was particularly high (117,075 ha) in IRAs in the Klamath-Siskiyou ecoregion, nearly equaling the amount of old conifer. The amount of mature conifer forest was considerably less in all the other ecoregions that contained IRAs.

There was approximately twice as much area of LSR (3,002,402 ha) than IRA throughout the Pacific Northwest; some of this area (743,000 ha, or 25%), however, overlapped with IRAs. Overall, 36% of the LSR area

(1,073,229 ha) was classified as old conifer, which is slightly lower than a previous estimate of 42% (USDA Forest Service & BLM 1994). The largest amounts of old growth were found in the Central and Southern Cascades, followed by the Klamath-Siskiyou and the Central Pacific Coastal Forest (Table 3). The Northern Cascades was fourth in old-conifer area within LSRs (139,019 ha) but had the largest percent area (57%) of any other ecoregion.

Total mature conifer forest area in LSRs was 710,730 ha, with 65% in LSRs in the Klamath-Siskiyou and the Central and Southern Cascades. Mature conifer area in the Central Pacific Coast also was significant, with 54% of the mature forest on public land in LSRs. The combined area of old conifer between current protected areas and LSRs was 2,274,921 ha, about 62% of the old-growth conifer currently on public land, 49% of the current old conifer in the region, and 14% of the amount that occurred historically.

Discussion

Historical and Current Extents

Because of the absence of historical field-survey data over most of the study area, we could only estimate historical conditions, but our estimates are useful for a general understanding of the regional landscape before industrial development. In fact, evaluating current condition with respect to its preindustrial development state is an extremely important contextual issue for addressing forest policy and management because establishing ecological sustainability goals requires a better understanding of natural or baseline conditions.

The few estimates of the historical extent of old-growth conifer forest throughout the Pacific Northwest that have been published focus on either particular forest types or within specific jurisdictional boundaries (i.e., state or agency ownership) rather than on ecoregions. For example, estimates of historical extent of old growth in the Douglas-fir region of the Pacific Northwest range from approximately 6 million ha (Franklin & Spies 1984; Society of American Foresters 1984) to nearly 8 million ha (Norse 1990). The comparable region in our study was 7 million ha, which falls directly between existing estimates for this major forest type.

Estimates for the extent of historical old-growth conifer forest for the Eastern Cascades region have not been published. Cowlin et al. (1942), however, reported that 74% of the commercial forest for the region was dominated by ponderosa pine, most of which was historically old growth. According to the 1930s forest layer for Washington and Oregon (USDA Forest Service 2003), approximately 25% of the Eastern Cascades ecoregion was not forested. Of the remaining forested land, approximately 70% was dominated by ponderosa pine or mixed pine forests, 14% was lodgepole pine (*P. contorta* Dougl. ex Loud.), and the remaining was in other forest types. If old-growth estimates of 90, 50, and 85% are respectively applied to these forest types, the total estimated old growth for the ecoregion is approximately 66%. Our estimate of 60% is lower, but should be adjusted downward with the inclusion of the California portion of the ecoregion, which is much less forested.

With regard to previously published estimates of current old-growth conifer forest extent in the Pacific Northwest, it is impossible to conduct a direct one-to-one comparison between our work and previous efforts for a variety of reasons. No other researchers have summarized the results by World Wildlife Fund ecoregions. Published estimates have focused exclusively on the publicly owned portion of the region. Overall study area extents differ. And lastly, many previous studies focused on a particular forest type rather than on all conifer forest types. Comparisons are further confounded by different definitions of old growth used by different researchers. For this same study area, the Society of American Foresters (1984), the Old-Growth Definition Task Group (1986), and The Wilderness Society (Morrison 1988) have all used different definitions of old growth.

In one case where we can loosely compare results, our findings generally agree with previous estimates. Marcot et al. (1991) reported a total of 2.5 million ha of old-conifer forest present in the national forests of Washington and Oregon, with another 440,000 ha estimated for northern California national forests, bringing the total old-growth area to 3.6 million ha. The earlier figure does not take into account the old-growth totals present on national park and BLM lands; our figure does. There has therefore been a reduction in old-growth conifer within the national forests and the BLM lands since the 1980s, but it is extremely difficult to obtain a reliable figure as to the exact amount of loss for the reasons outlined above.

Variability of Historical and Current Conditions

The original extent of old growth and its subsequent decline have not been uniform across the Pacific Northwest. Some ecoregions (i.e., Willamette Valley) had small amounts of old-growth conifer forests historically. For the Willamette Valley, the old-growth forest that greeted the first European settlers has been largely lost. The other small lowland ecoregion (Puget Lowland) contained a much higher proportion of old-growth conifer forest historically, but it too has been largely transformed by modern human development. The Central Pacific Coast and Eastern Cascades contained relatively high levels of old growth, but those forests have undergone considerable changes because of modern forestry practices and fire-suppression effects. Only the three Cascade ecoregions

and the Klamath-Siskiyou contain 38% or more of their historical levels of old growth, in large part owing to their high elevation and overall rugged terrain. Some of the remaining old-growth forests in these ecoregions are now under the same development pressures that already have dramatically affected the forests in neighboring ecoregions. These less-affected ecoregions, which contain relatively high levels of public ownership, also provide some of the last conservation opportunities to protect relatively large, intact old-growth forests not only for the Pacific Northwest but also anywhere in the nation.

Two ecoregions that are of particular interest to conservationists are the Central Pacific Coast and the Klamath-Siskiyou. Both have been identified as Global 200 ecoregions by the World Wildlife Fund (Ricketts et al. 1999) for their outstanding biological values. The Central Pacific Coast region has been heavily altered primarily by modern forestry practices, and the remaining old growth exists in relatively small patches. Lack of significant public ownership imposes additional constraints on protecting the remaining stands in this ecoregion, which is in need of widespread restoration if its old-growth conservation values are to be recovered.

Conservation opportunity is greater for the Klamath-Siskiyou, which has more old growth remaining, greater public ownership, and far more IRA area. Level of forest fragmentation is comparatively low (J.R.S. et al., unpublished data), but the frequency and severity of natural fire disturbance are high (Odion et al. 2004). Furthermore, the Klamath-Siskiyou continues to be highly threatened by a number of newly enacted or proposed federal forest management policies, particularly salvage logging within LSRs regenerating from fire and the potential elimination of LSRs on BLM lands through anticipated changes to the plan.

Conservation Implications

The Northwest Forest Plan of 1994 represented a bold departure from the post-World War II era emphasis on timber production on federal forests. After that war, timber harvest on federal lands increased dramatically, reaching a peak of approximately 11.8 million m^3 annually between 1965 and 1973 (Haynes 2001). At that time, federal forests provided about one-fourth of the nation's timber supply (Haynes 2001). Today, federal forests in the region supply roughly 2% of the nation's timber and are increasingly relied on for biodiversity and watershed protections. The plan assumed that federal lands would bear the brunt of species protections because a significant portion of old-growth forests were included in LSRs (Haynes 2001; Thomas et al. 2006). Another objective of the plan was to create a connected old-growth forest ecosystem to more effectively ensure the viability of hundreds of associated species. It was recognized, however, that the reserve network would not be functional for at least a century because much of the plan area remained highly fragmented and the forests within a significant portion (~40%) of the reserves were not classic old growth.

A decade later, logging of mature and old-growth forests, although substantially reduced from preplan levels, continues within matrix areas, within some LSRs, and especially on private lands. Our results indicate that there are significant levels (1.3 million ha) of older forests remaining in public ownership outside GAP 1 and 2 protected areas and LSRs that if captured by increasing protections and adjusting protected area or LSR boundaries would increase the amount of old growth protected and contribute to regional connectivity of older forests. Furthermore, more than 1 million ha of older forest remain on private lands where conservation easements and land acquisitions offer additional conservation opportunities. Notably, although the federal agencies claim that 80% of the remaining old-growth forests have been "set aside," this estimate was apparently derived by assigning equivalent protections to land-use categories with greatly differing management objectives (e.g., LSRs, managed LSRs, administrative and congressionally withdrawn areas, adaptive management areas, and riparian reserves; USDA Forest Service & BLM 1994). In contrast, our estimates indicated that only about one-third of current old-growth forest is protected, based on GAP 1 and 2 definitions. That is not to say that the LSRs have no formal protection; the uncertainties, however, in how LSRs are managed under postfire conditions and the growing pressure to increase timber harvest on federal lands to fulfill timber targets warranted omission from protected-area coverages derived from more standardized definitions.

In particular, salvage logging obscures the distinction between timber production and old-growth forest protection because this activity is virtually always damaging to regenerative processes following fire (Lindenmayer et al. 2004). Recognizing similar inconsistencies among LSRs, Noss et al. (1999) did not include them in protection estimates derived from GAP classifications for the Klamath-Siskiyou ecoregion. Strengthening protection requirements for the LSRs and including IRAs, however, can greatly improve the functionality of the reserve network. This combination of increased LSR and IRA protections would add 1.3 million ha of old conifer forest to the reserve network, increasing the total protection of older forests to 2,533,456 ha (or 69% of the old forest on public lands) and, because these areas are close to existing protected areas, increasing functional connectivity across the region as well.

Any policy decisions designed to reduce the protection of LSRs and IRAs would greatly hinder establishment and sustainability of a functional reserve network for old-growth forests throughout the Pacific Northwest—a region that has already experienced widespread and significant declines in older forests and where only 7% of the

historical old-growth area is protected by a scattered network of reserves. For example, if LSRs managed by the BLM in western Oregon were eliminated from the LSR network, as is now being proposed by the current administration, more than 102,000 ha of old-growth conifer forest (or 22% of the old conifer present in LSRs in Oregon) would be opened to logging. These changes would affect the reserve network on federal lands and the regulatory framework on private and state lands. For instance, under the plan, large, private industrial-forestry operations in the region received regulatory relief from the U.S. Endangered Species Act through habitat conservation plans. These agreements allow landowners to "take" Spotted Owl habitat under the act based on the assumption that nearby federal lands are providing the bulk of species' protections. Absent a functional reserve network on federal lands, however, it is doubtful that the reserve network would be sufficient to absorb impacts from logging in surrounding ownerships; thus, the viability of the plan would be placed at risk.

There is also growing concern that the network of reserves may not be functional in portions of the plan area where fire is a major disturbance factor (Marcot 2001; Spies et al. 2006 [this issue]). Although localized and broad-scale disturbances operate west of the Cascade Crest in Washington and Oregon, landscape-level disturbances are more common in drier forests east of the crest. The functionality of the reserve network in disturbance-prone landscapes is related to a number of factors at the site or landscape level, including disturbance and management history, stand resiliency, reserve size, redundancy in forest conditions among reserves, and interconnectedness of the reserve network. Thus the reserve network can be managed more effectively to accommodate large-scale disturbances by (1) increasing the redundancy and connectivity of reserves by protecting remaining older forests, (2) increasing the size of the reserves to withstand large disturbances (although this may not be practical because many large fires eclipse the size of individual reserves), and (3) building fire resiliency into the reserves through restorative actions. Reducing fuel loads in fire-suppressed forests through low-density thinning (small trees and ladder fuels) and using prescribed burning are ways to increase resiliency (Brown et al. 2004; Spies et al. 2006). Top-down processes such as global climate change may, however, limit the efficacy of such treatments as fire seasons lengthen and fire events become more severe under a moderating climate scenario (McKenzie et al. 2004). Therefore additional research is needed to determine effects and patterns of fire, insects, disease, climate change, wind, flooding, and other disturbances on the long-term sustainability of the reserves and their conservation.

Our results are likely to further the debate among conservation groups, timber advocates, decision makers, and federal agencies concerned about the appropriate balance between forest protection and timber production on federal lands. In particular, determining the age at which forests should be protected (i.e., where to draw the line) is the subject of policy measures aimed at assigning protection to forests at 80, 120, or 150 years and older. Using age as a surrogate of forest condition has inherent limitations because age is but one factor important to old-growth function (Old-Growth Definition Task Force 1986). Other factors such as forest structure (e.g., snags and downed logs, canopy stratification) are difficult to map and classify with remote sensing. We chose broad age classes to discriminate forest conditions in our analysis; we recognize, however, that our results may overestimate the amount of mature forests because our mid-seral category included forests of 50–150 years instead of the more typical 80–150 years used in the literature. Nevertheless, management of this mid-seral component is important to regional integrity of older forests because these forests represent the next cohort with potential to develop old-growth characteristics over time and replace those areas lost through disturbance.

The levels of old growth over a large portion of the Pacific Northwest are so low that even seemingly minor adjustments in policy or management can have a profound impact. If all the remaining old growth on public land were protected, roughly 21% of the historical area of old growth would not be subjected to industrial development. And although 21% seems like a luxury compared with many regions, it still may be insufficient to maintain all of the old-growth forest values present in the region. Thus, although the plan was a major leap in land-use planning and conservation over large landscapes of the federal land base, the process of adaptive management, a key concept from which the plan evolved, should now respond to new research that has emerged. This research and the growing public interest in protecting older forests support the conservation need to set aside old-growth forests on federal lands and to manage the maturing conifer forest to reach old-growth condition to ensure that the many biological values associated with older forests are maintained in perpetuity.

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Literature Cited

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

Brown, R., J. K. Agee, and J. F. Franklin. 2004. Forest restoration and fire: principles in the context of place. Conservation Biology 18:903–912.

CBI (Conservation Biology Institute). 2003. Conservation Biology Institute protected areas GIS data layer. Conservation Biology Institute, Corvallis, Oregon. Available from http://www.consbio.org (accessed March 2003).

Cowlin, R. W., P. A. Briegleb, and F. L. Moravets. 1942. Forest resources of the ponderosa pine region of Washington and Oregon. Miscellaneous publication 490. U.S. Department of Agriculture, Washington, D.C.

Fierst, J. 1993. Region 6 interim old growth definitions for Douglas-fir series, grand fir/white fir series, interior Douglas-fir series, lodgepole pine series, Pacific silver fir series, ponderosa pine series, Port-Orford-cedar and tanoak (redwood) series, subalpine fir series, and Western hemlock series. U.S. Department of Agriculture Forest Service, Timber Management Group, Portland, Oregon.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the FEMAT. U.S. Government Printing Office, Washington, D.C.

Franklin, J. F., K. Cromack Jr., W. Dennison, A. McKee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. General technical report PNW-118. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Franklin, J. F., and T. A. Spies. 1984. Characteristics of old growth Douglas-fir forests. Pages 328–334 in Proceedings of the 1983 National Convention. Society of American Foresters, Washington, D.C.

Franklin, J. F., and T. A. Spies. 1991*a*. Composition, function, and structure of old-growth Douglas-fir forests. Pages 71–90 in L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. General technical report PNW-GTR-85. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Franklin, J. F., and T. A. Spies. 1991*b*. Ecological definitions of old-growth Douglas-fir forests. Pages 61–69 in L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. General technical report PNW-GTR-85. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Franklin, J. F., et al. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management **155**:399–423.

Haynes, R. W. 1986. Inventory and value of old-growth in the Douglas-fir region. Research note PNW-437. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Haynes, R. W. 2001. Overview. Pages 2–9 in R. W. Haynes and G. E. Perez, technical editors. Northwest Forest Plan research synthesis. General technical report PNW-GTR-498. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Jiang, H., J. R. Strittholt, P. A. Frost, and N. C. Slosser. 2004. The classification of late seral forests in the Pacific Northwest, USA using Landsat ETM+ imagery. Remote Sensing and Environment **91**:320–331.

Johannessen, C. L., W. A. Davenport, A. Millet, and S. McWilliams. 1971. The vegetation of the Willamette Valley. Annals of the Association of American Geographers **61**:286–302.

Lindenmayer, D. B., and J. F. Franklin. 2002. Conserving forest biodiversity: a comprehensive multiscaled approach. Island Press, Washington, D.C.

Lindenmayer, D. B., D. R. Foster, J. F. Franklin, M. L. Hunter, R. F. Noss, F. A. Schmiegelow, and D. Perry. 2004. Salvage harvesting policies after natural disturbance. Science **303**:1303.

Marcot, B. 2001. Research results to date. Pages 24–29 in R. W. Haynes and G. E. Perez, technical editors. Northwest Forest Plan research synthesis. General technical report PNW-GTR-498. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Marcot, B. G., R. S. Holthausen, J. Teply, and W. D. Carrier. 1991. Old-growth inventories: status, definitions, and visions for the future. Pages 47–60 in L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. General technical report PNW-GTR-85. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

McKenzie, D., Z. Gedalof, D. L. Peterson, and P. Mote. 2004. Climatic change, wildfire, and conservation. Conservation Biology **18**:890–902.

Morrison, P. M. 1988. Old growth in the Pacific Northwest: a status report. The Wilderness Society, Washington, D.C.

NRC (Natural Research Council). 2000. Environmental issues in Pacific Northwest forest management. Committee on Environmental Issues in Pacific Northwest Management, Board on Biology, NRC, Washington, D.C.

Norse, E. A. 1990. Ancient forests of the Pacific Northwest. The Wilderness Society, Washington, D.C.

Noss, R. F., E. T. LaRoe, and J. M. Scott. 1995. Endangered ecosystems of the United States: preliminary assessment of loss and degradation. Biological Report 28. U.S. National Biological Survey, Washington, D.C.

Noss, R. F., J. R. Strittholt, K. Vance-Borland, C. Carroll, and P. Frost. 1999. A conservation plan of the Klamath-Siskiyou ecoregion. Natural Areas Journal **19**:392–411.

Odion, D. C., J. R. Strittholt, H. Jiang, E. Frost, D. A. DellaSala, and M. Moritz. 2004. Fire severity patterns and forest management in the Klamath National Forest, northwest California, USA. Conservation Biology **18**:927–936.

Old-Growth Definition Task Group. 1986. Interim definitions for old-growth Douglas-fir and mixed-conifer forests in the Pacific Northwest and California. Research note PNW-447. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Ricketts, T., et al. 1999. A conservation assessment of the terrestrial ecoregions of North America. Island Press, Washington, D.C.

Ripple, W. J., G. A. Bradshaw, and T. A. Spies. 1991. Measuring forest landscape patterns in the Cascade Range of Oregon, USA. Biological Conservation **57**:73–88.

Sachs, D. L., P. Sollins, and W. B. Cohen. 1998. Detecting landscape changes in the interior of British Columbia from 1975 to 1992 using satellite imagery. Canadian Journal of Forest Research **28**:23–36.

Scott, J. M., F. W. Davis, R. G., McGhie, R. G. Wright, C. Groves, and J. Estes. 2001. Nature reserves: do they capture the full range of American's biological diversity? Ecological Applications **11**:999–1007.

Society of American Foresters. 1984. Scheduling the harvest of old growth. Society of American Foresters, Bethesda, Maryland.

Spies, T. A., and J. F. Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. Pages 91–109 in L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. General technical report PNW-GTR-85. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Spies, T. A., W. J. Ripple, and G. A. Bradshaw. 1994. Dynamics and pattern of a managed coniferous forest landscape. Ecological Applications **4**:555–568.

Spies, T. A., M. A. Hemstrom, A. Youngblood, and S. Hummel. 2006. Conserving old-growth forest diversity in disturbance-prone landscapes. Conservation Biology **20**:351–362.

Strittholt, J. R., and D. A. DellaSala. 2001. Importance of roadless areas in biodiversity conservation in forested ecosystems: case study—Klamath-Siskiyou ecoregion of the United States. Conservation Biology **15**:1742–1754.

Thomas, J. W. 1991. Research on wildlife in old-growth forests: setting the stage. Pages 1–4 in L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. Huff, technical coordinators. Wildlife and vegetation of unmanaged

Douglas-fir forests. General technical report PNW-GTR-85. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Thomas, J. W., J. F. Franklin, J. Gordon, and K. N. Johnson. 2006. The Northwest Forest Plan: origins, components, implementation experience, and suggestions for change. Conservation Biology **20**:277–287.

USDA (U.S. Department of Agriculture) Forest Service and BLM (Bureau of Land Management). 1994. Final supplemental environmental impact statement. Volume 1. USDA Forest Service, Portland, Oregon, and BLM, Moscow, Idaho.

USDA (U.S. Department of Agriculture) Forest Service. 2000. Inventoried roadless areas GIS data layer. USDA Forest Service, Washington, D.C. Available from http://roadless.fs.fed.us (accessed August 2002).

USDA (U.S. Department of Agriculture) Forest Service. 2001. Forest Service roadless conservation final environmental impact statement. USDA Forest Service, Washington, D.C.

USDA (U.S. Department of Agriculture) Forest Service. 2003. The 1930s survey of forest resources in Washington and Oregon. General technical report PNW-GTR-584. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Wimberly, M. C., T. A. Spies, C. J. Long, and C. Whitlock. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. Conservation Biology **14**:167–180.