Available online at www.sciencedirect.com
SCIENCE DIRECT®
Forest Ecology and Management 226 (2006) 26–40
Forest Ecology and Management
www.elsevier.com/locate/foreco

Characterizing and contrasting instream and riparian coarse wood in western Montana basins

Michael K. Young *, Ethan A. Mace, Eric T. Ziegler, Elaine K. Sutherland

Forestry Sciences Laboratory, Rocky Mountain Research Station, 800 East Beckwith Avenue, Missoula, MT 59801, USA

Received 12 October 2005; received in revised form 10 January 2006; accepted 13 January 2006

Abstract

The importance of coarse wood to aquatic biota and stream channel structure is widely recognized, yet characterizations of large-scale patterns in coarse wood dimensions and loads are rare. To address these issues, we censused instream coarse wood (≥2 m long and ≥10 cm minimum diameter) and sampled riparian coarse wood and channel characteristics in and along 13 streams in western Montana. Instream coarse wood tended to be shorter but of larger diameter than riparian pieces, presumably because of fluvial processing. Instream coarse wood also displayed highly variable spatial patterns. Most segments lacked significant spatial correlation in coarse wood abundance in adjacent 50 m reaches and when present, coarse wood patch sizes (100–1200 m) were specific to particular streams. Estimation of instream and riparian piece dimensions within 25% of the mean required samples of 13–314 pieces, whereas estimation of wood loads instream segments required samples of 8–210 reaches (400–10 500 m). If these results are representative of other systems, few previous studies have used sample sizes adequate to characterize instream coarse wood loads.

Keywords: Abundance; Channel type; Reach length; Sample size; Volume; Woody debris

1. Introduction

Coarse woody debris (hereafter, coarse wood) is widely recognized as a critical component of aquatic environments in temperate and tropical forested ecosystems, as is evident from the burgeoning literature on this subject (Harmon et al., 1986; Gregory, 2003). It is fundamental to fish habitat formation, diversity, and stability in small streams draining forested basins (Angermeier and Karr, 1984; Fausch and Northcote, 1992; Dolloff and Warren, 2003), and influences sediment dynamics, hydrologic response, and channel complexity along the hierarchy from riverscapes to channel units, and its presence even defines some channel types (Bilby and Likens, 1980; Montgomery et al., 1995, 2003). Recognition of the biological and geomorphological significance of coarse wood has led to the establishment of thresholds for coarse wood abundance instreams (USDA, 1995; USDA/USDI, 1995). Stream segments falling short of these levels may be considered outside the range of natural variation (Overton et al., 1995) and warrant anthropogenic additions of coarse wood (Bisson et al., 2003) or riparian thinning to enhance conifer establishment or growth to more rapidly produce trees capable of forming coarse wood (Beechie et al., 2000; Boyer et al., 2003).

Although landslides and debris torrents are major contributors of coarse wood to streams in regions where such disturbances are frequent (Benda et al., 1998; May and Gresswell, 2003; Reeves et al., 2003), riparian zones contribute the bulk of coarse wood in many areas (Murphy and Koski, 1989; Bragg et al., 2000; Martin and Benda, 2001). Models accounting for additions, losses, and storage of coarse wood in streams (see Gregory et al., 2003 for examples) often assume a strong correlation between riparian stand structure and instream coarse wood abundance and characteristics, although evidence of this association is often weak or absent (Andrus et al., 1988; Rot et al., 2000; Wing and Skaugset, 2002). This may in part result from the difficulty in characterizing riparian stands (Bate et al., 1999) and from variability in rates of tree death and snagfall (Everett et al., 1999; Clark et al., 2002). Though often overlooked, terrestrial coarse wood in riparian zones may exhibit a stronger link to both riparian stands and instream coarse wood (Bragg et al., 2000). In basins dominated by inputs from the riparian zone, riparian and instream coarse wood potentially share many characteristics, such as size and abundance. Differences in these elements may yield important

* Corresponding author. Tel.: +1 406 542 3254; fax: +1 406 543 2663.
E-mail address: mkyoung@fs.fed.us (M.K. Young).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2006.01.021

insights into the post-fall processing and storage of coarse wood in each location. Moreover, awareness of the characteristics of instream and riparian coarse wood can inform the management and modeling of stream channels and streamside forests.

Also important is understanding the patterns of variation in coarse wood loads. Although many assessments of instream wood stratify sampling sites by hydrologic regime, valley form, stream order, channel type, gradient, substrate, bankfull width, forest type and age, route of coarse wood delivery, and other variables to reduce sample heterogeneity and facilitate comparisons of coarse wood among streams (e.g., Hedman et al., 1996; McHenry et al., 1998; Rot et al., 2000), few acknowledge the inherent spatial variability of coarse wood within individual streams (Elosegi et al., 1999; Diez et al., 2001; Archer et al., 2004). This is surprising because spatial variability is critical to determining the reach lengths needed to estimate coarse wood loads with a given level of precision and confidence. A commonly applied alternative has been to calculate reach lengths based on distances thought necessary for describing geomorphological variables, such as 20–40 multiples of bankfull or wetted width (Leopold et al., 1964; Fitzpatrick et al., 1998; Kaufmann et al., 1999). Whereas this approach is legitimate for studying relations between coarse wood and geomorphological characteristics, it is uncertain whether it is appropriate for quantifying coarse wood.

Although much attention has been devoted to calculating coarse wood abundance or volume, characterizing individual pieces is also relevant because they affect the probability of pool or debris jam formation (Bilby and Ward, 1989; Abbe and Montgomery, 2003) or piece movement in channels (Young, 1994; Braudrick and Grant, 2001). As noted earlier, the underlying distribution of piece dimensions (Richmond and Fausch, 1995) may afford a better understanding of the relation between instream coarse wood and the available sources.

To address these issues, we sampled coarse wood and channel characteristics in and adjacent to long segments (i.e., a portion of a stream of a single geomorphological class; Frissell et al., 1986) of streams in forested basins in western Montana. Our objectives were to (1) evaluate spatial and statistical distributions of coarse wood, (2) investigate the relations between instream and riparian coarse wood, (3) determine the number of pieces to measure to estimate coarse wood dimensions with a specified level of precision, and (4) determine the length of stream to measure to similarly estimate coarse wood abundance and volume. Here we emphasize patterns and relations in coarse wood characteristics within individual segments. Among-stream differences in coarse wood and their relation to time since disturbance are the subject of forthcoming work (M. Young and E. Sutherland, in preparation).

2. Methods

2.1. Site selection

Our goal was to characterize patterns in channel and riparian coarse wood over long segments of streams that represented natural ecosystem processes uninfluenced by land management, such as timber harvest, road construction, or fire suppression. In addition, we hypothesized that relations between instream and riparian coarse wood might be most evident in relatively small channels where the majority of coarse wood originates from streamside forests rather than from tributaries, debris torrents, landslides, or upstream sources. We followed a two-step process to select segments meeting these specifications. To classify streams into relatively homogeneous sets for sampling, we used cluster analysis to group similar sixth-code hydrologic units (29–167 km^2; Maxwell et al., 1995). Variables used to discriminate among different hydrologic units included basin size and shape, orientation, elevation, relief, valley slope, precipitation, drainage density, road density, number of fire starts since 1960, proportion of the basin in federal ownership, and proportion of the basin in forest and herbaceous vegetation (R. Ahl and E. Sutherland, unpublished data). Once a set of comparable basins had been identified, we used further criteria verified by site visits and examinations of topographic maps and aerial photographs to locate a segment of the largest stream in each hydrologic unit that reflected natural processes and favored near-channel contributions of coarse wood. Downstream boundaries of sampled segments were at least 100 m above areas influenced by roads or forest management, and often coincided with a tributary junction. Sampled segments sometimes ended upstream at the junction of another tributary, but no large (bankfull width > 1 m) tributaries entered elsewhere. Because lower-gradient channels are thought to readily respond to watershed disturbances and serve as sites of coarse wood and sediment deposition (Montgomery and MacDonald, 2002), we chose segments consisting almost entirely of gradients $< 4\%$ and sinuosities > 1.2. To avoid modern anthropogenic influences, we selected only those segments with little or no timber harvest or road construction upstream from the surveyed locations, and above low-elevation sites dominated by ponderosa pine (*Pinus ponderosa* P. & C. Lawson) that might support those stands most altered by modern fire suppression (Arno et al., 1995). Although the interval since stand-replacing fire varied among basins (based on cohort analyses of riparian trees aged from increment cores; E. Sutherland, unpublished data), it was relatively homogeneous adjacent to any given segment.

We sampled 14 segments of 13 streams and adjacent portions of their riparian zones in western Montana in the Bitterroot and Clark Fork river basins from 2001 to 2003 (Fig. 1; Table 1). In 2001, we sampled single 4-km segments of Chicken and Martin Creeks and adjacent 2- and 6-km segments of Sheephead Creek. The boundary between the segments in Sheephead Creek was defined by a tributary mouth; disturbance histories also varied between these segments. To increase the number of streams in our sample, we inventoried shorter (1.0–2.5 km) segments of 10 additional streams in 2002 and 2003. Belt series deposits constitute the dominant surficial geology in the basins (Jensen et al., 1997) and all channels are third- or fourth-order. Peaks in stream discharge arising from snowmelt runoff are usually in May or June. Mixed stands of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea*

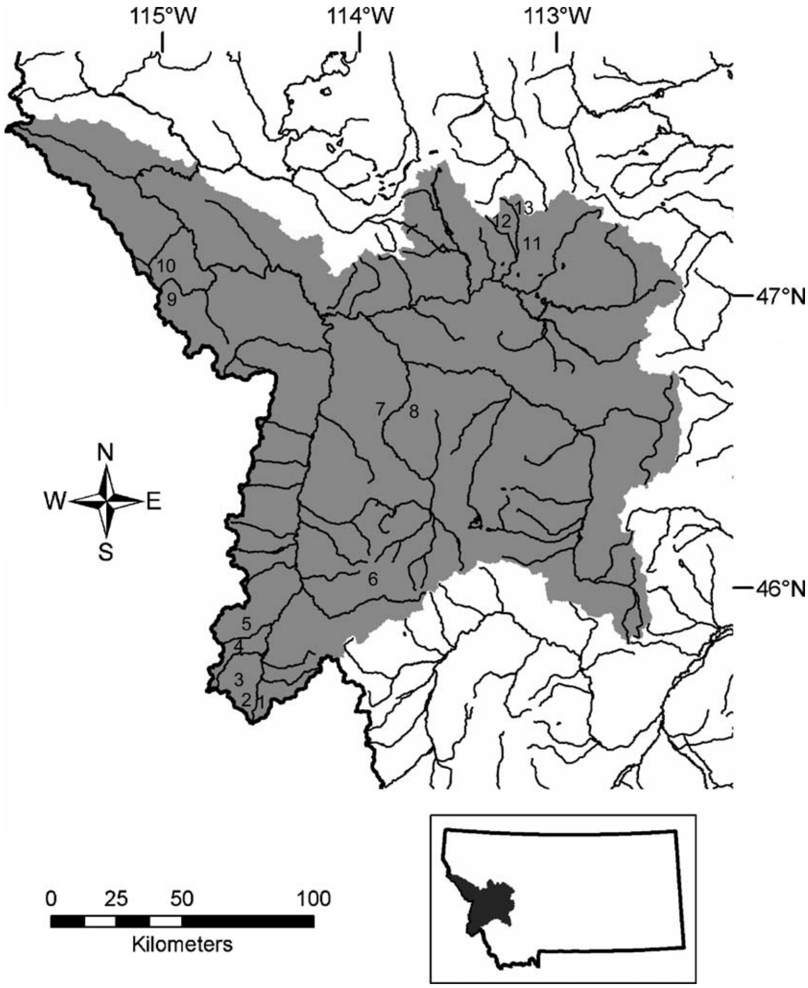

Fig. 1. Map of the Clark Fork and Bitterroot river basins showing the locations of the study streams. The inset map depicts the state of Montana, USA, and an outline of these river basins. Numbers in the shaded area denote streams: (1) West Fork Bitterroot River; (2) Deer Creek; (3) Chicken Creek; (4) Blue Joint Creek; (5) Sheephead Creek; (6) Martin Creek; (7) Welcome Creek; (8) Ranch Creek; (9) North Fork Fish Creek; (10) Straight Creek; (11) Falls Creek; (12) Lodgepole Creek; (13) Monture Creek.

Table 1
Characteristics of sample segments of streams in the Bitterroot and Clark Fork river basins, western Montana

Stream	Length (m)	Elevation (m)	Mean bankfull width (m)	Mean gradient (%)	D_{50} particle size (mm)	Years since disturbance[a]
Blue Joint	1000	1789	7.4	0.9	44	160
Chicken	4150	1576	4.5	2.3	32	250[b]
Deer	1050	1603	6.3	1.0	55	220
Falls	1250	1284	6.2	1.3	20	180
Lodgepole	1000	1672	6.0	1.1	39	360[b]
Martin	4000	1753	6.9	2.8	105	180
Monture	1000	1593	7.7	1.3	49	290[b]
N.Fk. Fish	1050	1312	6.6	3.0	64	140
Ranch	2000	1403	6.0	1.8	49	200
Sheephead-lower	2150	1570	8.8	1.7	43	220
Sheephead-upper	5850	1621	5.9	2.7	63	115
Straight	1500	1091	7.8	3.1	110	95
Welcome	1500	1215	5.2	3.1	74	190
W.Fk. Bitterroot	1500	1792	4.5	1.9	86	150

[a] Cohort analysis of years since riparian-stand-replacing fire, based on interpretations of stand ages estimated from increment cores of riparian trees (E. Sutherland, unpublished data).

[b] Fire killed nearly all trees adjacent to the study segment in 2000, but most remained standing during our 2001–2003 surveys.

engelmannii Parry ex. Engelm.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) dominated riparian zones, and fell into *P. engelmannii*/*Cornus stolonifera* and *A. lasiocarpa*/*Calamagrostis canadensis* riparian community types (Hansen et al., 1995). Virtually all coarse wood consisted of coniferous species.

2.2. Data collection

We measured segments by dragging a tape along the channel thalweg (point of deepest flow) and flagging locations at 50-m intervals. Sampling of channel and riparian characteristics was referenced to the flagged locations. We censused instream coarse wood (pieces at least 2.0 m long with one end at least 10 cm in diameter) that had at least 0.1 m of their length in or suspended over the bankfull channel in 2001 but inadvertently changed this to at least 2.0 m in 2002 and 2003; each piece was assigned to a 50-m increment of stream. With a tape and rod (or calipers), we measured the total length and maximum and minimum diameters of each piece, noted the presence or absence of a rootwad, and surmised – from the presence of a broken snag or root pit within 10 m – whether a piece was conclusively of local origin. Although May and Gresswell (2003) observed that pieces derived from streamside forests often moved up to 60 m after falling, presumably because of steep side slopes or slope instability, McDade et al. (1990) noted that movements after falling tended to be under 5 m on slopes with median gradients of 8%. Because median slope gradient adjacent to our study streams was 4%, post-fall movements of terrestrial coarse wood were likely to be small. Piece volume was estimated by calculating the volume of a cylinder with that total length and mean diameter. May and Gresswell (2003) noted this was appropriate because most pieces were broken and taper equations for a frustum did not apply. Pieces leaning or suspended over the stream at an angle greater than 30° above the local surface were considered snags and excluded from our counts.

To assess riparian coarse wood, at 250-m intervals along the thalweg we established a 50-m transect on each side of the stream that began 20 m from the stream bank and ran parallel to the valley azimuth. We measured the total length and maximum and minimum diameters of each piece of coarse wood intercepted by each transect, then pooled the counts from each side of the channel for analysis. We also noted the presence or absence of a rootwad for riparian pieces along Chicken, Martin, and Sheephead Creeks. We ensured that riparian pieces were comparable to those in channels by measuring only pieces with an intact bole, i.e., not substantially yielding when stepped on or disintegrating into the soil.

Stream gradient was measured with a stadia rod and hand level or clinometer every 100 m over a 50-m interval centered on the flagged location. Following Rosgen (1996), we conducted channel type surveys throughout each segment. As part of these surveys, we measured bankfull width in all riffles. We characterized substrate by performing modified pebble counts (Bevenger and King, 1995) at 100–250-m intervals.

2.3. Data analysis

All analyses were run in SPSS version 10.1 and we accepted $P \leq 0.05$ as indicating significance. We divided our analyses into two groups: (1) those based on individual pieces and (2) those based on counts or volumes of coarse wood in 50-m increments (hereafter, reach-scale analyses). Initially we assumed that coarse wood shorter than the bankfull width of each stream was likely to be mobile and that larger pieces would be relatively stable (Lienkaemper and Swanson, 1987; Nakamura and Swanson, 1993; Abbe and Montgomery, 2003). Because differences in distributions between these size classes might warrant separate analyses for each, we used regression to examine the relation between reach counts of pieces shorter and longer than mean bankfull width for each stream. Furthermore, we were uncertain whether instream pieces sampled in 2001 and 2002–2003 were comparable because rules for inclusion, i.e., the minimum distance they extended into the channel, differed between sampling occasions. To address this issue, we divided pieces measured in the four segments sampled in 2001 into groups that extended 0.1–1.9 and $\geq$2.0 m into the channel and compared their dimensions and rootwad prevalence.

We assumed that most instream pieces of coarse wood were derived from fallen riparian trees, regardless of whether they had been fluvially redistributed. To examine whether piece characteristics reflected this relation, we compared distributions of lengths and minimum and maximum diameters of individual pieces from streams and riparian zones with two-sample Kolmogorov–Smirnov tests. Because detection of pieces is proportional to their length in line-intercept sampling, we used piece length as an inverse weighting factor (Van Wagner, 1982) to correct distributions of length and maximum diameter for riparian pieces. No correction was applied to minimum diameters because they were not correlated with piece length. Attempts to model riparian piece volumes with length-based corrections of piece length and maximum diameter produced severely biased estimates. Consequently, we calculated volumes of riparian coarse wood based on uncorrected line-transect data but did not make comparisons between instream and riparian piece volumes. We also evaluated the normality of distributions of instream piece length, minimum and maximum diameter, and volume using one-sample Kolmogorov–Smirnov tests, with bin classes of 1 m for length, 5 cm for diameters, and 0.1 m^3 for volume. Because of the varying analytical treatments of riparian wood dimensions, no tests of normality of their distributions were conducted. For segments sampled in 2001 we used chi-square tests to compare the proportion of pieces with rootwads in streams and riparian zones. For all segments, we summarized the proportion of pieces known to be of local origin.

Instream coarse wood may represent a legacy from earlier stands of pieces no longer present in the riparian zone (Hyatt and Naiman, 2001; Abbe et al., 2003). This difference may arise from two factors: coarse wood deposited following a previous riparian forest disturbance can be much larger than that being generated by the current stand (Swanson and Lienkaemper, 1978; Long, 1987) and terrestrial coarse wood may decompose rapidly relative to that in stream channels (Brown et al., 1998; Bilby, 2003; Dahlström et al., 2005). Consequently, we used Mann–Whitney *U*-tests to compare maximum diameters of those instream and riparian pieces constituting the upper 10% of maximum diameters in each segment.

We conducted several analyses at the reach scale to better understand the distribution of instream coarse wood loads. We constructed correlograms based on 50-m distance classes to assess patterns in the spatial distribution of counts and volumes of coarse wood in each stream. Measurement of coarse wood in consecutive, equidistant increments enabled us to use time series analysis to create correlograms (Legendre and Fortin, 1989). A correlogram was deemed significant if the correlation coefficient for at least one distance class exceeded the confidence interval for that class. Because samples sizes for calculating correlations were sometimes very small for larger distances, we only evaluated correlations for the first 10 distance classes for segments less than 1500 m and the first 15 for longer segments. We interpreted the number of distance classes between the initial significant positive value, if present, and the *x*-intercept (point of zero correlation) as indicating the radius of a relatively homogeneous patch of coarse wood (Legendre and Legendre, 1998). In upper Sheephead Creek, we observed a progressive upstream increase in piece counts. To meet the assumption of stationarity for analysis of this segment, we used the differences between adjacent reach counts to generate the correlogram. We also used one-sample Kolmogorov–Smirnov tests to determine whether reach counts and volumes of coarse wood were normally distributed in each stream. We did not subject reach-scale counts or volumes of riparian coarse wood to distributional analyses because pieces were not censused and counts derived from line transects may under- or overrepresent true abundance (Williams and Gove, 2003; Bate et al., 2004). We did assess relations in counts and volumes of instream and riparian coarse wood using regression analysis.

The transport capacity of streams is related to channel slope (Leopold et al., 1964), thus we hypothesized that coarse wood loads would be greater in low-gradient reaches. Relations between counts and volumes of coarse wood and stream gradient were assessed using regression analysis for each stream segment. To compare the abundance or volume of coarse wood between low-gradient (<2.0%) and moderate-gradient (2.0–3.9%) channel types (sensu "C" and "B" channel types, Rosgen, 1996; pool-riffle and plane-bed channel types, Montgomery and Buffington, 1997), we used two-way analysis of variance with stream and channel type as main effects and examined only the channel type main effect and channel type by stream interaction for significance.

Finally, we used a sample size estimator (Cochran, 1977, p. 77) to determine the number of pieces necessary to estimate the mean length, maximum diameter, and volume of individual pieces from channels and riparian zones and the number of 50-m reaches necessary to estimate the mean density and volume of instream coarse wood within 25% of the mean values with $\alpha = 0.05$. For the sake of comparison, we also calculated the hypothetical length of sample reaches based on 20 multiples of the bankfull channel width.

3. Results

3.1. Coarse wood abundance

We measured 7289 pieces of coarse wood in 29.1 km of channels and 1548 pieces intercepting 13.0 km of riparian transects associated with the 14 stream segments. On average, 50-m reaches contained 13 pieces (range of means, 4–20 pieces) and 4.96 m^3 (range of means, 1.51–9.41 m^3) of coarse wood (Table 2). Coarse wood shorter than bankfull width accounted for 55% (range, 28–78%) of the abundance of coarse wood in these streams. Counts of pieces shorter than bankfull

Table 2
Mean volumes and counts (S.D. in parentheses) of coarse wood in 50-m reaches and relation between counts of coarse wood shorter and longer than bankfull channel width

Stream	N[a]	Mean volume (m^3)	Mean count			Regression coefficients		
			All pieces	>BFW[b]	<BFW	Intercept	Slope	r
Blue Joint	20	6.24 (4.40)	15.1 (8.9)	9.0	6.1	2.86	0.36*	0.55
Chicken	83	4.75 (3.82)	13.9 (9.6)	6.6	7.3	3.34	0.60*	0.42
Deer	21	4.07 (3.22)	11.6 (7.1)	6.0	5.6	1.65	0.66*	0.54
Falls	25	5.85 (4.92)	13.8 (7.2)	4.6	9.2	7.90	0.28	0.19
Lodgepole	20	8.38 (5.04)	18.9 (5.5)	7.8	11.1	10.25	0.11	0.10
Martin	80	6.28 (6.14)*	18.0 (14.6)*	4.3	13.7	5.16	1.98*	0.56
Monture	20	6.44 (4.18)	10.4 (6.2)	5.8	4.7	2.20	0.43	0.34
N.Fk. Fish	21	3.33 (3.48)	10.5 (8.3)	3.0	7.4	4.07	1.10	0.37
Ranch	40	4.1 (3.24)	6.3 (4.5)	4.0	2.3	1.27	0.26*	0.38
Sheephead-lower	43	9.41 (7.15)	19.7 (12.0)	4.7	15.0	7.65	1.59*	0.52
Sheephead-upper	116	1.51 (1.23)	8.7 (7.2)*	1.9	6.8	2.94	1.03*	0.54
Straight	30	2.31 (4.24)*	3.8 (4.0)	1.2	2.6	2.10	0.45	0.23
Welcome	30	3.05 (2.66)	5.8 (3.1)	4.2	1.6	1.11	0.12	0.20
W.Fk. Bitterroot	30	3.73 (2.69)	20.0 (11.3)	13.2	6.8	3.67	0.24*	0.54

An asterisk next to a mean count or volume indicates a significant nonnormal distribution ($P \leq 0.05$). An asterisk next to slope indicates that the regression of pieces shorter than bankfull width on pieces longer than bankfull width was significant.

[a] N, number of reaches.

[b] BFW, bankfull channel width.

Table 3
Median characteristics of pieces of instream and riparian coarse wood sampled in 14 stream segments

Stream	Instream					Riparian				
	N[a]	Length (m)	D_{min}[b] (cm)	D_{max}[c] (cm)	Volume (m^3)	N	Length (m)	D_{min} (cm)	D_{max} (cm)	Volume (m^3)
Blue Joint	301	8.5*	12*	23*	0.21	101	12.4	4	13	0.07
Chicken	1152	4.5*	15*	23*	0.13	182	5.4	11	19	0.10
Deer	244	6.6*	16*	24*	0.19	94	8.4	10	20	0.15
Falls	344	4.4*	16*	24*	0.13	89	9.3	12	23	0.22
Lodgepole	378	5.1*	16*	25*	0.17	86	5.7	10	19	0.09
Martin	1442	4.2*	17*	24*	0.14	228	8.6	6	17	0.09
Monture	208	8.2	17	28*	0.33	36	7.0	12	19	0.13
N.Fk. Fish	220	4.7*	13	23	0.12	14	9.5	13	18	0.18
Ranch	250	8.2	14*	27*	0.22	192	8.6	6	16	0.08
Sheephead-lower	847	4.7*	17*	25*	0.18	143	6.4	10	19	0.11
Sheephead-upper	1014	3.8*	13*	20*	0.09	167	7.6	3	14	0.04
Straight	115	5.3	18	32*	0.28	34	5.5	15	26	0.18
Welcome	175	7.5	15*	24*	0.21	62	7.9	6	16	0.08
W.Fk. Bitterroot	599	6.1*	11*	20*	0.11	120	12.6	3	15	0.08

Asterisks by instream coarse wood characteristics denote a significant difference between instream and riparian coarse wood for that characteristic and stream based on two-sample Kolmogorov–Smirnov tests ($P \leq 0.05$). No comparisons were made for piece volumes.
[a] N, number of pieces.
[b] D_{min}, minimum diameter.
[c] D_{max}, maximum diameter.

width were significantly positively correlated with counts of longer pieces in 8 of 14 segments, and slope coefficients were positive in the rest. Inspection of residual plots indicated that linear models fit these data. The slopes of the regressions tended to be less than one (mean, 0.66; S.E., 0.15), indicating that as wood abundance increased in stream reaches, pieces longer than bankfull width accounted for a greater proportion of all pieces. Because these results indicated a linear, positive correlation between pieces of each length class, further analyses were performed on the pooled sample of pieces in each stream. Pieces extending less than 2 m into the bankfull channel constituted 10–13% of all coarse wood sampled in 2001. There were no significant differences in piece dimensions or rootwad prevalence between pieces extending more or less than 2 m into the bankfull channel in Martin or upper Sheephead Creeks, although pieces extending less than 2 m into the bankfull channel were significantly shorter (medians, 4.0 versus 4.5; $P = 0.024$) and had a significantly greater minimum diameter (medians, 17 cm versus 15 cm; $P = 0.039$) in Chicken Creek and had a significantly greater minimum diameter (medians, 20 cm versus 17 cm; $P = 0.039$), maximum diameter (medians, 29 cm versus 25 cm; $P = 0.039$), and rootwad prevalence in lower Sheephead Creek (percentage with rootwad, 15 versus 33; $P = 0.001$). Nonetheless, we regarded pieces extending less than 2 m into the bankfull channel as similar enough to warrant their retention in analyses of streams sampled in 2001.

3.2. Piece-scale patterns

Distributions of lengths and minimum and maximum diameters usually differed between instream and riparian coarse wood. Overall, instream coarse wood tended to be shorter (median difference, 1.8 m) and have a larger minimum diameter (median difference, 7 cm) and a larger maximum diameter (median difference, 6 cm) than did riparian coarse wood (Table 3). Frequency distributions of individual piece dimensions of instream coarse wood (Fig. 2) were almost never normally distributed, tending to be positively skewed; only for length in Monture Creek, minimum diameter in Straight and Welcome Creeks, and maximum diameter in Straight Creek did one-sample Kolmogorov–Smirnov tests fail to reject the hypothesis that these distributions were normal.

For all segments, a mean of 23.0% (range, 12.0–36.5%) of instream pieces retained rootwads (Table 4). For the four streams sampled in 2001, rootwads were present on a greater percentage of pieces in the riparian zone than in the channel (mean difference, 4.8%), but this difference was not significant in three of four comparisons. On average, 52.0% (range, 23.8–77.6%) of measured coarse wood could be conclusively identified as being of local origin (Table 4).

Comparisons of instream and riparian coarse wood constituting the largest 10% of pieces by maximum diameter revealed no consistent differences (Table 5). In 9 of 14 segments, median maximum diameters were not significantly different although among all segments riparian coarse wood was somewhat larger (median difference, 3 cm).

3.3. Reach-scale patterns

Distributions of counts and volumes of coarse wood measured in 50-m reaches did not reveal consistent spatial autocorrelation (Fig. 3). Only 6 of 14 correlograms of counts were significant (Fig. 4). Alternating patterns of significant correlations indicated patch sizes of 100, 550, 800, or 1200 m in four segments. In the remaining two segments with significant patterns, one showed significant positive correlations up to three lags (150 m) long and the other showed significant negative correlations over the same distance. Nine of the correlograms of volume were significant, but five of these were difficult to interpret because of a lack of significance of initial

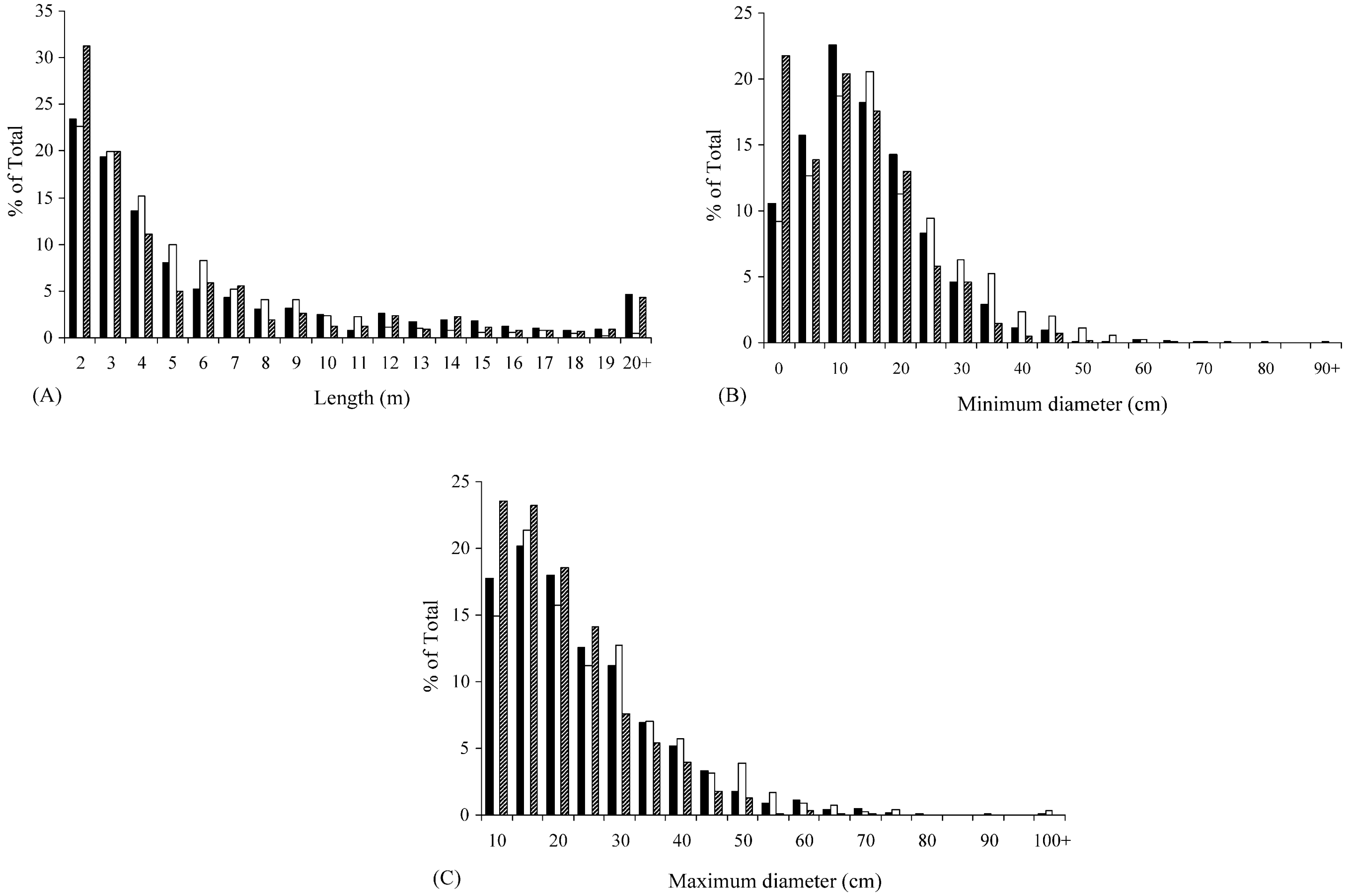

Fig. 2. Frequency distributions of dimensions of instream coarse wood from Chicken (black bars), Martin (white bars), and upper Sheephead Creeks (gray bars), the segments with the largest sample sizes. (A) lengths (m); (B) minimum diameters (cm); (C) maximum diameters.

Table 4
Frequency of local (untransported) and transported coarse wood in channels and prevalence of rootwads on coarse wood from channels and riparian zones

Stream	Wood source (%)		Rootwad present (%)	
	Local	Transported	Channel	Riparian
Blue Joint	72.4	27.6	36.5	
Chicken	37.9	62.1	24.7	25.4
Deer	23.8	76.2	13.1	
Falls	63.7	36.3	17.7	
Lodgepole	66.9	33.1	12.2	
Martin	30.4	69.6	23.3	28.9
Monture	48.6	51.4	22.6	
N.Fk. Fish	42.7	57.3	28.2	
Ranch	77.6	22.4	22.4	
Sheephead-lower	31.4	68.6	31.0	33.6
Sheephead-upper*	37.3	62.7	31.8	41.9
Straight	44.3	55.7	23.5	
Welcome	77.1	22.9	22.3	
W.Fk. Bitterroot	68.9	31.1	12.0	

The asterisk denotes a significant difference in the proportion of pieces with and without rootwads between instream and riparian coarse wood ($P \leq 0.05$). The differences in Chicken, Martin, and lower Sheephead Creeks were not significant.

Table 5
Median maximum diameters of the largest (by maximum diameter) 10% of pieces of instream and riparian coarse wood

Stream	Instream		Riparian	
	N[a]	D_{max}[b] (cm)	N	D_{max} (cm)
Blue Joint	30	53*	10	31
Chicken	115	50*	18	58
Deer	24	50	9	49
Falls	34	60	9	62
Lodgepole	38	51	9	54
Martin	144	53*	23	59
Monture	21	59	4	49
N.Fk. Fish	22	52	1	56
Ranch	25	59*	19	52
Sheephead-lower	85	59	14	63
Sheephead-upper	101	42	17	43
Straight	12	62	3	72
Welcome	18	54	6	57
W.Fk. Bitterroot	60	37*	12	33

Asterisks by instream coarse wood maximum diameters denote a significant difference between instream and riparian coarse wood for that stream based on Mann–Whitney U-tests ($P \leq 0.05$).
[a] N, number of pieces.
[b] D_{max}, maximum diameter.

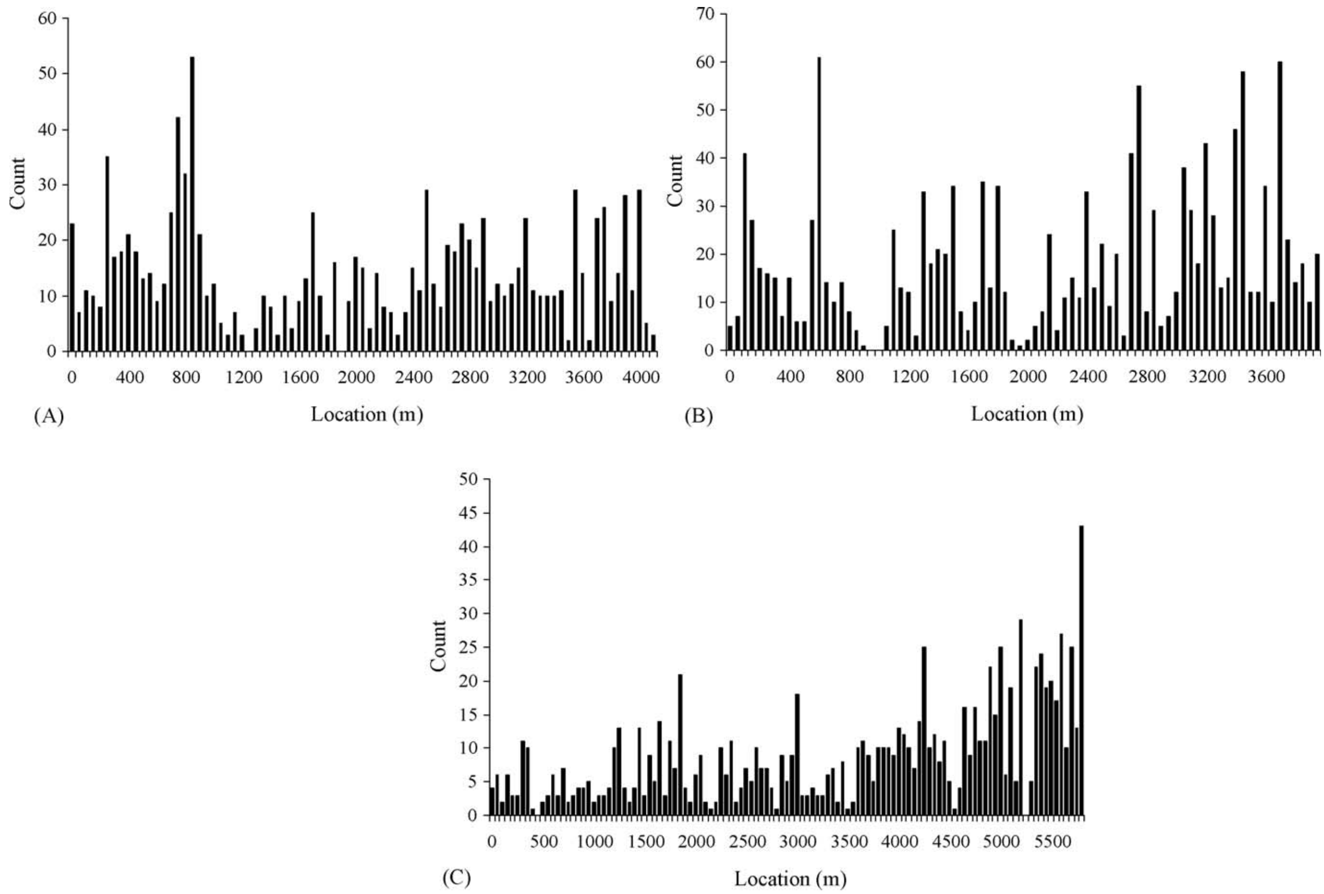

Fig. 3. Distribution of coarse wood counts by location in a segment. (A) Chicken Creek; (B) Martin Creek; (C) upper Sheephead Creek.

lags followed by one or two significant correlations at irregular intervals, and in the remainder only volumes in the first distance class (i.e., in adjacent reaches) were significantly positively correlated. Finally, just 2 of 14 one-sample Kolmogorov–Smirnov tests (for counts or volumes) rejected the hypothesis that these metrics were normally distributed.

Counts and volumes of coarse wood were largely unrelated to channel gradient and type. Only in upper Sheephead Creek were correlations between counts or volumes and gradient significant and they were positive, counter to expectations. Moreover, there was no difference between channel types in coarse wood abundance (average difference between low- and moderate-gradient channel types, −0.3 pieces/50 m; main effect of channel type, $F = 0.394$, $P = 0.675$; channel type by stream interaction, $F = 0.512$, $P = 0.882$) or volume (average difference between low- and moderate-gradient channel types, $-0.48\ m^3/50\ m$; main effect of channel type, $F = 2.229$, $P = 0.120$; channel type by stream interaction, $F = 1.044$, $P = 0.405$).

Relations between instream and riparian coarse wood at the reach scale were inconsistent. There was a significant positive correlation between counts of instream and riparian coarse wood in all segments but one (Chicken Creek) with sample sizes of eight or more reaches (segment lengths ≥2000 m). In shorter segments, no significant correlations were observed; smaller sample sizes likely reduced the power of these tests. Nevertheless, the correlation between instream and riparian counts was positive for just five of nine shorter segments. Different relations were evident for volume. Although volumes of instream and riparian coarse wood were positively related in all five longer segments, this relation was significant for only two (Chicken and lower Sheephead Creeks). For the nine shorter segments, five correlations were positive (one significant; West Fork Bitterroot River), three were negative (one significant; Straight Creek), and one was zero.

3.4. Sample size estimation

The number of pieces one should measure to estimate mean dimensions of coarse wood differed little between channels and riparian zones but depended much on the dimension being estimated. Sample sizes necessary to estimate length or maximum diameters of individual pieces of coarse wood in channels or riparian zones within 25% of the mean were modest (mean, 23 pieces; range, 10–53 pieces), but estimating mean volume required a much larger sample (mean, 173 pieces; range 81–314 pieces; Table 6). Choosing between counts and volumes also influenced sample sizes at the reach scale in streams. The number of 50-m reaches necessary to estimate mean abundance of instream coarse wood with this level of precision averaged 28 (1400 m; range, 400–2250 m), whereas 55 reaches (2750 m; range, 1250–10 500 m) were needed for

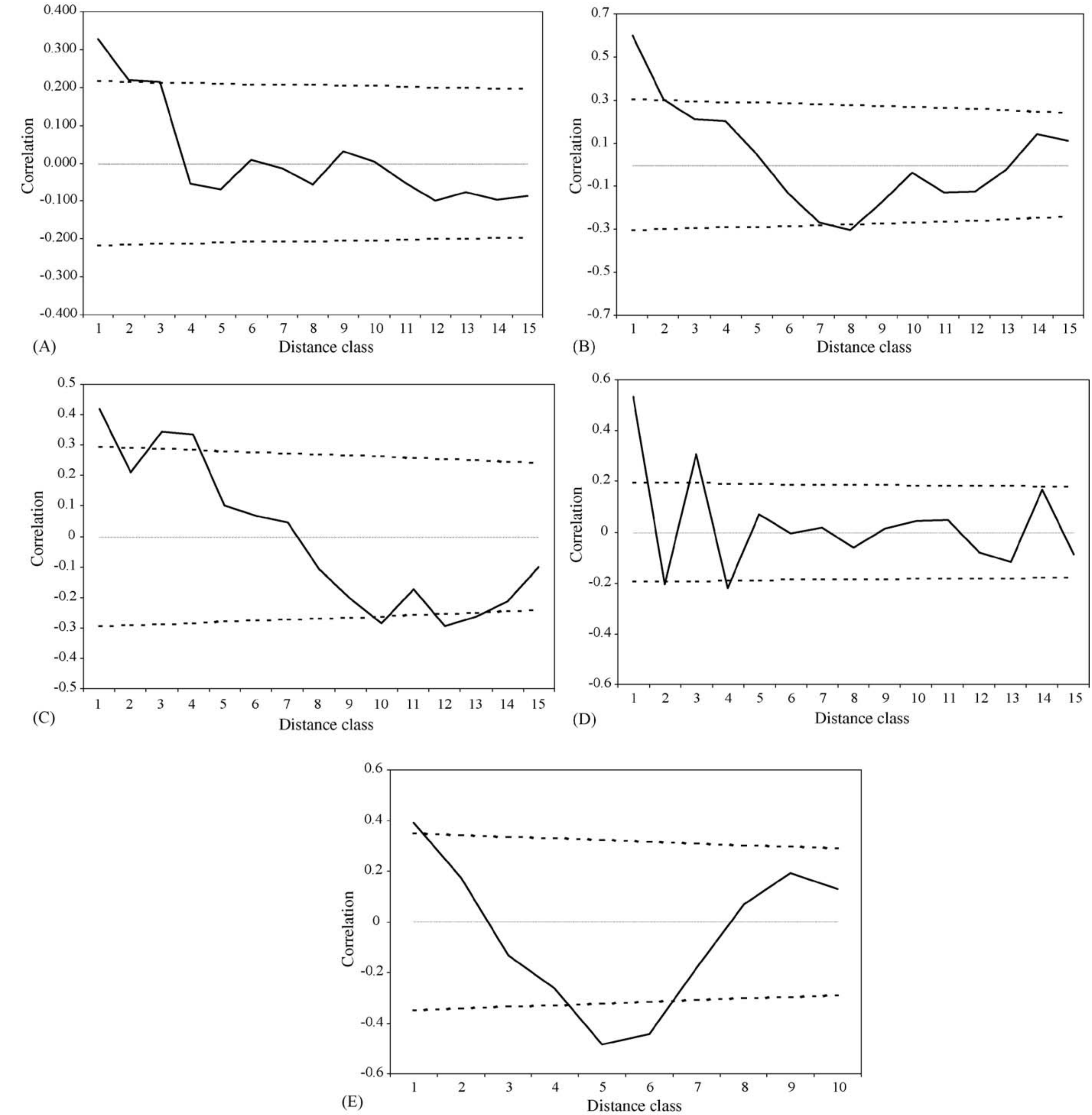

Fig. 4. Correlograms of instream coarse wood counts by distance class for five stream segments. Shown are those correlograms with significant positive – valuesthose exceeding the 95% confidence bands (dotted lines) – in at least the first distance class. (A) Chicken Creek; (B) Ranch Creek; (C) lower Sheephead Creek; (D) upper Sheephead Creek; (E) West Fork Bitterroot River.

comparable estimates of mean volume. If one regards the sample size estimate for volume in Straight Creek as an outlier (it is three-fold larger than for any other segment), the overall mean sample size for volume declines to 43 reaches (2150 m). Lengths of stream to sample based on 20 multiples of bankfull channel width were more than an order of magnitude shorter (mean, 128 m; range, 90–175 m) than those based on sample size equations.

4. Discussion

4.1. Instream piece relations

We expected the relation in counts between instream coarse wood smaller and larger than bankfull channel width to be nonlinear and to reject the hypothesis of normality of count distributions, because pieces less than bankfull channel width

Table 6
Sample sizes needed to estimate coarse wood abundance or volume per 50 m reach or individual piece characteristics within 25% of the mean at $\alpha = 0.05$ or as a multiple of bankfull width

Stream	No. of reaches		No. of instream pieces			No. of riparian pieces			20 × bankfull width[b] (m)
	Abundance	Volume	Length	D_{max}[a]	Volume	Length	D_{max}	Volume	
Blue Joint	25 (1250)	34 (1700)	23	17	126	10	15	146	148
Chicken	32 (1600)	43 (2150)	46	17	207	33	21	162	90
Deer	26 (1300)	41 (2050)	20	15	105	14	15	81	127
Falls	20 (1000)	46 (2300)	39	20	216	17	17	85	125
Lodgepole	8 (400)	25 (1250)	35	17	283	26	17	137	120
Martin	43 (2150)	62 (3100)	29	20	285	18	28	258	139
Monture	27 (1350)	29 (1450)	17	16	124	17	18	130	153
N.Fk. Fish	32 (1600)	70 (3500)	25	26	314	14	20	110	131
Ranch	27 (1350)	41 (2050)	36	19	168	22	25	203	120
Sheephead-lower	26 (1300)	38 (1900)	53	18	210	28	23	160	175
Sheephead-upper	45 (2250)	44 (2200)	53	15	115	17	27	235	119
Straight	38 (1900)	210 (10500)	26	26	225	27	18	131	157
Welcome	17 (850)	50 (2500)	31	19	121	14	29	190	105
W.Fk. Bitterroot	23 (1150)	34 (1700)	28	13	167	11	14	156	90

For reach-scale characteristics, samples sizes are expressed in the number of 50-m reaches (metres in parentheses). For individual piece characteristics, samples sizes are in number of pieces.
[a] D_{max}, maximum diameter.
[b] The bankfull channel width (m) multiplied by 20, a common reach length for assessing coarse wood abundance instreams.

constituted over half of the wood we measured and in other studies have tended to be redistributed into accumulations in low-gradient channel types (Martin, 2001; Kraft and Warren, 2003). Instead, the distribution of shorter pieces mirrored that of larger, more stable ones. The correspondence between mobile and stable pieces was also observed by Hauer et al. (1999), who reported positive linear correlations in abundance between pieces <30 and ≥30 cm in diameter, pieces attached to the bank versus not, and pieces with or without rootwads. Despite that nearly 50% of the coarse wood that we measured appeared to have been transported from upstream, pieces of all sizes rarely formed discrete clumps (except for single debris jams in Monture and Straight Creeks and the West Fork Bitterroot River) and counts were not related to local gradient or to channel type (cf. Berg et al., 1998; Fox, 2001), although we acknowledge the restricted range of gradients and channel types represented in our samples. It may be that rather than forming clumps where large amounts of smaller coarse wood were racked on more stable pieces, sufficient numbers of stable pieces were present to trap most transportable debris in much smaller accumulations.

4.2. Instream–riparian coarse wood relations

Because our protocol for selecting stream segments presumably limited the source of most instream coarse wood to the riparian zone, we hypothesized that piece dimensions in both locations should be similar. Instead, instream coarse wood tended to be shorter and of greater minimum and maximum diameter. In addition, frequency distributions of lengths and diameters of instream coarse wood were generally nonnormal as has been observed elsewhere (Bilby and Ward, 1989; Richmond and Fausch, 1995; Beechie and Sibley, 1997; Gomi et al., 2001), and differed from such distributions for riparian pieces. Yet support for the probable riparian origin of most instream pieces included the comparable proportions of pieces with rootwads from both locations, as well as the similarity in maximum diameters among the largest 10% of pieces. We believe the differences in piece dimensions between locations probably reflected differences in post-fall processing in streams and riparian zones. Many, perhaps most, trees and snags break upon falling, usually into several pieces (Nakamura and Swanson, 1993; Sobota, 2003). Pieces less than 15 cm in maximum diameter and long pieces tapering to small diameters were abundant in riparian zones, despite the relatively rapid decomposition of terrestrial downed wood (half-lives of density often <50 years; Lambert et al., 1980; Spies et al., 1988; Alban and Pastor, 1993; Tyrrell and Crow, 1994). Similar-diameter pieces were far less prevalent in the channel, and probably had floated away or were sheared off, rapidly transported downstream, and broken down by impact and abrasion; depending on disturbances upstream, they may or may not have been replaced by other transported pieces.

We also attribute much of the spatial variability in abundance to local riparian forest structure. Coarse wood in low-order channels is thought to be randomly distributed because it results from random treefall in the riparian zone and most intact pieces exceed the transport capacity of the channel (Swanson and Lienkaemper, 1978; Robison and Beschta, 1990; Gurnell, 2003), which is consistent with our failure to detect an influence of channel gradient or type on coarse wood abundance. Moreover, forest stands exhibit a spatial structure of live, dead, and down trees that can be extremely patchy and difficult to characterize (Van Sickle and Gregory, 1990; Muller and Liu, 1991; Lee et al., 1997; Bate et al., 1999; Clark et al., 2002; Woldendorp et al., 2004). For example, Everett et al. (1999) noted that snag densities (and we infer, coarse wood) within a single stand were so spatially variable as a result of microtopographic variation and different fall rates among species that extrapolation of counts from small plots to entire stands was unreliable. Consequently, the absence of consistent correlations between coarse wood counts in adjacent stream reaches may indicate that coarse wood patches in those areas are lacking or exist on a scale smaller than our 50-m sampling frame (Legendre and Legendre, 1998). Even when we found evidence of spatial patterns in instream coarse wood, patch sizes were often unique to particular streams and on the order of hundreds of metres. Although we explicitly considered stand structure in our selection of study segments, variation detectable from aerial photographs or stand maps may not adequately represent the stand variation affecting distributions of coarse wood in these channels.

Yet the variation in instream coarse wood counts was not consistently captured in the reach-scale relations between the abundance of coarse wood in channels and riparian zones. The paucity of significant correlations between instream and riparian coarse wood abundance could not be attributed to small sample sizes alone; at least four factors may have played a role. First, we cannot discount the possibility that the riparian stand immediately adjacent to the channel differed from that found at least 20 m away. Robison and Beschta (1990) indicated that 50–75-cm-dbh trees 20 m from the stream channel would have a 25–35% chance of entering the stream. Most riparian coarse wood that we measured was smaller than this threshold, and only 3.2% of riparian coarse wood we sampled also entered the bankfull channel. Whether such pieces are representative of pieces in closer proximity to the channel is unknown.

Second, although we selected segments to minimize distant off-channel contributions of coarse wood, the in-channel transport of instream wood may have partially accounted for the discrepancy in riparian and instream coarse wood quantities. Despite that these channels were relatively small (bankfull widths 4.5–8.8 m), a large proportion of the coarse wood appeared to have been transported some distance from its source. The probability that pieces moved and the distance they moved were probably related to piece length and the presence of a rootwad (Young, 1994; Braudrick and Grant, 2001). Also, late-winter ice jams have been observed to reshape channels and shift positions of even the largest coarse wood in this area (Robert Brassfield, Bitterroot National Forest, unpublished data).

Third, the inconsistency of the relation between instream and riparian coarse wood loads to some degree may represent an artifact of sampling riparian pieces by using transects. Bate et al. (2004) observed that regressions between line-transect density estimates and known counts of coarse wood in unharvested upland forests (with random treefall direction) accounted for only 65% of the variation in the relation, and recommended that 1–3.8 km of 100-m transects within a particular stand be used to achieve adequate precision. Nevertheless, such estimates were unbiased, and the tendency for riparian trees to fall toward the stream (Sobota, 2003) implies that transects parallel to the valley azimuth would probably intercept the majority of available pieces.

Fourth, perhaps the most likely solution to this problem is that forests in different stages of succession are likely to be generating coarse wood with different probabilities of persistence, and not all instream coarse wood may be associated with the present riparian stand. Immediately following fire, relations between instream and riparian coarse wood may be decoupled because of the combustion of coarse wood in the riparian zone (Skinner, 2002). In subsequent years to decades, riparian stands probably deliver large amounts of coarse wood (Morrison and Raphael, 1993; Harrington, 1996; Mitchell and Preisler, 1998), initially favoring smaller-diameter snags (Lyon, 1984), and at such times the relation between riparian and instream coarse wood may be high if snagfall rates exceed transport and processing rates of coarse wood by streams. Thereafter, decomposition of downed wood in relatively warm, moist riparian zones (Mackensen et al., 2003) and long-term storage of instream wood inundated or buried shortly after the recent disturbance (Hyatt and Naiman, 2001; Bilby, 2003) could begin to decouple this relation, although larger snags may remain standing for decades and represent a continuing source of coarse wood to both areas (Lyon, 1984; Everett et al., 1999) and suggest why we saw no differences in maximum diameters of the largest pieces of instream and riparian coarse wood. Self-thinning of the aging riparian stand would lead to prolonged contributions of small-diameter downed wood that would be retained in the riparian zone but rapidly altered, transported, or destroyed in the channel. Late in succession the relation between instream and riparian coarse wood abundance might reemerge, but this depends on the legacy of coarse wood still stored in the channel following the most recent and perhaps previous disturbances, individual pieces of which may persist for centuries (Guyette et al., 2002). Also, further disturbance at any point in the successional sequence would add additional complexity to the riparian–instream linkage.

Given these potential influences, the absence of a correlation between instream and riparian coarse wood loads might be the norm rather than the exception. Yet we regard these explanations as speculative because definitive answers await further investigation of the relations between instream and riparian coarse wood.

4.3. Sampling issues

Although variation in instream coarse wood dimensions and abundance (Swanson et al., 1976; Hauer et al., 1999; Archer et al., 2004) has long been recognized, rarely have large-scale sampling schemes been tailored to address it (but see Richmond and Fausch, 1995; Kraft and Warren, 2003). We found that sample sizes to estimate mean length and maximum diameter of coarse wood within 25% of the mean value were modest: 53 or fewer pieces in our study segments. Samples suggested by some researchers (e.g., Bilby and Ward, 1991) would be adequate to calculate these parameters with this level of precision. In contrast, sample sizes necessary to assess mean piece volume were up to six-fold greater and fewer studies met this threshold (e.g., Andrus et al., 1988; Ralph et al., 1994). At the scale of stream segments, our findings demonstrated that to quantify coarse wood loads with the specified precision one must sample on average about 1.5 km of channel. Based on their work in streams in the Pacific Northwest, Ralph et al. (1994) and Benda et al. (2003) also suggested measuring 1–3 km of channel to reliably characterize coarse wood abundance. Yet the vast majority of estimates reported in the literature have been derived from far shorter reaches. Most were based on 20–40 multiples of bankfull or wetted width, the length necessary to characterize geomorphological variation over at least one meander wavelength (Harrelson et al., 1994). Because coarse wood does not appear to vary on a similar scale, abundance estimates based on short stream reaches are potentially unrepresentative of true values. However, sampling following this protocol does not detract from the validity of conclusions about the geomorphological effect of wood (e.g., Buffington et al., 2002), but only calls into question those findings related to coarse wood abundance. For example, wood budgets relying on such sampling probably underestimate variation and may yield spurious results.

Spatial variability in coarse wood abundance coupled with the typical sampling schemes implies that adoption of coarse wood targets should be approached with caution. Swanson et al. (1984) recognized the desire to develop guidelines for coarse wood abundance to maintain quantities in managed streams comparable to those in unaltered basins. More recently these have been codified into thresholds below which streams are deemed to be wood-depauperate and in need of management to increase its abundance (USDA, 1995; USDA/USDI, 1995; Fox, 2001 and citations therein). Harmon (2002) and Lisle (2002), however, noted that management by generic, fixed thresholds fails to recognize the spatial and temporal variation in coarse wood abundance; they argued instead for acknowledging stream- and stand-specific processes in establishing targets for coarse wood quantities (also see Buffington et al., 2002; Bisson et al., 2003; Boyer et al., 2003). For example, all of the streams we sampled contained reaches with little or no coarse wood (Fig. 3), despite that none had undergone modern forest management. One might argue that such reaches would be unlikely to be sampled, but without sampling protocols that account for variation in wood abundance, reaches considered representative are likely to under- or overestimate coarse wood loads.

Our results also suggest revisiting the definition of coarse wood, particularly the smallest sizes. Gurnell et al. (2002) proposed that channel size be classified based on median coarse wood length, but piece length could shift as a result of time since disturbance and the species composition of the reestablishing forest. Alternatively, several studies have defined "effective" coarse wood based on the dimensions of large pieces individually capable of forming habitat or anchoring debris jams (e.g., Abbe and Montgomery, 2003; Rosenfeld and Huato, 2003). In contrast, there has been little emphasis on defining the minimum size of pieces that merit inclusion in overall estimates of coarse wood instreams. Instead, most researchers – ourselves included – have used minimum lengths of 1–3 m and minimum diameters of 10–20 cm, with diameter being variously measured at the midpoint or the large end of a piece. Ralph et al. (1994) pointed out that these minimum sizes may have been adopted from those applied in studies of logging slash (Froehlich et al., 1972). Although Harmon and Sexton (1996) and Gregory et al. (2003) argued for retaining similar minimum dimensions to facilitate comparisons with estimates of terrestrial fuel loads or other studies of aquatic systems, we suggest that a more fluvially relevant standard might be based on the prevalence of piece sizes in channels, particularly relative to those in riparian zones. For example, in our basins the abundance of instream coarse wood peaked in the smallest length class (2–3 m) for most segments (a length class that was never most abundant in riparian zones). Furthermore, although Hauer et al. (1999) defined coarse wood as pieces $\geq$1 m long, they found that the modal value of coarse wood lengths in northwestern Montana streams was 2–3 m and that pieces 1–2 m long were rare (also see Bragg et al., 2000). If these findings are typical, they argue for defining coarse wood as pieces at least 2 m long for small Rocky Mountainstreams. With regard to diameter, we observed that the smallest maximum diameter class (10–15 cm) was most abundant for riparian pieces, whereas modal sizes for instream pieces were larger in 11 of 14 samples. This might support increasing the maximum diameter threshold to at least 15 cm in future studies of similar streams. Whether this approach for specifying minimum dimensions has merit elsewhere is unknown, partly because reporting of size class distributions of coarse wood is relatively rare. We recommend that future studies at least include such data.

Authors have variously favored describing coarse wood loads in terms of counts, volume, or biomass (Harmon et al., 1986; Fox, 2001; Gurnell, 2003). Our calculations demonstrated that sample sizes needed to estimate reach-scale volumes were 50–100% larger than those necessary to estimate counts, and that estimating volumes of individual pieces required vastly more effort than that needed to characterize length or maximum diameter. We attribute both results to four factors: (1) volume being estimated as a combination of length and mean diameter, (2) differences in taper characteristics among different conifers (Husch et al., 2002), (3) differences in shape between intact pieces and broken ones (also see Williams and Gove, 2003), and (4) for reach-scale volumes, the disproportionately large effect of single large pieces. If the variation we encountered is typical of streams in other regions, few studies have measured coarse wood with sufficient intensity to reasonably characterize mean volume of pieces or total volume in segments. Biomass estimation may be even more problematic because wood density varies with species, age, and stage of decomposition (Brown and See, 1981; Hardy, 1996), which are rarely assessed. Consequently, counts may serve as the most efficient metric for describing coarse wood loads in small streams.

We emphasize that the sample size estimator we used anticipates that all samples will be independent, i.e., there is no spatial autocorrelation among piece dimensions or reach totals, and our sampling of consecutive reaches met this assumption in most streams. Even in those streams with spatial autocorrelation, channel lengths necessary to estimate mean coarse wood loads were similar to those in segments lacking small-scale correlation. Thus, we suggest that samples of approximately 2.0 km would provide reasonably precise counts and more than adequate samples for piece dimensions, given a similar distribution of coarse wood. We recognize that many geomorphologically homogeneous stream segments are shorter, and in such cases recommend a complete census or obtaining a smaller sample at the cost of reduced precision and less confidence in the estimate. In either circumstance, however, only a relatively small proportion of individual pieces (in our streams, $<23\%$) would need to be measured to characterize piece dimensions other than volume. In an alternative approach for assessing coarse wood loads, Elosegi et al. (1999) and Diez et al. (2001) calculated lengths of stream to sample based on variation in wood abundance in 1-m increments and ceased sampling when a 10% increase in reach length produced a $<5\%$ change in variation in average wood volume. This method (and similar approaches; Wing et al., 1999; Keim et al., 2000; Kraft and Warren, 2003) appears practical for characterizing a particular site, but given the structure of the variation we encountered it would seem difficult to extrapolate the results to the remainder of a stream or predict sample sizes for other streams. Also, changes in our sampling frame produced surprising results. Increasing the sampling frame to 100-m reaches (i.e., pooling counts from adjacent 50-m reaches) increased the channel length that needed to be surveyed (2100 m; range, 600–4100 m) relative to that needed for 50-m reaches, further emphasizing the localized variation in coarse wood loads.

Finally, we acknowledge that based on the variation we observed and the aforementioned sampling rule, we undersampled some of our study streams and riparian zones. Moreover, the spatial variation we observed could be unique to our suite of stream sizes, forest types and ages, elevations, and climatic and hydrological regimes. But despite differences in definitions of the size and position of qualifying pieces among studies, the quantities of coarse wood in these 14 stream segments in western Montana were broadly comparable to those sampled in other Rocky Mountain and Sierra Nevada basins (Richmond and Fausch, 1995; Berg et al., 1998; Hauer et al., 1999; Bragg et al., 2000). Regardless of the location, landscape and riverscape perspectives on the distribution and abundance of coarse wood are a critical gap in our understanding of stream ecosystems (Swanson, 2003), and there is a great need for additional information here and elsewhere on the fine-scale (i.e., metres) and large-scale (i.e., kilometres) distribution of coarse wood in order to establish appropriate sampling protocols, recognize the effects of management and disturbance, and construct spatially realistic models of coarse wood dynamics for streams draining forested watersheds (Benda and Sias, 2002; Gregory et al., 2003).

Acknowledgements

We thank V. Barger, M. Burbank, D. Cremins, P. Delhomme, B. Dobrowski, M. Foster, S. Fowler, R. Hannah, K. Izlar, M. Olson, M. Rayton, C. Saunders, A. Seibel, J. Shaffer, H. Smith, T. Toth, N. Weber, and J. Zerr for assistance in the field, R. Ahl for assistance with the cluster analysis of basins, K. Stockman for help with Fig. 1, E. Heyerdahl for early discussions of sampling strategies, and the Bitterroot Ecosystem Management Research Project, the Region 1/Rocky Mountain Research Station Science Leadership Interaction Committee, and the National Fire Plan for funding. Rudy King provided a thorough biometrical review. Comments by John Buffington, Ann Carlson, Kelly Elder, Christine May, Gordon Reeves, Elizabeth Reinhardt, and Jordan Rosenfeld substantially improved this manuscript.

References

Abbe, T.B., Montgomery, D.R., 2003. Patterns and processes of wood debris accumulation in the Queets River basin, Washington. Geomorphology 51, 81–107.

Abbe, T.B., Brooks, A.P., Montgomery, D.R., 2003. Wood in river rehabilitation and management. Am. Fish. Soc. Symp. 37, 367–389.

Alban, D.H., Pastor, J., 1993. Decomposition of aspen, spruce, and pine boles on two sites in Minnesota. Can. J. For. Res. 23, 1744–1749.

Andrus, C.W., Long, B.A., Froehlich, H.A., 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Can. J. Fish. Aquat. Sci. 45, 2080–2086.

Angermeier, P.L., Karr, J.R., 1984. Relationships between woody debris and fish habitat in a small warmwater stream. Trans. Am. Fish. Soc. 113, 716–726.

Archer, E.K., Roper, B.B., Henderson, R.C., Bouwes, N., Mellison, S.C., Kershner, J.L., 2004. Testing common stream sampling methods for broad-scale, long-term monitoring. RMRS-GTR-122. USDA Forest Service, Rocky Mountain Research Station.

Arno, S.F., Scott, J.H., Hartwell, M.G., 1995. Age-class structure of old growth ponderosa pine/Douglas fir stands and its relationship to fire history. General Technical Report INT-42. USDA Forest Service, Intermountain Research Station.

Bate, L.J., Garton, E.O., Wisdom, M.J., 1999. Estimating snag and large tree densities and distributions on a landscape for wildlife management. PNW-GTR-425. USDA Forest Service, Pacific Northwest Research Station.

Bate, L.J., Torgersen, T.R., Wisdom, M.J., Garton, E.O., 2004. Performance of sampling methods to estimate log characteristics for wildlife. For. Ecol. Manage. 199, 83–102.

Beechie, T.J., Sibley, T.H., 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Trans. Am. Fish. Soc. 126, 217–229.

Beechie, T.J., Pess, G., Kennard, P., Bilby, R.E., Bolton, S., 2000. Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington streams. N. Am. J. Fish. Manage. 20, 436–452.

Benda, L.E., Sias, J.C., 2002. A quantitative framework for evaluating the mass balance of in-stream organic debris. For. Ecol. Manage. 172, 1–16.

Benda, L.E., Miller, D.J., Dunne, T., Reeves, G.H., Agee, J.K., 1998. Dynamic landscape systems. In: Naiman, R.J., Bilby, R.E. (Eds.), River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer-Verlag, New York, pp. 261–288.

Benda, L., Miller, D., Sias, J., Martin, D., Bilby, R., Veldhuisen, C., Dunne, T., 2003. Wood recruitment processes and wood budgeting. Am. Fish. Soc. Symp. 37, 49–73.

Berg, N., Carlson, A., Azuma, D., 1998. Function and dynamics of woody debris in stream reaches in the central Sierra Nevada, CA. Can. J. Fish. Aquat. Sci. 55, 1807–1820.

Bevenger, G.S., King, R.M., 1995. A pebble count procedure for assessing watershed cumulative effects. RM-RP-319. USDA Forest Service, Rocky Mountain Research Station.

Bilby, R.E., 2003. Decomposition and nutrient dynamics of wood in streams and rivers. Am. Fish. Soc. Symp. 37, 135–147.

Bilby, R.E., Likens, G.E., 1980. The importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61, 1107–1113.

Bilby, R.E., Ward, J.W., 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Trans. Am. Fish. Soc. 118, 368–378.

Bilby, R.E., Ward, J.W., 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Can. J. Fish. Aquat. Sci. 48, 2499–2508.

Bisson, P.A., Wondzell, S.M., Reeves, G.H., Gregory, S.V., 2003. Trends in using wood to restore aquatic habitats and fish communities in western North American rivers. Am. Fish. Soc. Symp. 37, 391–406.

Boyer, K.L., Berg, D.R., Gregory, S.V., 2003. Riparian management for wood in rivers. Am. Fish. Soc. Symp. 37, 407–420.

Bragg, D.C., Kershner, J.L., Roberts, D.W., 2000. Modeling large woody debris recruitment for small streams of the central Rocky Mountains. RMRS-GTR-55. USDA Forest Service, Rocky Mountain Research Station.

Braudrick, C.A., Grant, G.E., 2001. Transport and deposition of large woody debris in streams: a flume experiment. Geomorphology 41, 263–283.

Brown, J.K., See, T.E., 1981. Downed dead wood fuel and biomass in the Northern Rocky Mountains. General Technical Report INT-117. USDA Forest Service, Intermountain Research Station.

Brown, P.M., Shepperd, W.D., Mata, S.A., McClain, D.L., 1998. Longevity of windthrown logs in a subalpine forest of central Colorado. Can. J. For. Res. 28, 932–936.

Buffington, J.M., Lisle, T.E., Woodsmith, R.D., Hilton, S., 2002. Controls on the size and occurrence of pools in coarse-grained forest rivers. River Res. Appl. 18, 507–531.

Clark, D.B., Clark, D.A., Brown, S., Oberbauer, S.F., Veldkamp, E., 2002. Stocks and flows of coarse woody debris across a tropical rain forest nutrient and topography gradient. For. Ecol. Manage. 164, 237–248.

Cochran, W.G., 1977. Sampling Techniques, 3rd ed. John Wiley and Sons, New York.

Dahlström, N., Jönsson, K., Nilsson, C., 2005. Long-term dynamics of large woody debris in a managed boreal forest stream. For. Ecol. Manage. 210, 363–373.

Diez, J.R., Elosegi, A., Pozo, J., 2001. Woody debris in north Iberian streams: influence of geomorphology, vegetation, and management. Environ. Manage. 28, 687–698.

Dolloff, C.A., Warren Jr., J.L., 2003. Fish relationships with large wood in small streams. Am. Fish. Soc. Symp. 37, 179–193.

Elosegi, A., Diez, J.R., Pozo, J., 1999. Abundance, characteristics, and movement of woody debris in four Basque streams. Arch. Hydrobiol. 144, 455–471.

Everett, R., Lehmkuhl, J., Schellhaas, R., Ohlson, P., Keenum, D., Reisterer, H., Spurbeck, D., 1999. Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington state, USA. Int. J. Wildland Fire 9, 223–234.

Fausch, K.D., Northcote, T.G., 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Can. J. Fish. Aquat. Sci. 49, 682–693.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., Maupin, M.A., Gurtz, M.E., 1998. Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program. U.S. Geological Survey, Water-Resources Investigations Report 98-4052.

Fox, M.J., 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington state. M.S. Thesis. University of Washington, Seattle, WA, USA.

Frissell, C.A., Liss, W.J., Warren, C.E., Hurley, M.D., 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environ. Manage. 10, 199–214.

Froehlich, H.A., McGree, D., Sedell, J.R., 1972. Natural debris within the stream environment. Coniferous forest biome. U.S. Int. Biol. Program Intern. Rep. 96, 1–9.

Gomi, T., Sidle, R.C., Bryant, M.D., Woodsmith, R.D., 2001. The characteristics of woody debris and sediment distribution in headwater streams, southeastern Alaska. Can. J. For. Res. 31, 1386–1399.

Gregory, K.J., 2003. The limits of wood in world rivers: present, past, and future. Am. Fish. Soc. Symp. 37, 1–19.

Gregory, S.V., Meleason, M.A., Sobota, D.J., 2003. Modeling the dynamics of wood in streams and rivers. Am. Fish. Soc. Symp. 37, 315–335.

Gurnell, A.M., 2003. Wood storage and mobility. Am. Fish. Soc. Symp. 37, 75–91.

Gurnell, A.M., Piegay, H., Swanson, F.J., Gregory, S.V., 2002. Large wood and fluvial process. Freshw. Biol. 47, 601–619.

Guyette, R.P., Cole, W.G., Dey, D.C., Muzika, R.-M., 2002. Perspectives on the age and distribution of large wood in riparian carbon pools. Can. J. Fish. Aquat. Sci. 59, 578–585.

Hansen, P.L., Pfister, R.D., Boggs, K., Cook, B.J., Joy, J., Hinckley, D.K., 1995. Classification and management of Montana's riparian and wetland sites. Miscellaneous Publication 54. Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, MT, USA, 646 pp.

Hardy, C.C., 1996. Guidelines for estimating volume, biomass, and smoke production for piled slash. PNW-GTR-364. USDA Forest Service, Pacific Northwest Research Station.

Harmon, M.E., 2002. Moving towards a new paradigm for woody detritus management. In: Laudenslayer, Jr., W.F., Shea, P.J., Valentine, B.E., Weatherspoon, C.P., Lisle, T.E. (Eds.), Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, PSW-GTR-181, USDA Forest Service, Pacific Southwest Research Station, pp. 929–944.

Harmon, M.E., Sexton, J., 1996. Guidelines for measurements of woody detritus in forest ecosystems. Publ. 20. U.S. LTER Network Office, University of Washington, Seattle, WA, USA.

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack Jr., K., Cummins, K.W., 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15, 133–302.

Harrelson, C.C., Potyondy, J.P., Rawlins, C.L., 1994. Stream channel reference sites: an illustrated guide to field techniques. General Technical Report RM-245. USDA Forest Service, Rocky Mountain Research Station.

Harrington, M., 1996. Fall rates of prescribed fire-killed ponderosa pine. INT-RP-489. USDA Forest Service, Intermountain Research Station.

Hauer, F.R., Poole, G.C., Gangemi, J.T., Baxter, C.V., 1999. Large woody debris in bull trout (*Salvelinus confluentus*) spawning streams of logged and wilderness watersheds in northwest Montana. Can. J. Fish. Aquat. Sci. 56, 915–924.

Hedman, C.W., Van Lear, D.H., Swank, W.T., 1996. In-stream large woody debris loading and riparian forest seral stage associations in the southern Appalachian Mountains. Can. J. For. Res. 26, 1218–1227.

Husch, B., Beers, T.W., Kershaw Jr., J.A., 2002. Forest Mensuration, 4th ed. Wiley, New York.

Hyatt, T.L., Naiman, R.J., 2001. The residence time of large woody debris in the Queets River, Washington, USA. Ecol. Appl. 11, 191–202.

Jensen, M., Goodman, I., Brewer, K., Frost, T., Ford, G., Nesser, J., 1997. Biophysical environments of the basin. In: Quigley, T.M., Arbelbide, S.J. (Eds.), An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins, PNW-GTR-405, vol. 1. USDA Forest Service, Pacific Northwest Research Station, pp. 99–335.

Kaufmann, P.R., Levine, P., Robison, E.G., Seeliger, C., Peck, D.V., 1999. Quantifying physical habitat in wadeable streams. EPA/620/R-99/003. U.S. Environmental Protection Agency, Washington, DC.

Keim, R.F., Skaugset, A.E., Bateman, D.S., 2000. Dynamics of coarse woody debris placed in three Oregon streams. For. Sci. 46, 13–22.

Kraft, C.E., Warren, D.R., 2003. Development of spatial pattern in large woody debris and debris dams in streams. Geomorphology 51, 127–139.

Lambert, R.L., Land, G.E., Reiners, W.A., 1980. Loss of mass and chemical change in decaying boles of a subalpine balsam fir forest. Ecology 61, 1460–1473.

Lee, P.C., Crites, S., Nietfeld, M., Van Nguyen, H., Stelfox, J.B., 1997. Characteristics and origins of deadwood material in aspen-dominated boreal forests. Ecol. Appl. 7, 691–701.

Legendre, P., Fortin, M.-J., 1989. Spatial pattern and ecological analysis. Vegetatio 80, 107–138.

Legendre, P., Legendre, L., 1998. Numerical Ecology, 2nd ed. Elsevier, Amsterdam.

Leopold, L.B., Wolman, M.G., Miller, J.P., 1964. Fluvial Processes in Geomorphology. W.H. Freeman, San Francisco.

Lienkaemper, G.W., Swanson, F.J., 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Can. J. For. Res. 17, 150–156.

Lisle, T.E., 2002. How much dead wood in stream channels is enough? In: Laudenslayer, Jr., W.F., Shea, P.J., Valentine, B.E., Weatherspoon, C.P., Lisle, T.E. (Eds.), Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, PSW-GTR-181, USDA Forest Service, Pacific Southwest Research Station, pp. 85–93.

Long, B.A., 1987. Recruitment and abundance of large woody debris in an Oregon coastal stream system. M.S. Thesis. Oregon State University, Corvallis, OR, USA.

Lyon, L.J., 1984. The Sleeping Child Burn—21 years of postfire change. Research Paper INT-330. USDA Forest Service, Intermountain Research Station.

Mackensen, J., Bauhus, J., Webber, E., 2003. Decomposition rates of coarse woody debris—a review with particular emphasis on Australian tree species. Aust. J. Bot. 51, 27–37.

Martin, D.J., 2001. The influence of geomorphic factors and geographic region on large woody debris loading and fish habitat in Alaska coastal streams. N. Am. J. Fish. Manage. 21, 429–440.

Martin, D.J., Benda, L.E., 2001. Patterns of instream wood recruitment and transport at the watershed scale. Trans. Am. Fish. Soc. 130, 940–958.

Maxwell, J.R., Edwards, C.J., Jensen, M.E., Paustian, S.J., Parrott, H., Hill, D.M., 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). General Technical Report NC-176. USDA Forest Service, North Central Research Station.

May, C.L., Gresswell, R.E., 2003. Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, USA. Can. J. For. Res. 33, 1352–1362.

McDade, M.H., Swanson, F.J., McKee, W.A., Franklin, J.F., Van Sickle, J., 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. Can. J. For. Res. 20, 326–330.

McHenry, M.L., Shott, E., Conrad, R.H., Grette, G.B., 1998. Changes in the quantity and characteristics of large woody debris in streams of the Olympic Peninsula, Washington, USA (1982–1993). Can. J. Fish. Aquat. Sci. 55, 1395–1407.

Mitchell, R.G., Preisler, H.K., 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. W.J. Appl. For. 13, 23–26.

Montgomery, D.R., Buffington, J.M., 1997. Channel-reach morphology in mountain drainage basins. Geol. Soc. Am. Bull. 109, 596–611.

Montgomery, D.R., MacDonald, L.H., 2002. Diagnostic approach to stream channel assessment and monitoring. J. Am. Water Resour. Assoc. 38, 1–16.

Montgomery, D.R., Buffington, J.M., Smith, R., Schmidt, K., Pess, G., 1995. Pool spacing in forest channels. Water Resourc. Res. 31, 1097–1105.

Montgomery, D.R., Collins, B.D., Buffington, J.M., Abbe, T.B., 2003. Geomorphic effects of wood in rivers. Am. Fish. Soc. Symp. 37, 21–47.

Morrison, M., Raphael, M., 1993. Modeling the dynamics of snags. Ecol. Appl. 3, 322–330.

Muller, R.N., Liu, Y., 1991. Coarse woody debris in an old-growth deciduous forest on the Cumberland Plateau, southeastern Kentucky. Can J. For. Res. 21, 1567–1572.

Murphy, M.L., Koski, K.V., 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. N. Am. J. Fish. Manage. 9, 427–436.

Nakamura, F., Swanson, F.J., 1993. Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon. Earth Surf. Proc. Landsc. 18, 43–61.

Overton, C.K., McIntyre, J.D., Armstrong, R., Whitwell, S.L., Duncan, K.A., 1995. User's guide to fish habitat: descriptions that represent natural conditions in the Salmon River basin, Idaho. INT-GTR-322. USDA Forest Service, Intermountain Research Station.

Ralph, S.C., Poole, G.C., Conquest, L.L., Naiman, R.J., 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Can. J. Fish. Aquat. Sci. 51, 37–51.

Reeves, G.H., Burnett, K.M., McGarry, E.V., 2003. Sources of large wood in the main stem of a fourth-order watershed in coastal Oregon. Can. J. For. Res. 33, 1363–1370.

Richmond, A.D., Fausch, K.D., 1995. Characteristics and function of large woody debris in subalpine Rocky Mountain streams in the northern Colorado. Can. J. Fish. Aquat. Sci. 52, 1789–1802.

Robison, E.G., Beschta, R.L., 1990. Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, USA. Earth Surf. Proc. Landsc. 15, 149–156.

Rosenfeld, J.S., Huato, L., 2003. Relationship between large woody debris characteristics and pool formation in small coastal British Columbia streams. N. Am. J. Fish. Manage. 23, 928–938.

Rosgen, D., 1996. Applied River Geomorphology. Wildland Hydrology. Pagosa Springs, Colorado, USA.

Rot, B.W., Naiman, R.J., Bilby, R.E., 2000. Stream channel configuration, landform, and riparian forest structure in the Cascade Mountains, Washington. Can. J. Fish. Aquat. Sci. 57, 699–707.

Skinner, C.N., 2002. Influence of fire on the dynamics of dead woody material in forests of California and southwestern Oregon. In: Laudenslayer, Jr., W.F., Shea, P.J., Valentine, B.E., Weatherspoon, C.P., Lisle, T.E. (Eds.), Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, PSW-GTR-181, USDA Forest Service, Pacific Southwest Research Station, pp. 445–454.

Sobota, D.J., 2003. Fall directions and breakage of riparian trees along streams in the Pacific Northwest. M.S. Thesis. Oregon State University, Corvallis, OR, USA.

Spies, T.A., Franklin, J.F., Thomas, T.B., 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology 69, 1689–1702.

Swanson, F.J., 2003. Wood in rivers: a landscape perspective. Am. Fish. Soc. Symp. 37, 299–313.

Swanson, F.J., Lienkaemper, G.W., 1978. Physical consequences of large organic debris in Pacific Northwest streams. General Technical Report PNW-69. USDA Forest Service, Pacific Northwest Research Station.

Swanson, F.J., Lienkaemper, G.W., Sedell, J.R., 1976. History, physical effects, and management implications of large organic debris in western Oregon streams. Physical consequences of large organic debris in Pacific Northwest streams. General Technical Report PNW-56. USDA Forest Service, Pacific Northwest Research Station.

Swanson, F.J., Bryant, M.D., Lienkaemper, G.W., Sedell, J.R., 1984. Organic debris in small streams, Prince of Wales Island, southeast Alaska. General Technical Report PNW-166. USDA Forest Service, Pacific Northwest Research Station.

Tyrrell, L.E., Crow, T.R., 1994. Dynamics of dead wood in old-growth hemlock-hardwood forests of northern Wisconsin and northern Michigan. Can. J. For. Res. 24, 1672–1683.

U.S. Department of Agriculture (USDA), 1995. Decision Notice/Decision Record, FONSI. Ecological analysis and appendices for the inland fish strategy (INFISH). Interim strategies for managing fish-producing watersheds in eastern Oregon and Washington, Idaho, western Montana, and portions of Nevada. USDA Forest Service, Region 1, Missoula, MT, USA.

U.S. Department of Agriculture/U.S. Department of Interior (USDA/USDI), 1995. Decision Notice/Decision Record, FONSI. Ecological analysis and appendices for the interim strategy for managing anadromous fish-producing watersheds in eastern Oregon and Washington, Idaho, and portions of California (PACFISH). USDA Forest Service, Region 6, Portland, OR, USA.

Van Sickle, J., Gregory, S.V., 1990. Modeling inputs of large woody debris to streams from falling trees. Can. J. For. Res. 20, 1593–1601.

Van Wagner, C.E., 1982. Practical aspects of the line intersect method. Information Report PI-X-12. Canadian Forest Service.

Williams, M.S., Gove, J.H., 2003. Perpendicular distance sampling: an alternative method for sampling downed coarse woody debris. Can. J. For. Res. 33, 1564–1579.

Wing, M.G., Skaugset, A., 2002. Relationships of channel characteristics, land ownership, and land use patterns to large woody debris in western Oregon streams. Can. J. Fish. Aquat. Sci. 59, 796–807.

Wing, M.G., Keim, R.F., Skaugset, A.E., 1999. Applying geostatistics to quantify distributions of large woody debris in streams. Comp. Geosci. 25, 801–807.

Woldendorp, G., Keenan, R.J., Barry, S., Spencer, R.D., 2004. Analysis of sampling methods for coarse woody debris. For. Ecol. Manage. 198, 133–148.

Young, M.K., 1994. Movement and characteristics of stream–borne coarse woody debris in adjacent burned and undisturbed streams in Wyoming. Can. J. For. Res. 24, 1933–1938.