NATURAL REGENERATION OF INTERIOR DOUGLAS-FIR IN THE NORTHERN ROCKY MOUNTAINS

Dennis E. Ferguson and Clinton E. Carlson

ABSTRACT

The regeneration period is a crucial time in the life of a stand because it determines species composition and tree density for the new stand. Silviculturists prescribe treatments to favor adequate and timely conifer regeneration of economically important species that grow well. This paper presents research results that will help silviculturists identify factors favoring natural regeneration of interior Douglas-fir. The data were obtained from retrospective examination of randomly chosen, conventionally harvested stands 3-20 years old in Idaho and Montana. The information covers the *Pseudotsuga menziesii, Abies grandis, Thuja plicata, Tsuga heterophylla,* and *Abies lasiocarpa* series of habitat types for common harvest and site preparation methods used in the northern Rocky Mountains.

Areas in or near the Bitterroot and Lolo National Forests have the best stocking of Douglas-fir regeneration, and Montana has more Douglas-fir than Idaho. The effect of aspect depends on the habitat type series. Northerly aspects are best and southerly aspects worst for Douglas-fir regeneration in the *Pseudotsuga menziesii, Abies grandis, and Abies lasiocarpa* series, but aspect is not significant for the *Thuja plicata* and *Tsuga heterophylla* series. Leaving residual overstory on the site is somewhat helpful on southwest and south aspects for the drier *Pseudotsuga menziesii* and *Abies grandis* series, but is detrimental on other aspects of these same series. Leaving Douglas-fir seed trees is beneficial only in the *Abies lasiocarpa* series. Simple categories of site preparation (none, mechanical, or burn) were not important—smaller microsites may be needed to characterize seedbeds for this species. Within most habitat type series, increasing elevation is associated with decreases in the occurrence of Douglas-fir. Western spruce budworm defoliation reduces Douglas-fir stocking in the *Abies grandis* and *Thuja plicata* series.

Keywords: Reproduction, succession, conifer establishment, *Pseudotsuga menziesii*

INTRODUCTION

Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) is one of the most wide ranging and valuable timber species in the Rocky Mountains. Douglas-fir has the largest volume of growing stock of all conifers on commercial forest lands in Montana and on State and private forests in Idaho. In Montana, it accounts for 29% of the growing stock and the Douglas-fir forest type is 43% of the acreage for all forest types (Green *et al.* 1985). On State and private forests in Idaho, Douglas-fir accounts for 27% of the growing stock and the Douglas-fir forest type is 28% of the acreage for all forest types (Van Hooser and Green 1985).

The ecological range of interior Douglas-fir is impressive. It occurs in a wide variety of environments except those that are too hot and dry and those at or near high elevation timberline. Of the 286 Rocky Mountain habitat types summarized by Alexander (1988), interior Douglas-fir occurs on 204, or 71.3% (Table 1). Ponderosa pine (*Pinus ponderosa*) was second with occurrence on 134 of 286 habitat types (46.9%), and lodgepole pine (*Pinus contorta*) third with occurrence on 114 of 186 habitat types (39.9%).

Table 1.—Occurrence of Douglas-fir by habitat type series in the Rocky Mountains; data summarized from Alexander (1988).

Habitat Type Series	Number of Habitat Types	Number with Douglas-fir	Percent with Douglas-fir
Pinus leiophylla	5	0	0.0
Pinus engelmannii	5	0	0.0
Pinus ponderosa	40	14	35.0
Pinus strobiformis	1	1	100.0
Pseudotsuga menziesii	38	38	100.0
Abies concolor	23	23	100.0
Picea pungens	17	17	100.0
Abies grandis	13	13	100.0
Thuja plicata	7	6	85.7
Tsuga heterophylla	5	3	60.0
Pinus flexilis	11	8	72.7
Populus tremuloides	17	9	52.9
Pinus contorta	9	6	66.7
Pinus aristata	5	2	40.0
Picea glauca	2	0	0.0
Picea engelmannii	27	18	66.7
Abies lasiocarpa	49	42	85.7
Tsuga mertensiana	5	4	80.0
Pinus albicaulis	6	0	0.0
Larix lyallii	1	0	0.0
Totals and average	286	204	71.3

Clearly, it is important to understand regeneration of this valuable species so that it can be established in cutover areas. From 1974 through 1982, we used retrospective examinations to survey establishment of 11 conifers in Idaho and Montana, but for purposes of this paper, the data are analyzed to determine only the occurrence of naturally regenerated Douglas-fir. The objective was to determine the effects of important site variables (slope, aspect, elevation, habitat type, time since disturbance, residual basal area, and site preparation) on the probability of obtaining natural Douglas-fir regeneration.

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

Results of these analyses should help land managers regenerate Douglas-fir for a variety of site and stand conditions in the northern Rocky Mountains.

LITERATURE REVIEW

A good deal of literature is available on ecology, regeneration, and growth of interior Douglas-fir. Douglas-fir is rated as intermediate in shade tolerance, being more shade tolerant than Engelmann spruce (*Picea engelmannii*), lodgepole pine, western larch (*Larix occidentalis*), and ponderosa pine but less shade tolerant than western white pine (*Pinus monticola*), grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), western redcedar (*Thuja plicata*), or western hemlock (*Tsuga heterophylla*) (Minore 1979). Minore also ranks Douglas-fir as being well adapted to heat and drought conditions.

Ryker (1975) makes an important point about understanding regeneration of Douglas-fir—success depends largely upon habitat type (Daubenmire (1952) developed the first habitat type classification; Wellner (1989) summarizes habitat type classifications throughout the western United States). This results partly from the wide range of environmental conditions where Douglas-fir can be found and partly from the fact that Douglas-fir is both a seral species and a climax species, depending on the habitat type. Knowledge of the habitat type, or at least the habitat type series, helps in the interpretation of results from various studies in the literature.

Haig (1936) studied factors controlling establishment of conifers at the Priest River Experimental Forest near Priest River, Idaho. Three sites were prepared on flat topography on a *Tsuga heterophylla* habitat type. The first site was a clearcut, the second a partial cut, and the third a dense, uncut stand. The three sites provided full sun, partial shade, and full shade. Six species were germinated on small plots that had either undisturbed, burned, or mineral soil surfaces. Seeds were also germinated in a separate plot at each site so that seedlings could be dug up throughout the summer to monitor root penetration and soil moisture.

Insolation (heat girdling) in 1932 was the most important cause of Douglas-fir mortality at the full sun site (72%), intermediate at the partial shade site (20%), and not important at the full shade site (Table 2). However, drought caused mortality to 17% of Douglas-fir seedlings at the full shade site, less than 1% at the partial shade site, and 11% at the full sun site. Similar results were obtained in the summer of 1933.

Table 2.—Douglas-fir seedling mortality caused by insolation and drought on mineral and burned soil surfaces by site and year (from Haig 1936)

Cause of Mortality	Full Sun 1932	Full Sun 1933	Full Sun Ave.	Partial Shade 1932	Partial Shade 1933	Partial Shade Ave.	Full Shade 1932	Full Shade 1933	Full Shade Ave.
					percent				
Insolation	72	86	79	20	14	17	0	0	0
Drought	11	1	6	1	0	1	17	18	18
Totals			85			18			18

Haig (1936) explained the beneficial effect of shade with the data on root penetration and the depth to which the topsoil was dry. By mid-September 1932, root penetration of Douglas-fir seedlings was 8.5-13.1 inches at the full sun site and 6.5-12.1 inches at the partial shade site, both of which were sufficient growth to keep roots below the dry topsoil. Meanwhile, maximum root penetration of Douglas-fir at the full shade site was only 2.5-5.6 inches—this meant that root penetration was not sufficient to keep roots below the dry topsoil, even though soils at the full shade site did not dry to the depth of the other two sites. Haig concluded that heat girdling caused most mortality at the full sun site and that later in the summer, drought caused most mortality at the full shade site. Partial shade offered protection from insolation damage while allowing good root penetration to prevent substantial mortality due to drought.

Other researchers have also noted the beneficial effects of shade on establishment of Douglas-fir (Buell 1965; Ryker 1975; Steele and Geier-Hayes 1987, 1989), but effects of shade depend on habitat type. In central Idaho, Steele and Geier-Hayes (1989) found that Douglas-fir regeneration was highest in group selection cuts and lowest in clearcuts in the *Pseudotsuga menziesii/Physocarpus* malvaceus habitat type. On the more moist *Abies grandis/Vaccinium globulare* habitat type, Steele and Geier-Hayes (1987) found the best Douglas-fir regeneration in seedtree cutting units. Partial shade did not improve survival on *Tsuga heterophylla* habitat types (Ryker 1975).

Aspect also influences the establishment of Douglas-fir. Douglas-fir regenerates best on north aspects and worst on south aspects (Buell 1965; Hatch and Lotan 1969), but this may again depend on habitat type.

The overall effects of seedbed type are not easy to determine from the literature, perhaps because of the different ways in which seedbeds have been classified. In central Idaho, plots receiving no site preparation had the fewest numbers of Douglas-fir seedlings, regardless of habitat type (Geier-Hayes 1987; Steele and Geier-Hayes 1987, 1989). In contrast to this, Hatch and Lotan (1969) found 1,140 Douglas-fir seedlings per acre on undisturbed duff but only 382 per acre on disturbed duff in central Montana. Fisher (1935) reported 60% germination of Douglas-fir on undisturbed duff and only 12% on disturbed duff. And Ryker (1975) found the best establishment of Douglas-fir seedlings on litter covered seedbeds, regardless of habitat type. In the *Tsuga heterophylla* habitat type of northern Idaho, Haig *et al.* (1941) reported little difference in Douglas-fir germination on seedbeds of residual duff, mineral soil, ash, or rotten wood.

Distance to seed source can also be important in establishment of Douglas-fir. While most seed falls within about 1 chain of the stand edge (Ryker 1975), Douglas-fir seeds are cast in nearly equal numbers from 4-12 chains (260-800 feet) from the seedwall (12 chains was the farthest distance tested) (Boe 1953). Proximity to the stand edge may be important in drier habitat types where more seeds are needed to successfully establish a seedling. On moist habitat types, distance to the stand edge is not important (Ryker 1975).

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

METHODS

Data for this paper came from three studies. Data for Idaho north of the Salmon River were collected in 1974 through 1976 (Ferguson *et al.* 1986). Data for Montana were collected in 1979 through 1982 (Carlson *et al.* 1982). Data for central Idaho (Payette and Boise National Forests) were collected in 1979 through 1982 (Ferguson and Stage 1982). The latter two studies were conducted with funding from the Canada/U.S. Spruce Budworms Program to include the effects of western spruce budworm (*Choristoneura occidentalis*) on regeneration success.

Study sites were selected using stratified random procedures. A list of stands cut in the previous 20 years was obtained from major land owners in Montana and Idaho. Most of stands were from USDA Forest Service ownership. All stands were conventionally harvested. Stands were categorized into cells of an information matrix—combinations of regeneration method, site preparation method, habitat type series, and geographic area. A random sample of four to five stands was selected from each cell. Treatment history of selected stands was obtained from office records and verified during sampling.

In the Idaho studies, transect lines were positioned to include variation due to site preparation, aspect, residual overstory density, or topographic position. Sample points were evenly distributed along the transects. In the Montana study, sample points were located uniformly throughout the stand.

At each sample point, a 1/300-acre circular fixed area plot was installed to sample regeneration, plot conditions, and competing vegetation. The overstory was characterized from the plot center using a prism with a 10 basal area factor. A plot was classified as stocked if one or more established seedlings were on the plot. Seedlings considered established were a minimum of 0.5 foot tall for shade tolerant species and 1 foot tall for shade intolerant species (approximate heights for 3-year old seedlings). Minimum establishment height for Douglas-fir was 1 foot tall; maximum size of regeneration was 3 inches diameter at breast height.

All established trees on the plot were recorded. A sample of the best trees on the plot was recorded by identifying:

- the two tallest trees regardless of species
- the one tallest tree of each additional species present
- the tallest of the remaining trees until at least four trees were selected, if possible.

Sampling the tallest tree of each species ensured that the presence or absence of established Douglas-fir regeneration was recorded on each plot. Best trees were cut at groundline to determine tree age and the advance/subsequent status of the regeneration. Advance regeneration germinated prior to the harvest and subsequent regeneration germinated after the harvest.

Data from the three studies were combined, resulting in 12,128 1/300-acre plots. These data are being used to expand the regeneration establishment model (Ferguson *et al.* 1986) to include additional habitat types, additional geographic areas, and the effects of western spruce budworm.

Data from the three studies can also be used to examine regeneration for each conifer species. Here we are interested in natural regeneration of Douglas-fir. In the analyses to follow, stands planted to Douglas-fir were eliminated so that results reflect only naturally regenerated stands. This resulted in 9,333 1/300-acre plots having the following ranges of data: all aspects, 0-110% slopes, 0-390 square feet of residual basal area, 2,400-7,400 feet elevation, and up to 16 years of budworm defoliation.

RESULTS OF DATA SUMMARIES

Stocking and Douglas-fir Regeneration

The 9,333 plots were sorted by habitat type series and geographic area. The geographic areas were:

- Central Montana (Deerlodge, Gallatin, and Helena National Forests)
- Western Montana (Bitterroot and Lolo National Forests)
- Northwestern Montana (Flathead and Kootenai National Forests)
- Northern Idaho (Nezperce, Clearwater, and Idaho Panhandle National Forests)
- Central Idaho (Boise and Payette National Forests)

For each habitat type series and geographic area, the percentage of plots with advance, subsequent, and either advance or subsequent Douglas-fir regeneration was calculated (Table 3). The general trend is that the proportion of advance Douglas-fir decreases as the habitat type series becomes cooler and wetter until the *Abies lasiocarpa* series where the proportion of advance increases. The opposite trend is noted for subsequent Douglas-fir where the proportion increases with increasingly cooler and wetter series except the *Abies lasiocarpa* series where the proportion decreases. Across habitat type series, the occurrence of advance and subsequent Douglas-fir compensate to produce about 16% of plots stocked with at least one Douglas-fir.

Forests in Montana have a higher percentage of Douglas-fir regeneration than do forests in Idaho. Central Idaho has the lowest percentage of Douglas-fir regeneration, which agrees with Ryker (1975) who found decreasing Douglas-fir stocking from north to south. We concur with Ryker that stocking figures do not reflect differences in the skills of land managers; differences are related to factors such as latitude, soils, elevation, and climate.

The percentage of plots stocked with any conifer species and those stocked by Douglas-fir are shown in Table 4 by habitat type series and geographic location. While the percentage of stocked plots increases with cooler, wetter habitat types, the percentage of plots stocked with Douglas-fir regeneration remains about the same.

Seedling Density

The same habitat type series and geographic locations used in calculating stocking were used to calculate seedling densities for all conifers and for Douglas-fir (Table 5). Western Montana forests have the highest densities of Douglas-fir followed by central Montana, northwestern Montana, northern Idaho, and central Idaho.

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

Table 3.—Percentage of 1/300-acre plots with one or more Douglas-fir seedlings by habitat type series and advance/subsequent status. Data are not reported for cells with less than 50 plots.

Habitat Type Series	Area	% Advance	% Subseq	% Either	# Plots Sampled
Pseudotsuga menziesii	C. Montana	8.6	9.5	17.8	545
	W. Montana	22.6	10.6	32.2	451
	NW Montana	–	–	–	9
	N. Idaho	6.2	3.1	8.5	389
	C. Idaho	7.7	1.5	9.1	547
Abies grandis	C. Montana	–	–	–	0
	W. Montana	15.7	14.0	27.9	344
	NW Montana	8.1	29.7	36.5	74
	N. Idaho	8.9	7.4	5.1	1,533
	C. Idaho	5.6	4.7	10.1	426
Thuja plicata	C. Montana	–	–	–	0
	W. Montana	1.3	11.7	13.0	77
	NW Montana	3.1	3.7	6.1	163
	N. Idaho	4.8	10.3	14.8	1,530
	C. Idaho	–	–	–	0
Tsuga heterophylla	C. Montana	–	–	–	0
	W. Montana	–	–	–	14
	NW Montana	2.7	17.9	18.8	112
	N. Idaho	2.9	15.1	17.3	992
	C. Idaho	–	–	–	0
Abies lasiocarpa	C. Montana	5.9	9.2	14.8	271
	W. Montana	21.9	5.0	26.1	544
	NW Montana	–	–	–	48
	N. Idaho	3.4	5.5	8.5	875
	C. Idaho	3.6	2.8	5.7	389
Habitat Type Averages:					
Pseudotsuga menziesii		11.1	6.2	16.7	1,941
Abies grandis		9.3	8.6	16.7	2,377
Thuja plicata		4.5	9.7	14.0	1,770
Tsuga heterophylla		2.9	15.4	17.4	1,118
Abies lasiocarpa		8.5	5.7	13.6	2,127
Area Averages:					
Central Montana		7.7	9.4	16.8	816
Western Montana		19.3	9.4	27.6	1,430
Northwestern Montana		3.7	14.3	17.0	406
Northern Idaho		5.5	9.0	13.9	5,319
Central Idaho		5.9	2.9	8.4	1,362
Overall Averages & Total:		7.8	8.5	15.6	9,333

The percentages of Douglas-fir are highest in the *Pseudotsuga menziesii* series (66%). They decrease substantially in the *Abies grandis* and *Abies lasiocarpa* series to 18 and 12%, respectively. The *Thuja plicata* and *Tsuga heterophylla* series have the lowest percentages (5 and 6%). Percentages change dramatically with habitat type series, but trees per acre for Douglas-fir range from only 97-158 trees per acre.

Table 4.—Percent stocking on 1/300-acre plots by habitat type series and geographic area all conifers and for Douglas-fir. Data are not reported for cells with less than 50 plots. The number of plots is the same as reported in Table 3.

Habitat Type Series	Area	% Stocking All Conifers	% Stocking Douglas-fir
Pseudotsuga menziesii	C. Montana	27.0	17.8
	W. Montana	42.6	32.2
	NW Montana	–	–
	N. Idaho	14.4	8.5
	C. Idaho	26.5	9.1
Abies grandis	C. Montana	–	–
	W. Montana	72.1	27.9
	NW Montana	62.2	36.5
	N. Idaho	49.6	15.1
	C. Idaho	37.6	10.1
Thuja plicata	C. Montana	–	–
	W. Montana	75.3	13.0
	NW Montana	42.3	6.1
	N. Idaho	64.2	14.8
	C. Idaho	–	–
Tsuga heterophylla	C. Montana	–	–
	W. Montana	–	–
	NW Montana	83.0	18.8
	N. Idaho	71.9	17.3
	C. Idaho	–	–
Abies lasiocarpa	C. Montana	53.9	14.8
	W. Montana	69.5	26.1
	NW Montana	–	–
	N. Idaho	54.5	8.5
	C. Idaho	47.3	5.7
Habitat Type Averages:			
Pseudotsuga menziesii		27.9	16.7
Abies grandis		51.1	16.7
Thuja plicata		62.7	14.0
Tsuga heterophylla		73.2	17.4
Abies lasiocarpa		56.7	13.6
Area Averages:			
Central Montana		35.9	16.8
Western Montana		62.1	27.6
Northwestern Montana		57.1	17.0
Northern Idaho		56.2	13.9
Central Idaho		35.9	8.4
Overall Averages:		52.4	15.6

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

Table 5.—Number of seedlings per acre for Douglas-fir and all conifers by habitat type series and geographic area. Data are not reported for cells with less than 50 plots. The number of plots is the same as reported in Table 3.

Habitat Type Series	Area	Density for Douglas-fir	Density for All Species	% Douglas-fir
Pseudotsuga menziesii	C. Montana	191.0	265.9	71.8
	W. Montana	325.9	439.7	74.1
	NW Montana	–	–	–
	N. Idaho	72.2	94.1	76.7
	C. Idaho	54.6	155.2	35.2
Abies grandis	C. Montana	–	–	–
	W. Montana	206.4	1,037.8	19.9
	NW Montana	242.5	693.2	35.0
	N. Idaho	114.6	671.6	17.1
	C. Idaho	42.7	345.8	12.3
Thuja plicata	C. Montana	–	–	–
	W. Montana	81.8	981.8	8.3
	NW Montana	13.0	605.5	2.1
	N. Idaho	105.2	2,208.0	4.8
	C. Idaho	–	–	–
Tsuga heterophylla	C. Montana	–	–	–
	W. Montana	–	–	–
	NW Montana	160.6	2,266.1	7.1
	N. Idaho	142.8	2,554.2	5.6
	C. Idaho	–	–	–
Abies lasiocarpa	C. Montana	85.2	747.2	11.4
	W. Montana	264.8	1,029.0	25.7
	NW Montana	–	–	–
	N. Idaho	56.2	1,134.9	5.0
	C. Idaho	37.5	505.9	7.4
Habitat Type Averages:				
Pseudotsuga menziesii		158.1	240.0	65.9
Abies grandis		118.9	666.9	17.8
Thuja plicata		96.6	2,007.1	4.8
Tsuga heterophylla		144.0	2,510.0	5.7
Abies lasiocarpa		115.4	964.9	12.0
Area Averages:				
Central Montana		155.9	425.7	36.6
Western Montana		258.5	845.7	30.6
Northwestern Montana		138.2	1,244.3	11.1
Northern Idaho		104.0	1,498.6	6.9
Central Idaho		46.0	315.0	14.6
Overall Averages:		125.4	1,121.0	11.2

REGRESSION ANALYSES

The previous section discussed general trends across broad groupings of the data. However, within any grouping, the data are not necessarily balanced with regard to number of plots for various elevations, aspects, times since disturbance, etc. Regression analysis isolates the variation due to independent variables so that effects of one variable can be displayed by holding the others constant.

Regression equations were developed to predict the probability of at least one subsequent Douglas-fir on a 1/300-acre plot by habitat type series. We chose to examine subsequent Douglas-fir because its likelihood can be increased (or decreased) by the reproduction method chosen to regenerate the stand. The amount and condition of advance regeneration can be determined by a preharvest inventory—the silviculturist then knows what regeneration is present on the site. The probability of obtaining subsequent regeneration is much less certain. Here, silviculturists play the odds, and the odds can be increased by knowing the factors that are associated with successful establishment of subsequent regeneration.

Independent variables tested in these equations were aspect and slope, residual overstory density, the presence of Douglas-fir in the overstory, site preparation, elevation, time since disturbance, and defoliation history for western spruce budworm.

The analysis package was RISK (Hamilton 1974), which uses a logistic equation to predict dichotomous dependent variables. The probability is continuous and bounded within the interval [0,1]. The dependent variable is dichotomous because there either was or was not a subsequent Douglas-fir on the plot. Significance of variables was determined at the 0.95 confidence level.

Aspect and Slope

The effect of aspect depends on habitat type series. On the *Pseudotsuga menziesii* series, the best aspect is northerly and the worst aspect southerly (Figure 1). Probability of subsequent Douglas-fir in the *Abies grandis* series is best when the aspect is northerly and worst when southerly. The amplitude (depth of the curve) for the *Abies grandis* series is larger compared to the *Pseudotsuga menziesii* series, and the overall probability is higher on the *Abies grandis* series.

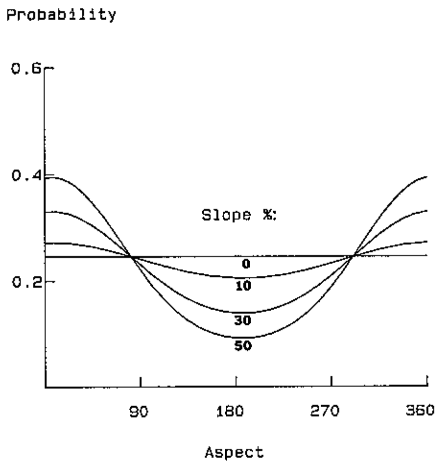
The interaction of aspect and slope is not a significant predictor of subsequent Douglas-fir regeneration on the *Thuja plicata* or *Tsuga heterophylla* habitat type series. Thus, no curves were drawn. In the *Abies lasiocarpa* series, the best aspect is northwest and the worst is southeast. The amplitude in the *Abies lasiocarpa* series is not as great as the amplitudes for the *Pseudotsuga menziesii* and *Abies grandis* series, indicating that aspect is not as critical in the *Abies lasiocarpa* series compared to the *Pseudotsuga menziesii* and *Abies grandis* series.

Residual Overstory Density

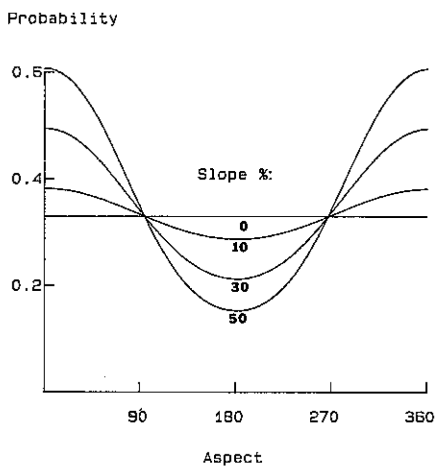
Residual overstory density was recorded as basal area per acre. This variable reflects the general amount of shade and potential seed in the vicinity of each plot, but basal area is not specific as to the duration of the shade nor the time of day it is cast on the plot. For subsequent Douglas-fir, the effect of basal area depends on aspect for two of the habitat type series. Residual overstory is beneficial on southwest-to-northwest aspects for the *Pseudotsuga menziesii* series, and beneficial on south aspects for the *Abies grandis* series (Figure 2). Increasing basal area on north-to-southeast aspects decreases subsequent Douglas-fir regeneration in the *Pseudotsuga menziesii* and *Abies grandis* series.

In the *Thuja plicata* series, there is a moderate quadratic effect of increasing overstory density being beneficial up to about 75 square feet per acre, then a decline with further increases in density (Figure 2). The *Tsuga heterophylla* and *Abies lasiocarpa* series have decreasing probabilities of subsequent Douglas-fir with increasing overstory density, regardless of aspect.

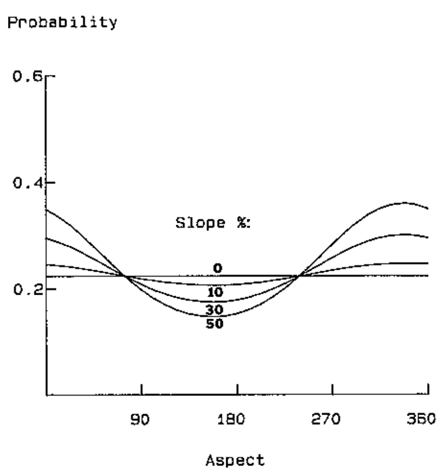
Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.



A. *Pseudotsuga menziessi* series

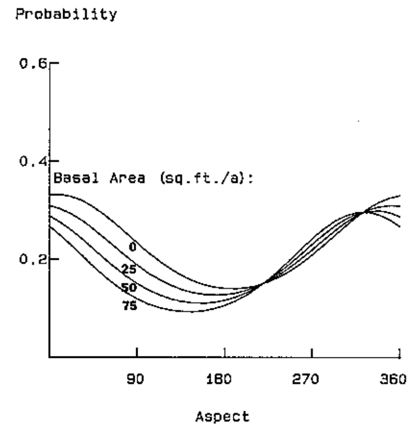


B. *Abies grandis* series

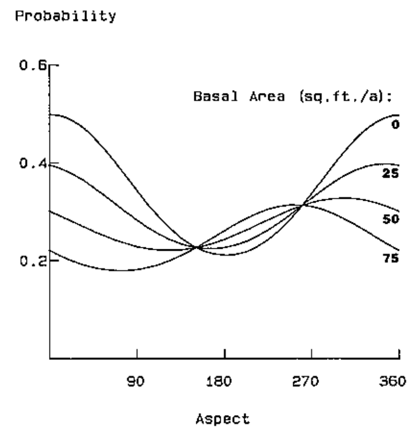


C. *Abies lasiocarpa* series

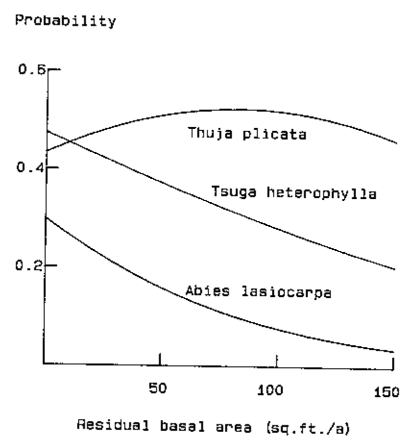
Figure 1. – The effect of slope and aspect on the probability of subsequent Douglas-fir regeneration. Variables held constant are: no overstory, no site preparation, 4,000 feet elevation, no budworm, and 20 years time since disturbance. A: The *Pseudotsuga menziesii* series on the Bitterroot National Forest. B: The *Abies grandis* series. C: *The Abies lasiocarpa series.*



A. *Pseudotsuga menziessi* series



B. *Abies grandis* series



C. Other habitat type series

Figure 2. – The effect of residual basal area on the probability of subsequent Douglas-fir regeneration. A: The *Pseudotsuga menziesii* series shows a slight increase in subsequent Douglas-fir regeneration as residual basal area is increased on southwest-to-northwest aspects; otherwise, increased basal area is detrimental. B: The *Abies grandis* series shows increases in subsequent Douglas-fir regeneration with increasing basal area on south-to-west aspects; otherwise, increased basal area is detrimental. C: Aspect is not important for the remaining series. The *Tsuga heterophylla* and *Abies lasiocarpa* series have decreases in subsequent Douglas-fir as basal area increases; there is a moderate quadratic effect for the Thuja plicata series.

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

Douglas-fir in the Variable Radius Plot

Species of trees in the variable radius plot were recorded; thus, there was or was not a Douglas-fir present. Only in the *Abies lasiocarpa* series was the presence of a Douglas-fir in the overstory a significant predictor of subsequent Douglas-fir regeneration. This result needs to be considered within the context of the study design. A subsequent Douglas-fir is one of the "best" trees on the plot. Trees not chosen as best trees are called "excess" trees. Excess trees would increase stand density and provide stocking in the event best trees died. Ferguson *et al.* (1986), using 4,964 of these same plots, showed that the presence of Douglas-fir in the variable radius plot increases the probability of excess Douglas-fir regeneration. Thus, the occurrence of one Douglas-fir on the plot is not affected by Douglas-fir in the overstory, but there is an effect of Douglas-fir in the overstory on multiple Douglas-fir seedlings on the plot.

Site Preparation

Site preparation is not a significant predictor of subsequent Douglas-fir regeneration for four of the five habitat type series. In the *Thuja plicata* series, mechanical site preparation is better than no site preparation or burn site preparation. The way site preparation was determined for each plot may partially explain the lack of a site preparation effect. The site preparation recorded for each plot was the one that covered the highest proportion of the plot—either none, mechanical, or burn. Microsites within plots were not evaluated separately. Additionally, the severity of the disturbance was not recorded because of the difficulty of determining this with a retrospective study. It may be necessary to look at smaller microsites to determine which seedbeds are best for germination of Douglas-fir.

Site preparation is significant when the data are combined and all habitat type series analyzed together. Ferguson *et al.* (1986) found that mechanical site preparation is better than none and burn is better than mechanical. Even though these coefficients were significant, they are not as large as coefficients for other species such as ponderosa pine, Engelmann spruce, or western redcedar.

Elevation

Within series, the probability of subsequent Douglas-fir decreases with increasing elevation except for the *Thuja plicata* series where elevation is not significant. The decrease as elevation increases is not as fast in the *Pseudotsuga menziesii* and *Abies grandis* series as it is in the *Tsuga heterophylla* and *Abies lasiocarpa* series (Figure 3).

Time Since Disturbance

Time since disturbance is the number of growing seasons from the last site preparation to the year of sampling. Time since disturbance has a significant and positive coefficient in all habitat type series. Increases in the probability of subsequent Douglas-fir over time are slowest in the *Pseudotsuga menziesii* series. The *Abies lasiocarpa* series regenerates to subsequent Douglas-fir slightly faster than the *Pseudotsuga menziesii* series. The remaining habitat type series are progressively faster in this order: *Abies grandis, Tsuga heterophylla,* and *Thuja plicata.*

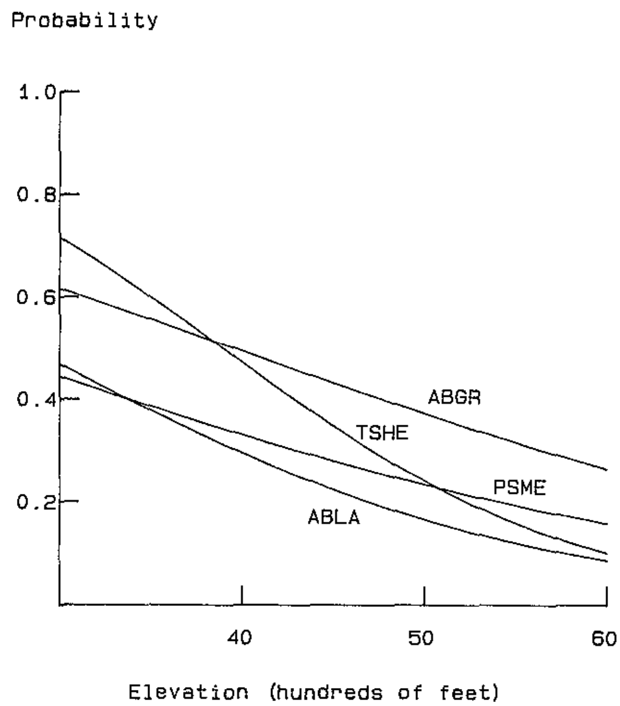


Figure 3.—The effect of increasing elevation on the probability of subsequent Douglas-fir regeneration by habitat type series. PSME= *Pseudotsuga menziesii* series, ABGR= *Abies grandis* series, TSHE= *Tsuga heterophylla* series, ABLA= *Abies lasiocarpa* series.

Western Spruce Budworm

Stands that were in budworm outbreak areas did have increases in the probability of subsequent Douglas-fir over time, but the increases were significantly slower than for stands in nonoutbreak areas. This is the case for two of the five habitat type series—budworm lowered the rate of stocking over time in the *Abies grandis* and *Thuja plicata* series.

The data contain only a few plots in budworm outbreak areas for the *Tsuga heterophylla series,* so it is not surprising to find no budworm effect in this series. In the *Pseudotsuga menziesii* and *Abies lasiocarpa* series, budworm apparently does not decrease the probability of subsequent Douglas-fir. Spruce budworm defoliation results in topkill of host trees. Because Douglas-fir produces cones throughout the crown, budworm effects on seed production may not be as great as for true firs where cones are produced in the top of the tree.

DISCUSSION

Success of Douglas-fir regeneration can be predicted from variables representing site and stand conditions such as aspect, slope, elevation, and residual overstory density. These variables are in common usage by foresters in the western United States. Knowledge of these variables can be used to develop prescriptions to favor establishment of natural Douglas-fir regeneration.

The data in this study were collected using stratified random stand selection procedures from a list of conventionally harvested stands. Results should reflect what can be expected

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.

from implementation of actual silvicultural prescriptions. Harvest dates are spread over a number of years to span the sporadic effects of weather and seed crops.

The regeneration process is a complex sequence of events proceeding from treatment and site conditions to seed production, seed dispersal, germination, and early mortality leading to an established seedling. Many different processes are taking place and interacting during the regeneration period. This retrospective survey quantifies the net effect of many of these processes.

ACKNOWLEDGEMENTS

Many people participated in acquiring data for the three studies mentioned in this paper. They include David L. Adams, Raymond J. Boyd, Margaret M. Harris, Susan E. Kesti, Ward McCaughey, Albert R. Stage, and William R. Wykoff.

LITERATURE CITED

Alexander, R. R. 1988. Forest vegetation in the Rocky Mountains and Intermountain regions: habitat types and community types. Gen. Tech. Rep RM-162. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta. 47 pp.

Boe, K. N. 1953. Western larch and Douglas-fir seed dispersal into clear-cuttings. Res. Note 129. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 3 pp.

Buell, J. 1965. Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco). *In:* Fowells, H.A., comp. Silvics of forest trees of the United States. Agriculture Handbook 271. Washington, DC: U.S. Dept.Agric.: 554-556.

Carlson, C. E., L. J. Theroux and W. W. McCaughey. 1982. The influence of silvicultural practices on the susceptibility and vulnerability of northern Rocky Mountain forests to the western spruce budworm: comprehensive progress report, April 1, 1981-March 31, 1982. Missoula, MT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 55 pp.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22:301-330.

Ferguson, D. E. and A. R. Stage. 1982. The effects of spruce budworm on regeneration success in Idaho's forest ecosystems: progress report, April 1, 1981-March 31, 1982. Moscow, ID: U.SDA Forest Service, Intermountain Forest and Range Exp. Sta. 25 pp.

Ferguson, D. E., A. R. Stage and R. J. Boyd. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. Forest Science Monograph 26. Washington, DC: Society of American Foresters. 41 pp.

Fisher, G. M. 1935. Comparative germination of tree species on various kinds of surface-soil material in the western white pine type. Ecology. 16:606-611.

Geier-Hayes, K. 1987. Occurrence of conifer seedlings and their microenvironments on disturbed sites in central Idaho. Res. Paper INT-383. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 12 pp.

Green, A. W., R. A. O'Brien and J. C. Schaefer. 1985. Montana's forests. Resource Bull. INT-38. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 70 pp.

Haig, I. T. 1936. Factors controlling initial establishment of western white pine and associated species. Yale University, School of Forestry Bulletin 41. New Haven, CN. 173 pp.

Haig, I. T., K. P. Davis and R. H. Weidman. 1941. Natural regeneration in the western white pine type. Tech. Bull. 767. Washington, DC: USDA Forest Service. 99 pp.

Hamilton, D. A., Jr. 1974. Event probabilities estimated by regression. Res. Paper INT-152. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 18 pp.

Hatch, C. R. and J. E. Lotan. 1969. Natural regeneration of Douglas- fir in central Montana. Res. Note INT-85. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 4 pp.

Minore, D. 1979. Comparative autecological characteristics of northwestern tree species—a literature review. Gen. Tech. Report PNW-87. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Exp. Sta. 72 pp.

Ryker, R. A. 1975. A survey of factors affecting regeneration of Rocky Mountain Douglas-fir. Res. Paper INT-174. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 19 pp.

Steele, R. and K. Geier-Hayes. 1987. The grand fir/blue huckleberry habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-228. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 66 pp.

Steele, R. and K. Geier-Hayes. 1989. The Douglas-fir/ninebark habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT-252. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 65 pp.

Van Hooser, D. D., and A. W. Green. 1985. Idaho's state and private forest resource. Resource Bull. INT-37. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 78 pp.

Wellner, C. A. 1989. Classification of habitat types in the western United States. *In:* Ferguson, D. E., P. Morgan, and F. D. Johnson, comp. Proceedingsland classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: USDA Forest Service, Intermountain Research Sta. p. 7-21.

Authors

Dennis E. Ferguson
Intermountain Research Station
USDA Forest Service
Moscow, ID 83843

Clinton E. Carlson
Intermountain Research Station
USDA Forest Service
Missoula, MT 59807

Published in proceedings of "Interior Douglas-Fir: The Species and Its Management" held February 27 – March 1, 1990 in Spokane, WA, USA.
Compiled and edited by D.M. Baumgartner and J.E. Lotan, Washington State University Extension, Pullman, WA.
(Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912.) MISC0230. 301 pp.