United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

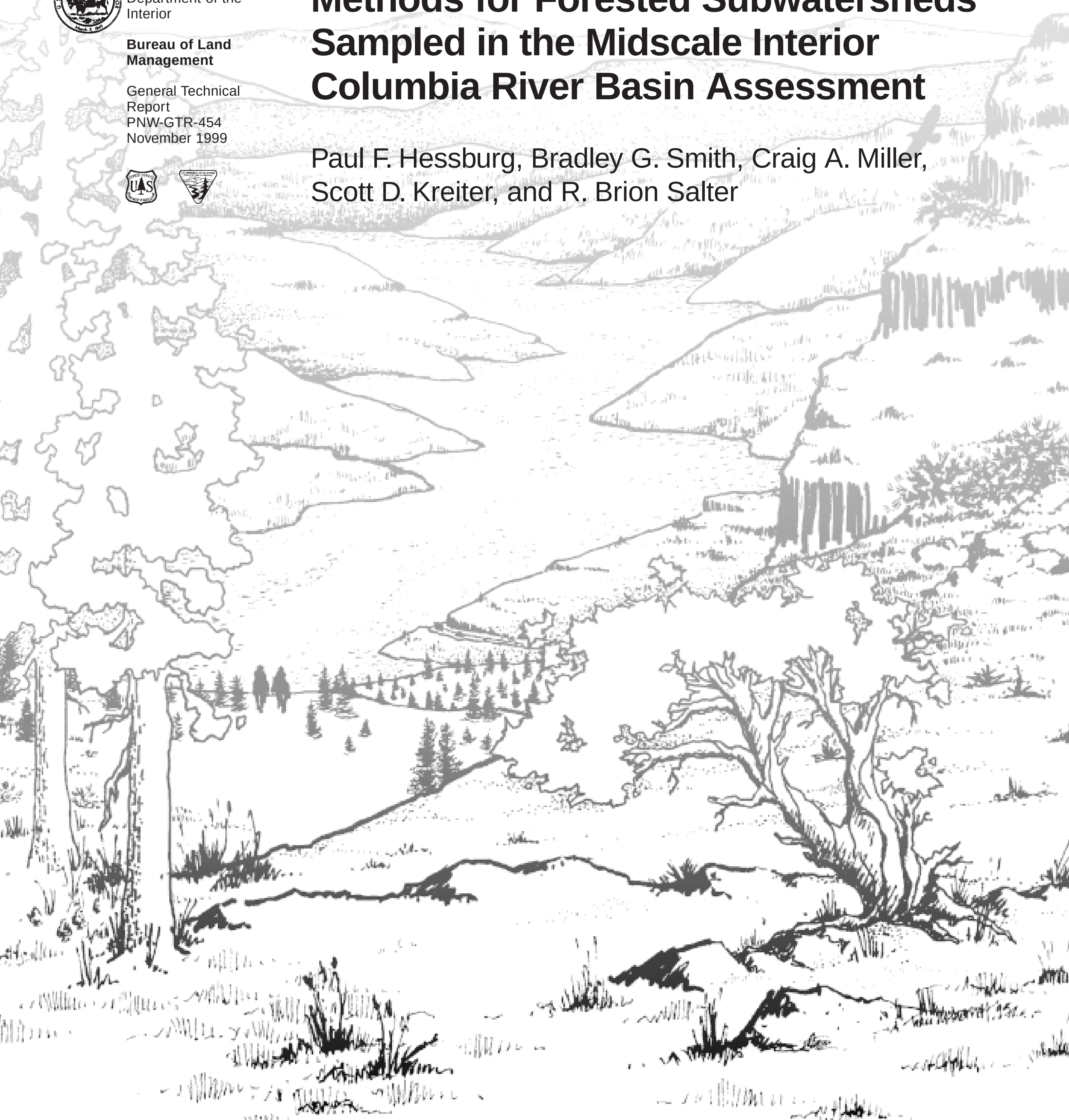
United States
Department of the
Interior

**Bureau of Land
Management**

General Technical
Report
PNW-GTR-454
November 1999

Modeling Change in Potential Landscape Vulnerability to Forest Insect and Pathogen Disturbances: Methods for Forested Subwatersheds Sampled in the Midscale Interior Columbia River Basin Assessment

Paul F. Hessburg, Bradley G. Smith, Craig A. Miller,
Scott D. Kreiter, and R. Brion Salter



Authors

PAUL F. HESSBURG is a research plant pathologist and area forest pathologist, Pacific Northwest Research Station and Pacific Northwest Region, Forestry Sciences Laboratory, 1133 N. Western Avenue, Wenatchee, WA 98801; BRADLEY G. SMITH is a quantitative ecologist, Pacific Northwest Region, Deschutes National Forest, 1645 Highway 20 E., Bend, OR 97701; and CRAIG A. MILLER is a geographer and SCOTT D. KREITER and R. BRION SALTER are geographical information system analysts, Pacific Northwest Research Station, Forestry Sciences Laboratory, 1133 N. Western Avenue, Wenatchee, WA 98801.

Modeling Change in Potential Landscape Vulnerability to Forest Insect and Pathogen Disturbances: Methods for Forested Subwatersheds Sampled in the Midscale Interior Columbia River Basin Assessment

Paul F. Hessburg, Bradley G. Smith, Craig A. Miller, Scott D. Kreiter, and R. Brion Salter

Interior Columbia Basin Ecosystem Management Project: Scientific Assessment

Thomas M. Quigley, Editor

U.S. Department of Agriculture
Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-454
November 1999

Abstract

Hessburg, Paul F.; Smith, Bradley G.; Miller, Craig A.; Kreiter, Scott D.; Salter, R. Brion. 1999. Modeling change in potential landscape vulnerability to forest insect and pathogen disturbances: methods for forested subwatersheds sampled in the midscale interior Columbia River basin assessment. Gen. Tech. Rep. PNW-GTR-454. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 56 p. (Quigley, Thomas M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

In the interior Columbia River basin midscale ecological assessment, including portions of the Klamath and Great Basins, we mapped and characterized historical and current vegetation composition and structure of 337 randomly sampled subwatersheds (9500 ha average size) in 43 subbasins (404 000 ha average size). We compared landscape patterns, vegetation structure and composition, and landscape vulnerability to 21 major forest insect and pathogen disturbances of historical and current forest vegetation coverages. Forest vegetation composition, structure, and patterns were derived from attributes interpreted and mapped from aerial photographs taken from 1932 to 1966 (historical), and from 1981 to 1993 (current). Areas with homogeneous vegetation composition and structure were delineated as patches to a minimum size of 4 ha. Results of change analyses were reported for province-scale ecological reporting units (ERU's). In this paper, we report on methods used to characterize historical and current patch and subwatershed vulnerability to each of 21 insect and pathogen disturbance agents.

We assessed landscape vulnerability to defoliator, bark beetle, dwarf mistletoe, root disease, blister rust, and stem decay disturbances. We used patch composition, structure, logging disturbance, and physical environment attributes to compare vegetation vulnerability of historical subwatersheds with that of their current condition. Patch vulnerability factors included items such as site quality, host abundance, canopy layers, host age or host size, patch vigor, patch (stand) density, connectivity of host patches, topographic setting, and presence of visible logging disturbance. Methods reported here can be used in landscape or watershed analysis to evaluate or monitor change in the magnitude and spatial pattern of vegetation vulnerability to insect and pathogen disturbances, and in planning to compare potential disturbance futures associated with alternative vegetation management scenarios.

Keywords: Ecological assessment, interior Columbia River basin, ecosystem health, insect disturbance, pathogen disturbance, vegetation vulnerability, ecosystem processes, succession processes.

Preface

The Interior Columbia Basin Ecosystem Management Project (ICBEMP) was initiated by the Forest Service and the Bureau of Land Management to respond to several critical issues including, but not limited to, forest and rangeland health, anadromous fish concerns, terrestrial species viability concerns, and the recent decline in traditional commodity flows. The charter given to the project was to develop a scientifically sound, ecosystem-based strategy for managing the lands of the interior Columbia River basin administered by the Forest Service and the Bureau of Land Management.

The Science Integration Team was organized to develop a framework for ecosystem management, a broad-scale assessment of the socioeconomic and biophysical systems in the basin, and an evaluation of alternative management strategies. The broad-scale assessment of the biophysical systems consisted of two parts: (1) a multiscale characterization of biophysical environments of the basin (Jensen and others 1997) and (2) a broad-scale landscape assessment of change in vegetation patterns and disturbance regimes of the basin (Hann and others 1997). In addition to the broad-scale landscape assessment, a midscale landscape assessment was conducted to validate the results of the broad-scale landscape assessment at a scale appropriate to observing the vegetation pattern-disturbance process interactions. This paper is one in a series of four papers developed to document the results of that midscale assessment.

The Science Integration Team, although organized functionally, worked hard at integrating the research approaches, analyses, and conclusions. It was the collective effort of the team that provided depth and understanding to the work of the project. The Science Integration Team leadership included deputy team leaders Russel Graham and Sylvia Arbelbide; landscape ecology—Wendel Hann, Paul Hessburg, and Mark Jensen; aquatic—Jim Sedell, Kris Lee, Danny Lee, Jack Williams, and Lynn Decker; economic—Richard Haynes, Amy Horne, and Nick Reyna; social science—Jim Burchfield, Steve McCool, and Jon Bumstead; terrestrial—Bruce Marcot, Kurt Nelson, John Lehmkuhl, Richard Holthausen, and Randy Hickenbottom; and broad-scale spatial analysis—Becky Gravenmier, John Steffenson, and Andy Wilson.

Thomas M. Quigley, Editor

United States
Department of
Agriculture

Forest Service

United States
Department of
the Interior

Bureau of Land
Management

Interior Columbia
Basin Ecosystem
Management Project

Contents

1 **Introduction**

11 **Insects Modeled**

11 Defoliators

15 Bark Beetles

27 **Pathogens Modeled**

27 Dwarf Mistletoes

27 Root Diseases

31 Butt Rots

39 Rusts

39 Stem Decays

43 **Acknowledgments**

43 **English Conversions**

44 **Literature Cited**

47 **Appendix 1**

50 **Appendix 2**

53 **Appendix 3**

Introduction

In this paper, we describe methods used in the mid-scale (1:24,000) ecological assessment of the interior Columbia River basin (the basin) to assess recent change in vulnerability of forest vegetation to disturbances caused by the major forest pathogens and insects of the basin (see Hessburg and others 1999). Change in potential vulnerability to forest insect and pathogen disturbances was characterized for continuously mapped recent historical (1932 to 1966) and current (1981 to 1993) vegetation coverages of 337 subwatersheds sampled in 43 subbasins (table 1, fig. 1). Subwatershed vulnerability characterizations modeled the potential susceptibility or conduciveness of vegetation patterns to alteration by insect or pathogen disturbance. Insect and pathogen disturbances were modeled as succession processes. Vulnerable subwatersheds displayed vegetation patterns conducive to propagating a given pathogen or insect disturbance within and among patches. Structural and compositional succession, as intended here, was the outcome of pathogen infection or insect infestation of susceptible vegetation at patch or landscape scales. Examples of growth and mortality effects leading to succession are tree topkilling, tree mortality, brooming, stem decay, tree collapse, butt rot, windthrow, top breakage, and defoliation. Methods reported here are a substantial revision of those reported in Lehmkuhl and others (1994). Figure 1 and table 2 display sampled subbasins by geographic area, province from Bailey (1995) and ecoregion from Omernik (1987).

We characterized subwatershed vulnerability to 21 different forest pathogen and insect disturbances. Forest pathogens and insects selected were those that frequently cause patch and landscape-scale disturbances resulting in measurable structural and compositional change in the interval between stand replacement fires. Landscape vulnerability was assessed for one defoliator disturbance, seven bark beetle disturbances, four dwarf mistletoe disturbances, four root disease disturbances, two root and butt rot disturbances, two blister rust disturbances, and one stem decay disturbance.

Vulnerability characterizations for two principal defoliators, the western spruce budworm[1] (table 3) and the Douglas-fir tussock moth, were collapsed into one vulnerability rating, but vulnerability factors used were most appropriate to the western spruce budworm. Vulnerability to bark beetle disturbance was quantified separately for the Douglas-fir, western pine, mountain pine, fir-engraver, and spruce beetles. Subwatershed vulnerability to western pine beetle disturbance was addressed in two separate submodels: one (type 1) for landscapes comprised of mature and old ponderosa pine, another (type 2) for landscapes comprised of immature and high-density ponderosa pine. Similarly, vulnerability to mountain pine beetle disturbance was addressed by two submodels: one (type 1) for landscapes comprised of high-density lodgepole pine, another (type 2) for landscapes comprised of immature, high-density ponderosa pine.

Subwatershed vulnerability to dwarf mistletoe disturbance was modeled separately for mistletoes of western larch, Douglas-fir, ponderosa pine, and lodgepole pine. Vulnerability to root disease disturbance was modeled separately for laminated root rot, *Armillaria* root disease, and S- and P-group annosum root diseases. Vulnerability to root and butt rot disturbance was modeled separately for tomentosus root and butt rot, and Schweinitzii root and butt rot. Vulnerability to white pine blister rust disturbance was addressed in two separate submodels: one (type 1) for western white pine and sugar pine cover types, another (type 2) for the whitebark pine-subalpine larch cover type. Finally, vulnerability to stem decay disturbance was modeled for rust-red stringy rot caused by the Indian paint fungus.

We used patch composition, structure, logging disturbance, and physical environment attributes to compare the vulnerability of vegetation of historical subwatersheds with that of their current condition. Appendix 1 lists attributes interpreted from historical and current aerial photographs in the midscale assessment, and used to derive patch vulnerability. Patch vulnerability factors were unique for each host-pathogen or host-insect interaction modeled, and included items such as (1) site quality (differences in ecological site potential), (2) host abundance, (3) canopy structure, (4) host size, (5) patch vigor, (6) patch (stand) density, (7) connectivity of host patches, (8) topographic setting, and (9) logging disturbance.

Text continues on page 9.

---

[1] Scientific and common names and abbreviations for all species mentioned in the text are provided in table 3.

Table 1—Photo years of resource aerial photography used to sample recent historical and current vegetation conditions of subbasins in the midscale ecological assessment of the interior Columbia River basin

			Subbasin percentage					Subbasin percentage	
Code	Subbasin name	Span, historical	1930s	1940s	1950s	1960s	Span, current	1980s	1990s
BFM	Blackfoot (Montana)	1934-53	63		37		1988-90	63	37
BOM	Boise-Mores	1962-66				100	1988	100	
BTR	Bitterroot	1936-58	83		17		1986-87	100	
BUR	Burnt	1954-60			83	17	1989	100	
BWD	Big Wood	1943-59		33	67		1988	100	
CRT	Crooked-Rattlesnake	1954-63			14	86	1989	100	
DUB	Donner und Blitzen	1958			100		1989	100	
FLR	Flint Rock	1947		100			1990-91		100
KET	Kettle	1944		100			1985-92	40	60
LCR	Lower Crooked	1943-51		33	67		1987-91	33	67
LDS	Little Deschutes	1943-59		50	50		1988-91	92	8
LFH	Lower Flathead	1934-55	86	14			1990		100
LGR	Lower Grande Ronde	1939-64	33	44	17	6	1987-91	78	22
LHE	Lower Henry's	1941-60		75		25	1991-93		100
LJD	Lower John Day	1937-51	50		50		1985-91	88	12
LMH	Lemhi	1960				100	1991-93		100
LOC	Lochsa	1937-62	29		42	29	1990		100
LST	Lost	1942		100			1984	100	
LWC	Lake Walcott	1950-58			100		1988	100	
LYK	Lower Yakima	1949		100			1988-91	87	13
MDL	Medicine Lodge	1941-60		80		20	1987-93	20	80
MET	Methow	1954-56			100		1981-92	18	82
NAC	Naches	1938-49	11	89			1991-92		100
PEN	Pend Oreille	1932-35	100				1985-86	100	
PLS	Palouse	1932-51	22		78		1990-92		100
PSD	Palisades	1956-60				100	1988-90	33	67
SFC	South Fork Clearwater	1959-60		17		83	1991		100
SFS	South Fork Salmon	1962				100	1987-88	100	
SHW	Snake Headwaters	1955-56			100		1987-93	63	37
SIL	Silvies	1956			100		1989	100	
SPO	Sanpoil	1936-44	50	50			1991-92		100
SWN	Swan	1934-54	75		25		1992		100
UCD	Upper Coeur d' Alene	1933-55	80		20		1990-91		100
UDS	Upper Deschutes	1943-59		30	70		1987-91	20	80
UGR	Upper Grande Ronde	1939-55	88		13		1987	100	
UJD	Upper John Day	1951-56			100		1990-91		100
UKL	Upper Klamath Lake	1952-57			100		1985-92	63	37
UMS	Upper Middle Fork Salmon	1959-62			11	89	1988-91	44	56
UOW	Upper Owyhee	1930-63	8			92	1984-91	67	33
UYK	Upper Yakima	1942-59		67	33		1985-92	89	11
WAL	Wallowa	1939-56	14	36	50		1980-91	57	43
WEN	Wenatchee	1949		100			1992		100
YAA	Yaak	1950-63			50	50	1990-92		100

Source: Hessburg and others 1999.

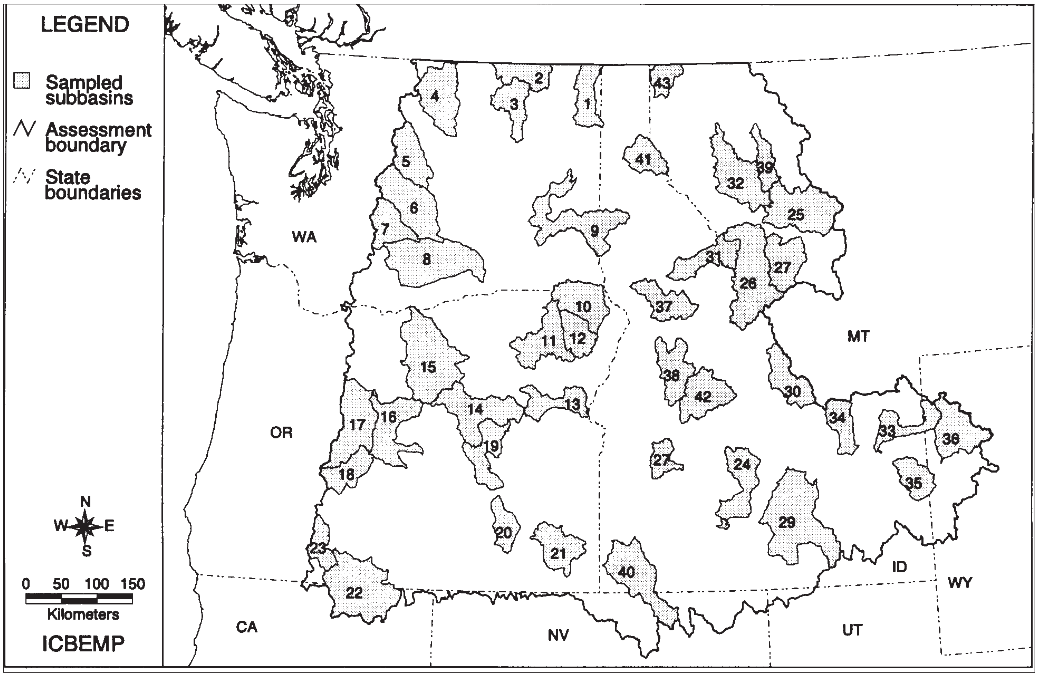


Figure 1—Sampled subbasins of the midscale assessment of the interior Columbia River basin (see table 2). The assessment area included the portion of the Columbia River basin occurring in the United States, east of the crest of the Cascade Range. Subbasins in the upper reaches of the Klamath River basin and the Northern Great Basin also were included to fully represent conditions in eastern Oregon and Washington, Idaho, and western Montana. Numbers in subbasins correspond with subbasins listed in table 2.

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins of the midscale ecological assessment of the interior Columbia River basin[a b]

Subbasin	4th code HUC no.	Samples	State	Bailey province	Omernik ecoregion
(1)[c] Pend Oreille	17010216	8	WA	M333-Northern Rocky Mountain	Northern Rockies
(2) Kettle	17020002	5	WA	M333-Northern Rocky Mountain	Northern Rockies
(3) Sanpoil	17020004	6	WA	M333-Northern Rocky Mountain	Northern Rockies
(4) Methow	17020008	17	WA	M242-Cascade	Cascades
(5) Wenatchee	17020011	11	WA	M242-Cascade	Cascades
(6) Upper Yakima	17030001	10	WA	M242-Cascade	Cascades
(7) Naches	17030002	9	WA	M242-Cascade	Eastern Cascades Slopes and Foothills
(8) Lower Yakima	17030003	8	WA	M242-Cascade	Columbia Basin
(9) Palouse	17060108	7	WA	331-Great Plains/ Palouse Dry Steppe	Columbia Basin
(9) Palouse	17060108	2	ID	331-Great Plains/ Palouse Dry Steppe	Columbia Basin

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins of the midscale ecological assessment of the interior Columbia River basin[a] [b] (continued)

Subbasin	4th code HUC no.	Samples	State	Bailey province	Omernik ecoregion
(10) Lower Grande Ronde	17060106	9	OR	M332-Middle Rocky Mountain	Blue Mountains
(11) Upper Grande Ronde	17060104	9	OR	M332-Middle Rocky Mountain	Blue Mountains
(12) Wallowa	17060105	7	OR	M332-Middle Rocky Mountain	Blue Mountains
(13) Burnt	17050202	6	OR	M332-Middle Rocky Mountain	Blue Mountains and Snake River Basin and High Desert
(14) Upper John Day	17070201	11	OR	M332-Middle Rocky Mountain and 342-Intermountain Semidesert	Blue Mountains
(15) Lower John Day	17070204	16	OR	M332-Middle Rocky Mountain and 342-Intermountain Semidesert	Columbia Basin and Blue Mountains
(16) Lower Crooked	17070305	6	OR	M332-Middle Rocky Mountain and M242-Cascade	Blue Mountains and Snake River Basin and High Desert and Eastern Cascades Slopes and Foothills
(17) Upper Deschutes	17070301	10	OR	M242-Cascade	Eastern Cascades Slopes and Foothills
(18) Little Deschutes	17070302	6	OR	M242-Cascade	Eastern Cascades Slopes and Foothills
(19) Silvies	17120002	4	OR	M332-Middle Rocky Mountain	Blue Mountains and Snake River Basin and High Desert
(20) Donner und Blitzen	17120003	4	OR	342-Intermountain Semidesert	Snake River Basin and High Desert
(21) Crooked Rattlesnake	17050109	7	OR	342-Intermountain Semidesert	Snake River Basin and High Desert
(22) Lost	18010204	5	OR	M261-Sierran	Eastern Cascades Slopes and Foothills and Snake River Basin and High Desert
(22) Lost	18010204	4	CA	M261-Sierran	Eastern Cascades Slopes and Foothills and Snake River Basin and High Desert
(23) Upper Klamath Lake	18010203	4	OR	M261-Sierran and M242-Cascade	Eastern Cascades Slopes and Foothills
(24) Big Wood	17040219	6	ID	342-Intermountain Semidesert and M332-Middle Rocky Mountain	Northern Rockies and Snake River Basin and High Desert

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins of the midscale ecological assessment of the interior Columbia River basin[a b] (continued)

Subbasin	4th code HUC no.	Samples	State	Bailey province	Omernik ecoregion
(25) Blackfoot (Montana)	17010203	16	MT	M332-Middle Rocky Mountain	Northern Rockies and Montana Valley and Foothill Prairies
(26) Bitterroot	17010205	8	MT	M332-Middle Rocky Mountain and M333-Northern Rocky Mountain	Northern Rockies and Montana Valley and Foothill Prairies
(27) Boise-Mores	17050112	3	ID	M332-Middle Rocky Mountain	Northern Rockies and Snake River Basin and High Desert
(28) Flint Rock	17010202	7	MT	M332-Middle Rocky Mountain	Northern Rockies and Montana Valley and Foothill Prairies
(29) Lake Walcott	17040209	9	ID	342-Intermountain Semidesert	Snake River Basin and High Desert and Northern Great Basin and Range
(30) Lemhi	17060204	6	ID	M332-Middle Rocky Mountain	Northern Rockies and Snake River Basin and High Desert
(31) Lochsa	17060303	7	ID	M333-Northern Rocky Mountain and M332-Middle Rocky Mountain	Northern Rockies
(32) Lower Flathead	17010212	14	MT	M333-Northern Rocky Mountain	Northern Rockies and Montana Valley and Foothill Prairies
(33) Lower Henry's	17040203	3	ID	M331-Southern Rocky Mountain and 342-Intermountain Semidesert	Middle Rockies and Snake River Basin and High Desert
(33) Lower Henry's	17040203	1	WY	M331-Southern Rocky Mountain	Middle Rockies and Snake River Basin and High Desert
(34) Medicine Lodge	17040215	5	ID	342-Intermountain Semidesert and M332-Middle Rocky Mountain	Northern Rockies and Snake River Basin and High Desert
(35) Palisades	17040104	5	ID	M331-Southern Rocky Mountain	Middle Rockies
(35) Palisades	17040104	1	WY	M331-Southern Rocky Mountain	Middle Rockies
(36) Snake Headwaters	17040101	8	WY	M331-Southern Rocky Mountain	Middle Rockies
(37) South Fork Clearwater	17060305	6	ID	M332-Middle Rocky Mountain	Northern Rockies and Columbia Basin

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins of the midscale ecological assessment of the interior Columbia River basin[a b] (continued)

Subbasin	4th code HUC no.	Samples	State	Bailey province	Omernik ecoregion
(38) South Fork Salmon	17060208	7	ID	M332-Middle Rocky Mountain	Northern Rockies
(39) Swan	17010211	4	MT	M333-Northern Rocky Mountain	Northern Rockies
(40) Upper Owyhee	17050104	12	ID	342-Intermountain Semidesert	Snake River Basin and High Desert and no. Great Basin and Range
(41) Upper Coeur d' Alene	17010301	5	ID	M333-Northern Rocky Mountain	Northern Rockies
(42) Upper Middle Fork Salmon	17060205	9	ID	M332-Middle RockyMountain	Northern Rockies
(43) Yaak	17010103	4	MT	M333-Northern Rocky Mountain	Northern Rockies

[a] A total of 337 subwatersheds were sampled in 43 subbasins.

[b] See also figure 1.

[c] Numbers in parentheses identify subbasins shown in figure 1.

Table 3—Common and scientific names, and abbreviations of species discussed in the text

Common name	Abbreviation	Scientific name
Pathogens:		
Annosum root disease	HEAN	*Heterobasidion annosum* (Fr.) Bref
Armillaria root disease	AROS	*Armillaria ostoyae* (Romag.) Herink
Douglas-fir dwarf mistletoe	DFDM	*Arceuthobium douglasii* Engelm.
Laminated root rot	PHWE	*Phellinus weirii* Murr. Gilb.
Lodgepole pine dwarf mistletoe	LPDM	*Arceuthobium americanum* Nuttex Engelm.
P-group annosum root disease	HEAN_p	*Heterobasidion annosum* (Fr.) Bref
Rust-red stringy rot (Indian paint fungus)	RRSR	*Echinodontium tinctorium* (Ell. & Ev.) Ell. & Ev.
Schweinitzii root and butt rot	SRBR	*Phaeolus schweinitzii* (Fr.) Pat.
S-group annosum root disease	HEAN_s	*Heterobasidion annosum* *H. annosum* (Fr.) Bref
Tomentosus root and butt rot	TRBR	*Inonotus tomentosus* (Fr.) Gilbertson
Western dwarf mistletoe	PPDM	*Arceuthobium campylopodum* Engelm.
Western larch dwarf mistletoe	WLDM	*A. laricis* (piper) St. John
White pine blister rust	WPBR	*Cronartium ribicola* Fisher ex. Rabh.
Insects:		
Douglas-fir beetle	DFB	*Dendroctonus pseudotsugae* Hopkins
Douglas-fir tussock moth	DFTM	*Orgyia pseudotsugata* McDunnough
Fir engraver beetle	FE	*Scolytus ventralis* Leconte
Mountain pine beetle	MPB	*Dendroctonus ponderosae* Hopkins
Spruce beetle	SB	*D. rufipennis* Kirby
Western pine beetle	WPB	*D. brevicomis* Leconte
Western spruce budworm	WSB	*Choristoneura occidentalis* Freeman

Table 3—Common and scientific names, and abbreviations of species discussed in the text (continued)

Common name	Abbreviation	Scientific name
Trees:		
Bigleaf maple		*Acer macrophyllum* Pursh
Bigtooth maple		*A. grandidentatum* Nutt.
Black cottonwood		*Populus trichocarpa* Torr. & Gary
Blue spruce	PIPU	*Picea pungens* Engelm.
Bog birch		*Betula glandulosa* Sary.
Douglas-fir	PSME	*Pseudotsuga menziesii* (Mirb.) Franco
Douglas maple		*Acer glabrum* var. *douglasii* Pursh
Engelmann spruce	PIEN	*Picea engelmannii* Parry ex Engelm.
Grand fir	ABGR	*Abies grandis* (Dougl. ex D. Don) Lindl.
Hemlocks		*Tsuga* spp. Carr.
Incense-cedar		*Calocedrus decurrens* (Torr.) Florin
Limber pine	PIFL	*Pinus flexilis* James
Lodgepole pine	PICO	*P. contorta* var. *latifolia* Dougl. ex Loud.
Mountain hemlock	TSME	*Tsuga mertensiana* (Bong.) Carr.
Narrow-leaved cottonwood		*P. angustifolia* James
Noble fir	ABPR	*Abies procera* Rehd.
Pacific silver fir	ABAM	*A. amabilis* Dougl. ex Forbes
Paper birch		*Betvia papyrifera* Marsh.
Pinyon pine		*Pinus monophylla* Dougl. ex D. Don
Ponderosa pine	PIPO	*P. ponderosa* Dougl. ex Laws.
Quaking aspen	Aspen	*Populus tremuloides* Michx.
Rocky Mountain juniper		*Junipers scopulorum* Sarg.
Rocky Mountain maple		*Acer glabrum* var. *glabrum* Torr.
Russian-olive		*Elaeagnus angustifolia* L.
Shasta red fir	ABMA	*Abies magnifica* A. Murr.
Subalpine fir	ABLA2	*A. lasiocarpa* (Hook.) Nutt.
Sugar pine	PILA	*Pinus lambertiana* Dougl.
True firs		*Abies* spp. Mill
Utah juniper		*Juniperus osteosperma* (Torr.) Little
Vine maple		*Acer circinatum* Pursh
Water birch		*Betvia occidentalis* Hook.
Western hemlock	TSHE	*Tsuga heterophylla* (Raf.) Sarg.
Western juniper		*Juniperus occidentalis* Hook.
Western larch	LAOC	*Larix occidentalis* Nutt.
Western redcedar	THPL	*Thuja plicata* Donn ex D. Don
Western white pine	PIMO	*Pinus monticola* Dougl. ex D. Don
Whitebark pine	PIAL	*P. albicaulis* Engelm.
White fir	ABCO	*Abies concolor* (Cord. of Glend.) Lindl. ex Hildebr:
White spruce	PIGL	*Picea glauca* (Moench) Voss
Shrubs:		
Alder	Alder	*Alnus* spp. Hill
Basin big sagebrush		*Artemisia tridentata* var. *tridentata* Nutt.
Bitterbrush		*Purshia tridentata* (Pursh) DC.
Bittercherry		*Prunus emarginata* (Dougl.) Walp.
Bog birch		*Betula glandulosa* Michx.

Table 3—Common and scientific names, and abbreviations of species discussed in the text (continued)

Common name	Abbreviation	Scientific name
Shrubs: (continued)		
Common chokecherry	Chokecherry	*Prunus virginiana* L.
Currant		*Ribes* spp. L.
Curlleaf mahogany		*Cercocarpus ledifolius* Nutt.
Dogwood		*Cornus* spp. L.
Greasewood		*Sarcobatus vermiculatus* (Hook.) Torr.
Low sagebrush		*Artemisia arbuscula* Nutt.
Mountain big sagebrush		*A. tridentata* var. *vaseyana* Nutt.
Mountain heather	Heather	*Phyllodoce* spp. Salisb.
Mountain mahogany		*Cercocarpus montanus* Raf.
Rabbitbrush		*Chrysothamnus* spp. Nutt.
Rocky Mountain maple	Mountain maple	*Acer glabrum* var. *glabrum* Torr.
Rose		*Rosa* spp. L.
Russet buffaloberry	Buffaloberry	*Sheperdia canadensis* (L.) Nutt.
Scouler's willow		*Salix scouleriana* Barratt
Serviceberry		*Amelanchier* spp. Medic.
Silver sagebrush		*Artemisia cana* Pursh
"Snowberry"	Snowberry	*Symphoricarpus* spp. Duhamel
Spiny hopsage		*Grayia spinosa* (Hook.) Collotz
Spiny saltbush, shadscale		*Atriplex confertifolia* (Torr. & Frem.) Wats.
"Willow"	Willow	*Salix* spp. L.
Winterfat		*Eurotia lanata* (Pursh) Mog.
Wyoming big sagebrush		*Artemisia tridentata wyomingensis* Nutt.
Grasses and forbs:		
Alkaligrass		*Pucinellia* spp. Parl.
Bluebunch wheatgrass		*Agropyron spicatum* (Pursh) Scribn. & Smith
Bottlebrush squirreltail		*Sitanion hystrix* (Nutt.) Smith, L.
Cheatgrass		*Bromus tectorum* L.
Crested wheatgrass		*Agropyron cristatum* (L.) Gaertn.
Idaho fescue		*Festuca idahoensis* Elmer.
Leafy spurge		*Euphorbia esula* L.
Medusahead		*Taeniatherum caput-medusae* L.
Rushes	Rushes	*Juncus* spp. L.
Sedges	Sedges	*Carex* spp. L.
Spotted knapweed		*Centaurea maculosa* Lam.
Wildrye	Wildrye	*Elymus* spp. L.
Yellowstar thistle		*Centaurea solstitialis* L.

Site quality was modeled by using plant series-level potential vegetation types as described in Hessburg and others (1999), and Smith and others (in press). Site quality was used as a vulnerability factor because hosts on poorer sites are often more vulnerable to a particular pathogen or insect disturbance than those occurring on more productive sites; we used site quality to capture some of those differences. Host abundance was used to estimate the proportion of a patch comprised of vegetation capable of hosting a particular pathogen or insect. Where differences in host susceptibility were known, hosts were weighted. Host abundance was estimated by using the photo-interpreted attributes total crown cover, overstory crown cover, understory crown cover, overstory species, and understory species (appendix 1). Canopy structure was used as a vulnerability factor to capture the influence of patch vertical structure on pathogen or insect dispersal, and was derived by using the photo-interpreted attributes: canopy layers, overstory species, and understory species.

Host size was used to indicate both sizes of hosts, and in some cases, to approximate host age, because host age could not be directly estimated by photointerpretation. Host size was used for a few insects because tree size thresholds, or size ranges were germane to estimating host vulnerability within patches. Host size also was used because patch structural attributes are more vulnerable to change as a consequence of disturbance when hosts are large than when hosts are small. Host size was estimated by using the photo-interpreted attributes overstory species, understory species, overstory size class, and understory size class.

Relative differences in patch vigor were represented by the overstory crown differentiation attribute (appendix 1). Relative differences in stand density were represented by using the total crown cover attribute. Connectivity of host patches was estimated by computing the percentage of the area within a specified dispersal radius comprised of host patches, at a scale of 30 m with raster coverages. Toe-slope topographic settings were modeled by using the riparian status attribute, and a 90-m digital elevation model. Environmental attributes such as site quality and topographic setting aided in defining the influence of selected biophysical conditions on vulnerability of vegetation to a disturbance agent. Logging disturbance was represented by type and apparent extent of harvest (appendix 1).

In brief, the procedure for quantifying subwatershed vulnerability to an insect or pathogen disturbance in the midscale assessment was as follows: (1) we rated patches in each historical and current subwatershed vegetation coverage for all vulnerability factors specified for each disturbance agent; (2) we summed factor ratings for each patch—this sum was the patch vulnerability rating; (3) we assigned a vulnerability class (low, moderate, or high) to each patch according to the patch vulnerability rating; and (4) we computed three FRAGSTATS metrics for each patch type, where patch types were vulnerability classes %LAND—the percentage of area within a patch type; MPS—the mean size in hectares of patches within a patch type; and PD—the estimated patch density, or number of patches per 10 000-ha area (see also McGarigal and Marks [1995] for complete descriptions of FRAGSTATS metrics). These metrics were used to describe changes in area and connectivity of area of vulnerability classes in subwatersheds of an ecological reporting unit (ERU). As described in Hessburg and others (1999), change from historical to current conditions was estimated as the difference between historical and current conditions, not as the percentage change from historical conditions. For the ERU pooling stratum, means, mean standard errors, and confidence intervals were estimated by using methods for simple random samples (Steel and Torrie 1980) with subwatersheds as sample units. Statistically significant ($P \leq 0.2$) change was determined by examining the 80-percent confidence interval around the mean difference for the ERU, which was estimated as the simple random mean from pairwise comparisons of historical and current subwatersheds. If the confidence interval included zero, no significant change was recorded.

We supplemented this statistical test with two additional analyses that enabled us to evaluate the potential ecological significance of patch type change in area or connectivity of area. First, we approximated the historical range of variation (Everett and others 1994, Morgan and others 1994, Swanson and others 1994) by calculating the historical sample median 75-percent range for each metric, and we compared the current sample median value with this estimate of the historical range. Second, we characterized the most significant changes in absolute area of a patch type within a sample by using transition analysis. Ecologically significant change was ultimately determined by examining each of the three pieces of information: the 80-percent confidence interval, differences between current median values and historical median 75-percent ranges, and principal transitions between historical and current conditions.

Transition analysis estimated the percentage of area in a pooling stratum that changed from any one cover type or structural condition in the historical vegetation coverage to any other condition in the current coverage, including transitions to the same condition. If change was narrowly focused to a few transition types (and those transitions were credible in light of known management history) and successional and disturbance regime changes, the transitions were provisionally judged as ecologically significant (Note that transition matrices were established from 30-m raster coverages of patch types. The total number of possible transition types within an ERU ranged from 10^2 to 10^3). Transition analysis enabled us to directly identify transitions responsible for the changes we observed and to detect statistically significant "nonsense" changes resulting from rasterization of historical and current vegetation coverages.

The median 75-percent range of the historical condition was used to estimate the significance of differences among current median values and the typical range of historical conditions. If the median value of the current condition (for any metric associated with any patch type) was outside the median 75-percent range of the historical condition, and transition analysis determined that no major transitions were nonsense changes, we judged the difference to be ecologically significant. Nearly all changes evaluated as ecologically significant were found to be statistically significant at $P \leq 0.2$ via examination of the 80-percent confidence interval.

We chose the median 75-percent range instead of the full 100-percent range as a meaningful measure of recent historical variation to portray typical variation exclusive of extreme observations. Historical (and current) data distributions were most often highly skewed and only in rare instances were normally distributed. Hence, the sample median value was a more accurate reflection of central tendency than either the mean or mode. Most observations clustered within the median 75- to 80-percent range, and few observations accounted for differences between the range of the clustered observations and the full range. We reasoned that more extreme variation usually results from either unique contexts or environments, or rare and often extreme events. By imposing the contrast between current median values and a typical range of historical conditions, we retained the ability to detect conditions resulting from management activities, random chance, or perhaps climate changes that were unique or abnormal.

We acknowledge shortcomings of modeling vegetation vulnerability to different pathogen and insect disturbances as intermediate ecological conditions or "indicators." Intermediate indicators such as patch or subwatershed vulnerability to an insect, require additional interpretation of modeled landscape outcomes. Interpreters rely on their experience, applicable scientific literature, and judgment. Interpretations should be calibrated, validated, and refined, and users of the interpretations must rely on the experience, knowledge, and judgment of those providing them. By comparison, estimating landscape vulnerability by using endpoint conditions or indicators, however crudely quantified, are more readily calibrated and validated.

We might have projected landscape vulnerability and potential ecosystem outcomes with endpoint indicators via stand or landscape growth and yield projection systems, inventory plot data, and insect and pathogen disturbance submodels as are available with the PROGNOSIS (FVS-forest vegetation simulator) modeling system (Stage 1973). Time and monetary constraints of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) project, and questionable or uneven quality of existing inventory data made this route infeasible. As an alternative to either of these courses of action, we considered the option of not characterizing landscape vulnerability to pathogen and insect disturbances. Knowing the policy and resource planning analyses that lay ahead and the decisions that would be made subsequent to the landscape assessment analyses, we thought "no action" an unacceptable course, and opted to assess changes in vulnerability and the spatial configuration of vulnerability, in the manner described. Although a formidable task, it is preferable to project changes in landscape vulnerability to disturbance with inventoried distributions of pathogens and insects (where practicable), patch-scale tree attribute data, measured density, structure, and composition, and modeled disturbance effects to ecosystems. Important endpoint indicators to model in future efforts would include relations among changing landscape structural attributes, site potentials, insect and pathogen disturbances, coarse wood accumulations, snag abundances, stand densities, disease center areas, shrub structures and densities, floral and faunal habitat abundances, and others.

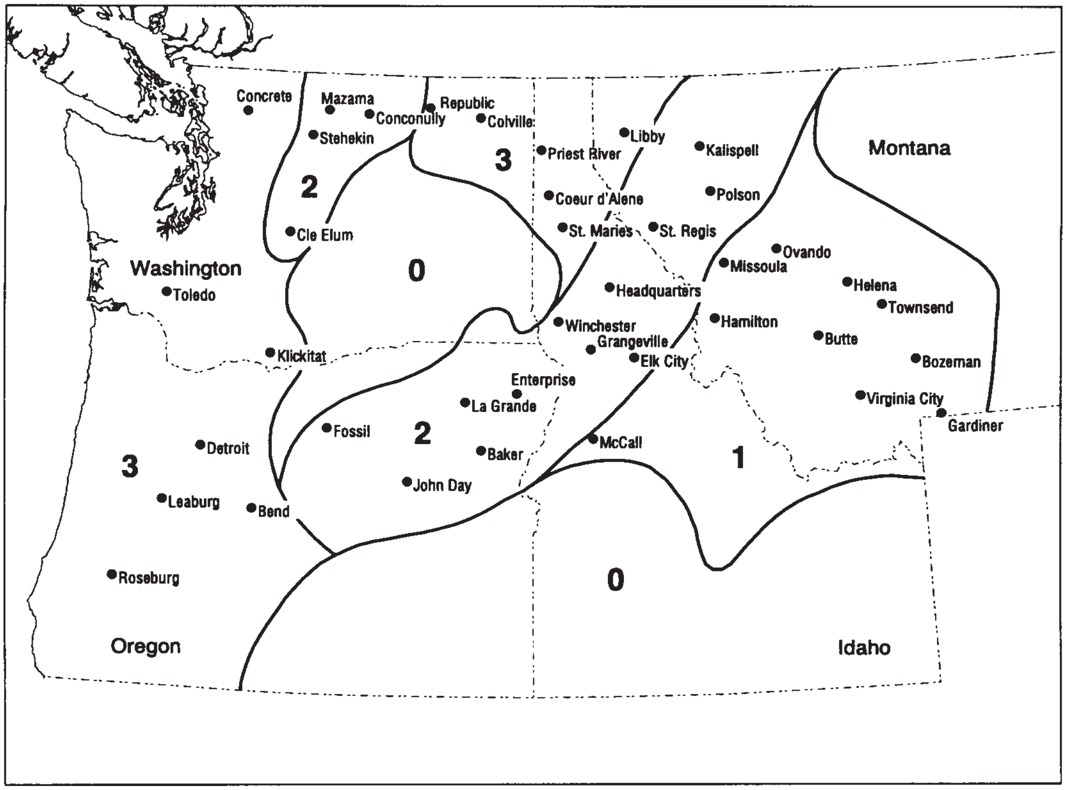


Figure 2—Classes of budworm defoliation frequency (1947-78) developed for forested areas of Idaho, Montana, Oregon, and Washington. High defoliation frequency = 1 ($\geq$ 60 years of visible defoliation in 100 years); medium defoliation frequency = 2 (7-48 years of visible defoliation in 100 years); low defoliation frequency = 3 (0-11 years of visible defoliation in 100 years); no defoliation frequency = 0 (nonhost type) (source: Kemp 1985b).

In addition to modeling changes in the measure and spatial pattern of landscape vulnerability to insect and pathogen disturbances, we describe for the first time, living and dead vegetation structures commonly associated with the insect and pathogen disturbances modeled (appendices 2 and 3). These are provided for persons interested in interpreting potential abundance and spatial distribution of microhabitat structures of importance to wildlife. Most living and dead vegetation structure at the patch scale occurs as a direct result of disturbance. Where effective fire prevention and suppression strategies have been in place for a half-century or more, microhabitat structure most often will be the result of insect and pathogen disturbances, and unavoidable fires. The inference is that microhabitat structures essential to wildlife will occur with high likelihood where vegetation is most vulnerable to insect, pathogen, and fire disturbances. Microhabitat structure shown in appendices 2 and 3 can be related to midscale historical or current subwatershed and subbasin vegetation conditions to estimate the potential area and spatial patterning of such structures for each period in time. Change analysis comparing conditions of the two periods would provide valuable insight into likely differences in the potential availability of microhabitat structures.

Insects Modeled

Defoliators

Principal lepidopteran defoliators of basin conifer forests are the western spruce budworm (WSB) and the Douglas-fir tussock moth (DFTM). Basin forests are comprised of areas of low (0-11 years of visible defoliation per 100 years), moderate (7-48 years of visible defoliation per 100 years), and high (60 or more years of visible defoliation per 100 years) budworm defoliation frequency areas (Kemp 1985a, 1985b). Areas of high defoliation frequency are characterized by low annual precipitation, droughty growing season conditions, cold winters, and cool spring and fall temperature regimes. Low defoliation frequency areas are characterized by higher annual precipitation, mild winter temperatures, and warmer spring and fall temperature regimes. Figure 2 shows defoliation frequency areas in Oregon, Washington, Idaho, and western Montana according to Kemp (1985b).

There appears to have been no obvious change in outbreak frequency in the basin since the region was first settled, but vegetation structural attributes (both composition and configuration) that strongly influence outbreak extent, duration, and severity, have changed (Gast and other 1991, Hessburg and others 1994, Lehmkuhl and others 1994, O'Laughlin and others 1993). Western spruce budworm outbreak extent, duration, and severity depend on (1) the amount, structure, quality, and spatial distribution of available host patches; (2) conducive environmental conditions for budworm life stages; and (3) dispersal opportunities to suitable host patches. Large areas that are successionally advanced and have multiple canopy layers within the Douglas-fir, grand fir, white fir, and subalpine fir zones (Franklin and Dyrness 1973), are vulnerable to defoliation by budworm. Warm, dry sites are more vulnerable to defoliator outbreaks than are cool mesic sites. During an outbreak, warm mesic sites may incur the greatest reduction in growth of host species (see Brookes and others [1985, 1987] and Sanders and others [1985] for further WSB references).

Defoliation extent increases with area and connectivity of budworm host patches. Duration varies with forage quality, vertical stratification of hosts, environmental conditions for each life stage, fecundity, survivorship, sex ratio, and dispersal efficiency. Severity varies with the duration and amount of defoliation, and host vigor before, during, and after defoliation episodes.

Douglas-fir tussock moth outbreak extent and severity depend on many of the same variables as the WSB, though there are several important differences. The WSB feeds primarily on new foliage and buds, and feeds earlier in spring; the DFTM feeds on both new and old foliage and readily defoliates entire trees in a single growing season. Vertical stratification of hosts can enhance both WSB and DFTM survival and defoliation severity. The DFTM is somewhat more sensitive to droughty sites than is the WSB; DFTM outbreaks typically begin in some of the driest Douglas-fir plant communities where the exclusion of fire has allowed an increased presence of Douglas-fir. Douglas-fir tussock moth outbreak duration is naturally regulated by parasites and predators, and nucleopolyhedrosis virus (NPV) epizootics. The interval between individual DFTM population increases is about 9 years, and the pattern of population fluctuation appears to be cyclic. Factors governing whether a population increase results in a DFTM outbreak are not well understood. When populations begin to increase but do not build to outbreak levels, parasites and predators are principal regulators. When populations build to outbreak levels, collapse is often the result of an NPV epizootic (see Brookes and others 1978 for additional DFTM references).

Mapping vulnerability to western spruce budworm and Douglas-fir tussock moth—Vulnerability characterizations for WSB and DFTM were collapsed into one, but vulnerability factors used here were most appropriate to the budworm. Vulnerability to WSB and DFTM was attributed to all forested vegetation patches; those containing no host species in the understory and overstory were given the lowest score for each of seven factors. The WSB vulnerability factors were (1) site quality—using climax conifer series group; (2) host abundance—using host crown cover percentage; (3) canopy structure—using number of canopy layers in host species; (4) patch (stand) density—using total crown cover percentage as a relative measure of stand density; (5) host age—estimated from overstory and understory size classes; (6) patch vigor—using estimated degree of overstory crown differentiation; and (7) connectivity of WSB host patches—estimating connectivity of patches of host types within a specified radius. Table 4 displays the seven WSB vulnerability factors and criteria for rating vegetation polygons for each factor.

When all patches in a historical or current vegetation coverage of a subwatershed were rated for each vulnerability factor, factor ratings were summed for individual patches. This sum was the patch WSB vulnerability rating. Patch vulnerability ratings were collapsed into three vulnerability classes as follows: low for patches with a composite rating of 7 to 10; moderate for patches rated 11 to 14; and high for patches rated 15 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to WSB disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 3A illustrates increased area vulnerable to WSB disturbance in a subwatershed of the Palisades subbasin.

Carlson and others (1985) used host age and an index of vigor to rate patch vulnerability to budworm. We interpreted and attributed the effect of existing stand density on overall patch vigor by using degree of overstory crown differentiation, and we estimated host age from size class. We could not reliably interpret age or density via photointerpretation. The degree of canopy layering also provided some indication of relative differences in site occupancy, density, and vigor. In the basin, patch age and vigor appear to influence the severity and extent of disturbance associated with budworm outbreaks, but relations are still poorly understood.

Table 4—Criteria for rating forest vegetation patch vulnerability to western spruce budworm (WSB) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality[a]	3	Warm-dry PSME/ABGR(ABCO) or warm-dry ABLA2/PIEN sites
	2	Cool-moist PSME/ABGR(ABCO) or cool-moist ABLA2/PIEN sites
	1	Other sites
Host abundance[b]	3	> 50 percent crown cover of host species
	2	30 to 50 percent crown cover of host species
	1	< 30 percent crown cover of host species, or other
Canopy structure[c]	3	2 layers of WSB host species, or 2 mixed-species layers with WSB host species
	2	1 layer of WSB host species
	1	1 mixed-species layer with WSB host species, or other
Patch (stand) density[d]	3	> 70 percent total crown cover (all species)
	2	40 to 70 percent total crown cover (all species)
	1	< 40 percent total crown cover (all species)
Host age[e]	3	Estimated as > 120 years old, overstory or understory PSME, ABGR(ABCO), ABAM, ABMA, ABPR or PIEN large trees (> 63.5 cm d.b.h.), or ABLA2 medium trees (40.6 to 63.5 cm d.b.h.)
	2	Estimated as 80 to 120 years old, overstory or understory PSME, ABGR(ABCO), ABAM, ABMA, ABPR, or PIEN medium trees (40.6 to 63.5 cm d.b.h.), or ABLA2 small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old, overstory or understory PSME, ABGR(ABCO), ABAM, ABMA, ABPR, or PIEN seedling, sapling, pole, or small trees (D 40.5 cm d.b.h.), or ABLA2 seedlings, saplings, or poles (< 22.9 cm d.b.h.)
Patch vigor[f]	3	Degree of differentiation among overstory crowns < 30 percent
	2	Degree of differentiation among overstory crowns 30 to 100 percent
	1	Degree of differentiation among overstory crowns >100 percent
Host patch connectivity[g]	3	> 40 percent of the area within a 1135-m radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1135-m radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1135-m radius of host patch boundaries is host type

---

[a] Site quality was estimated by using a modeled climax conifer series or series group patch attribute. Series group was a midscale estimate of potential natural vegetation. Series group options here and following were PIPO, PSME/ABGR (ABCO), TSHE/THPL, ABAM, TSME, ABLA2/PIEN, PIAL/LALY, PICO, and ABMA (see table 3 for a complete listing of tree species abbreviations). Series group was modeled by using the overstory and understory species attributes of both the recent historical and current vegetation coverages, coupled with elevation and aspect setting attributes derived from a 90-m digital elevation model (see Hessburg and others 1999 and Smith and others (in press) for complete descriptions of modeling methods and subbasin rule sets). A patch rating of "3" in site quality here and following indicated that temperature and moisture conditions during the growing season contributed maximally to host vulnerability to disturbance.

[b] Budworm hosts were PSME, ABGR(ABCO), ABLA2, ABAM, ABMA, ABPR, and PIEN. Here and following, ABGR was treated as being synonymous with ABCO; this was indicated by the notation, ABGR(ABCO). LAOC, although vulnerable, was omitted from this host list because even older larch are considerably less vulnerable than the shade-tolerant conifers included in this list (Wulf and Carlson 1985). Host abundance, here and following, was calculated by using the photo-interpreted attributes total crown cover, overstory crown cover, understory crown cover, overstory species, and understory species. Overstory crown cover was subtracted from total crown cover to obtain apparent understory crown cover. Note that forested crown cover was estimated by photo-interpretation in 10-percent cover increments (e.g., 10 percent = 5-14 percent; 20 percent = 15-24 percent). Maximum crown cover was 100 percent. In reality, overstory and understory crown cover of some patches would sum to a value greater than 100 percent. Photo-interpreted patch overstory and understory species attributes allowed for pure and mixed compositions. When a patch overstory or understory was attributed as having more than one species, each species represented at least 20 percent of the crown cover of the layer. Mixes of two and three species were commonly attributed. Host abundance was obtained by computing overstory and understory crown cover in each defoliator host species. When budworm hosts were PSME or ABGR(ABCO) or ABLA2, or PIEN, the host abundance weighting factor was 1.5; i.e., the host abundance rating was multiplied by 1.5. When hosts were ABAM or ABMA or ABPR, the host abundance weighting factor was 1.0. When hosts were other than these, the host abundance weighting factor was 0.5.

[c] Canopy structure here and following was derived from photo-interpreted attributes: overstory species, understory species, and canopy layers.

[d] Density here and following was estimated by using total crown cover of all species.

[e] Host age here and following was approximated by using photo-interpreted attributes—overstory species, overstory size class, understory species, and understory size class. When hosts occurred in the overstory and understory, the size class of the overstory was used to estimate host age.

[f] Patch vigor here and following was estimated by using the patch overstory crown differentiation attribute. See appendix 1 for complete descriptions of photo-interpreted attributes.

[g] Here and following, connectivity of host patches was rated by computing the percentage of the area within a specified dispersal radius (buffer) comprised of host patches, at a scale of 30 m with raster coverages. Patches were classified as host or nonhost in a geographical information system based on the presence or absence of a host species (see factor 2 above) in the overstory and understory. A 1135-m radius around host patch boundaries represents an area of about 400 ha used by Wulf and Carlson (1985) to estimate connectivity of host patches for WSB. Using this radius, we assume that budworm larvae and adults will locate host patches with high probability when hosts are within the identified search radius. Beyond this radius, we assume that dispersal losses of larvae or adults are significant.

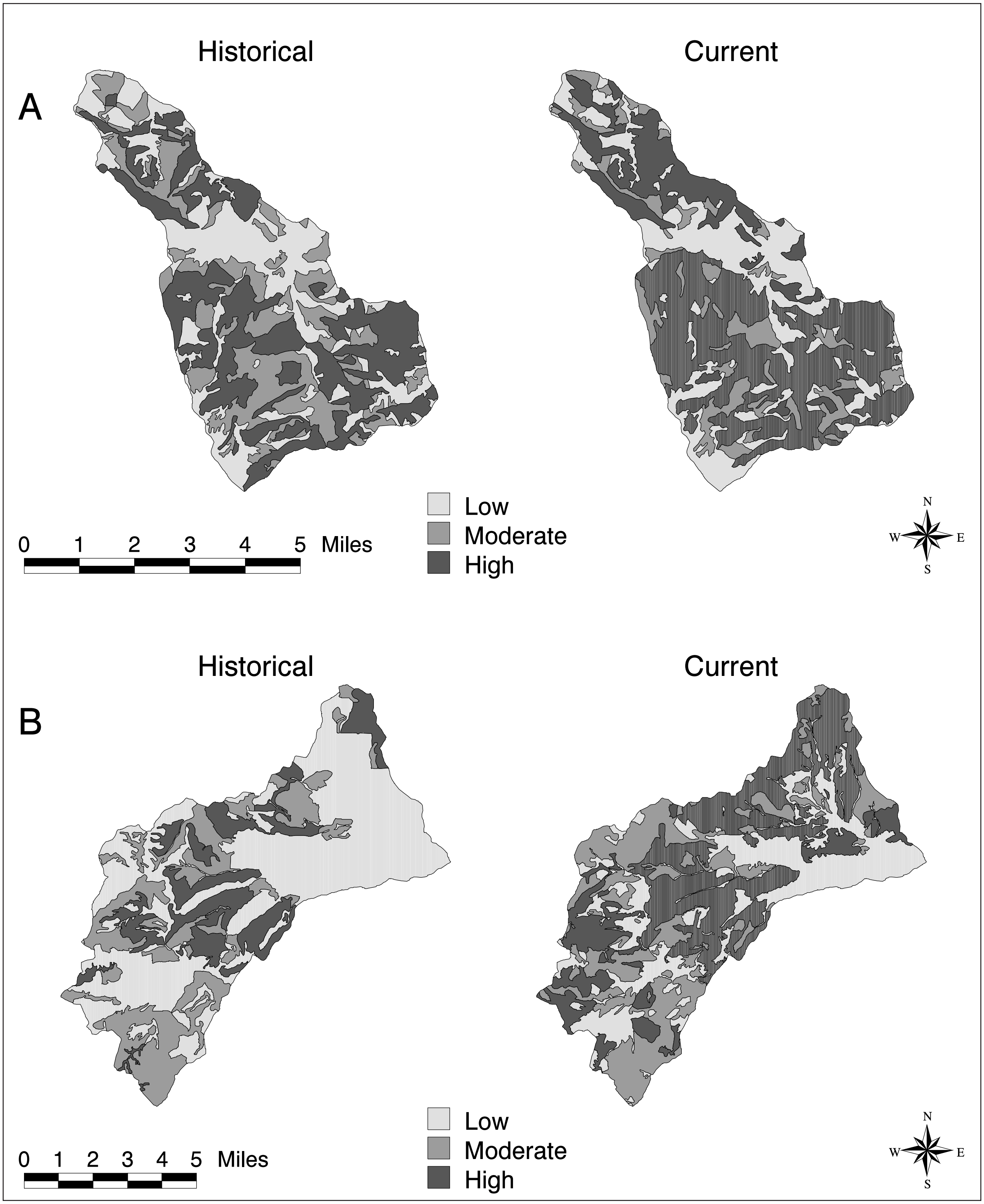


Figure 3—Historical and current vegetation vulnerability to (A) western spruce budworm disturbance in subwatershed 1102 in the Palisades subbasin of the Snake Headwaters Ecological Reporting Unit, (B) Douglas-fir beetle disturbance in subwatershed 40c in the Silvies subbasin of the Blue Mountains Ecological Reporting Unit.

Bark Beetles

Vulnerability of forest vegetation to the Douglas-fir beetle, western pine beetle, mountain pine beetle, fir engraver, and spruce beetle was characterized. In endemic populations, each bark beetle species attacks low vigor, diseased, weakened or injured trees, and recent wind-thrown or collapsed trees. In outbreaks, vigorous hosts are mass attacked and killed, occasionally across large areas. In pine-dominated patches, stressed trees are commonly associated with high-density growing conditions, droughty growing seasons, or protracted droughts. In successionally advanced patches comprised of shade-tolerant species, root pathogens, dwarf mistletoes, drought, and overstocking maintain an abundance of beetle-vulnerable stressed trees.

In endemic populations, mountain pine and western pine beetles typically attack stressed or declining pines. Lacking regular underburning fires or tree density management, vigor-depressed pockets or patches of ponderosa or lodgepole pine often develop. Under the right environmental conditions, when host stems are sufficiently large, and when phloem thickness (mountain pine beetle) is adequate to support beetle brood development, beetles attack and kill trees in the manner of an indiscriminant thinning or a thinning from above. Under these outbreak conditions, pockets or patches of trees, whole stands, and even large forests of similar type are destroyed, often yielding new cover types, structural conditions, and significantly increased fuels. In outbreak conditions, vigorous host-dominated patches and landscapes also are affected. During extended drought periods, the western pine beetle may replace or join the mountain pine beetle in attacking small-diameter ponderosa pine.

Between 1987 and 1994, widespread pine bark beetle mortality in ponderosa, lodgepole, and western white pines was recorded throughout the basin within the grand fir, white fir, Douglas-fir, and ponderosa pine zones[2] (see also Gast and others 1991, Hessburg and others 1994, O'Laughlin and others 1993 and references therein). Over the last several decades, lodgepole pine mortality associated with large-scale mountain pine beetle outbreaks also has been recorded throughout the cover type in eastern Oregon and Washington (Gast and others 1991, Hessburg and others 1994), and elsewhere in the upper Columbia basin. This mortality is an excellent indicator of forest aging as a result of fire exclusion, synchronous landscapes, high-density growing conditions, drought vulnerability, vigor depression of forests and stands, and spatial connectivity of vulnerable conditions. Ground fuel inputs associated with pine bark beetle mortality over the same timeframe also have been significant (Huff and others 1995; Ottmar and others, in press).

Douglas-fir beetle—Douglas-fir beetle (DFB) outbreaks are primarily associated with large-scale wind, fire, or drought events, or defoliator (WSB or DFTM) outbreaks. Areas with severe dwarf mistletoe and root disease in Douglas-fir also tend to support elevated DFB populations. At least 40 percent of the Douglas-fir in eastern Oregon and Washington are infected with Douglas-fir dwarf mistletoe (Bolsinger 1978); infection rates are comparable in the upper Columbia basin.[3] An additional 5 to 10 percent are root-diseased (Byler 1988).

Mapping vulnerability to the Douglas-fir beetle— The primary host of the DFB is Douglas-fir (PSME), although western larch (LAOC) windthrow is occasionally infested. Vulnerability to DFB disturbance was attributed to all forested vegetation patches; those containing no hosts in either the understory or overstory were given the lowest score for each factor where host was identified. Douglas-fir beetle vulnerability factors were (1) site quality, (2) host abundance, (3) canopy structure, (4) patch (stand) density, (5) host age, and (6) connectivity of DFB host patches. Table 5 displays the six DFB vulnerability factors and criteria for rating vegetation polygons for each factor.

When all patches in a historical or current vegetation coverage of a subwatershed were rated for each vulnerability factor, factor ratings were summed for individual patches. This sum was the patch DFB vulnerability rating. Patch vulnerability ratings were collapsed into three vulnerability classes as follows: low for patches with a composite rating of 6 to 9; moderate for patches rated 10 to 13; and high for patches rated 14 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to DFB disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 3b illustrates increased area vulnerable to DFB disturbance in a subwatershed of the Silvies subbasin.

---

[2] Refer to the annual aerial detection survey maps and insect and disease conditions reports of the USDA Forest Service, Pacific Northwest, Northern, and Intermountain Regions, Forest Pest Management Group, for the period 1987-94.

[3] Hoffman, James. 1994. Insect, disease, animal, and abiotic damages associated with central Idaho habitat types. 2 p. Unpublished data. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 1133 N. Western Avenue, Wenatchee, WA 98801-1713.

Table 5—Criteria for rating forest vegetation patch vulnerability to Douglas-fir beetle (DFB) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Vulnerability factor
Site quality	3	Warm-dry PSME/ABGR(ABCO) sites
	2	Cool-moist PSME/ABGR(ABCO); warm-dry ABLA2/PIEN sites
	1	Other sites
Host abundance[a]	3	> 50 percent crown cover in PSME 22.9 cm d.b.h. and larger
	2	30 to 50 percent crown cover in PSME 22.9 cm d.b.h. and larger
	1	< 30 percent crown cover in PSME 22.9 cm d.b.h. and larger, or other
Canopy structure	3	2 or more PSME layers with PSME 22.9 cm d.b.h. or larger, or 2 or more mixed-species layers with PSME 22.9 cm d.b.h. or larger
	2	1 PSME layer 22.9 cm d.b.h. or larger
	1	1 mixed-species layer with PSME 22.9 cm d.b.h. or larger
Patch (stand) density	3	> 70 percent total crown cover (all species)
	2	40 to 70 percent total crown cover (all species)
	1	< 40 percent total crown cover (all species)
Host age[b]	3	Estimated as > 120 years old, PSME overstory large trees (> 63.5 cm d.b.h.)
	2	Estimated as 81 to 120 years old, PSME overstory or understory medium trees (40.6 to 63.5 cm d.b.h.)
	1	Estimated as 40 to 80 years old, PSME overstory or understory small trees (22.9 to 40.5 cm d.b.h.)
Host patch connectivity[c]	3	> 40 percent of the area within a 1-km radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1-km radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1-km radius of host patch boundaries is host type

[a] Host abundance was obtained by computing overstory and understory crown cover in PSME 22.9 cm d.b.h. and larger, because PSME smaller than 22.9 cm are infrequently attacked by the DFB.

[b] Here and following, when the host species, in this case PSME, occurred in both the overstory and understory, the size class of the overstory was used to attribute host age.

[c] Connectivity was computed for patches with PSME 22.9 cm d.b.h. and larger. Using a 1-km radius, we assumed that DFB adults would locate host patches with high probability when hosts were within the identified search radius. Beyond this radius, we assumed that adult dispersal losses were significant.

Table 6—Criteria for rating forest vegetation patch vulnerability to type 1 western pine beetle (WPB) disturbance of mature and old ponderosa pine (PIPO) in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	PIPO sites
	2	Warm-dry PSME/ABGR(ABCO) sites
	1	Cool-moist PSME/ABGR(ABCO), other sites
Host abundance	3	> 50 percent crown cover in PIPO 22.9 cm d.b.h. and larger
	2	30 to 50 percent crown cover in PIPO 22.9 cm d.b.h. and larger
	1	< 30 percent crown cover in PIPO 22.9 cm d.b.h. and larger, or other
Patch (stand) density	3	> 60 percent total crown cover (all species)
	2	40 to 60 percent total crown cover (all species)
	1	< 40 percent total crown cover (all species)
Host age	3	Estimated as > 120 years old, PIPO overstory large trees (> 63.5 cm d.b.h.)
	2	Estimated as 80 to 120 years old, PIPO overstory or understory medium trees (40.6 to 63.5 cm d.b.h.)
	1	Estimated as < 80 years old, PIPO overstory or understory small trees (22.9 to 40.5 cm d.b.h.)
Host patch connectivity[a]	3	> 40 percent of the area within a 1-km radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1-km radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1-km radius of host patch boundaries is host type

[a] Connectivity was computed for patches with PIPO 22.9 cm d.b.h. and larger. Using a 1-km radius, we assumed that WPB adults would locate host patches with high probability when hosts were within the identified search radius. Beyond this radius, we assumed that adult dispersal losses were significant.

Western pine beetle—The western pine beetle (WPB) primarily affects ponderosa pine (PIPO) in the basin. Large, mature, and old ponderosa pine are vulnerable as are immature pole, small, and medium-sized pine growing in high-density conditions. The WPB is often responsible for the demise of ponderosa pine infected with the western dwarf mistletoe, P-group annosum root disease, *Armillaria* root disease, and those stressed by persistent drought or winter dessication injury.

***Mapping vulnerability to the western pine beetle*—**Vulnerability to WPB disturbance was attributed to all forested vegetation patches; those containing no hosts in either the understory or overstory were given the lowest score for each factor where host was identified. Two types of WPB vulnerability evaluated were type 1 vulnerability of mature and old PIPO patches; and type 2 vulnerability of immature, high-density PIPO patches. Western pine beetle vulnerability factors (types 1 and 2) were (1) site quality, (2) host abundance, (3) patch (stand) density, (4) host age, (5) patch vigor, and (6) connectivity of WPB host patches. Table 6 displays type 1 WPB vulnerability factors and criteria for rating vegetation polygons for each factor; table 7 displays type 2 WPB vulnerability factors and criteria for rating vegetation polygons for each factor.

Table 7—Criteria for rating forest vegetation patch vulnerability to type 2 western pine beetle (WPB) and type 2 mountain pine beetle (MPB) disturbance of immature, high-density ponderosa pine (PIPO) in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	PIPO sites
	2	Warm-dry PSME/ABGR(ABCO) sites
	1	Cool-moist PSME/ABGR(ABCO), or other sites
Host abundance	3	> 50 percent crown cover in 12.7 to 40.5 cm d.b.h. PIPO
	2	30 to 50 percent crown cover in 12.7 to 40.5 cm d.b.h. PIPO
	1	< 30 percent crown cover in 12.7 to 40.5 cm d.b.h. PIPO, or other
Patch (stand) density	3	> 60 percent total crown cover (all species)
	2	40 to 60 percent total crown cover (all species)
	1	< 40 percent total crown cover (all species)
Host age	3	Estimated as 41 to 80 years old, PIPO overstory or understory small trees (22.7 to 40.5 cm d.b.h.)
	2	Estimated as 21 to 40 years old, PIPO overstory or understory poles (12.7 to 22.6 cm d.b.h.)
	1	Estimated as 20 years old, PIPO overstory or understory seedlings and saplings (< 12.7 cm d.b.h.)
Patch vigor	3	Degree of differentiation among overstory crowns < 30 percent
	2	Degree of differentiation among overstory crowns 30 to 100 percent
	1	Degree of differentiation among overstory crowns > 100 percent
Host patch connectivity[a]	3	> 40 percent of the area within a 1-km radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1-km radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1-km radius of host patch boundaries is host type

[a] Connectivity was computed for patches with PIPO 12.7 to 40.5 cm d.b.h. Using a 1-km radius, we assumed that WPB adults would locate host patches with high probability when hosts were within the identified search radius. Beyond this radius, we assumed that dispersal losses were significant.

As described above, factor ratings were summed for individual patches. Type 1 WPB patch vulnerability ratings were collapsed into vulnerability classes as follows: low for patches with a composite rating of 5 to 7; moderate for patches rated 8 to 10; and high for patches rated 11 and above. Type 2 WPB patch vulnerability ratings were collapsed into vulnerability classes as follows: low for patches with a composite rating of 6 to 8; moderate for patches rated 9 to 11; and high for patches rated 12 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to type 1 and type 2 WPB disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 4a illustrates reduced area vulnerable to WPB type 1 disturbance in a subwatershed of the Lower John Day subbasin. Figure 4b illustrates increased area vulnerable to WPB type 2 disturbance in a subwatershed of the Lower John Day subbasin.

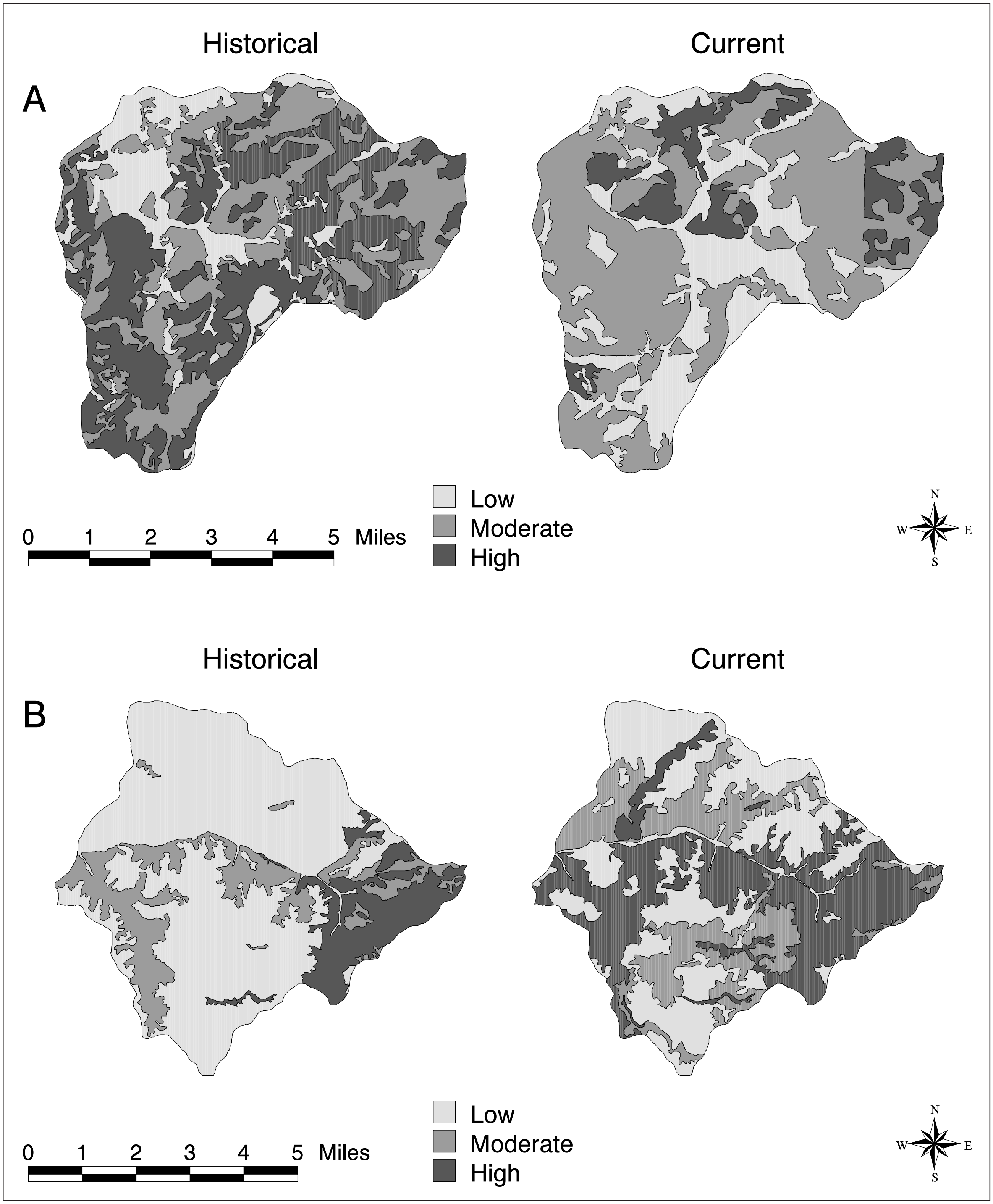


Figure 4—Historical and current vegetation vulnerability to (A) western pine beetle type 1 disturbance in subwatershed 1303 in the Lower John Day subbasin of the Columbia Plateau Ecological Reporting Unit, (B) western pine beetle type 2 disturbance in subwatershed 1903 in the Lower John Day subbasin of the Columbia Plateau Ecological Reporting Unit.

Table 8—Criteria for rating forest vegetation patch vulnerability to type 1 mountain pine beetle (MPB) disturbance of immature, high-density lodgepole pine (PICO) in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Edaphic PICO; warm-dry ABLA2/PIEN; cool-moist PSM ABGR (ABCO) sites
	2	ABMA; cool-moist ABLA2/PIEN; TSME sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PICO 12.7 cm d.b.h. and larger
	2	30 to 50 percent crown cover in PICO 12.7 cm d.b.h. and larger
	1	< 30 percent crown cover in PICO 12.7 cm d.b.h. and larger, or other
Patch (stand) density	3	> 70 percent total crown cover (all species)
	2	50 to 70 percent total crown cover (all species)
	1	< 50 percent total crown cover (all species)
Host size	3	PICO overstory or understory small, medium, and large trees (≥ 22.7 cm d.b.h.)
	2	PICO overstory or understory poles (12.7 to 22.6 cm d.b.h.)
	1	PICO overstory or understory seedling and saplings (< 12.7 cm d.b.h.)
Patch vigor	3	Degree of differentiation among overstory crowns < 30 percent
	2	Degree of differentiation among overstory crowns 30 to 100 percent
	1	Degree of differentiation among overstory crowns > 100 percent
Host patch connectivity[a]	3	> 40 percent of the area within a 1-km radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1-km radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1-km radius of host patch boundaries is host type

[a] Connectivity was computed for patches with PICO 12.7 cm d.b.h. and larger. Using a 1-km radius, we assumed that MPB adults would locate host patches with high probability when hosts were within the identified search radius. Beyond this radius, we assumed that dispersal losses were significant.

Mountain pine beetle—The mountain pine beetle (MPB) primarily attacks lodgepole (PICO) and ponderosa pines; poles and small trees growing in overcrowded conditions are vulnerable. Western white pine (PIMO) 35.6 cm d.b.h. and larger, having more than 13 m^2 of associated basal area, and older than 140 years often are killed by the MPB, as are those with severe white pine blister rust bole cankers. In addition, the mountain pine beetle kills stressed, injured, or old sugar pine, whitebark pine, and limber pine, and those with blister rust bole infections. Large, old lodgepole pine, and those injured or stressed also are attacked.

Mapping vulnerability to the mountain pine beetle— Vulnerability to MPB disturbance was attributed to all forested vegetation patches; those containing no hosts in either the understory or overstory were given the lowest score for each factor where host was identified. Two types of MPB vulnerability were evaluated: type 1 vulnerability of high-density PICO; and type 2 vulnerability of immature, high-density PIPO. Type 1 MPB vulnerability factors were (1) site quality, (2) host abundance, (3) patch (stand) density, (4) host size, (5) patch vigor, and (6) connectivity of WPB host patches. Type 2 MPB vulnerability factors were identical to those used to assess type 2 WPB vulnerability. Table 8 displays type 1 MPB vulnerability factors and criteria for rating vegetation polygons for each factor; table 7 displays type 2 WPB (and type 2 MPB) vulnerability factors and criteria for rating vegetation polygons for each factor.

Type 1 and type 2 MPB patch vulnerability ratings were collapsed into vulnerability classes as follows: low for patches with a composite rating of 6 to 8; moderate for patches rated 9 to 11; and high for patches rated 12 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to type 1 and type 2 MPB disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 5A illustrates reduced area vulnerable to type 1 MPB disturbance in a subwatershed of the Wallowa subbasin. Figure 5B illustrates expanded area vulnerable to type 2 MPB disturbance in a subwatershed of the Palouse subbasin.

Fir engraver—All true firs (*Abies* spp.) are host to the fir engraver beetle (FE)^B. Fir engraver beetles often are described as "secondary" bark beetles—beetles lacking a means of overcoming robust trees, that instead attack and overcome trees stressed by drought, other insects, or pathogens. Grand fir, white fir, and subalpine fir are primarily affected by FE^B. Each seems to be drought-sensitive and vulnerable to three root pathogens: *Phellinus weirii,* which causes laminated root rot, *Heterobasidion annosum,* which causes S-type annosum root disease, and *Armillaria ostoyae,* which causes *Armillaria* root disease. During drought-free periods, FE^B mortality reliably indicates root disease distribution and severity within the grand and white fir zones (Lane and Goheen 1979).

Mapping vulnerability to the fir engraver beetle— Vulnerability to FE^B disturbance was attributed to all forested vegetation patches; those containing no hosts in either the understory or overstory, were given the lowest score for each factor where host was identified. Fir engraver vulnerability factors were (1) site quality, (2) host abundance, (3) canopy structure, (4) patch (stand) density, (5) host size, and (6) connectivity of FE^B host patches. Table 9 displays the six FE^B vulnerability factors and criteria for rating vegetation polygons for each factor.

Factor ratings were summed for individual patches. Fir engraver patch vulnerability ratings were collapsed into vulnerability classes as follows: low for patches with a composite rating of 6 to 9; moderate for patches rated 10 to 12; and high for patches rated 13 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to FE disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 6A illustrates expanded area vulnerable to FE disturbance in a subwatershed of the South Fork Clearwater subbasin. Figure 6B illustrates reduced area vulnerable to FE disturbance in a subwatershed of the lower Grande Ronde subbasin.

Spruce beetle—In the basin, Engelmann spruce (PIEN) is host to the spruce beetle (SB). Spruce beetles attack injured trees and those stressed by drought, pathogens, or other insects. Like the Douglas-fir beetle, spruce beetle outbreaks often are associated with large wind, fire, drought, or defoliation events. Engelmann spruce appear to be sensitive to extended drought and often succumb to any of four root diseases: S-type annosum root disease, *Armillaria* root disease, tomentosus root and butt rot, and Schweinitzii root and butt rot. In the latter two cases, Engelmann spruce with significant tomentosus root and butt rot or Schweinitzii root and butt rot eventually collapse and are typically colonized by the spruce beetle.

Mapping vulnerability to the spruce beetle—Vulnerability to SB disturbance was attributed to all forested vegetation patches; those containing no hosts in either the understory or overstory were given the lowest score for each factor where host was identified. Spruce beetle vulnerability factors were (1) site quality, (2) host abundance, (3) topographic setting, (4) host size, (5) patch (stand) density, and (6) connectivity of SB host patches. Table 10 displays the six SB vulnerability factors and criteria for rating vegetation polygons for each factor.

Factor ratings were summed for individual patches. Spruce beetle vulnerability ratings were collapsed into vulnerability classes as follows: low for patches with a composite rating of 6 to 8; moderate for patches rated 9 to 11; and high for patches rated 12 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to SB disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 7A illustrates reduced area vulnerable to SB disturbance in a subwatershed of the Upper Grande Ronde subbasin.

Text continues on page 27.

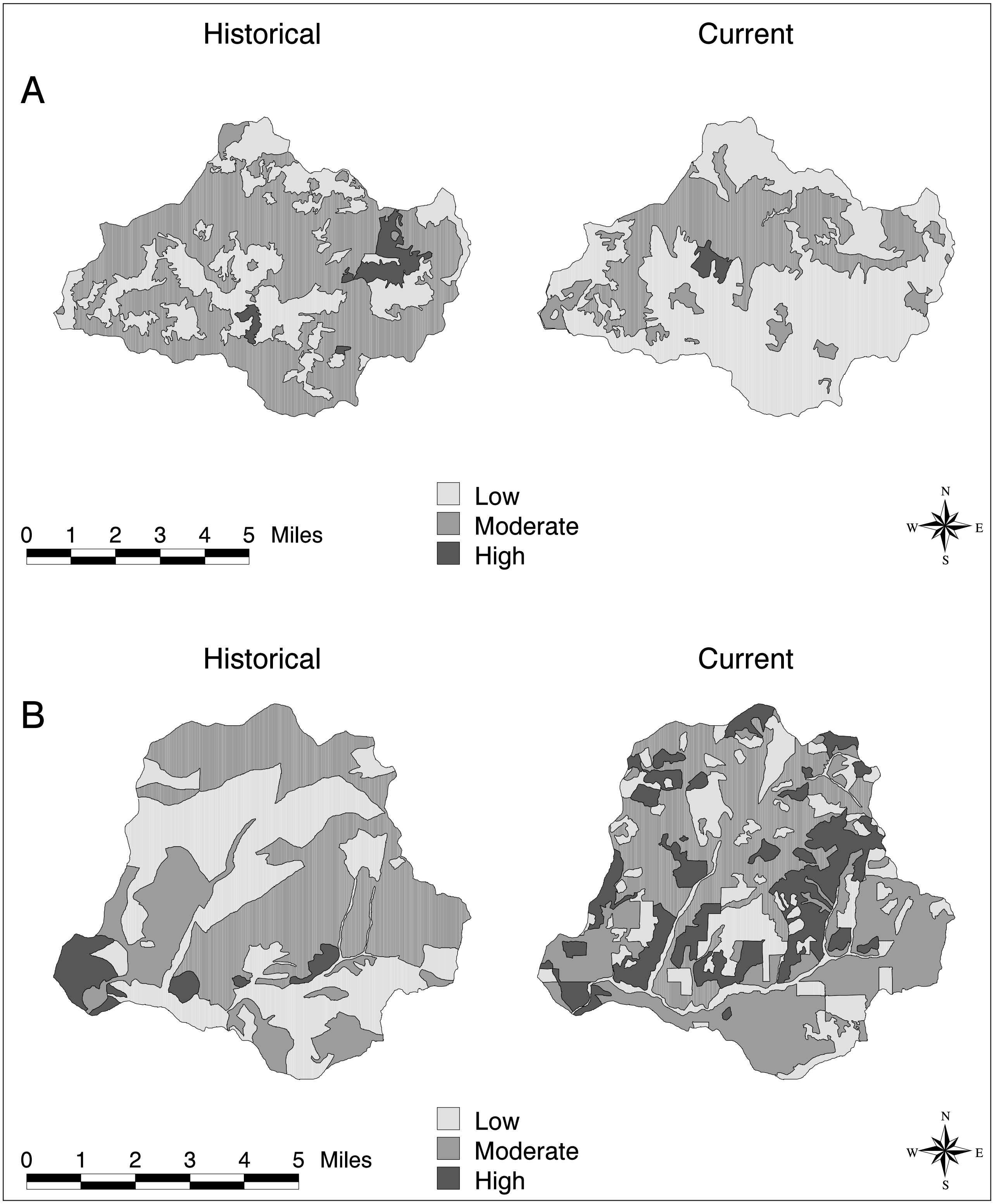


Figure 5—Historical and current vegetation vulnerability to (A) mountain pine beetle type 1 disturbance in subwatershed 40 in the Wallowa subbasin of the Blue Mountains Ecological Reporting Unit (B) mountain pine beetle type 2 disturbance in subwatershed 2002 in the Palouse subbasin of the Columbia Plateau Ecological Reporting Unit.

Table 9—Criteria for rating forest vegetation patch vulnerability to fir engraver (FE) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Warm-dry PSME/ABGR(ABCO); warm-dry ABLA2/PIEN
	2	Cool-moist PSME/ABGR(ABCO); ABMA; cool-moist ABLA2/PIEN
	1	Other sites
Host abundance[a]	3	> 50 percent crown cover in FE host species 12.7 cm d.b.h. and larger
	2	30 to 50 percent crown cover in FE host species 12.7 cm d.b.h. and larger
	1	< 30 percent crown cover in FE host species 12.7 cm d.b.h. and larger, or other
Patch (stand) density	3	> 70 percent total crown cover (all species)
	2	50 to 70 percent total crown cover (all species)
	1	< 50 percent total crown cover (all species)
Host size	3	Overstory or understory medium or large trees, FE host species (≥ 40.6 cm d.b.h.)
	2	Overstory or understory small trees, FE host species (22.9 to 40.5 cm d.b.h.)
	1	Overstory or understory seedlings, saplings or poles, FE host species (< 22.9 cm d.b.h.)
Canopy structure	3	2 or more layers FE host species 12.7 cm d.b.h. and larger, or 2 or more mixed-species layers with FE host species 12.7 cm d.b.h. and larger
	2	1 layer FE host species 12.7 cm d.b.h. and larger
	1	1 mixed-species layer with FE host species 12.7 cm d.b.h. and larger
Host patch connectivity[b]	3	> 40 percent of the area within a 1-km radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1-km radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1-km radius of host patch boundaries is host type

[a] FE hosts were ABGR(ABCO), ABLA2, ABAM, ABPR, and ABMA. When hosts were ABGR(ABCO), the host abundance weighting factor was 1.5. When hosts were ABLA2, ABAM, ABMA, or ABPR, the host abundance weighting factor was 1.0. When hosts were other than these, the host abundance weighting factor was 0.5.

[b] Connectivity was computed for patches with ABGR(ABCO), ABLA2, ABMA, ABAM, ABPR 12.7 cm d.b.h. and larger. Using a 1-km radius, we assumed that FE adults would locate host patches with high probability when hosts were within the identified search radius. Beyond this radius, we assumed that dispersal losses were significant.

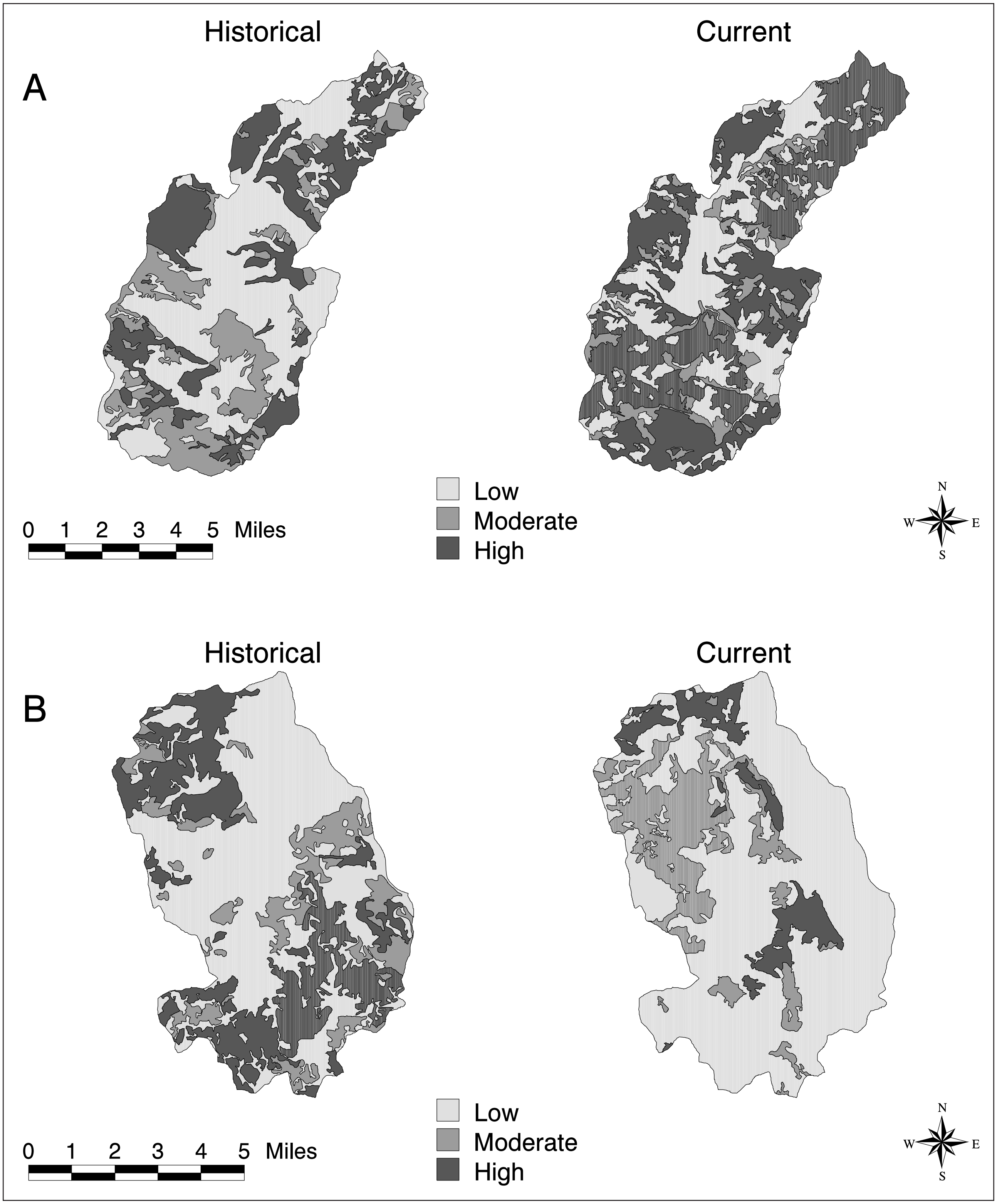


Figure 6—Historical and current vegetation vulnerability to (A) fir engraver disturbance in subwatershed 0703 in the South Fork Clearwater subbasin of the Central Idaho Mountains Ecological Reporting Unit, (B) fir engraver disturbance in subwatershed 12 in the Lower Grande Ronde subbasin of the Blue Mountains Ecological Reporting Unit.

Table 10—Criteria for rating forest vegetation patch vulnerability to spruce beetle (SB) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Cool-moist PSME/ABGR(ABCO); warm-dry ABLA2/PIEN sites
	2	Cool-moist ABLA2/PIEN sites, TSHE/THPL, ABAM, ABMA sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PIEN 22.9 cm d.b.h. or larger
	2	30 to 50 percent crown cover in PIEN 22.9 cm d.b.h. or larger
	1	< 30 percent crown cover in PIEN 22.9 cm d.b.h. or larger, or other
Patch (stand) density	3	> 70 percent total crown cover (all species)
	2	50 to 70 percent total crown cover (all species)
	1	< 50 percent total crown cover (all species)
Host size	3	Large PIEN overstory trees (> 63.5 cm d.b.h.)
	2	Medium PIEN overstory or understory trees (40.6 to 63.5 cm d.b.h.)
	1	Small PIEN overstory or understory trees (22.9 to 40.5 cm d.b.h.)
Topographic setting	3	Valley bottom settings (toe-slope to valley bottom) with PIEN ≥ 22.7 cm d.b.h.
	1	Other settings
Host patch connectivity[a]	3	> 40 percent of the area within a 1-km radius of host patch boundaries is host type
	2	20 to 40 percent of the area within a 1-km radius of host patch boundaries is host type
	1	< 20 percent of the area within a 1-km radius of host patch boundaries is host type

[a] Connectivity was computed for patches with PIEN 22.9 cm d.b.h. and larger. Using a 1-km radius, we assumed that SB adults would locate host patches with high probability when hosts were within the identified search radius. Beyond this radius, we assumed that dispersal losses were significant.

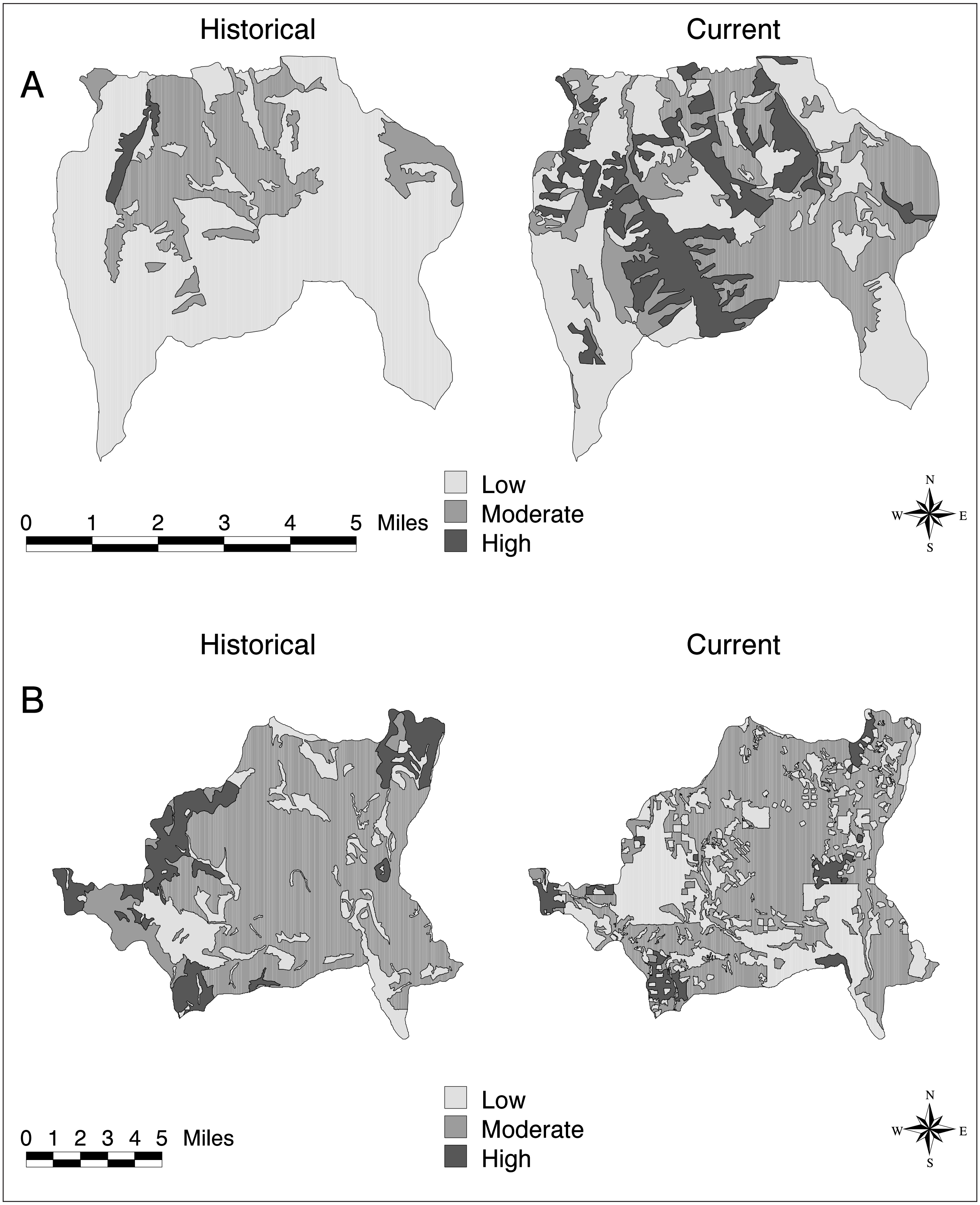


Figure 7—Historical and current vegetation vulnerability to (A) Douglas-fir dwarf mistletoe disturbance in subwatershed 29 in the Wallowa subbasin of the Blue Mountains Ecological Reporting Unit, (B) spruce beetle disturbance in subwatershed 28 in the Upper Grande Ronde subbasin of the Blue Mountains Ecological Reporting Unit.

Pathogens Modeled

Dwarf Mistletoes

Ponderosa pine, western larch, Douglas-fir, and lodgepole pine are dominant early-seral species in the basin; a host-specialized dwarf mistletoe is associated with each tree species. It is likely that under pre-European settlement fire regimes, dwarf mistletoe presence in these cover types favored compositions dominated by early-seral tree species, in the manner of a positive feedback. Fires associated with nonlethal and mixed-severity fire regimes favored the establishment and perpetuation of early seral tree species, maintaining spatial and temporal continuity of hosts, and local persistence of host-specialized mistletoes. Locally severe mistletoe infestations favored the torching of the most infested trees or tree groups. By this mechanism, dwarf mistletoes of early-seral species were potentially well distributed under presettlement conditions, but perhaps at lower infestation levels within host populations than is observed today. Dwarf mistletoes of shade-tolerant species occurring in mid- and late-successional communities were likely destabilizing to those communities, favoring tree group torching, crowning fires, and regeneration of early-seral species, in the manner of a negative feedback.

Mapping vulnerability to dwarf mistletoes—At least 40 percent of the Douglas-fir east of the crest of the Cascade Range in Oregon and Washington are infected with dwarf mistletoe (Bolsinger 1978). An equivalent proportion are infected in the upper Columbia basin (see footnote 2). About one-quarter of the ponderosa pine, one-half of the western larch, and 40 percent of the lodgepole pine in eastern Oregon and Washington are infected with a host-specialized dwarf mistletoe (Bolsinger 1978). It is estimated that an even greater proportion of the lodgepole pine in the upper Columbia basin are infected (see footnote 2). Landscape vulnerability to dwarf mistletoe disturbance is correlated with host abundance, pathogen distribution,[4] patch structure, host size and age, site quality, and host connectivity. Vulnerability to Douglas-fir (DFDM), ponderosa pine (PPDM), western larch (WLDM), and lodgepole pine (LPDM) dwarf mistletoe disturbances was attributed to all forested vegetation patches; those containing no host species in either the overstory or understory were given the lowest score for each factor where host was identified. Vulnerability factors for each host-specific dwarf mistletoe disturbance were (1) site quality, (2) host abundance, (3) canopy structure, (4) host age, and (5) connectivity of host patches. Tables 11-14 display vulnerability factors for DFDM, PPDM, WLDM, and LPDM, respectively, and criteria for rating vegetation polygons for each factor.

Patch vulnerability ratings for each of the four dwarf mistletoe disturbances were collapsed into vulnerability classes as follows: low for patches with a composite rating of 5 to 7; moderate for patches rated 8 to 10; and high for patches rated 11 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to each dwarf mistletoe disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 7B illustrates expanded area vulnerable to DFDM disturbance in a subwatershed of the Wallowa subbasin. Figure 8A illustrates reduced area vulnerable to WLDM disturbance in a subwatershed of the Swan subbasin.

Root Diseases

Landscape vulnerability to four root diseases was evaluated. Root pathogens of interest were *Phellinus weirii,* which causes laminated root rot, *Armillaria ostoyae,* which causes *Armillaria* root disease, and *Heterobasidion annosum,* which causes both the S (spruce)- and P (pine)-group annosum root diseases. Collectively, these root pathogens cause extensive mortality to Douglas-fir, grand fir, white fir, subalpine fir, and ponderosa pine, and cause butt rot and tree failure of most other conifers. Throughout the Douglas-fir, grand fir, and white fir zones (Franklin and Dyrness 1973), three root diseases have increased dramatically in distribution and severity in this century—laminated root rot, *Armillaria* root disease, and the S-group annosum root disease (Gast and other 1991, Hessburg and others 1994, Schmitt and others 1991). The noted increase is attributable to marked increases in the abundance of vulnerable shade-tolerant, fire-sensitive hosts as a result of fire exclusion and selective harvest activities (Agee 1993, 1994; Hessburg and others 1994, 1999; Lehmkuhl and others 1994; Oliver and others 1994; Schmitt and others 1991).

---

[4] Note here and following, actual inventory data on the distribution of dwarf mistletoes are needed for most accurate vulnerability characterization. Such inventories are needed Columbia basin-wide on a sampling basis. Lacking these data, vulnerability characterizations are based on the distribution and arrangement of vulnerable host patches, and presence of each host-specific mistletoe is assumed.

Table 11—Criteria for rating forest vegetation patch vulnerability to Douglas-fir dwarf mistletoe (DFDM) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Warm-dry PSME/ABGR(ABCO) sites
	2	Cool-moist PSME/ABGR(ABCO) sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PSME
	2	30 to 50 percent crown cover in PSME
	1	< 30 percent crown cover in PSME, or other
Canopy structure	3	2 or more PSME layers
	2	2 or more mixed-species layers with PSME
	1	1 PSME layer, or 1 mixed-species layer with PSME
Host age	3	Estimated > 120 years old, overstory large tree PSME (> 63.5 cm d.b.h.)
	2	Estimated 80 to 120 years old, overstory or under story medium tree PSME (40.6 to 63.5 cm d.b.h.)
	1	Estimated < 80 years old, overstory or understory seedling, sapling, pole, or small tree PSME (≤ 40.5 cm d.b.h.)
Host patch connectivity[a]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] Connectivity was computed for patches with PSME. Using a 1-hm radius (1 hm = 100 m), we assumed that DFDM seeds would spread disease to adjacent patches with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities including occasional seed dispersal by birds were insignificant.

Table 12—Criteria for rating forest vegetation patch vulnerability to western dwarf mistletoe (PPDM) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	PIPO sites
	2	Warm-dry PSME/ABGR(ABCO) sites
	1	Cool-moist PSME/ABGR(ABCO) sites, and other sites
Host abundance	3	> 50 percent crown cover in PIPO
	2	30 to 50 percent crown cover in PIPO
	1	< 30 percent crown cover in PIPO, or other
Canopy structure	3	2 or more layers of PIPO
	2	2 or more mixed-species layers with PIPO
	1	1 PIPO layer, or 1 mixed-species layer with PIPO
Host age	3	Estimated > 120 years old, overstory large tree PIPO (> 63.5 cm d.b.h.)
	2	Estimated 80 to 120 years old, overstory or understory medium tree PIPO (40.6 to 63.5 cm d.b.h.)
	1	Estimated < 80 years old, overstory or understory seedling, sapling, pole, or small tree PIPO (< 40.6cm d.b.h.)
Host patch connectivity[a]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] Connectivity was computed for patches with PIPO. Using a 1-hm radius (1 hm = 100 m), we assumed that PPDM seeds would spread disease to adjacent patches with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities including occasional seed dispersal by birds were insignificant.

Table 13—Criteria for rating forest vegetation patch vulnerability to western larch dwarf mistletoe (WLDM) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Cool-moist PSME/ABGR(ABCO) sites
	2	ABLA2/PIEN sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in LAOC
	2	30 to 50 percent crown cover in LAOC
	1	< 30 percent crown cover in LAOC, or other
Canopy structure	3	2 or more layers with LAOC
	2	2 or more mixed-species layers with LAOC
	1	1 LAOC layer, or 1 mixed-species layer with LAOC
Host age	3	Estimated > 120 years old, large tree LAOC (> 63.5 cm d.b.h.) overstory
	2	Estimated 80 to 120 years old, medium tree LAOC (40.6 to 63.5 cm d.b.h.) overstory or understory
	1	Estimated < 80 years old, overstory or understory seedling, sapling, pole, or small tree LAOC (< 40.6 cm d.b.h.)
Host patch connectivity[a]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] Connectivity was computed for patches with LAOC. Using a 1-hm radius (1 hm = 100 m), we assumed that WLDM seeds would spread disease to adjacent patches with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities including occasional seed dispersal by birds were insignificant.

Table 14—Criteria for rating forest vegetation patch vulnerability to lodgepole pine dwarf mistletoe (LPDM) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Edaphic PICO sites, ABLA2/PIEN sites
	2	PSME/ABGR(ABCO) or ABMA sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PICO
	2	30 to 50 percent crown cover in PICO
	1	< 30 percent crown cover in PICO, or other
Canopy structure	3	2 or more layers of PICO
	2	2 or more mixed-species layers with PICO
	1	1 PICO layer, or 1 mixed-species layer with PICO
Host age	3	Estimated as > 120 years old, PICO overstory or understory medium and large trees (≥ 40.6 cm d.b.h.)
	2	Estimated as 80 to 120 years old, PICO overstory or understory small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old, PICO overstory or understory seedling/saplings, poles (< 22.9 cm d.b.h.)
Host patch connectivity[a]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] Connectivity was computed for host patches with PICO. Using a 1-hm radius (1 hm = 100 m), we assumed that LPDM seeds would have the ability to spread disease to adjacent patches with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities including occasional seed dispersal by birds were insignificant.

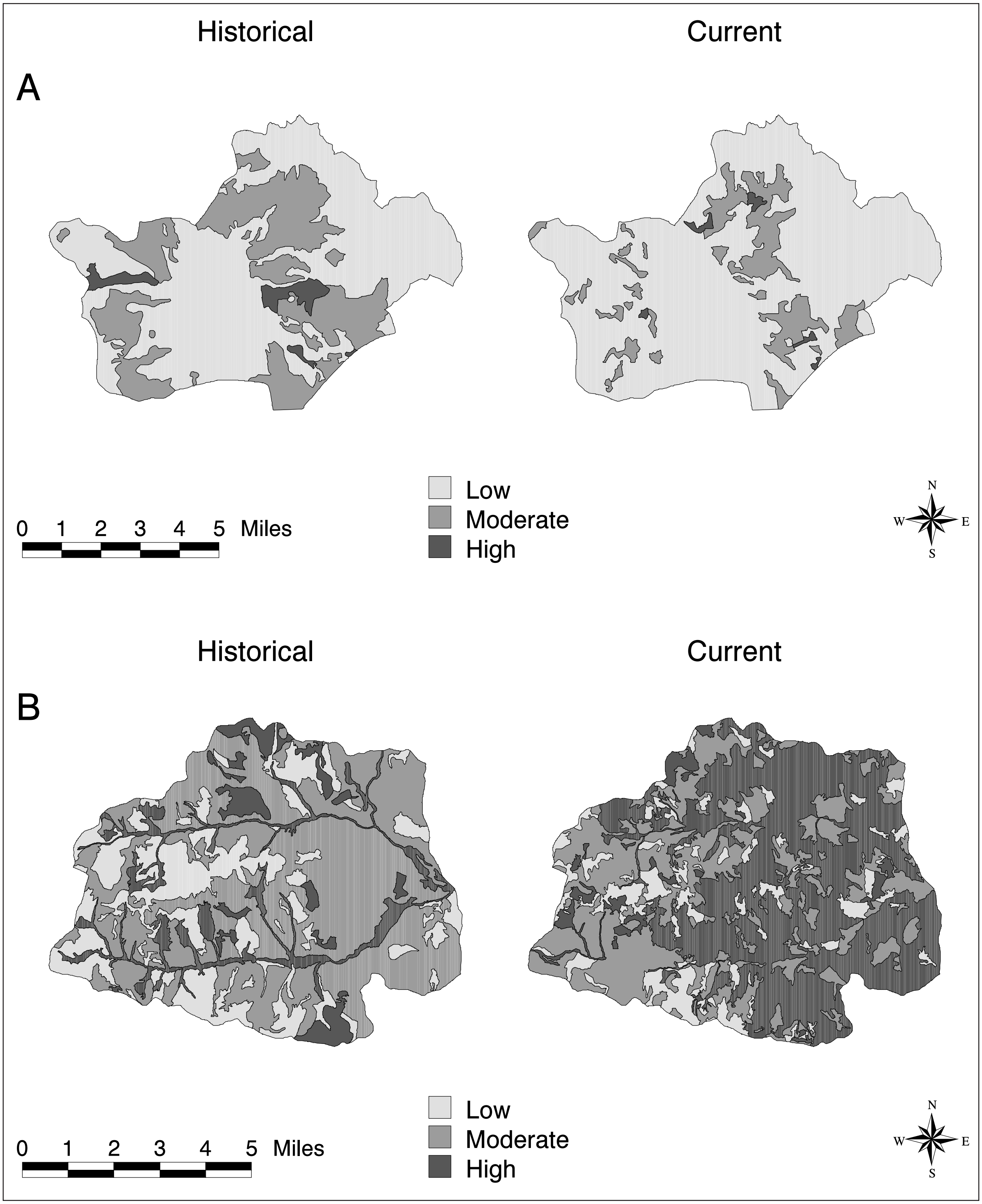


Figure 8—Historical and current vegetation vulnerability to (A) western larch dwarf mistletoe disturbance in subwatershed 0202 in the Swan subbasin of the Northern Glaciated Mountains Ecological Reporting Unit, (B) *Armillaria* root disease disturbance in subwatershed 20 in the Kettle subbasin of the Northern Glaciated Mountains Ecological Reporting Unit.

Native true firs other than grand and white fir, Engelmann spruce, and western hemlock often develop severe butt rot associated with either S-group annosum root disease or laminated root rot, especially when they are infected as large trees. Mountain hemlock is also highly vulnerable to butt rot and mortality effects of laminated root rot. Increased S- and P-group annosum root disease incidence and severity is correlated with increased selective harvest activity (Schmitt and others 1991). New centers of disease are initiated when freshly cut stump surfaces are infected by spores of either host-specialized variant. P-group annosum root disease mortality is most prevalent on hot, dry climax ponderosa pine sites (Goheen and Goheen 1989). Ponderosa pine is commonly infected on more productive ponderosa pine sites within the Douglas-fir and grand fir zones, but mortality is infrequent except in drought years or during prolonged droughts when tree vigor is depressed. In general, root disease mortality produces abundant gaps in host forest canopies, and mosaics of dead, dying, and symptomless trees and tree groups. In the Douglas-fir, grand fir, and white fir zones, this gradual and continuous thinning favors release and regeneration of additional vulnerable shade-tolerant trees.

Mapping vulnerability to root diseases—Landscape vulnerability to root disease disturbance is correlated with site quality, host abundance, pathogen distribution, host size and age, patch (stand) density and structure, logging disturbance history, host vigor, and connectivity of host patches. Vulnerability to *Armillaria* root disease (AROS), laminated root rot (PHWE), and S- and P-group annosum root disease (HEAN_s and HEAN_p) disturbances was attributed to all forested vegetation patches; those containing no host species in either the overstory or understory were given the lowest score for each factor where host was identified. Vulnerability factors for the four root disease disturbances were (1) site quality, (2) host abundance, (3) canopy structure, (4) host age, (5) disturbance history by using visible logging entry, and (6) connectivity of host patches. Tables 15-18 display vulnerability factors for AROS, PHWE, HEAN_s, and HEAN_p disturbances, respectively, and criteria for rating vegetation polygons for each factor.

Patch vulnerability ratings for AROS and PHWE root disease disturbances were collapsed into vulnerability classes as follows: low for patches with a composite rating of 5 to 8; moderate for patches rated 9 to 11; and high for patches rated 12 and above. Patch vulnerability ratings for HEAN_s and HEAN_p root disease disturbances were collapsed into slightly different vulnerability classes: low for patches with a composite rating of 6 to 9; moderate for patches rated 10 to 12; and high for patches rated 13 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to each root disease disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 8B illustrates expanded area vulnerable to AROS disturbance in a subwatershed of the Kettle subbasin. Figure 9A illustrates expanded area vulnerable to PHWE disturbance in a subwatershed of the Upper Deschutes subbasin. Figure 9B illustrates expanded area vulnerable to HEAN_s disturbance in a subwatershed of the Snake Headwaters subbasin.

Butt Rots

Tomentosus root and butt rot—The fungus *Inonotus tomentosus* causes a root and butt rot common on spruces and is occasionally reported on most western coniferous species. Local intertree spread is via mycelial extension between diseased and healthy roots, and by ectotrophic or surface growth on roots. Long-distance spread occurs via spores. The fungus acts as a "nibbler" on root systems of most conifers, causing both localized and extensive root and butt decay. But, on spruces, root and butt decay can be quite spectacular. Severely affected trees are predisposed to windthrow or collapse especially on moist sites. Wind-thrown or collapsed spruce are almost immediately colonized by the spruce beetle. In moist to wet soils, Engelmann spruce tends to exhibit a shallow "pancake" rooting habit. Significant windthrow in mature spruce patches often is predicated on initial windthrow of trees with root disease.

Text continues on page 37.

Table 15—Criteria for rating forest vegetation patch vulnerability to *Armillaria* root disease (AROS) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality[a]	3	Cool-moist PSME/ABGR(ABCO); cool-moist ABLA2/PIEN; cool-moist TSHE/THPL sites
	2	Warm-dry PSME/ABGR(ABCO); warm-dry ABLA2/PIEN; warm-dry TSHE/THPL sites
	1	Other sites
Host abundance[b]	3	> 50 percent crown cover in host species
	2	30 to 50 percent crown cover in host species
	1	< 30 percent crown cover in host species, or other
Canopy structure	3	2 or more layers PSME or ABGR(ABCO) or ABLA2/PIEN; or 2 or more mixed-species layers with PSME or ABGR(ABCO) or ABLA2/PIEN in both layers
	2	1 layer PSME or ABGR(ABCO) or ABLA2/PIEN
	1	1 mixed-species layer with PSME or ABGR(ABCO) or ABLA2/PIEN
Host age[c]	3	Estimated as > 120 years old, overstory or under story PSME, ABGR(ABCO), ABAM, ABMA, ABPR, PIEN, PIPO, PIMO, PILA, TSHE/THPL, CADE or LAOC large trees (> 63.5 cm d.b.h.), or overstory or understory ABLA2, PICO, or TSME medium and large trees (≥ 40.6 cm d.b.h.)
	2	Estimated as 80 to 120 years old, overstory or understory PSME, ABGR(ABCO), ABAM, ABMA, ABPR, PIEN, PIPO, PIMO, PILA, TSHE/THPL, CADE or LAOC medium trees (40.6 to 63.5 cm d.b.h.), or overstory or understory ABLA2, PICO, or TSME small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old overstory or understory PSME, ABGR(ABCO), ABAM, ABMA, ABPR, PIEN, PIPO, PIMO, PILA, TSHE/THPL, CADE or LAOC seedling/sapling, pole, or small trees (< 40.6 cm d.b.h.), or overstory or understory ABLA2, PICO, or TSME seedling/sapling, or pole trees (< 22.9 cm d.b.h.)
Host patch connectivity[d]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] McDonald (1990, 1991) reports that in Idaho and Montana, mortality effects associated with *Armillaria* root disease (NABS I) were more likely expressed on sites of intermediate productivity (mesic sites), and rarely expressed on dry or wet sites.

[b] All conifers are host to *Armillaria ostoyae*, but some are more susceptible than others. Differences in susceptibility to infection were captured by weighting host abundance. When hosts were PSME, ABGR(ABCO), or ABLA2/PIEN, the host abundance weighting factor was 1.5. When hosts were PIPO, PICO, PIMO, PILA, ABAM, ABPR, ABMA, and TSHE/THPL, TSME the host abundance weighting factor was 1.0. When hosts were other than these, the host abundance weighting factor was 0.5.

[c] Host age was primarily used as a vulnerability factor for AROS because patch structural and compositional attributes are more vulnerable to change as a consequence of root disease disturbance when hosts are large than when hosts are small. Host age differences also were estimated to incorporate a measure of patch vulnerability as a function of inoculum potential. Large infected host trees, whether living or dead, will persist as viable infectious inoculum longer than smaller trees, thereby potentially bridging the disease to subsequent generations of vulnerable trees. Older trees of some species, not including PSME or ABGR(ABCO), are also more vulnerable to damage by AROS than younger trees.

[d] Connectivity was computed for patches with PSME, ABGR(ABCO), PIPO, PICO, PIMO, PILA, ABAM, ABPR, ABMA, TSHE/THPL, ABLA2/PIEN, TSME, LAOC, or CADE. Using a 1-hm radius (1 hm = 100 m), we assumed that vegetative spread of AROS to adjacent patches would occur with high probability when areas of hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities by vegetative spread or spore infection were insignificant.

Table 16—Criteria for rating forest vegetation patch vulnerability to laminated root rot (PHWE) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Cool-moist PSME/ABGR(ABCO); cool-moist ABLA2/PIEN; TSME; cool-moist TSHE/THPL sites
	2	Warm-dry PSME/ABGR(ABCO); warm-dry ABLA2/PIEN; warm-dry TSHE/THPL; ABAM sites
	1	Other sites
Host abundance[a]	3	> 50 percent crown cover in host species
	2	30 to 50 percent crown cover in host species
	1	< 30 percent crown cover in host species, or other
Canopy structure	3	2 or more layers of PSME or ABGR(ABCO) or TSME; or 2 or more mixed-species layers with PSME or ABGR(ABCO) or TSME
	2	1 layer PSME or ABGR(ABCO) or TSME
	1	1 mixed-species layer with PSME or ABGR(ABCO) or TSME
Host age[b]	3	Estimated as > 120 years old, overstory or understory PSME or ABGR(ABCO) or ABAM or ABMA or ABPR or PIEN or PIPO or PIMO or PILA or TSHE/THPL or CADE or LAOC large trees (> 63.5 cm d.b.h.), or ABLA2 or PICO or TSME medium and large trees (≥ 40.6 cm d.b.h.)
	2	Estimated as 80 to 120 years old, overstory or understory PSME or ABGR(ABCO) or ABAM or ABMA or ABPR or PIEN or PIPO or PIMO or PILA or TSHE/THPL or CADE or LAOC medium trees (40.6 to 63.5 cm d.b.h.), or ABLA2 or PICO or TSME small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old, overstory or understory PSME or ABGR(ABCO) or ABAM or ABMA or ABPR or PIEN or PIPO or PIMO or PILA or TSHE/THPL or CADE or LAOC seedling, sapling, pole, or small trees (≤ 40.5 cm d.b.h.), or ABLA2 or PICO or TSME seedlings, saplings, or poles (< 22.9 cm d.b.h.)
Host patch connectivity[c]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] All conifers are host to *Phellinus weirii*, but differences in susceptibility to infection and mortality effects are well documented (Filip and Schmitt 1979, Hadfield and others 1986, Hadfield and Johnson 1977). When hosts were PSME, ABGR(ABCO), or TSME, the host abundance weighting factor was 1.5. When hosts were ABAM, ABPR, ABMA, TSHE/THPL, ABLA2/PIEN, or LAOC, the host abundance weighting factor was 1.0. When hosts were other than these, host abundance weighting was 0.5.

[b] Host age was used as a vulnerability factor for PHWE because patch structural attributes are more vulnerable to change as a consequence of root disease disturbance when hosts are large than when hosts are small. Host age differences also were estimated to incorporate a measure of patch vulnerability as a function of inoculum potential. Large infected host trees, whether living or dead, will persist as viable infectious inoculum longer than smaller trees, thereby potentially bridging the disease to subsequent generations of vulnerable trees.

[c] Connectivity was computed for patches with PSME, ABGR(ABCO), ABAM, ABPR, ABMA, TSHE/THPL, ABLA2/PIEN, or TSME. Using a 1-hm radius (1 hm = 100 m), we assumed that vegetative spread of PHWE to adjacent patches would occur with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities by vegetative spread or spore infection were insignificant.

Table 17—Criteria for rating forest vegetation patch vulnerability to S-group annosum ($HEAN_s$) root disease disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Cool-moist PSME/ABGR(ABCO); cool-moist ABLA2/PIEN; cool-moist TSHE/THPL; TSME; ABAM; ABMA sites
	2	Warm-dry PSME/ABGR(ABCO); warm-dry TSHE/THPL; warm-dry ABLA2/PIEN sites
	1	Other sites
Host abundance[a]	3	> 50 percent crown cover in host species
	2	30 to 50 percent crown cover in host species
	1	< 30 percent crown cover in host species, or other
Canopy structure[b]	3	2 or more layers host species; or 2 or more mixed-species layers with host species
	2	1 layer with host species
	1	1 mixed-species layer with host species
Host age[c]	3	Estimated as > 120 years old, overstory or understory ABGR(ABCO), PSME (Idaho and Montana subbasins only), ABAM, ABMA, ABPR, PIEN or TSHE/THPL large trees (> 63.5 cm d.b.h.), or overstory or understory ABLA2 or TSME medium and large trees (≥ 40.6 cm d.b.h.)
	2	Estimated as 80 to 120 years old, overstory or understory ABGR(ABCO), PSME (Idaho and Montana subbasins only), ABAM, ABMA, ABPR, PIEN or TSHE/THPL medium trees (40.6 to 63.5 cm d.b.h.), or overstory or understory ABLA2 or TSME small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old, overstory or understory ABGR(ABCO), PSME (Idaho and Montana subbasins only), ABAM, ABMA, ABPR, PIEN, TSHE/THPL seedling/saplings, poles, small trees (≤ 40.5 cm d.b.h.), or overstory or understory ABLA2 or TSME seedling/saplings, poles (< 22.9 cm d.b.h.)
Logging disturbance	3	Selective harvest visible with hosts present history
	2	Regeneration harvest (including patch clearcutting) or commercial thinning visible with hosts present
	1	No visible logging entry, or other
Host patch connectivity[d]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] True firs, hemlocks, Douglas-fir (Idaho and Montana subbasins only), and spruces are host to S-group *Heterobasidion annosum*. When hosts were ABGR(ABCO), PSME (Idaho and Montana subbasins only), ABLA2/PIEN, ABAM, or TSME, the host abundance weighting factor was 1.5. When hosts were ABPR, ABMA, and TSHE/THPL, the host abundance weighting factor was 1.0. When hosts were other than these, the host abundance weighting factor was 0.5.

[b] Hosts were ABGR (ABCO), PSME (Idaho and Montana subbasins only), ABLA2/PIEN, ABAM, ABPR, ABMA, TSME, and TSHE/THPL.

[c] Host age was used as a vulnerability factor for $HEAN_s$ because patch structural attributes are more vulnerable to change as a consequence of root disease disturbance when hosts are large than when hosts are small. Host age differences also were estimated to incorporate a measure of patch vulnerability as a function of inoculum potential. Large vulnerable trees, whether living or dead, will persist as viable infectious inoculum longer than smaller trees, thereby potentially bridging the disease to subsequent generations of vulnerable trees.

[d] Connectivity was computed for host patches with ABGR(ABCO), PSME (Idaho and Montana subbasins only), ABAM, ABPR, ABMA, TSHE/THPL, ABLA2/PIEN, or TSME. Using a 1-hm radius (1 hm = 100 m), we assumed that vegetative spread of $HEAN_s$ to adjacent patches would occur with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities by vegetative spread or spore infection were insignificant. Because spore infection of freshly cut stumps and injured trees is a common occurrence, this estimate of connectivity may be highly conservative. Patch-specific data on harvest history and borax treatment of stumps for all sampled subwatersheds, were unavailable. Logging disturbance was photo-interpreted, but we assumed occurrence was underestimated.

Table 18—Criteria for rating forest vegetation patch vulnerability to P-group annosum ($HEAN_p$) root disease disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	PIPO sites
	2	Warm-dry PSME/ABGR(ABCO) sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PIPO
	2	30 to 50 percent crown cover in PIPO
	1	< 30 percent crown cover in PIPO, or other
Canopy structure	3	2 or more layers of PIPO, or 2 or more mixed-species layers with PIPO
	2	1 layer PIPO
	1	1 mixed-species layer with PIPO
Host age[a]	3	Estimated as > 120 years old, PIPO large trees (> 63.5 cm d.b.h.)
	2	Estimated as 80 to 120 years old, PIPO medium trees (40.6 to 63.5 cm d.b.h.)
	1	Estimated as < 80 years old, PIPO seedling, sapling, pole, or small trees (≤ 40.5 cm d.b.h.)
Logging disturbance	3	Selective harvest visible with hosts present history
	2	Regeneration harvest (including patch clearcutting) or commercial thinning visible with hosts present
	1	No visible logging entry, or other
Host patch connectivity[b]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] Host age was used as a vulnerability factor for $HEAN_p$ because patch structural attributes are more vulnerable to change as a consequence of root disease disturbance when hosts are large than when hosts are small. Host age differences also were estimated to incorporate a measure of patch vulnerability as a function of inoculum potential. Large vulnerable trees, whether living or dead, will persist as viable infectious inoculum longer than smaller trees, thereby potentially bridging the disease to subsequent generations of vulnerable trees.

[b] Connectivity was computed for patches with PIPO. Using a 1-hm radius (1 hm = 100 m), we assumed that vegetative spread of $HEAN_p$ to adjacent patches would occur with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities by vegetative spread or spore infection were insignificant. Because spore infection of freshly cut stumps and injured trees commonly occurs, this estimate of connectivity may be highly conservative. Patch-specific data on harvest history and borax treatment of stumps for all sampled subwatersheds, were unavailable. Logging disturbance was photo-interpreted, but we assumed occurrence was underestimated.

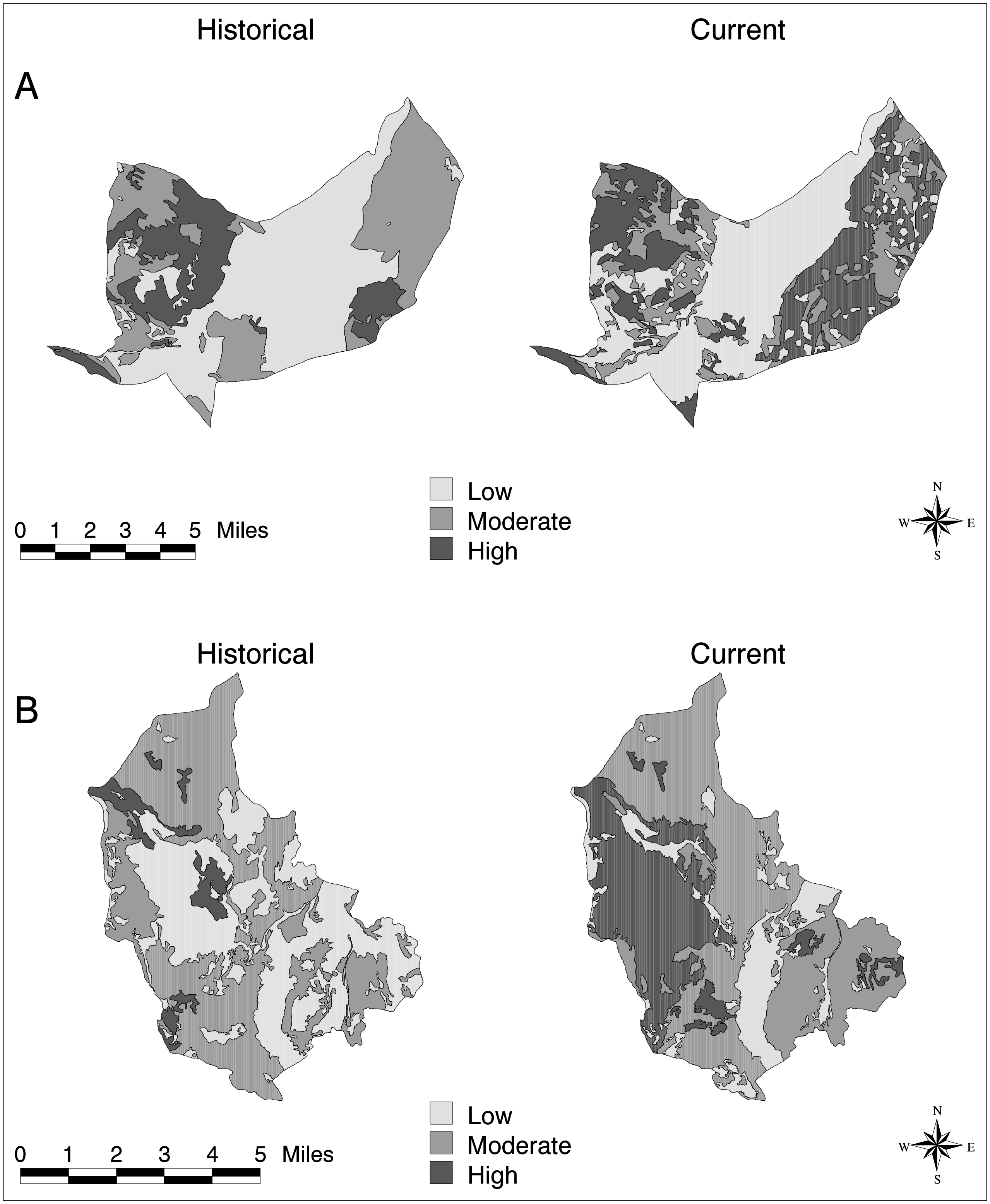


Figure 9—Historical and current vegetation vulnerability to (A) laminated root rot disturbance in subwatershed 30 in the Upper Deschutes subbasin of the Southern Cascades Ecological Reporting Unit, (B) S-group annosum root disease disturbance in subwatershed 0305 in the Snake Headwaters subbasin of the Snake Headwaters Ecological Reporting Unit.

Table 19—Criteria for rating forest vegetation patch vulnerability to tomentosus root and butt rot (TRBR) root disease disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Host abundance	3	> 50 percent crown cover in PIEN
	2	30 to 50 percent crown cover in PIEN
	1	Other spp. or < 30 percent crown cover in PIEN
Host age	3	Estimated as > 120 years old, PIEN large trees (> 63.5 cm d.b.h.) overstory or understory
	2	Estimated as 80 to 120 years old, PIEN medium trees (40.6 to 63.5 cm d.b.h.) overstory or understory
	1	Estimated as < 80 years old, PIEN small trees (22.9 to 40.5 cm d.b.h.) overstory or understory
Topographic setting	3	Valley bottom settings (toe-slopes to valley bottoms) with hosts present
	1	Other settings
Host patch connectivity[a]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] Connectivity was computed for host patches with PIEN. Using a 1-hm radius (1 hm = 100 m), we assumed that vegetative spread of TRBR to adjacent patches would occur with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities were insignificant.

Mapping vulnerability to tomentosus root and butt rot—Landscape vulnerability to tomentosus root and butt rot (TRBR) disturbance is correlated with host abundance, pathogen distribution, topographic setting, host size and age, and connectivity of host patches. Site quality is not included because most patches of older spruce, regardless of site quality, appear to be affected by this disease. Vulnerability to TRBR disturbance was attributed to all forested vegetation patches; those containing no spruce in either the overstory or understory were given the lowest score for each factor where host was identified. The TRBR host in this analysis was PIEN. Vulnerability factors for TRBR disturbance were (1) host abundance, (2) host age, (3) topographic setting by using the riparian status attribute, and (4) connectivity of host patches. Table 19 displays vulnerability factors for TRBR disturbance and criteria for rating vegetation polygons for each factor.

Patch vulnerability ratings for TRBR disturbance were collapsed into vulnerability classes as follows: low for patches with a composite rating of 4 to 6; moderate for patches rated 7 to 8; and high for patches rated 9 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to TRBR disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum.

Table 20—Criteria for rating forest vegetation patch vulnerability to Schweinitzii root and butt rot (SRBR) root disease disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Cool-moist PSME/ABGR(ABCO); cool-moist TSHE/THPL; ABAM; ABMA; cool-moist ABLA2/PIEN; TSME sites
	2	Warm-dry ABLA2/PIEN; warm-dry PSME/ABGR(ABCO); warm-dry TSHE/THPL sites
	1	Other sites
Host abundance[a]	3	> 50 percent crown cover in host species
	2	30 to 50 percent crown cover in host species
	1	< 30 percent crown cover in host species, or other
Host age	3	Estimated as > 120 years old, overstory or understory PSME, LAOC, PIPO, or PIEN large trees (> 63.5 cm d.b.h.), or PICO medium and large trees (≥ 40.6 cm d.b.h.)
	2	Estimated as 80 to 120 years old, overstory or understory PSME, LAOC, PIPO, or PIEN medium trees (40.6 to 63.5 cm d.b.h.), or PICO small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old, overstory or understory PSME, LAOC, PIPO, or PIEN seedling, sapling, pole, or small trees (< 40.6 cm d.b.h.), or PICO seedling, sapling, or pole trees (<22.9 cm d.b.h.)
Host patch connectivity[b]	3	> 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	2	30 to 50 percent of the area within a 1-hm radius of host patch boundaries is host type
	1	< 30 percent of the area within a 1-hm radius of host patch boundaries is host type

[a] All conifers are host to *Phaeolus schweinitzii*, but some species are more susceptible to infection and tree collapse than others. When hosts were PSME or LAOC, the host abundance weighting factor was 1.5. When hosts were PIPO, PIEN, and PICO, the host abundance weighting factor was 1.0. When hosts were other than these, the host abundance weighting factor was 0.5.

[b] Connectivity was computed for patches with PSME, LAOC, ABGR(ABCO), PIPO, PICO, PIMO, PILA, ABAM, ABPR, ABMA, TSHE/THPL, ABLA2/PIEN, or TSME. Using a 1-hm radius (1 hm = 100 m), we assumed that SRBR would spread to adjacent patches with high probability when hosts were within the 1-hm radius. Beyond this radius, we assumed that dispersal opportunities were insignificant.

Schweinitzii root and butt rot—The fungus *Phaeolus schweinitzii* causes an important root and butt rot (Schweinitzii root and butt rot—also called brown cubical butt rot) of western larch, Douglas-fir, ponderosa pine, Engelmann spruce, lodgepole pine, and occasionally most other western conifers. Over several centuries, ongoing tree collapse associated with this pathogen has been responsible for significant structural and compositional change of patches and landscapes dominated by hosts. Local intertree spread is slow, occurring via mycelial extension through duff between diseased and healthy roots. Long-distance spread occurs via spore infections of recent scars, especially fire scars. In its primary hosts, the fungus causes an extensive decay of the roots and butt. Butt decay may extend 6 to 9 m or more up the bole. Severely affected trees are predisposed to collapse, breaking off in a characteristic "barber-chair" fashion. Wind-thrown or collapsed trees often are colonized by bark beetles native to each host. In the case of western larch, which lacks primary bark beetle associates, the Douglas-fir beetle occasionally colonizes recent wind-thrown or collapsed larch.

Mapping vulnerability Schweinitzii root and butt rot— Landscape vulnerability to Schweinitzii root and butt rot (SRBR) disturbance is correlated with site quality, host abundance, pathogen distribution, host size and age, and connectivity of host patches. Vulnerability to SRBR disturbance was attributed to all forested vegetation patches; those containing no host species in either the overstory or understory were given the lowest score for each factor where host was identified. Schweinitzii root and butt rot hosts in this analysis were LAOC, PSME, PIPO, PIEN, and PICO. Vulnerability factors for SRBR disturbance were (1) site quality, (2) host abundance, (3) host age, and (4) connectivity of host patches. Table 20 displays vulnerability factors for SRBR disturbance, and criteria for rating vegetation polygons for each factor.

Patch vulnerability ratings for SRBR disturbance were collapsed into vulnerability classes as follows: low for patches with a composite rating of 4 to 6, moderate for patches rated 7 to 8, and high for patches rated 9 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to SRBR disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 10A illustrates expanded area vulnerable to SRBR disturbance in a subwatershed of the Burnt subbasin.

Rusts

White pine blister rust—Since its introduction into North America in the early part of this century (1909-10), the fungus that causes white pine blister rust (*Cronartium ribicola*) has devastated native five-needle pines throughout their ranges. Throughout the basin, western white pine, sugar pine and whitebark pine have been significantly impacted. The blister rust is macrocyclic (has a long life cycle including five separate spore stages) and heteroecious, completing its life cycle on two different types of hosts—five-needle pines and native currants (*Ribes* spp.). Effects of the rust on native five-needle pines are primarily mortality and topkilling, although some genotypes of native five-needle pines exhibit resistance. Bark beetles are frequently involved in the demise of trees with bole infections. Monnig and Byler (1992) estimated that in the West (Idaho and Montana[5]), about 90 percent of the western white pine have been killed by the fungus to date. Efforts to reintroduce western white and sugar pines are ongoing via the deployment of genetically resistant stock. Whitebark pine is also severely damaged throughout its range, but efforts to select and deploy genetically resistant whitebark pine stock have been minimal to date. This is perhaps because of a combination of factors: a lack of public awareness of the current plight of whitebark pine; little commercial value of the species, and limited access to whitebark pine forests (Keane and Arno 1993)—whitebark pine is a subalpine species occurring primarily in high-elevation wilderness settings.

***Mapping vulnerability to white pine blister rust*—** Vulnerability to white pine blister rust (WPBR) disturbance was attributed to all forested vegetation patches; those containing no hosts in either the understory or overstory were given the lowest score for each factor where host was identified. Hosts of WPBR are western white pine (PIMO), sugar pine (PILA), and whitebark pine (PIAL). Two types of WPBR vulnerability were evaluated: type 1 vulnerability of PIMO and PILA, and type 2 vulnerability of PIAL. Three vulnerability factors were used to attribute patch vulnerability to types 1 and 2 WPBR disturbance: (1) site quality, (2) host abundance, and (3) host size. Tables 21 and 22 display type 1 and 2 WPBR vulnerability factors and criteria for rating vegetation polygons for each factor, respectively.

Type 1 and type 2 WPBR patch vulnerability ratings were collapsed into vulnerability classes as follows: low for patches with a composite rating of 3 to 4, moderate for patches rated 5 to 6, and high for patches rated 7 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to type 1 and type 2 WPBR disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum. Figure 10B illustrates reduced area vulnerable to type 1 WPBR disturbance in a subwatershed of the Pend Oreille subbasin.

Stem Decays

Rust-red stringy rot—The Indian paint fungus (*Echinodontium tinctorium*) causes an important heartrot of true firs and hemlocks (*Tsuga* spp.). Severe stem decay reduces most of the heartwood to a rust-red stringy rot. Live and dead trees with rotted heartwood are important to cavity-excavating birds, and other birds and small mammals for their soft, rotted interiors, and for the arthropod prey species they house. Severely decayed live trees collapse in high winds and under the burden of heavy snow and ice accumulation. True firs and hemlocks suppressed 40 years or more are most vulnerable to infection. Windborne spores infect lateral branchlet vascular traces of suppressed hosts. Infections lie dormant until trees are injured. Common injuries that initiate heartwood decay include logging injuries, basal frost cracks, basal fire scalding, and bark beetle strip attacks. In recent years, significant increase of this defect in the grand fir, white fir, and subalpine fir zones has been associated with effective fire exclusion and selective harvest practices (Gast and others 1991, Hessburg and others 1994), both of which encourage regeneration and release of shade-tolerant true firs.

---

[5] Personal communication. 1996. Jim Byler, Group Leader. USDA Forest Service, Idaho Panhandle National Forests, 1201 Ironwood Drive, Coeur d'Alene, ID 83814.

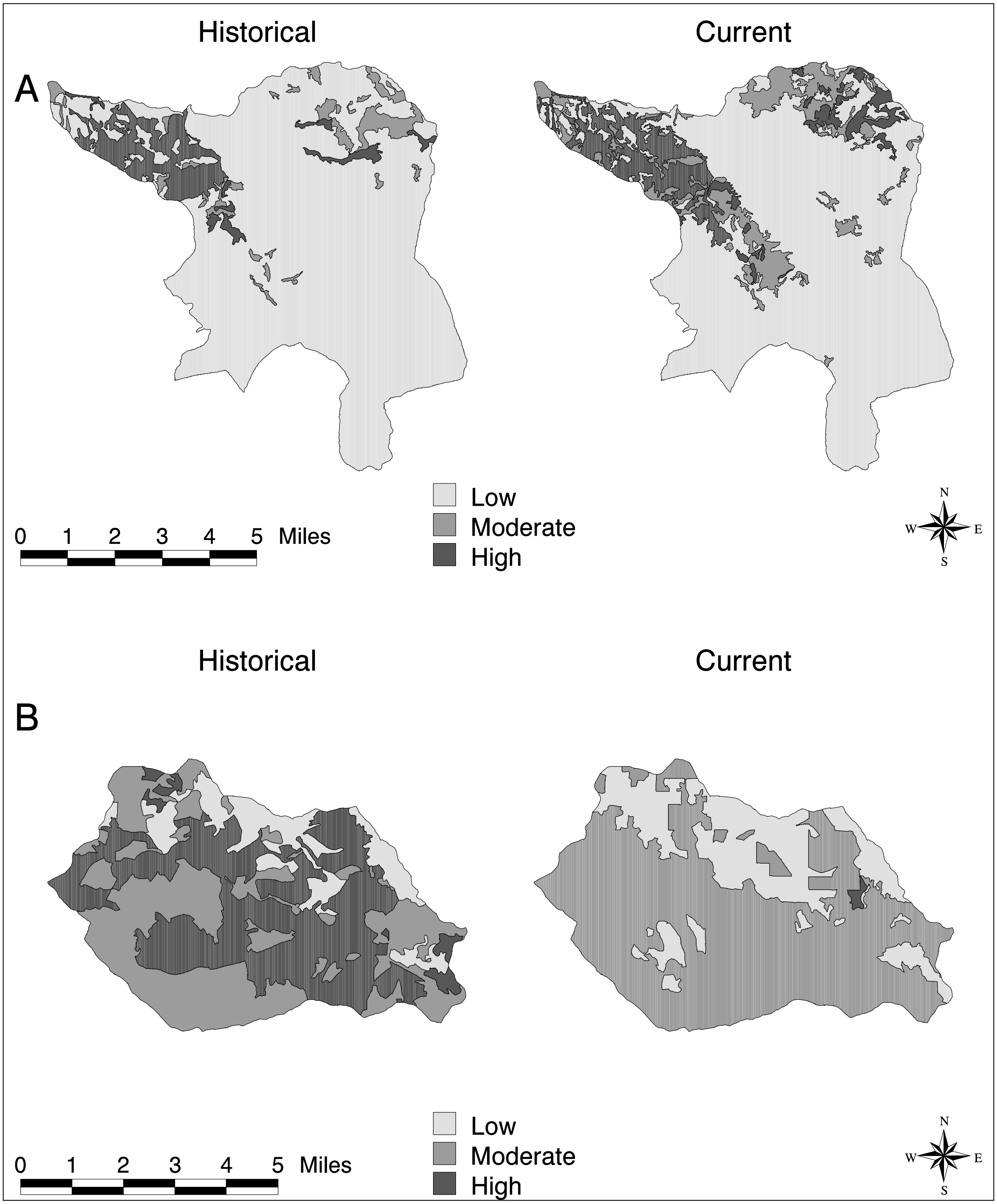


Figure 10—Historical and current vegetation vulnerability to (A) Schweinitzii root and butt rot disturbance in subwatershed 0901 in the Burnt subbasin of the Blue Mountains Ecological Reporting Unit, (B) white pine blister rust type 1 disturbance in subwatershed 09 in the Pend Oreille subbasin of the Northern Glaciated Mountains Ecological Reporting Unit.

Table 21—Criteria for rating forest vegetation patch vulnerability to type 1 white pine blister rust (WPBR) disturbance of western white pine (PIMO) and sugar pine (PILA) in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	ABAM; TSME; cool-moist TSHE/THPL; cool-moist ABLA2/PIEN sites
	2	Warm-dry TSHE/THPL; ABMA; cool-moist PSME/ABGR(ABCO); warm-dry ABLA2/PIEN sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PIMO or PILA
	2	30 to 50 percent crown cover in PIMO or PILA
	1	Other spp. or < 30 percent crown cover in PIMO or PILA
Host size[a]	3	Overstory or understory PIMO or PILA medium or large trees (≥ 40.6 cm d.b.h.)
	2	Overstory or understory PIMO or PILA poles or small trees (12.7 to 40.5 cm d.b.h.)
	1	Overstory or understory PIMO or PILA seedling/saplings, (< 12.7 cm d.b.h.)

[a] Host size was used as a vulnerability factor for WPBR because patch structural attributes are more vulnerable to change as a consequence of rust disturbance when hosts are large than when hosts are small.

Table 22—Criteria for rating forest vegetation patch vulnerability to type 2 white pine blister rust (WPBR) disturbance of whitebark pine (PIAL) in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Warm-dry ABLA2/PIEN; cold-dry-harsh ABLA2/PIEN sites
	2	TSME; ABMA; cool-moist ABLA2/PIEN sites
	1	Other sites
Host abundance	3	> 50 percent crown cover in PIAL
	2	30 to 50 percent crown cover in PIAL
	1	<30 percent crown cover in PIAL, or other
Host size[a]	3	Overstory or understory PIAL medium or large trees (≥ 40.6 cm d.b.h.)
	2	Overstory or understory PIAL poles or small trees (12.7 to 40.5 cm d.b.h.)
	1	Overstory or understory PIAL seedling-saplings, (< 12.7 cm d.b.h.)

[a] Host size was used as a vulnerability factor for WPBR because patch structural attributes are more vulnerable to change as a consequence of rust disturbance when hosts are large than when hosts are small.

Table 23—Criteria for rating forest vegetation patch vulnerability to rust-red stringy rot (RRSR) disturbance in the midscale assessment of the interior Columbia River basin

Vulnerability factor	Patch rating	Rating criteria
Site quality	3	Cool-moist PSME/ABGR(ABCO); cool-moist TSHE/THPL; ABMA; TSME; ABAM sites
	2	Warm-dry PSME/ABGR(ABCO); cool-moist ABLA2/PIEN; warm-dry TSHE/THPL sites
	1	Other sites
Host abundance[a]	3	> 50 percent overstory and understory crown cover in host species
	2	30 to 50 percent overstory and understory crown cover in host species
	1	< 30 percent overstory and understory crown cover in host species, or other
Canopy structure	3	> 2 canopy layers
	2	2 canopy layers
	1	1 canopy layer
Host age	3	Estimated as > 120 years old, overstory or understory ABGR(ABCO), ABAM, ABMA, ABPR, or TSHE/THPL large trees (> 63.5 cm d.b.h.), or ABLA2 or TSME medium trees (40.6 to 63.5 cm d.b.h.)
	2	Estimated as 80 to 120 years old, overstory or understory ABGR(ABCO), ABAM, ABMA, ABPR or TSHE/THPL medium trees (40.6 to 63.5 cm d.b.h.), or ABLA2 or TSME small trees (22.9 to 40.5 cm d.b.h.)
	1	Estimated as < 80 years old, overstory or understory ABGR(ABCO), ABAM, ABMA, ABPR, or TSHE/THPL (22.9 to 40.5 cm d.b.h.) or ABLA2 or TSME seedling, sapling, or pole trees (< 22.9 cm d.b.h.)
Logging disturbance	3	Selective harvest visible with hosts present history
	2	Regeneration harvest (incl. patch clearcutting) or thinning (commercial or recommercial) visible with hosts present
	1	No visible logging entry

[a] RRSR hosts were ABGR(ABCO), ABLA2, ABAM, ABMA, ABPR, TSHE, and TSME.

Mapping vulnerability to rust-red stringy rot—Vulnerability to RRSR disturbance was attributed to all forested vegetation patches; those containing no hosts in either the overstory or understory were given the lowest score for each factor where host was identified. Vulnerability factors for RRSR disturbance were (1) site quality, (2) host abundance, (3) canopy structure, (4) host age and (5) disturbance history by using visible logging entry. Table 23 displays vulnerability factors for RRSR disturbance, and criteria for rating vegetation polygons for each factor.

Patch vulnerability ratings for RRSR disturbance were collapsed into vulnerability classes as follows: low for patches with a composite rating of 5 to 8, moderate for patches rated 9 to 12, and high for patches rated 13 and above. Vulnerability classes were used to characterize change in area and connectivity of area vulnerable to RRSR disturbance between historical and current vegetation conditions of subwatersheds of a pooling stratum.

Acknowledgments

We thank Jim Byler, Paul Flanagan, Don Goheen, Ellen Michaels Goheen, Jim Hadfield, Al Harvey, Jim Hoffman, and Julie Weatherby for critical reviews of an earlier draft of this paper. Their comments and suggestions improved the modeling logic and its presentation in this paper.

English Conversions

When you know:	Multiply by:	To find:
Centimeters (cm)	0.39370	Inches
Hectares (ha)	2.47105	Acres
Hectometers (hm)	328.08398	Feet
Kilometers (km)	3280.83989	Feet
Kilometers (km)	0.62137	Mile
Meters (m)	0.04971	Chain
Meters (m)	3.28084	Feet
Square meters (m^2)	10.76391	Square feet

Literature Cited

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Agee, J.K. 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. Gen. Tech. Rep. PNW-GTR-320. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 52 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Hessburg, Paul F., science team leader and tech. ed., Volume III: assessment.)

Bailey, R.G. 1995. Description of ecoregions of the United States. 2d ed. Misc. Publ. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p.

Bolsinger, C.L. 1978. The extent of dwarf mistletoe in six principal softwoods in California, Oregon, and Washington, as determined from forest survey records. In: Scharpf, R.F.; Parmeter, J.R., Jr., tech. coords. Proceedings of the symposium on dwarf mistletoe control through forest management; 1978 April 11-13; Berkeley, CA. Gen. Tech. Rep. PSW-GTR-31. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 190 p.

Brookes, M.H.; Campbell, R.W.; Colbert, J.J. [and others], tech. coords. 1987. Western spruce budworm. Tech. Bull. 1694. Washington, DC: U.S. Department of Agriculture, Forest Service; Cooperative State Research Service. 198 p.

Brookes, M.H.; Colbert, J.J.; Mitchell, R.G. [and others], tech. coords. 1985. Managing trees and stands susceptible to western spruce budworm. Tech. Bull. 1695. Washington, DC: U.S. Department of Agriculture, Forest Service; Cooperative State Research Service. 111 p.

Brookes, M.H.; Stark, R.W.; Campbell, R.W., eds. 1978. The Douglas-fir tussock moth: a synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture, Forest Service. 331 p.

Byler, J.W. 1988. Root diseases in western forests. In: Forest health through silviculture and integrated pest management—a strategic plan. Washington, DC: U.S. Department of Agriculture, Forest Service. [Irregular pagination]. (Supporting appendices; appendix E).

Carlson, C.E.; Schmidt, W.C.; Fellin, D.G.; Wulf, N.W. 1985. Silvicultural approaches to western spruce budworm management in the northern U.S. Rocky Mountains. In: Sanders, C.J.; Stark, R.W.; Mullins, E.J. [and others], eds. Recent advances in spruce budworms research: Proceedings of the CANUSA spruce budworms research symposium; 1984 September 16-20; Bangor, MA. Ottawa, Ontario: Canadian Forestry Service. 527 p.

Everett, R.; Hessburg, P.; Jensen, M. [and others]. 1994. Volume I: executive summary. Gen. Tech. Rep. PNW-GTR-317. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 61 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment).

Filip, G.M.; Schmitt, C.L. 1979. Susceptibility of native conifers to laminated root rot east of the Cascade Range in Oregon and Washington. Forest Science. 25: 261-265.

Franklin, J.F.; Dyrness, C.T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-GTR-118. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 452 p.

Gast, W.R., Jr.; Scott, D.W.; Schmitt, C.L. [and others]. 1991. Blue Mountains forest health report: "new perspectives in forest health." Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; Malheur, Umatilla, and Wallowa-Whitman National Forests. [Irregular pagination].

Goheen, E.M.; Goheen, D.J. 1989. Losses caused by annosus root disease in Pacific Northwest forests. In: Otrosina, W.J.; Scharpf, R.F., tech. coords. Proceedings of the symposium on research and management of annosus root disease (*Heterobasidion annosum*) in western North America; 1989 April 18-21; Monterey, CA. Gen. Tech. Rep. PSW-GTR-116. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 177 p.

Hadfield, J.S.; Johnson, D.W. 1977. Laminated root rot: a guide for reducing and preventing losses in Oregon and Washington forests. [Unnumbered publication]. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Pest Management. 16 p.

Hadfield, J.S.; Goheen, D.J.; Filip, G.M. [and others]. 1986. Root diseases in Oregon and Washington conifers. R6-FPM-250-86. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 27 p.

Hann, W.J.; Jones, J.L.; Karl, M.G. [and others]. 1997. Landscape dynamics of the Basin. In: Quigley, T.Q; Arbelbide, S.J., tech. eds. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins: volume 2. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 vol. (Quigley, Thomas, M., tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Hessburg, P.F.; Mitchell, R.G.; Filip, G.M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW-GTR-327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Hessburg, Paul F., science team leader and tech. ed., Volume III: assessment.)

Hessburg, P.F.; Smith, B.G.; Kreiter, S.D. [and others]. 1999. Historical and current forest and range landscapes in the interior Columbia River basin and portions of the Klamath and Great Basins. Part I: Linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. Gen. Tech. Rep. PNW-GTR-458. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 357 p. (Quigley, Thomas M., tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Huff, M.H.; Ottmar, R.D.; Lehmkuhl, J.F. [and others]. 1995. Historical and current forest landscapes of eastern Oregon and Washington. Part II: Linking vegetation characteristics to potential fire behavior and related smoke production. Gen. Tech. Rep. PNW-GTR-355. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 43 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Hessburg, Paul F., science team leader and tech. ed., Volume III: assessment.)

Jensen, M.; Goodman, I.; Brewer, K. [and others]. 1997. Biophysical environments of the basin. In: Quigley, T.Q; Arbelbide, S.J., tech. eds. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: volume 1. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 4 vol. (Quigley, Thomas, M., tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Keane, R.E.; Arno, S.F. 1993. Rapid decline of whitebark pine in western Montana: evidence from 20-year remeasurements. Western Journal of Applied Forestry. 8(2): 44-47.

Kemp, W.P. 1985a. Historical western spruce budworm outbreak frequency. In: Sanders, C.J.; Stark, R.W.; Mullins, E.J. [and others], eds. Recent advances in spruce budworms research: Proceedings of the CANUSA spruce budworms research symposium; 1984 September 16-20; Bangor, MA. Ottawa, ON: Canadian Forestry Service. 527 p.

Kemp, W.P. 1985b. Rating stand hazard to western spruce budworm: climatological discriminant model. In: Brookes, M.H.; Colbert, J.J.; Mitchell, R.G. [and others], tech. coords. Managing trees and stands susceptible to western spruce budworm. Tech. Bull. 1695. Washington, DC: U.S. Department of Agriculture, Forest Service; Cooperative State Research Service. 111 p.

Lane, B.B.; Goheen, D.J. 1979. Incidence of root disease in bark beetle-infested eastern Oregon and Washington true firs. Plant Disease Reporter. 63: 262-266.

Lehmkuhl, J.F.; Hessburg, P.F.; Everett, R.L. [and others]. 1994. Historical and current forest landscapes of eastern Oregon and Washington. Part I: Vegetation pattern and insect and disease hazards. Gen. Tech. Rep. PNW-GTR-328. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 88 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Hessburg, Paul F., science team leader and tech. ed., Volume III: assessment.)

McDonald, G.I. 1990. Connecting forest productivity to behavior of soil borne diseases. In: Harvey, A.E.; Neuenschwander, L.F., comps. Proceedings, management and productivity of western montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-GTR-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 254 p.

McDonald, G.I. 1991. Relationships among site quality, stand structure, and *Armillaria* root rot in Douglas-fir forests. In: Baumgartner, D.M.; Lotan, J.E., eds. Interior Douglas-fir: the species and its management. Pullman, WA: Washington State University, Cooperative Extension Service. 301 p.

McGarigal, K.; Marks, B.J. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 122 p.

Monnig, E.; Byler, J.W. 1992. Forest health and ecological integrity in the northern Rockies. Forest Pest Management Report 92-7, R1-92-32. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. [Not paged].

Morgan, P.; Aplet, G.H.; Haufler, J.B. [and others]. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. In: Sampson, R.N.; Adams, D.L. eds., Assessing forest ecosystem health in the inland Northwest. New York: Food Products Press (The Haworth Press): 87-111.

O'Laughlin, J.; MacCracken, J.M.; Adams, D.L. [and others]. 1993. Forest health conditions in Idaho. Policy Analysis Group Report No. 11. Moscow, ID: University of Idaho, Idaho Forest, Wildlife, and Range Policy Analysis Group. 244 p.

Oliver, C.D.; Irwin, L.L.; Knapp, W.H. 1994. Eastside forest management practices: historical overview, their extent of application, and their effects on sustainability of ecosystems. Gen. Tech. Rep. PNW-GTR-328. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Hessburg, Paul F., science team leader and tech. ed., Volume III: assessment.)

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers. 77(1): 118-125.

Ottmar, R.D.; Alvarado, E.; Hessburg, P.F. [and others]. [In press]. Historical and current forest and range landscapes in the interior Columbia River basin and portions of the Klamath and Great Basins. Part II: Linking vegetation patterns and potential smoke production and fire behavior. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. (Quigley, Thomas, M., tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Sanders, C.J.; Stark, R.W.; Mullins, E.J. [and others], eds. 1985. Recent advances in spruce budworms research: Proceedings of the CANUSA spruce budworms research symposium; 1984 September 16-20; Bangor, MA. Ottawa, Ontario: Canadian Forestry Service. 527 p.

Schmitt, C.L.; Goheen, D.G.; Gregg, T.F.; Hessburg, P.F. 1991. Effects of management activities and stand type on pest-caused losses in true fir and associated species on the Wallowa Whitman National Forest, Oregon. Blue Mountains Pest Management Zone Paper BMPMZ-01-91. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 78 p.

Smith, B.G.; Hessburg, P.F.; Kreiter, S.D. [and others]. [In press]. Modelling plant series-level forest potential vegetation types for subbasins sampled in the midscale ecological assessment of the interior Columbia River basin. Gen. Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. (Quigley, Thomas, M., tech. ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

Stage, A.R. 1973. PROGNOSIS Model for stand development. Res. Pap. INT-RP-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 32 p.

Steel, R.G.D.; Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. New York: McGraw-Hill. 633 p.

Swanson, F.J.; Jones, J.A.; Wallin, D.O. [and others]. 1994. Natural variability—implications for ecosystem management. Gen. Tech. Rep. PNW-GTR-318. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 376 p. (Everett, Richard L., assessment team leader; Eastside forest ecosystem health assessment; Jensen, M.E.; Bourgeron, P.S., tech. eds., Volume II: Ecosystem management: principles and applications.)

Thomas, J.W., ed. 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture, Forest Service. 512 p.

Wulf, N.W.; Carlson, C.E. 1985. Rating stand hazard to western spruce budworm—generalized indexing model. In: Brooks, M.H.; Colbert, J.J.; Mitchell, R.G. [and others], tech. coords. Managing trees and stands susceptible to western spruce budworm. Tech. Bull. 1695. Washington, DC: U.S. Department of Agriculture, Forest Service; Cooperative State Research Service. 111 p.

Appendix 1

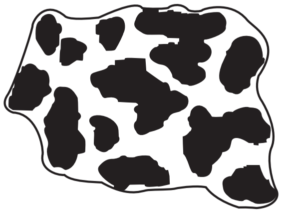
Attributes of forest and nonforest patches interpreted from aerial photographs in the midscale ecological assessment of the interior Columbia River basin.

Total crown cover and overstory crown cover— Total and overstory forest crown cover were estimated to the nearest 10 percent for all forest patches. Forest patches were defined as having at least 10 percent of their patch area under a forest canopy. A new patch was delineated by total crown cover alone when two adjacent patches similar in all attributes differed in average total crown cover by at least 20 percent.

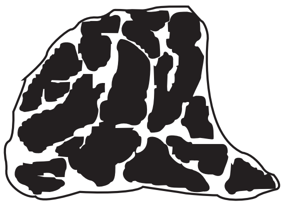
Clumpiness— Horizontal "patchiness" of tree cover within a patch. Patches were rated as (1) clumpy-yes or no; (2) if clumpy, clump distribution was widely scattered, moderately dense, or dense (see below); and (3) average clump size was < 0.4 ha, 0.4 to 2.0 ha, or > 2.0 ha, but < 4.0 ha.

Widely scattered

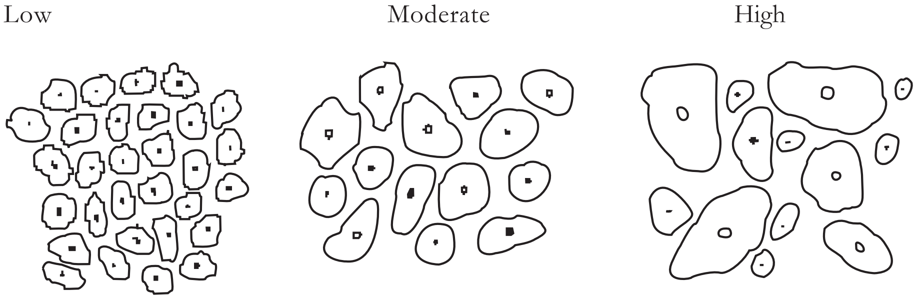
Moderately dense



Dense



Crown differentiation— Degree of differentiation among overstory tree crowns. Estimated as low (< 30-percent difference), moderate (30- to 100-percent difference), and high (> 100-percent difference). Visual templates are provided below.



Canopy layers— Estimated as 1, 2, or > 2 layers visible.

Riparian or wetland— Indicated whether a patch resided within a riparian or wetland setting. Used with overstory vegetation to estimate forest and nonforest riparian and wetland area.

Nonforest type— A vegetation patch was interpreted as nonforest when total crown cover was < 10 percent. Categories were rock, water (lake or pond), wet meadow or marsh (year-round saturated soils), alpine meadow, dry meadow (seasonally saturated soils), grasses or forbs after logging, shrubland (with at least 5 percent shrub canopy cover), bare ground (burned or logged), bare ground (from slumps or erosion), agriculture cropland, urban or rural development, pasture (irrigated grasses or forbs), grassland (with at least 20 percent canopy cover), woodland (< 10 percent total crown cover and at least 2 trees per acre), bare ground (from roadcuts or sidecast adjacent to highways), stream channel and nonvegetated flood plains, grass or forbs after wildfire, sand dune, glacier, bare ground (dry lake beds, playa).

Visible logging entry— Visible logging was interpreted as no logging apparent, regeneration harvested (clearcut, shelterwood, seedtree), selection harvested (overstory removal, final removal, selective harvest), thinned (commercial or precommercial), or patch clearcut (clearcut patches were < 4 ha). If patch clearcut, we estimated the percentage of patch area in clearcut patches to the nearest 10 percent.

Overstory and understory tree size classes— Tree sizes were estimated as seedlings and saplings (< 12.7 cm d.b.h.), poles (12.7 to 22.6 cm d.b.h.), small trees (22.7 to 40.4 cm d.b.h.), medium trees (40.5 to 63.5 cm d.b.h.), and large trees (> 63.5 cm d.b.h.).

Overstory and understory species— Dominant overstory and understory species were recorded. To be named as an overstory species in pure or mixed compositions, a species comprised at least 20 percent of the basal area. To be named as an understory species in pure or mixed compositions, a species comprised at least 20 percent of the trees per hectare.

Primary overstory species or species mixes were ponderosa pine; western larch; lodgepole pine; Douglas-fir; grand fir and/or white fir; Pacific silver fir; subalpine fir and/or Engelmann spruce; western hemlock and/or western redcedar; mountain hemlock; whitebark pine and/or subalpine larch; western white pine or sugar pine; hardwoods (Oregon and Washington subbasins only); juniper; noble fir; Shasta red fir; ponderosa pine and sugar pine; ponderosa pine and Douglas-fir; Douglas-fir and mountain hemlock; lodgepole pine and Engelmann spruce; mountain hemlock and white fir; Douglas-fir and Engelmann spruce; incense-cedar; western larch and lodgepole pine; Douglas-fir and western larch; limber pine; blue spruce; pinyon pine; white spruce; maple; birch; aspen; cottonwood; Douglas-fir and limber pine; pinyon pine and juniper; Douglas-fir and western white pine; grand fir and western white pine; subalpine fir and western white pine; western larch and western white pine; western larch, lodgepole pine, and western white pine; western larch and ponderosa pine; western larch and Engelmann spruce; lodgepole pine and subalpine fir; lodgepole pine and Douglas-fir; lodgepole pine and grand fir; subalpine fir and limber pine; grand fir and Engelmann spruce; Douglas-fir and aspen; lodgepole pine and aspen; subalpine fir and Douglas-fir; grand fir and ponderosa pine; grand fir and subalpine fir; grand fir and western larch; Russian olive; subalpine fir and whitebark pine.

Primary understory species or species mixes were ponderosa pine; western larch and lodgepole pine; Douglas-fir and/or grand fir and/or white fir and/or Pacific silver fir; western hemlock and/or western redcedar; mountain hemlock; subalpine fir and/or Engelmann spruce; hardwood (Oregon and Washington subbasins only); juniper; grasses and forbs; shrubs; bare ground; lodgepole pine; ponderosa pine and lodgepole pine; ponderosa pine and Douglas-fir; grand fir or white fir; mountain hemlock and white fir; mountain hemlock and lodgepole pine; Douglas-fir and mountain hemlock; lodgepole pine and Engelmann spruce; whitebark pine and/or subalpine larch; Shasta red fir; incense-cedar; western white pine; Douglas-fir and western larch; Douglas-fir and Engelmann spruce; limber pine; blue spruce; pinyon pine; white spruce; maple; aspen; cottonwood; Douglas-fir and limber pine; lodgepole pine and Douglas-fir; beargrass; and Pacific silver fir.

Dead trees and snags— Dead tree and snag abundance was estimated as none apparent, < 10 percent of trees dead, 10 to 39 percent of trees dead, 40 to 70 percent of trees dead, and > 70 percent of trees dead.

Elevation zones of nonforest types— Elevation zones were interpreted as colline (below lower timberline); lower montane (above lower timberline but *not* including such forest types as subalpine fir, lodgepole pine, Engelmann spruce, mountain hemlock, Pacific silver fir, noble fir, and/or Shasta red fir); upper montane (below upper timberline and including the forest types listed immediately above); subalpine (above upper timberline but with trees as islands or krummholz); and alpine (above upper treeline).

Nonforest overstory species— Dominant herbland and shrubland overstory species were recorded. The primary species groups were native bunchgrasses (examples—wildrye, bluebunch wheatgrass, Idaho fescue, alkali grass, bottlebrush squirreltail); annual grasses (examples—cheatgrass, medusahead); seeded wheatgrasses (examples—crested wheatgrass, other seeded dryland grasses); exotic forbs (examples—spotted knapweed, yellowstar thistle, leafy spurge); native moist site herbs (examples—sedges, rushes); low sagebrush (examples—low sagebrush, salt desert shrub); low alpine shrubs (examples—meadow heathers); sagebrush and bitterbrush (examples—basin big sagebrush, Wyoming sagebrush, mountain big sagebrush, silver sagebrush, bitterbrush, rabbitbrush); mahoganies (examples—mountain and curlleaf mahoganies); mountain shrubs (examples—serviceberry, rose, snowberry, Rocky Mountain maple, Scouler's willow, buffaloberry, chokeberry, bittercherry); wet site shrubs (examples—willow, alder, bog birch, dogwood); beargrass.

Overstory canopy cover nonforest types— Canopy cover of herbland and shrubland patches was estimated to the nearest 15 percent. A new patch was delineated by canopy cover alone when two adjacent patches similar in all attributes, differed in average total canopy cover by at least 15 percent. Cover classes were estimated as 0 to 15 percent canopy cover, 16 to 33 percent cover, 33 to 66 percent cover, and more than 66 percent cover.

Tree cover of herbland and shrubland types— Tree cover was identified, where present, in herbland and shrubland patches.

Source: Hessburg and others 1999.

Appendix 2

Table 24—Living and dead vegetation structure commonly associated with major insect disturbances of forest vegetation in the interior Columbia River basin

Insect spp.[a]	Primary factors influencing vulnerability	Hosts[a]	Effects	Tree sizes affected (d.b.h.)[b]	Down wood	Estimated snag residence time (yr)[c] <20	20-50	>50[d]	Hard snags[c]	Soft snags[c]	Structure in living or dead trees[e]	Bark beetle assoc.	Channelizing invertebrates associates[f]	Shrub understory development encouraged
				Centimeters										
WSB and DFTM	Hosts occurring over large (≥ 404.7 ha) contiguous areas; multilayered host canopies; outbreaks are typically initiated on warm, dry to mesic PSME, ABGR, or ABCO climax sites	*PSME*[g] ABGR ABCO ABLA2 ABAM ABPR PIEN	Tree mortality	< 12.7	Minor[h]	+	—	—	+	—[i]	—	+	+	+
				12.7-22.6	+	+	—	—	+	+	—	+	+	+
				22.7-40.5	+	+	—	—	+	+	—	+	+	+
				40.6-63.5	+	+	+[j]	—	+	+	—	+	+	+
				> 63.5	+	+	+	+[j]	+	+	—	+	+	+
			Topkilling	< 12.7	Minor	n/a[k]	n/a	n/a	n/a	n/a	New top(s), spike top,[l] stem crook[m] (potential nest platforms)	In dead tops	In dead tops	—
				12.7-22.6	Minor[h]	n/a	n/a	n/a	n/a	n/a				—
				22.7-40.5	Minor[h]	+	—	—	+	+				—
				40.6-63.5	+	+	+[n]	—	+	+	New top(s), toprot,[o] major stem crook, or snag top (potential nest platforms)		In dead tops and toprotted area	
				> 63.5	+	+	+	+[n]	+	+				+
DFB	Warm, dry to mesic PSME, ABGR, and ABCO climax sites; abundant medium and large fire-killed, wind-thrown, stressed, injured, or diseased hosts are needed to initiate an outbreak	PSME	Tree mortality	22.7-40.5	+	+	—	—	+	+	—	+	+	+
				40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	+	+	+	—	+	+	+
			Topkilling	40.6-63.5	+	+	+	—	+	+	New top(s), toprot, major stem crook, or snag top (potential nest platforms)	In dead tops	In dead tops and toprotted area	+
				> 63.5	+	+	+	+	+	+				+
			Bole strip attack[q]	22.7-40.5	Minor	+	—	—	+	+	Mainstem saprot,[p] heartrot,[r] and dead branches associated with strip-attacked length of bole	In strip-attacked area	In strip-attacked and heartrotted area	—
				40.6-63.5	Minor	+	+	—	+	+				—
				> 63.5	Minor	+	+	+	+	+				—
WPB type 1	Warm to hot dry sites; abundant medium to large PIPO; stressed, injured, or severely diseased hosts are needed to initiate an outbreak	PIPO	Tree mortality	22.7-40.5	+	+	—	—	+	+	—	+	+	—
				40.6-63.5	+	+	+	—	+	+	—	+	+	—
				> 63.5	+	+	+	+	+	+	—	+	+	—
			Topkilling	40.6-63.5	+	+	+	+	+	+	New top(s), toprot, major stem crook, or snag top (potential nest platforms)	In dead tops	In dead tops and toprotted area	—
				> 63.5	+	+	+	+	+	+				
			Bole strip attack	22.7-40.5	Minor	+	—	—	+	+	Mainstem saprot, heartrot and dead branches associated with strip-attacked length of bole	In strip-attack area	In strip-attacked and heartrotted area	—
				40.6-63.5	Minor	+	+	—	+	+				—
				> 63.5	Minor	+	+	+	+	+				—

WPB type 2 and MPB type2	Warm, dry sites; abundant pole and small PIPO growing in dense thickets or stands; stressed or injured hosts are needed to initiate an outbreak	PIPO	Tree mortality	12.7-22.6	+	+	—	—	+	+	—	+	+	+
				22.7-40.5	+	+	—	—	+	+	—	+	+	+
			Topkilling	22.7-40.5	+	+	—	—	+	+	New top(s), toprot, stem crook (potential nest platforms, roosts)	In dead tops	Indead tops and toprotted area	—
			Bole strip attack	12.7-22.6	Minor	+	—	—	+	+	Mainstem saprot, heartrot and dead branches associated with strip-attacked length of bole	In strip-attacked area	In strip-attacked and heartrotted area	—
				22.7-40.5	Minor	+	—	—	+	+				—
MPB type1	Mesic and cool sites; abundant pole, small, and medium PICO; stressed or injured hosts needed to initiate an outbreak	PICO	Tree mortality	12.7-22.6	+	+	—	—	+	—[i]	—	+	+	+
				22.7-40.5	+	+	—	—	+	—[i]	—	+	+	+
				40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5 (rare)	+	+	+	—	+	+	—	+	+	+
			Topkilling	22.7-40.5	Minor	+	+	—	+	—[i]	New top(s), spike top, stem crook potential	In dead tops	In dead tops nest platforms)	—
				40.6-63.5	+	+	+	—	+	+	New top(s), toprot, major stem crook, or snag top (potential nest platforms)		In dead tops and toprotted area	—
				> 63.5 (rare)	+	+	+	—	+	+				—
			Bole strip attack	12.7-22.6	Minor	+	—	—	+	—	Mainstem saprot, heartrot and dead branches associated with strip-attacked length of bole	In strip attacked area	In strip attacked and heartrotted area	
				22.7-40.5	Minor	+	+	—	+	+				
				40.6-63.5	Minor	+	+	—	+	+				
				> 63.5 (rare)	+	+	+	—	+	+		—		
FE	Mesic and cool-moist sites; abundant pole and larger true fir often growing in dense layered stands; stressed, injured, or diseased hosts needed to initiate an outbreak	ABGR ABCO ABLA2 ABAM ABPR ABMA	Tree mortality	12.7-22.6	+	+	—	—	+	+	—	+	+	—
				22.7-40.5	+	+	—	—	+	+	—	+	+	—
				40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	—[s]	+	+	—	+	+	+
			Topkilling	22.7-40.5	Minor	+	—	—	+	+	New top(s), spike top, stem crook (potential nest platforms)	In dead tops	In dead tops	—
				40.6-63.5	+	+	+	—	+	+	New top(s), toprot, major stem crook or snag top (potential nest platforms)		In dead tops and toprotted area	—
				> 63.5	+	+	+	+	+	+				—
			Bole strip attack	12.7-22.6	Minor	+	—	—	+	—	—	In strip-attacked area	In strip-attacked and heartrotted area	—
				22.7-40.5	Minor	+	+	—	+	+	Mainstem saprot, heart-rot and dead branches associated with strip-attacked length of bole			—
				40.6-63.5	Minor	+	+	+	+	+				—
														—
				> 63.5	Minor	+	+	+	+	+				—

Table 24—Living and dead vegetation structure commonly associated with major insect disturbances of forest vegetation in the interior Columbia River basin (continued)

Insect spp.[a]	Primary factors influencing vulnerability	Hosts[a]	Effects	Tree sizes affected (d.b.h.)[b]	Down wood	Estimated snag residence time (yr)[c]			Hard snags[c]	Soft snags[c]	Structure in living or dead trees[e]	Bark beetle assoc.	Channelizing invertebrates associates[f]	Shrub understory development encouraged
						<20	20-50	>50[d]						
				Centimeters										
SB	Cool-moist to wet sites; abundant PIEN ≥ 22.7 cm d.b.h., fire-killed, windthrown, stressed, diseased or injured PIEN needed to initiate an outbreak	PIEN	Tree mortality	22.7-40.5	+	+	—	—	+	+	—	+	+	+
				40.6-63.5	+	+	—	—	+	+	—	+	+	+
				> 63.5	+	+	+	—	+	+	—	+	+	+
			Topkilling	22.7-40.5	Minor	+	—	—	+	+	New top(s), spike top, stem crook	In dead tops	In dead tops	—
				40.6-63.5	+	+	+	—	+	+	New top(s), toprot, major stem crook or sang top		In dead tops and toprotted area	—
				> 63.5	+	+	+	+	+	+				—
			Bole strip attack	22.7-40.5	Minor	+	+	—	+	+	Mainstem saprot, heartrot and dead branches associated with strip-attacked length of bole	+	In strip-attacked land heartrotted area	—
				40.6-63.5	Minor	+	+	+	+	+		+		—
				> 63.5	Minor	+	+	+	+	+		+		—

---

[a] See table 3 for common and scientific names.

[b] Size classes are seedlings and saplings < 12.7 cm d.b.h.; poles 12.7 to 22.6 cm d.b.h.; small trees 22.7 to 40.5 cm d.b.h.; medium trees 40.6 to 63.5 cm d.b.h.; large trees > 63.5 cm d.b.h.

[c] Snags are defined as dead trees or partially dead trees with diameters 10.2 cm at d.b.h., and heights 1.8 m tall (*sensu* Thomas and others 1979); live trees with dead tops or exposed heartrot of the bole also function as snags and are included here.

[d] Note that for each estimated residence time we assume continuous fall down of individuals within each size range, only a portion of the original population within a size range will persist; ABGR, ABCO, ABLA2, and ABAM decay and fall down rapidly; these will be lost first; large PSME, THPL, LAOC, and PIPO will tend to have the highest residence times.

[e] Structures include forked or multiple tops, toprot associated with injuries to tree tops and subsequent infection by wound parasites, mainstem heartrot cavities, and dwarf mistletoe brooms.

[f] Channelizing invertebrates noted here are primarily Cerambycid and Buprestid woodboring beetles (Coleoptera) and carpenter ants (*Camponotus* spp. /Hymenoptera).

[g] Hosts in italics are primary hosts of the DFTM.

[h] May be significant under extreme outbreak conditions.

[i] Saprot occurs, but thin-barked, small-caliper stems and tops dry out quickly and typically do not function as soft snags.

[j] Some snags will reside, especially when hosts are Douglas-fir.

[k] Not applicable; snag tops will seldom meet the minimum size requirements.

[l] A spike top is a small-diameter (< 12.2 cm) remnant of a former tree top that is retained when a lateral branch turns upward and becomes a new top. Spike tops are often embedded in stemwood of the new top and may be retained for decades. Presence of a spike top usually indicates that a topkilling event occurred high in the crown. Larger diameter dead tops typically break out once decayed. Birds and small mammals often build nests between a spike top and the main stem once a new top has developed.

[m] Stem crook describes the residual structure occurring after a new top develops adjacent to topkilling or breakage of a large-diameter (12.2 cm) top. Vertical displacement of the new top increases with increasing diameter of broken or killed tops. When crooked stems display a significant horizontal component in the crook, and when crooks are associated with a spike top, birds or small mammals often use these as elevated platforms for nests.

[n] Some snag tops that meet the minimum size requirements will reside, especially when hosts are Douglas-fir.

[o] Toprot often occurs in living trees that have been damaged by top breakage or a prior topkilling disturbance. Opportunistic wood decay fungi such as *Fomitopsis pinicola* and wound parasites such as *F. officinalis* and *F. cajenderi* invade the top portion of the remaining live tree, decaying the heartwood. When a new top has developed, the heartwood of the new top and that occurring below the new top often is decayed, thereby making the toprotted area above and below the new top vulnerable to re-injury by top breakage. Severely toprotted trees typically loose their top. Raptor stick nests are common on broken topped trees.

[p] Saprot describes fungal decay confined to the sapwood. Saprotting can begin once the vascular cambium associated with sapwood has been killed by insects, fungi, or injury. Some saprotting fungi are directly introduced by attacking bark beetles (e.g., *Cryptoporus volvatus*). Others invade the sapwood once young adult beetles have emerged. In most cases, sapwood of recently killed trees, or of dead portions of living trees, is decayed within 3 or 4 years of cambial mortality.

[q] Bole strip attack is one of several consequences of bark beetle mass attack. Strip attack occurs when beetles systematically attack a vertical section or strip of the bole. Brood development is similarly confined to that vertical strip. Following the strip attack, the strip-attacked section of the bole provides access to sapwood and heartwood decay fungi. Large-diameter trees with evidence of a prior strip attack event often will have significant heartrot associated with the strip-attacked area. When the strip-attacked area is wide, or when the attacked tree is old and declining in vigor, the area of strip attack may never be enclosed by new sapwood and bark.

[r] Heartrot describes fungal decay of the heartwood. Many heartrotting fungal species are uniquely associated with heartwood substrates of living trees.

[s] Some ABPR and ABMA snags will reside > 50 years.

Appendix 3

Table 25—Living and dead vegetation structure commonly associated with major pathogen disturbances of forest vegetation in the interior Columbia River basin

Insect spp.[a]	Primary factors influencing vulnerability	Hosts[a]	Effects	Tree sizes affected (d.b.h.)[b]	Down wood	Estimated snag residence time (yr)[c]			Hard snags[d]	Soft snags[d]	Structure-in living or dead trees[e]	Bark beetle assoc.	Channelizing invertebrates associates[f]	Shrub understory development encouraged
						<20	20-50	>50[d]						
				Centimeters										
DFDM	Warm, dry sites; layered PSME stand	PSME	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	Dead upright fine-structured mistletoe brooms	+[h]	+	—
				12.7-22.6	+	+	—	—	+	+		+[h]	+	—
				22.7-40.5	+	+	—	—	+	+		+[h]	+	—
				40.6-63.5	+	+	+	—	+	+	Dead coarse-structured and often massive mistletoe brooms	+[h]	+	—
				> 63.5	+	+	+	+	+	+		+[h]	+	—
			Topkilling	22.7-40.5	Minor	+	+	—	+	+	Toprot,[i] large live mistletoe brooms, snag top	In dead tops[h]	In dead tops	—
				40.6-63.5	+	+	+	+	+	+			—	
				> 63.5	+	+	+	+	+	+				—
			Growths loss	< 12.7	—	n/a[j]	n/a	n/a	n/a	n/a	Live mistletoe brooms, dense shrublike or tree	—	—	—
				12.7-22.6	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				22.7-40.5	Minor[k]	n/a	n/a	n/a	n/a	n/a		—	—	—
				40.6-63.5	Minor	n/a	n/a	n/a	n/a	n/a	Large upright or pendulous mistletoe brooms	—	—	—
				> 63.5	Minor	n/a	n/a	n/a	n/a	n/a		—	—	—
WLDM	Cool, moist sites; layered LAOC stands	LAOC	Tree mortality	40.6-63.5	+	+	+	+	+	+	Lead upright fine-structured mistletoe brooms	—	—	—
				> 63.5	+	+	+	+	+	+		—	+	—
			Topkilling	40.6-63.5	+	+	+	+	+	+	Toprot, fine-structured live mistletoe brooms, snag top	—	+	—
				> 63.5	+	+	+	+	+	+		—		—
			Growth loss	< 12.7	—	n/a	n/a	n/a	n/a	n/a	Fine-structured live mistletoe brooms, tree growth form	—	In dead tops	—
				12.7-22.6	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				22.7-40.5	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				40.6-63.5	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				> 63.5	—	n/a	n/a	n/a	n/a	n/a		—	—	—
PPDM	Warm, dry sites; layered PIPO stands	PIPO	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	Dead upright mistletoe brooms	+[h]	+	—
				12.7-22.6	+	+	—	—	+	+		+[h]	+	—
				22.7-40.5	+	+	—	—	+	+		+[h]	+	—
				40.6-63.5	+	+	+	—	+	+	Dead coarse-structured often massive upright mistletoe brooms	+[h]	+	—
				> 63.5	+	+	+	+	+	+		+[h]	+	—
			Topkilling	22.7-40.5	Minor	+	+	—	+	+	Toprot, large live mistletoe brooms snag top	Indead tops[h]	Indead tops	—
				40.6-63.5	+	+	+	+	+	+				—
				> 63.5	+	+	+	+	+	+				—
			Growth loss	< 12.7	—	n/a[j]	n/a	n/a	n/a	n/a	Live mistletoe brooms, dense shrublike or tree growth form	—	—	—
				12.7-22.6	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				22.7-40.5	Minor[k]	n/a	n/a	n/a	n/a	n/a		—	—	—
				40.6-63.5	Minor	n/a	n/a	n/a	n/a	n/a	Large upright and often massive mistletoe brooms	—	—	—
				>63.5	Minor	n/a	n/a	n/a	n/a	n/a		—	—	—

Table 25—Living and dead vegetation structure commonly associated with major pathogen disturbances of forest vegetation in the interior Columbia River basin (continued)

Insect spp.[a]	Primary factors influencing vulnerability	Hosts[a]	Effects	Tree sizes affected (d.b.h.)[b]	Down wood	Estimated snag residence time (yr)[c]			Hard snags[d]	Soft snags[d]	Structure-in living or dead trees[e]	Bark beetle assoc.	Channelizing invertebrates associates[f]	Shrub understory development encouraged
						<20	20-50	>50[d]						
				Centimeters										
LPDM	Cool, moist sites; layered PICO stands	PICO	Tree mortality	12.7-22.6	+	+	—	—	+	—[g]	Dead upright mistletoe brooms	+[h]	+	
				22.7-40.5	+	+	—	—	+	+	Dead coarse-structured and occasionally massive upright mistletoe brooms	+[h]	+	—
				40.6-63.5	+	+	+	—	+	+		+[h]	+	—
				> 63.5	+	+	+	—	+	+		+[h]	+	—
			Topkilling	22.7-40.5	Minor	+	+	—	+	+	Toprot, mistletoe brooms, snag top	+[h]	In dead tops	—
				40.6-63.5	+	+	+	—	+	+		+[h]	—	
				> 63.5	+	+	+	—	+	+		+[h]		—
			Growth	< 12.7	—	n/a	n/a	n/a	n/a	n/a	Live upright, occasionally massive mistletoe brooms, tree growth form	—	—	—
				12.7-22.6	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				22.7-40.5	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				40.6-63.5	—	n/a	n/a	n/a	n/a	n/a		—	—	—
				> 63.5	—	n/a	n/a	n/a	n/a	n/a		—	—	—
AROS	Hosts; layered stands; viable inoculum	PSME	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	—	+	+	+
		ABGR		12.7-22.6	+	+	—	—	+	—[g]	—	+	+	+
		ABCO		22.7-40.5	+	+	—	—	+	+	—	+	+	+
		present		40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	—	+	+	—	+	+	+
	Stressed hosts; viable inoculum present	PIEN ABLA2	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	—	+	+	+
		PICO TSHE TSME		12.7-22.6	+	+	—	—	+	+	—	+	+	+
		ABAM PILA		22.7-40.5	+	+	—	—	+	+	—	+	+	+
		PIPO LAOC ABPR		40.6-63.5	+	+	+	—	+	+	—	+	+	+
		PIMO ABMA PHWE		> 63.5	+	+	+	—	+	+	—	+	+	+
	Hosts; viable inoculum present present;	PSME	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	—	+	+	+
		ABGR		12.7-22.6	+	+	—	—	+	+	—	+	+	+
		ABCO		22.7-40.5	+	+	—	—	+	+	—	+	+	+
		TSME		40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	—	+	+	—	+	+	+
	Hosts, viable inoculum present; mature and older trees	PSME ABGR ABCO TSME TSHE ABLA2	Butt rot and tree collapse	40.6-63.5	+	+	+	+	+	—	≤10.5 m of decayed heartwood in the butt section of the bole (potential cavity excavation sites)	With tree collapse	Often with carpenter ants in the decayed butt	With tree colapse

		PIEN ABAM ABMA ABPR LAOC *Pinus* supp.		> 63.5	+	+	+	+	+	—		With tree collapse		
HEAN$_S$	Mesic to cool, moist sites; hosts; layered stands; viable inoculum present; logging entry	PSME^l ABGR ABCO ABLA2	Tree mortality	< 12.7	Minor	+	—	—	+	—^{g}	—	+	+	+
				12.7-22.6	+	+	—	—	+	—^{g}	—	+	+	+
				22.7-40.5	+	+	—	—	+	+	—	+	+	+
				40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	—	+	+	—	+	+	+
	Hosts; viable inoculum present	PIEN TSHE TSME ABAM ABMA ABPR	Butt rot and tree	40.6-63.5	+	+	+	+	+	—	≤ 4.9 m of decayed heartwood in the butt section of the bole (potential cavity excavation sites	With tree collapse	Often with carpenter ants in the decayed butt	With tree collapse
				> 63.5	+	+	+	+	+	—		With tree collapse		
HEAN$_P$	Warm to hot, dry sites; hosts; viable inoculum present	PIPO	Tree mortality	< 12.7	Minor	+	—	—	+	—^{g}	—	+	+	+
				12.7-22.6	+	+	—	—	+	+	—	+	+	+
				22.7-40.5	+	+	—	—	+	+	—	+	+	+
				40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	+	+	+	—	+	+	+
TRBR	Cool moist to wet sites; hosts and viable inoculum present	PIEN	Butt rot and tree collapse	40.6-63.5	+	+	+	+	+	—	≤ 4.9 m of decayed heartwood in the butt section of the bole (potential cavity excavation sites)	With tree collapse	Often with carpenter ants in the decayed butt	With tree collapse
				> 63.5	+	+	+	+	+	—		With tree collapse		
SRBR	Mesic to cool moist to wet sites; hosts; viable inoculum present	PSME LAOC PIPO PIEN PICO^m	Butt rot and tree collapse	40.6-63.5	+	+	+	+	+	—	≤ 9.8 m of decayed heartwood in the butt section of the bole (potential cavity excavation sites)	With tree collapse	Often with carpenter ants in the decayed butt	With tree collapse
				> 63.5	+	+	+	+	+	—		With tree collapse		
RRSR	Mesic to cool moist sites; hosts present and supressed more than 40 years prior to release; hosts injured once released	ABGR ABCO ABLA2 ABAM ABPR TSHE TSME	Main stem heartrot and mid- or lower-stem collapse	40.6-63.5	+	+	+	+	+	—	< 9.8 m of decayed heartwood in the butt section of the bole (potential cavity excavation sites)	With tree collapse	Often with carpenter ants in the decayed butt	With tree collapse
				> 63.5	+	+	+	+	+	—		With tree collapse		

Table 25—Living and dead vegetation structure commonly associated with major pathogen disturbances of forest vegetation in the interior Columbia River basin (continued)

Insect spp.[a]	Primary factors influencing vulnerability	Hosts[a]	Effects	Tree sizes affected (d.b.h.)[b]	Down wood	Estimated snag residence time (yr)[c] <20	20-50	>50[d]	Hard snags[d]	Soft snags[d]	Structure-in living or dead trees[e]	Bark beetle assoc.	Channelizing invertebrates associates[f]	Shrub understory development encouraged
				Centimeters										
WPBR type 1	Cool, moist sites; hosts present	PIMO PILA	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	—	+	+	+
				12.7-22.6	+	+	—	—	+	+	—	+	+	+
				22.7-40.5	+	+	—	—	+	+	—	+	+	+
				40.6-63.5	+	+	+	—	+	+	—	+	+	+
				> 63.5	+	+	+	—	+	+	—	+	+	+
			Topkilling	< 12.7	Minor	—	—	—	—	—	—	+	+	—
				12.7-22.6	Minor	+	—	—	+	—[g]	Short-term, small-diameter snag top	+	+	+
				22.7-40.5	+	+	—	—	+	+		+	+	—
				40.6-63.5	+	+	+	—	+	+	Large-diameter snag top (potential cavity excavation sites)	+	+	—
				> 63.5	+	+	+	—	+	+		+	+	—
WPBR type2	Cool, moist to cold, harsh high elevation sites; hosts present	PIAL	Tree mortality	< 12.7	Minor	+	—	—	+	—[g]	—	+	+	—
				12.7-22.6	+	+	—	—	+	—[g]	—	+	+	—
				22.7-40.5	+	+	+	—	+	+	—	+	+	—
				40.6-63.5	+	+	+	+	+	+	—	+	+	—
				> 63.5	+	+	+	+	+	+	—	+	+	—
			Topkilling	< 12.7	Minor	—	—	—	—	—	—	+	+	—
				12.7-22.6	Minor	+	—	—	+	—[g]	Short-term, small-diameter snag top	+	+	—
				22.7-40.5	+	+	+	—	+	+		+	+	—
				40.6-63.5	+	+	+	+	+	+	Large-diameter snag top (potential cavity excavation sites)	+	+	—
				> 63.5	+	+	+	+	+	+		+	+	—

---

[a] See table 3 for common and scientific names.

[b] Size classes are seedlings and saplings < 12.7 cm d.b.h.; poles 12.7 to 22.6 cm d.b.h.; small trees 22.7 to 40.5 cm d.b.h.; medium trees 40.6 to 63.5 cm d.b.h.; large trees > 63.5 cm d.b.h.

[c] Note that for each estimated residence time we assume continuous fall down of individuals within each size range; only a portion of the original population within a size range will persist; ABGR, ABCO, ABLA2, and ABAM decay and fall down rapidly; these will be lost first; large PSME, THPL, LAOC, and PIPO will tend to have the highest residence times.

[d] Snags are defined as dead trees or partially dead trees (e.g., dead tops or partially dead stems) with diameters 10.2 cm at d.b.h. and heights 1.8 m tall (*sensu* Thomas and others 1979); live trees with dead tops or exposed heartrot of the bole also function as snags, and are included here.

[e] Structures include forked or multiple tops, toprot associated with injuries to tree tops and subsequent infection by wound parasites, mainstem heartrot cavities, brooms.

[f] Channelizing invertebrates noted here are primarily Cerambycid and Buprestid woodboring beetles (Coleoptera) and carpenter ants (*Camponotus* spp. /Hymenoptera).

[g] Saprot occurs, but thin-barked, small-caliper stems and tops dry out quickly and typically do not function as soft snags.

[h] Conventional wisdom suggests that bark beetles are typically associated with dwarf mistletoe-induced tree mortality and topkilling. Our observations suggest that bark beetles are often not associated.

[i] Toprot often occurs in living trees that have been damaged by top breakage or a prior topkilling disturbance. Opportunistic wood decay fungi such as *Fomitopsis pinicola* and wound parasites such as *F. officinalis* and *F. cajenderi* invade the top portion of the remaining live tree, decaying the heartwood. When a new top has developed, the heartwood of the new top and that occurring below the new top often are decayed making the toprotted area above and below the new top vulnerable to reinjury by top breakage. Severely toprotted trees typically lose their top. Raptor stick nests are common on broken topped trees.

[j] Not applicable.

[k] Fuel accumulations are minor in the form of fallen dwarf mistletoe brooms and branch litter.

[l] PSME is an important host in Idaho and Montana in the Clearwater, Lolo, and Nez Perce National Forests.

[m] All conifers are host to *Phaeolus schweinitzii* ; those listed are primary hosts that contribute most significantly to standing and down structure.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890