Joseph E. Means, PNW Research Station, 3200 Jefferson Way, Corvallis, Oregon 97331

Richard R. Harris, Department of Forestry and Resource Management, University of California, Berkeley, California 94720

Thomas E. Sabin, Department of Forest Science, Oregon State University, Corvallis, Oregon 97331, and

Cynthia N. McCain, Siuslaw National Forest, 4077 SW Research Way, Corvallis, Oregon 97333.

Spatial Variation in Productivity of Douglas-fir Stands on a Valley Floor in the Western Cascades Range, Oregon[1]

Abstract

We studied 80 to 130 yr-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands occurring on fluvial terraces and alluvial fans in the French Pete Creek valley. Our primary goals were to estimate productivity of these stands, examine relationships among landform characteristics, stand characteristics and productivity measures, and determine if productivity differs on terraces and fans. Productivity was measured as site index, leaf area index, mean annual volume increment, and periodic annual volume increment. Productivity on terraces did not differ significantly from that on fans for any measure. Spatial variability (due to plots within stands) in height (p=0.0002) and site index (p=0.004) was significantly greater within terrace stands than fan stands.

Site index of Douglas-fir stands (King 1966) on the valley floor (34 m) was greater than that estimated for surrounding uplands (31, 25 or 24 m depending on data source). In the South Fork McKenzie basin only 16-28 % of the riparian zones are on wide alluvial deposits similar to those on our French Pete valley floor study area. In part for this reason the results of this study cannot be extended directly to the nearby landscape. The current President's Plan (USDA Forest Service and USDI Bureau of Land Management 1994) calls for approximately 4,400,000 ha of riparian reserves on which timber harvest would be significantly restricted. This study indicates that when riparian reserves in the Western Cascades include wide valley floors, they may include some of the more productive stands in a basin.

Introduction

There is little published information on stocking or productivity of conifer forests in valley floors of the Pacific Northwest, and how this compares with adjacent uplands. Most studies of Pacific Northwest riparian plant communities have focused on productivity of hardwood, shrub, and herb species (e.g., Campbell and Franklin 1979), successional trends and processes (e.g., Fonda 1974, Agee 1988, Gecy 1988, Van Pelt 1991) or characterization of plant associations (Lee 1979, 1983). Some have included tree density, basal area, biomass or leaf area, but do not include productivity or make comparisons with uplands sites (e.g., Lee 1983, Gregory et al. 1991). Andrus and Froehlich (1987) estimated tree density, basal area and volume from samples of riparian vegetation along 28 streams (estimated second to third order) in the Central Coast Range of Oregon. Productivity (e.g., increment, site index) was not measured, however, and all but one stream had terraces dominated by hardwoods.

This lack of information is particularly acute because potential uses of these stands—for example, cutting for timber versus maintaining shade and logs for stream ecosystems (Gregory et al. 1991) and riparian habitat for wildlife (see papers in Raedeke 1988)—often conflict (Pedersen 1988). The President's current plan calls for about 4,400,000 ha (10,800,000 ac) of riparian reserves (Espy and Babbitt 1994). Thus estimates of the productivity of these areas, especially relative to adjacent upslope areas, are important.

The goals of this study were to document Douglas-fir productivity on the floor of a fifth-order stream valley in the western Oregon Cascades, examine relationships among stand characteristics and productivity measures, test for differences in productivity and in spatial variability of productivity between landforms (fluvial terraces and alluvial fans, terms defined in Study Area), and compare productivity of valley-floor stands with existing data for upland stands.

A fifth-order stream was chosen because they are common enough to be important, and they are typically bordered by fluvial terraces and alluvial

---

[1] Paper 2284, Forest Research Laboratory, Oregon State University, Corvallis, OR

fans. Smaller streams in the region often lack such landforms and are dominated by adjacent upland stands (Swanson and James 1975). Larger streams may have broader flood plains and terraces so alluvial fans are unimportant, and may be bordered by extensive stands of deciduous riparian vegetation (Hawk and Zobel 1974), complicating comparisons with adjacent coniferous stands.

Productivity measures and stand characteristics were determined on two valley-floor landforms, fluvial terraces and alluvial fans, both supporting mature Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands. These landforms differ in several characteristics, including genesis, soil and shape. The productivity measures chosen were site index, leaf area index, periodic annual volume increment, and mean annual volume increment. The stand characteristics chosen were age, mean diameter, height, tree density, Reineke's stand density index, basal area and volume.

Study Area

Research was conducted on the valley floor of French Pete Creek, a fifth-order tributary of the McKenzie River in the western portion of the Oregon Cascades Range (Figure 1). The 6-km-long study reach is located upstream from the South Fork McKenzie River and drains a watershed area of 84 km^2. Altitude of the valley-floor study area ranges from 550 m to 800 m. Mature Douglas-fir stands now dominate the forest; however, the late-successional vegetation type is the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) series (Hemstrom et al. 1987).

French Pete Creek lies within the Three Sisters Wilderness Area and has never been logged. The preponderance of even-aged stands 80 to 130 years-old (based on ages of the oldest trees; stand origins 1856 to 1906) result from large fires in the basin during the late 19th century. Older stands are rare and occur as isolated patches. Mixed stands of alder (*Alnus rubra* Bong.), bigleaf maple (*Acer macrophyllum* Pursh), western redcedar (*Thuja plicata* Donn ex D. Don), western hemlock, and Douglas-fir occur on some terraces along with 80 to 130-yr-old Douglas-fir stands. Flood plains usually support alder. The Douglas-fir stands we studied are classified in the *Tsuga heterophylla/ Berberis nervosa, Tsuga heterophylla/ Berberis nervosa-Gaultheria shallon,* and *Tsuga heterophylla/ Gaultheria shallon* plant associations, all of which are common on well-drained, gravelly soils in the western Cascades (Hemstrom et al. 1987).

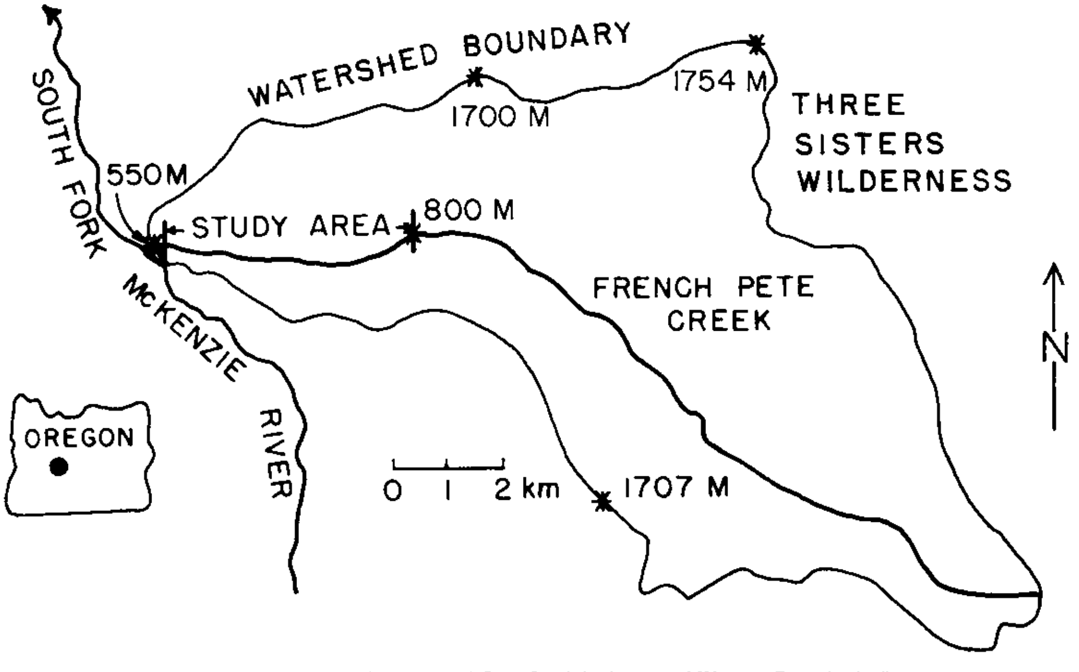

Figure 1. Location of the study area along lower French Pete Creek in the central Western Cascades in Oregon.

Four major landforms make up the French Pete Creek valley floor: the channel, active flood plain, fluvial terraces and alluvial fans. A geomorphic surface (or "surface") is a specific example of a landform, such as an individual fluvial terrace or alluvial fan (Figures 2 and 3). The width of the valley floor ranges from 9 m to 170 m in the study area. The active flood plain, and low-flow and flood channels, together occupy 14% of the valley floor, are frequently flooded, and generally do not support mature forest.

Methods

The channel, active flood plains, fluvial terraces, and alluvial fans were identified, and the entire valley floor was mapped according to these landforms (Figure 3, Table 1) as part of another study. We wanted to summarily characterize the soil environment of this valley floor, not to examine effects of soils on inter- or intra-stand variability in productivity. Soil was described in one 60-100 cm deep pit on each of three terraces and three fans chosen at random from those sampled for tree growth. Texture (hygrometer method, Day 1965), organic matter (Walkley-Black method, Nelson and Sommers 1982) and total nitrogen (micro-Kjeldahl method, Jackson 1958) of soil at the depths 0-15 cm and 15-60 cm were determined.

Stand Selection

Color infrared aerial photographs (1:8000) were used to map tree cover based on composition (hardwood, conifer, or mixed) and approximate stand age based on crown characteristics on the valley floor. The landform map was overlaid with the tree cover map.

Stands selected for vegetation sampling met the following criteria: they were (1) located on terraces or fans (since other valley floor landforms did not support Douglas-fir), (2) dominated by 80- to 130-yr-old Douglas-fir (>80% of stand basal area), and (3) located in stands large enough to contain at least five dominant or codominant Douglas-fir trees (generally 0.1 ha or larger). Old-growth stands (all with dominants much older than 130 years) and mixed stands (mixtures of broadleaved trees and conifers) were not sampled to avoid confounding landform with large differences in age and species composition. Portions of stands with pockets of canopy tree mortality apparently caused by root rot, and deeply incised channels (up to 15 m) on alluvial fans that often did not support Douglas-fir made up a small, unknown proportion of the area and were avoided.

Seventeen percent (by area) of the terraces and 86 % of the fans met these criteria (Table 1). Many terraces supported over 20 % broadleaved species and so were not sampled. Stands on 14 fans and 10 terraces were chosen for sampling.

Field Sampling

French Pete Creek field sampling, conducted in 1986 and 1989, varied in relation to the size of the geomorphic surface. On surfaces large enough to contain them, systematically located

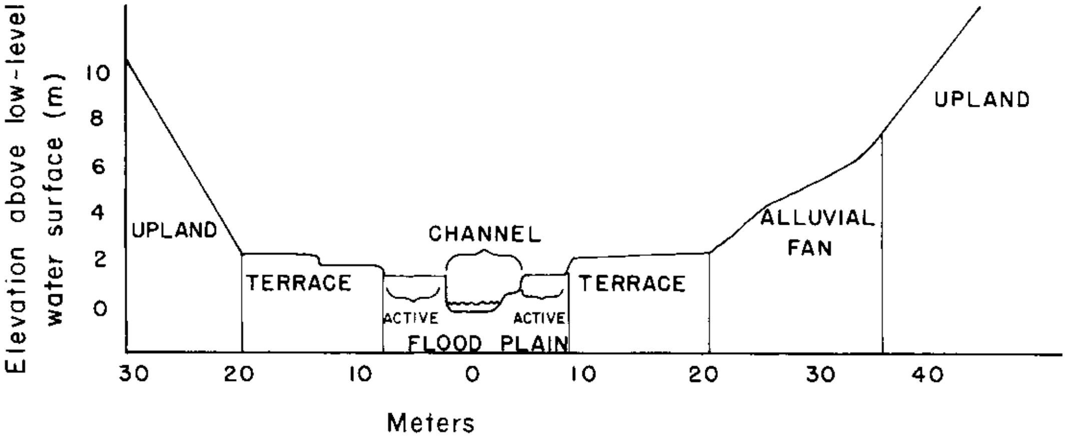

Figure 2. Diagrammatic cross-section of a hypothetical valley floor illustrating typical topographical relations of the four landforms identified in the study area. Note that alluvial fans are not necessarily paired.

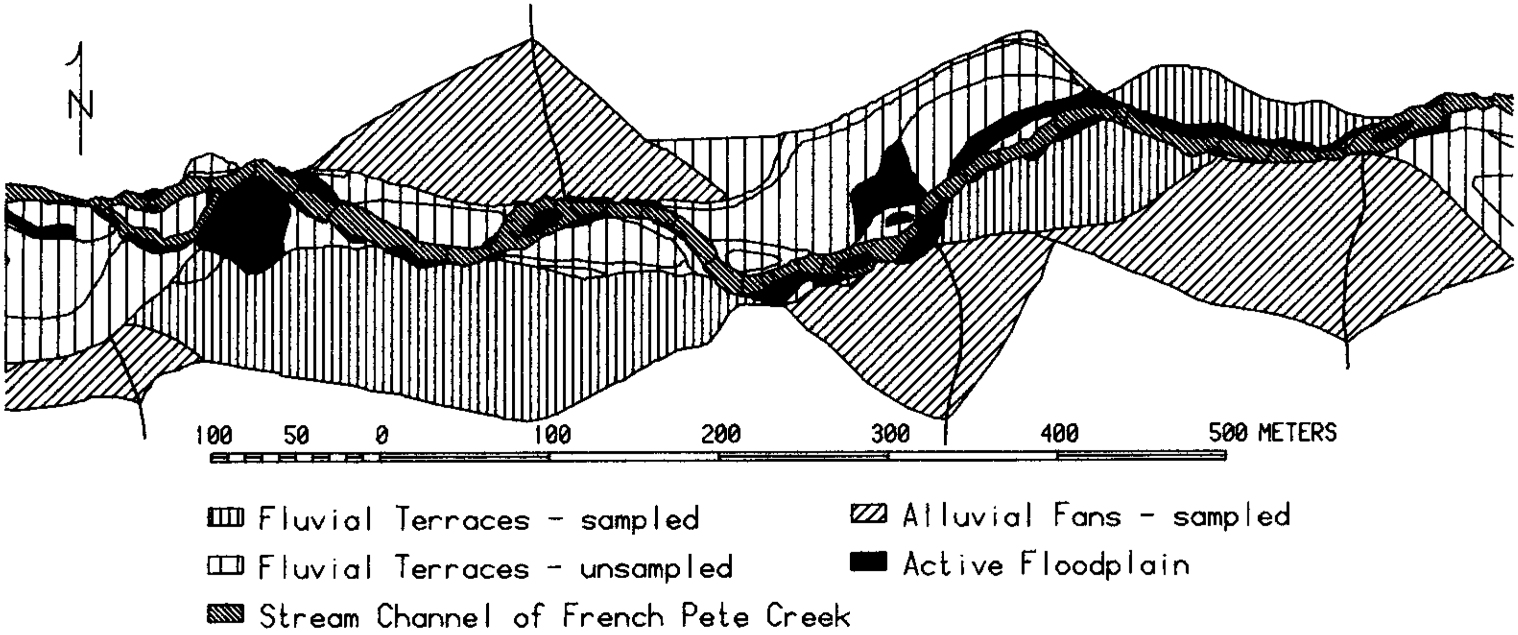

Figure 3. A GIS map of a portion of the French Pete Creek study area showing the French Pete Creek stream channel, active flood plain, fluvial terraces with abandoned channels, alluvial fans and tributary streams.

TABLE 1. Cover types on the French Pete Creek valley floor, total area 41.2 ha.

Cover type	Percent of total area	
Channels	14	
Terraces:	62	
Conifer, suitable for sampling		11
Conifer, unsuitable, old-growth		12
Conifer, unsuitable, not old-growth		15
Conifer/Hardwood mix		4
Pure alder		5
Maple, maple/alder mix, other hardwood		5
Non-tree		10
Fans:	24	
Conifer, suitable for sampling		20
Conifer, unsuitable, old-growth		3
Conifer, unsuitable, not old-growth		1

variable-radius prism plots were used to estimate site index and stand productivity measures. Variable-radius plots were placed at 25 m intervals on lines spaced 20 to 30 m apart. Plots were placed 20 m from the edge of the surface to avoid the potential effects of abrupt topographic changes at surface edges.

In each plot, tree counts were obtained using a prism with a basal-area factor of 4.6 m^2/ha. Diameter-outside-bark at breast height (dbh) was recorded for tallied trees. Five (rarely 3 to 8) dominant or codominant Douglas-fir trees (herein called site index trees) were selected for increment coring (2 cores), height measurement and site index estimation. We chose only trees with no evidence of radial growth suppression to avoid problems from early competition from over topping trees and shrubs. Age at breast height (1 core only), bark thickness, sapwood thickness, and number of rings in the outer-most centimeter were recorded for these trees. A total of 56 prism plots on 5 terraces and 6 fans were sampled.

On 5 additional terraces and 8 additional fans with stands too small to contain prism plots, a minimum of 5 dominant or codominant Douglas-fir trees were selected for site index estimation.

Calculation of Productivity Measures

Several characteristics of the current stand were estimated from the field sampling. Data obtained from dominant and codominant trees were used to estimate site index at 50 yr (King 1966) for all plots and surfaces. Current volume of trees with measured height was estimated directly from dbh and height of site index trees (Walters et al. 1985). We modeled volume of these trees as: log(volume, m^3) = -8.181 + 2.146*log(DBH, cm) + 0.02900*(Plot SI, m) using standard regression procedures (n=395, r2=0.96, s.e.e.=0.11 m^3). The resulting equation was used to estimate tree volumes that were in turn used to estimate prism plot volumes using the tree-factor approach (Husch et al. 1982:220-241).

From trees with the needed measurements, equations were developed for diameter increment: DBHinc (cm/yr) = 2.9417 + 0.55930 lnDBH + 0.29084 ln(BAL+1) - 0.47469 ln(BAL+5) - 1.23306 ln (plot age) (n=249, r^2=0.166, s.e.e.= 0.3764 cm/yr) where BAL=basal area of larger trees (m^2/ha); for diameter inside bark: DIB=0.89963 DBH; and for height increment: HTinc (m/yr) = 1.1469 + 0.007398 PlotSI - 0.259045 ln(plot age) (n=344, r^2=.67, s.e.e.=0.028 m/yr).

These equations were used to estimate annual volume increment, when tree measurements of radial increment and site index were not available. Growth for each plot was expressed as periodic annual increment, and mean annual increment, and was averaged for each stand. We present net growth rates (gross growth minus mortality) because we could not estimate mortality on these temporary plots. We chose to not use a regional stand growth model (e.g., DFSIM by Curtis et al. 1981, SPS by Arney 1984) to calculate growth rates because we had much radial growth data specific to these stands.

Reineke's stand density index (SDI) was calculated according to Daniel et al. (1979). Leaf area was estimated by assigning a value of 0.54 (m^2/cm^2) to the ratio leaf area:sapwood area (Waring et al. 1982) for 337 trees with measured sapwood. For 311 trees without sapwood measurements, sapwood was estimated by a regression model of the form: log(sapwood area, cm^2) = 0.2895 + 0.7819*log(BA, cm^2) (n=337, r^2=0.62, s.e.e.=0.26 cm^2), then leaf area was estimated as above. Leaf area index (LAI) was calculated for each plot using the tree-factor approach in which values for individual trees are weighted by the tree factor to obtain an areal estimate for the plot (Husch et al. 1982:220-241).

Volumes and leaf areas of trees in lower canopy classes were probably overestimated because data from dominants and codominants were used to build the estimating equations. The effect of this bias on reported volumes, volume growth rates, and LAI values is probably unimportant because smaller trees make up a small proportion of the total volume and leaf area. Additionally, the effect on estimates in each stand is in the same direction (overestimation), and of similar size because stand diameter distributions are all similar (not significantly different from normal, $p>0.05$ in all cases, Shapiro and Wilk 1965, and variances are not significantly different, $p>0.05$ by Bartlett's test for homogeneity of variances, Steel and Torrie 1980). For these reasons it probably has little effect on comparisons of stand means in an analysis of variance.

Statistical Analyses for French Pete Creek Data

For each of 13 measures (for all plots: average age, mean dbh and height of site index trees; additionally for prism plots: mean dbh, site index, stand density, basal area, volume, mean annual volume increment, periodic annual basal area and volume increments, stand density index and leaf area index), we tested the hypotheses that productivity of north-facing and south-facing fans was equal and that productivity of terraces and fans was equal. We used independent contrasts in an analysis of variance for a nested, unbalanced design (general linear modeling, Steel and Torrie 1980) to test each hypothesis:

	Degrees of freedom	
Source	Prism plots	Age & SI plots
Landform	2	2
N-facing fans vs. S-facing fans	1	1
Fans vs. Terraces	1	1
Stands within Landforms (experimental error)	8	21
Plots within Stands (sampling error)	45	43
Corrected total	55	66

Kendall's Tau rank correlation coefficient (Conover 1980) was used to evaluate relationships among elevation above stream, slope, age, and measures of productivity. Rank correlation was used since variance of some of the correlated variables was not uniform and some of the relationships were nonlinear.

For each measure we also tested the hypothesis that variability within north-and south-facing fans was equal using an F-ratio of the plot-within-stand variance for the north-facing fans over the plot-within-stand variance for the south-facing fans. For each measure we then tested the hypothesis that variability within fans and terraces was equal using an F-ratio of the plot-within-stand variance for the fans over the plot-within-stand variance for the terraces. Correlations between stand means and variances were negative for most measures but were not significant (all $p > 0.05$), so no correction for correlation of the variance with the mean was needed.

Comparisons with Uplands Data

We compared data for stands on the French Pete Creek Valley floor with prism plot data for stands in the surrounding central portion of the western Cascades in Oregon collected by Hemstrom et al. (1987) (eco-plot data) and by the Willamette National Forest in the 1981 National Forest Inventory (NFI data). We used eco-plot data for the South Fork McKenzie River basin that met our sampling criteria for French Pete valley floor stands, Douglas-fir basal area at least 80 % and stand age 80-130 years. We used NFI data (Willamette National Forest 1990) from stands within 48 km of French Pete Creek that were in the NFI stand types mapped for the slopes above our study reach and in the elevation range of those slopes (520-1680 m). Restricting NFI stands to those that met the Douglas-fir basal area and stand age criteria gave too few stands to make comparisons, so we were unable to calculate stocking or productivity measures. We selected dominant and codominant trees that had no damage or defect and calculated Douglas-fir site index (King 1966) for each stand.

Comparisons between French Pete valley floor and uplands stands used F-ratios in ANOVAs for unbalanced designs weighted by the number of prism plots in the stand (general linear modeling, Steel and Torrie 1980):

	Degrees of freedom	
Source	Prism plots	Age & SI plots
Data source (French Pete valley floor vs. surrounding western Cascades)	1	1
Stands within Data source (error)	25	38
Corrected total	26	39

Degrees of freedom were less for measures available only on our prism plots.

TABLE 2. Characteristics of sampled fluvial terraces and alluvial fans.

Characteristic		Fluvial terraces	Alluvial fans
Number sampled		10	14
Percent of valley floor		11% (all terraces 62%)	20% (all fans 24%)
Average width		8-83 m	23-202 m
Length		30-345 m	22-180 m
Size		<0.1-0.6 ha (1 is 2.3 ha)	0.1-1.4 ha
Origin of material		French Pete Cr.: gravel bars, abandoned channels, channel levees	Tributary streams: bedload and debris torrent material
Shape		Usually oblong, parallel French Pete Creek	Cone-shaped with apex where a tributary stream exits a side valley
Slope		<2%	8-25%
Aspect		Down stream (approx. West)	Towards main channel (10 face North, 4 face South)
Average elevation above low-flow water surface		1.5-5.4 m	3-17 m
Rock fragments[a]		Rounded, 40-70% by vol.	Angular, 40-70% by vol.
Soil texture[a]		Sandy loam to loam	Sandy loam to loam
Soil organic matter[a]	0-15 cm:	1.2-8.5%	5.7-9.0%
	15-60 cm:	3.5-5.7%	2.6-4.0%
Total soil nitrogen[a]	0-15 cm:	0.03-0.10%	0.06-0.17%
	51-60 cm:	0.04-0.12%	0.04-0.06%
Soil classification[a,b]		Usually Typic Ustochrepts, rarely Typic Ustorthents	Usually Typic Ustochrepts

[a] Based on one pit in each of three terraces and three fans.

[b] Based on soil pits and unpublished soil temperature and climatic data from similar elevations on the H.J. Andrews Experimental Forest, 30 km north.

The above ANOVAs were performed on ranks of the data (Conover and Iman 1981) for measures with variances found to be nonuniform using Bartlett's test (Steel and Torrie 1980) or residuals found to be non-normally distributed using the Shapiro-Wilk test (Conover 1980).

Results and Discussion

Terraces and Fans

Fluvial terraces cover over 60 % of the valley floor, are oblong, and slope gently downstream (Table 2). Alluvial fans cover only 24 % of the valley floor, are cone shaped, and slope more steeply either north or south towards French Pete Creek. Terraces are made of gravel bars, abandoned channels (Figure 3), and channel levees—material that has been worked over and sorted by a fifth order stream so that rock fragments are rounded (Table 3). Fans are relatively unsorted deposits of bedload and debris flow material from first and second order streams, and rock fragments are angular. Terraces commonly support deciduous vegetation and many did not meet our sampling criteria.

Douglas-fir Stands

In general, there was a canopy of dominant and codominant Douglas-fir over fewer, comparably-aged intermediate and overtopped Douglas-fir. Younger trees of any species were very rare in the understory. Average diameter (all prism-plot trees) ranged from 43 to 65 cm, height ranged from 44 to 62 m, stand density ranged from 159 to 461 stems/ha, stand volume ranged from 638 to 1432 m^3/ha, and mean annual increment ranged from 5.9 to 12.0 m^3/ha/yr (Table 3).

Comparing north- versus south-facing fans, no productivity measures were found to be significantly different (all $p > 0.05$), though the small number of south-facing fans ($n=4$) limits the power of this test.

All productivity measures, stand density, stand density index, basal area and volume were greater on fans than on terraces (Table 3), however, none of these differences was significant (all $p > 0.05$).

TABLE 3. Stand characteristics and productivity measures on fluvial terraces and alluvial fans.

		Stand characteristics							Productivity measures			
Stand num	Num of plots	Age[a] (yr)	DBH (cm)	Height (m)	Stand density (stem/ha)	Stand density index[b]	Basal area (m^2/ha)	Volume (m^3/ha)	Site index[a] (m)	Leaf area index (m^2/m^2)	Mean ann. inc. (m^3/ha/yr)	Periodic ann. inc. (m^3/ha/yr)
		Fluvial terraces										
1	8	109 (6)	55 (18)	46 (12)	159 (43)	682 (32)	39 (32)	638 (34)	31 (11)	5.3 (31)	5.9 (33)	7.8 (31)
2	3	100 (10)	53 (1)	48 (22)	198 (27)	799 (29)	46 (26)	822 (45)	34 (21)	6.3 (32)	8.2 (41)	11.4 (47)
3	2	122 (8)	60 (7)	54 (7)	235 (12)	1082 (7)	69 (0)	1314 (4)	35 (4)	9.1 (7)	10.8 (3)	15.4 (1)
10	5	92 (7)	57 (6)	44 (8)	188 (17)	808 (15)	50 (18)	795 (21)	32 (7)	7.0 (19)	8.7 (22)	13.0 (24)
14	11	113 (4)	60 (6)	53 (7)	184 (31)	929 (23)	54 (23)	1009 (24)	35 (6)	6.9 (24)	8.8 (26)	12.7 (26)
All	29	107 (10)	58 (11)	48 (13)	183 (31)	837 (26)	49 (28)	872 (33)	33 (10)	6.6 (27)	8.0 (31)	11.2 (34)
		Alluvial fans										
4	10	87 (6)	53 (8)	47 (3)	219 (23)	907 (18)	51 (16)	901 (14)	36 (5)	7.0 (19)	10.4 (14)	14.0 (17)
5	7	114 (2)	57 (8)	49 (4)	210 (37)	925 (26)	55 (24)	922 (22)	33 (4)	7.0 (26)	7.9 (24)	9.8 (24)
114	2	120 (2)	58 (31)	62 (5)	250 (73)	1396 (61)	64 (30)	1335 (34)	39 (5)	7.8 (18)	11.1 (32)	14.7 (41)
116	2	120 (11)	43 (12)	55 (3)	461 (20)	2124 (2)	80 (4)	1432 (5)	35 (1)	10.9 (1)	12.0 (6)	17.5 (10)
204	2	107 (12)	60 (2)	49 (6)	241 (15)	1633 (9)	73 (9)	1261 (5)	32 (1)	9.1 (15)	11.9 (17)	15.8 (17)
205	4	112 (12)	65 (20)	55 (6)	173 (34)	1012 (24)	57 (10)	1071 (10)	35 (6)	7.2 (18)	9.8 (25)	12.4 (29)
All	17	103 (15)	55 (9)	51 (10)	232 (41)	1107 (40)	57 (22)	1030 (23)	36 (8)	7.5 (24)	10.0 (22)	13.6 (25)

Note: Values given are stand means and coefficients of variation (in parentheses).

[a] Ages and site indices (King 1966) for all terraces and all fans are based on 10 terraces and 14 fans, respectively.

[b] Stand density index in trees per hectare at reference quadratic mean DBH of 25 cm (Husch et al. 1982).

Partitioning the within-landform variance components (Hartley, Rao and LaMotte 1978) showed, for 10 of 13 response variables, more variation was due to plots within stands (60 to 94 %) than to stands within landforms. Age showed the least percentage variation within stands, only 12 %. This probably reflects common stand-initiating disturbances and regeneration lag times within stands.

Variability Within Stands

Comparing south- and north-facing fans, tree age was more variable among plots ($p = 0.005$) on south-facing fans, and was the only measure with a significant difference. On nearby uplands sites, natural regeneration commonly takes longer on drier south aspects than on north aspects (Means 1982). The higher summer evaporative demand and temperatures expected on south slopes, and lack of topographic shading by an adjacent valley wall, probably make seedling establishment more difficult, increasing the length of the regeneration period and the plot-to-plot variability in tree age.

We found plot-to-plot variability within stands to be significantly greater on terraces than on fans for height ($p = 0.0002$) and site index ($p = 0.004$) but not for other measures. Greater plot to plot differences probably reflect greater soil spatial variability on terraces than fans caused by the different processes that build these landforms. Swanson and James (1975) describe these processes for the nearby Blue River drainage. French Pete Creek creates stream channels, levees, and areas of sorted rock fragments (of different average size classes) such as gravel bars in flood plains that become terraces with abandoned channels (Figure 3) when the stream cuts to a lower level. Rounded rock fragments in terraces (Table 2) reflect fluvial reworking and sorting of deposits. In this way fluvial processes create patterns in soil parent material and micro-relief that may cause similar patterns in tree height growth rate, and therefore in site index. Our plots 25 m apart could have picked up variability caused by these patterns.

Tributary streams form the larger alluvial fans (large enough for prism plots) primarily by accretion of deposits from debris flows that overflow the incised channels, depositing relatively unsorted material (clay to large boulders), as they emerge from steep-walled side valleys. This material is not sorted by flowing water after deposition because water flow occurs on fan surfaces only during very brief debris flows and at other times is in the channels. Angular rock fragments in fans (Table 2) reflect less reworking of deposits than occurs on terraces. We thus hypothesize soils are more variable spatially on terraces than on fans. This could be tested with extensive soil sampling in another study.

On both landforms variability within stands, as indexed by coefficient of variation (CV), was relatively high (22 to 41 %) for measures such as basal area, volume, mean annual increment and

TABLE 4. Comparison of characteristics of 24 stands on the French Pete Creek valley floor with 18 eco-plot stands in the South Fork McKenzie Basin (Hemstrom et al. 1987). 13 NFI stands from within 48 km of French Pete Creek, and site quality from the Forest Survey map (Isaac 1949).

Location	Age (yr)	DBH (cm)	Stem density (stems/ha)	Stand density index[b]	Basal area (m^2/ha)	Volume m^3/ha)	Site index (m)	Mean annual increment (m^3/ha/yr)
French Pete Creek	105 (12)	57 (4)	206 (55)	779 (145)	53 (10)	779 (145)	35[a] (2)	7.4 (1.4)
McKenzie Basin	111 (11)	55 (10)	344 (150)	1031 (269)	68 (17)	1061 (274)	31 (4)	9.9 (3.0)
P-value	0.3	0.5	0.001	0.003	0.006	0.009	0.0001	0.014
NFI				972 (228)			25 (3)	
P-value				0.0505			0.0001	
Forest Survey map							24[c]	

Note: Values are means and standard deviations in parentheses.

[a] Site index (King 1966) of French Pete stands based on the tallest tree, like McKenzie Basin eco-plots.

[b] Stand density index in trees per hectare at reference quadratic mean DBH of 25 cm (Husch et al. 1982).

[c] Approximate site index calculated from mid point of site class IV on Forest Survey map (Isaac 1949) following King (1966).

LAI (Table 3) that are directly affected by stocking. Variability within stands was smaller (CV's ranged from 8 to 16), however, for stand age, height, dbh and site index, measures that are not directly affected by stocking (Table 3). The greater variability of measures such as basal area, volume, and mean annual increment makes differences in spatial variability between landforms more difficult to detect.

Comparisons with Uplands

Table 4 compares all our French Pete Creek valley floor stands with upland eco-plot stands in the surrounding South Fork Mckenzie River basin (Hemstrom et al. 1987), with upland NFI (National Forest Inventory) stands (Willamette National Forest, 1990), and with site index of the valley walls immediately above our study reach based on Forest Survey site class maps (Isaac 1949) converted to approximate site index following King (1966). Douglas-fir stands on the valley floor have significantly greater site index (34 m) than do eco-plot stands (31 m) or NFI stands (25 m) in the uplands. The valley floor stands generally have five site trees per prism plot whereas the eco-plot stands have only one and the NFI stands typically have 1-2. The French Pete valley floor stands show even greater site index (37 m) when based on the tallest tree, as might be done if only one site tree had been selected. The Forest Survey mapped the French Pete Creek basin as site class IV which corresponds to about site index 24 m (King 1966), also lower than the valley floor.

The valley floor stands, however, have lower stem density, SDI, basal area, volume, and mean annual increment than the eco-plot stands, and possibly lower SDI than the NFI stands (Table 4). Productivity comparisons with the NFI stands would not indicate site differences because some were outside the age range of the valley floor stands and not dominated by Douglas-fir, so this comparison is not considered further. The eco-plot stands were selected subjectively so chosen stands tended to have greater stocking (Hemstrom et al. 1987). We cannot conclude the apparently greater stocking on the uplands is real, though it may be. The known suppression of Douglas-fir height growth by higher stocking on low site land (Harrington and Reukema 1983, Reukema 1979) may contribute to the site index differences. We conclude, however, that the French Pete valley floor has higher site index than the surrounding uplands because we believe the magnitude of the site index differences out weighs a possible but unclear effect of stocking to reduce site index in the uplands.

Leaf area index of forests along French Pete Creek (5.3-10.9 m^2/m^2) was similar to or lower than that of subjectively selected Douglas-fir forests (7.3-12.0 m^2/m^2) sampled by Marshall and Waring (1986) in the region.

Frequent disturbances and high moisture content of riparian sites often leads to significant representation or dominance by early seral or broadleaved vegetation, as was found by Andrus and Froehlich (1987) in a study of terraces and uplands along 28 second- and third-order streams in the Oregon Coast Range. Their only valley floor stand that was comparable in age and composition to ours had conifer density, basal area, and volume very close to those of terrace 1 (Table 3). Future studies should stratify riparian zones by several of the following: width of valley floor, slope towards stream, estimated height of growing-season water table, approximate age of surface (or at a minimum, relative height of surface), relative frequency of fluvial disturbances, and species composition, and should pair adjacent riparian and upland samples.

Putting this Work in Context

The difference in productivity we found between the valley floor and uplands cannot be extrapolated directly to the surrounding landscape for two reasons. First, many riparian zone stands are less productive than those we sampled. On the French Pete Creek valley floor about 30 % of the surfaces support broad leaved, broad leaved/conifer mix, herbaceous or no vegetation, often with younger, less well-developed soils, which we did not sample. New surfaces with pure alder, shrub, herb or no vegetation (Table 1) probably would not support conifers, and surfaces supporting other pure hardwoods (Table 1) may have lower Douglas-fir site index than stands we sampled. We also did not sample riparian stands on steep and over-steepened toe slopes with thinner, less well-developed soils from which trees commonly topple into the stream, where there is no valley floor. These sites are usually closer to the stream and experience fluvial disturbances such as erosion and deposition relatively frequently.

Second, we sampled only one stream valley. In the surrounding South Fork McKenzie basin, narrower valley floors with fewer or no terraces and fans are more common than wide valley floors such as those we sampled. In this basin fans and terraces occur along approximately 28 % of the total perennial stream length when steep valley wall tributary streams are not included and along 16 % when they are (C. McCain, unpublished data, 1994).

The recent Northwest Federal Forest Plan (Espy and Babbitt 1994) calls for about 4,400,000 ha of riparian reserves in which harvest would be restricted. The reserve for our 4.4 km study reach would be 88.2 ha (41.2 ha valley floor with channel and 47.0 ha uplands) of which 25.4 ha is in nearly pure Douglas-fir stands on the valley floor, of which we sampled 12.7 ha. This work indicates that, when riparian reserves include wide valley floors, they may remove from potential harvest some of the more productive stands in a basin. This is likely to be one consequence of implementation of the recent Northwest Federal Forest Plan. This deserves further study because the magnitude of this effect cannot be assessed from this study alone.

Conclusions

Productivity of Douglas-fir stands on the valley floor of French Pete Creek is very similar on fluvial terraces and alluvial fans. It is quite variable within terraces and fans, and is high locally.

Spatial variability in productivity, as measured by tree height and site index, is greater within terraces than within fans. We hypothesize this is caused in part by greater variability in soil parent materials and topography caused by processes that create terraces.

Site index on the valley floor of French Pete Creek is greater than that of sites in the surrounding uplands. Though this result may hold for other undisturbed riparian sites with developed soils on terraces and fans, it cannot be extrapolated to recently created surfaces or stream valleys without terraces and fans, the most common riparian geomorphic setting in the South Fork McKenzie River Valley.

Acknowledgements

This study was funded in part by grants from the National Science Foundation (BSR 8508356 and BSR 8514325) to Oregon State University. We thank M. Hemstrom, D. Henshaw, G. Johnson, A. McKee, F. Swanson and J. Zasada for reviews, T. Bohle, P. Rabenold, C. Swanberg and S. Wondzell for field assistance, George Lienkaemper and Melissa Richmond for GIS assistance, and D. Henshaw, T. Max and G. Howe for statistical advice. The idea for the research was derived from conversations with L. Wensel, University of California, Berkeley, in 1979.

Literature Cited

Agee, J.K. 1988. Successional dynamics in forest riparian zones. In Raedeke, K.J. (ed.) Streamside Management: Riparian Wildlife and Forestry Interactions. Contribution No. 59, Institute of Forest Resources, Univ. Washington, Seattle. p. 31-43.

Andrus, C., and H.A. Froehlich. 1987. Riparian forest development after logging or fire in the Oregon Coast Range: wildlife habitat and timber value. *In* Raedeke, K.J. (ed.) Streamside Management: Riparian Wildlife and Forestry Interactions. Contribution No. 59, Institute of Forest Resources, Univ. Washington, Seattle. p. 139-152.

Arney, J.D. 1984. A modeling strategy for the growth projection of managed stands. Can. J. For. Res. 15:511-518.

Campbell, A.G., and J.F. Franklin. 1979. Riparian vegetation in Oregon's western Cascade Mountains: composition, biomass and autumn phenology. University of Washington, Seattle, WA. Coniferous For. Biome Bull. 14.

Conover, W.J. 1980. Practical nonparametric statistics. 2nd ed. John Wiley and Sons. New York.

Conover, W.J. and R.L. Iman. 1981. Rank transformation as a bridge between parametric and nonparametric statistics. The Amer. Stat. 35(3):124-129.

Curtis, R.O., G.W. Clendenen, and D.J. DeMars. 1981. A new stand simulator for coast Douglas-fir: DFSIM user's guide. USDA For. Serv. Gen. Tech. Rep. PNW-128. PNW Res. Sta., Portland, Or. 79 p.

Daniel, T.W., R.L. Meyn, and R.R. Moore. 1979. Reineke's stand density index in tabular form in English and metric units with its applications. Utah Agric. Exp. Stn., Utah State University, Logan. Res. Rep. 37.

Day, P.R. 1965. Particle fractionation and particle size analysis. Chapter 43 *In* Black, C.A., et al. (eds.) Methods of soil analysis, Part 1 physical and mineralogical properties, including statistics of measurement and sampling. Amer. Soc. Agron., Madison, Wis. Pp. 545-567.

Espy, M., and B. Babbitt. 1994. Record of Decision for amendments to Forest Service and Bureau of Land Management documents within the range of the northern spotted owl. Washington, DC. USDA Forest Service, USDI Bureau of Land Management.

Fonda, R.W. 1974. Forest succession in relation to river terrace development in Olympic National Park. Ecology 55(5):927-942.

Gecy, J.L. 1988. Propagule sources, disturbance characteristics and the initial establishment of riparian vegetation after debris flows. M.S. Thesis, Oregon State Univ., Corvallis. 135 p.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8):540-551.

Harrington, C.A. and D.L. Reukema. 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. For. Sci. 29(1):33-46.

Hartley, H.O., J.N.K. Rao, and L. LaMotte. 1978. A simple synthesis-based method of variance component estimation. Biometrics 34:233-242.

Hawk, G.M., and D.B. Zobel. 1974. Forest succession on alluvial landforms of the McKenzie River Valley, Oregon. Northw. Sci. 48:245-265.

Hemstrom, M.A., S.E. Logan, and W. Pavlat. 1987. Plant association and management guide. Willamette National Forest. USDA For. Serv., Pacific Northwest Region. Portland. OR.

Husch, B., C.I. Miller, and T.W. Beers. 1982. Forest mensuration (3rd edition). John Wiley and Sons, NY.

Isaac, Leo A. 1949. Better Douglas-fir forests from better seed. Univ. Wash. Press, Seattle. 65 p.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc., Edgewood Cliffs. New Jersey.

King, J.E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Research Center, Centralia, WA. Weyerhaeuser Forestry Pap. No. 8.

Lee, L.C. 1979. A study of plant associations in upland riparian habitats in western Montana. M.S. Thesis, University of Montana, Missoula. 163 p.

Lee, L.C. 1983. The floodplain and wetland vegetation of two Pacific Northwest river ecosystems. Ph.D. Thesis, University of Washington, Seattle. 268 p.

Marshall, J.D., and R.H. Waring. 1986. Comparison of methods of estimating leaf area index in old-growth Douglas fir. Ecology, 67:975-979.

Received 9 September 1995
Accepted for publication 27 March 1996

Means, J.E. 1982. Developmental history of dry coniferous forests in the western Oregon Cascades. In Means, J.E. (ed.). Forest succession and stand development research in the Northwest. For. Res. Lab., Oregon State Univ., Corvallis. Pp. 142-148.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. Chapter 29. In Page, A.L., et al. (eds.) Methods of soil analysis, Part 2 chemical and microbiological properties, second edition. Amer. Soc. Agron., Soil Sci. Soc. Amer., Madison. Wis. Pp. 539-579.

Pedersen, R.J. 1988. Riparian management practices of the USDA Forest Service. *In* Raedeke, K.J. (ed.) Streamside Management: Riparian Wildlife and Forestry Interactions. Contribution No. 59, Institute of Forest Resources, Univ. Washington, Seattle. p. 197-199.

Raedeke, K.J. 1988. Streamside management: riparian wildlife and forestry interactions. Inst. For. Resour., Univ. Washington, Seattle. 277 p.

Reukema, D.L. 1979. Fifty-year development of Douglas-fir stands planted at various spacings. USDA For. Serv. Res. Pap. PNW-253. PNW Res. Sta., Portland. Or. 21 p.

Shapiro, S.S. and M.B. Wilk. 1965. An analysis of variance test for normality (complete samples). Biometrica 52:591-611.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill, New York.

Swanson, F.J. and M.E. James. 1975. Geomorphic history of the lower Blue River-Lookout Creek area, Western Cascades, Oregon. Northw. Sci. 49(1): 1-11.

Van Pelt, R. 1991. Colonization of alluvium along two rivers in western Washington. M.S. Thesis, Univ. Washington, Seattle. 104 p.

Walters, D.K., D.W. Hann, and M.A. Clyde. 1985. Equations and tables predicting gross total stem volumes in cubic feet for six major conifers of southwest Oregon. For. Res. Lab., Oregon State University, Corvallis, OR. Res. Bull. 50.

Waring, R.H., P.E. Schroeder, and R. Oren. 1982. Application of the pipe model theory to predict canopy leaf area. Can. J. For. Res. 12:556-560.

Willamette National Forest. 1990. Land and Resource Management Plan, Final Environmental Impact Statement. USDA Forest Service, Eugene, OR. 621 p. + Append.