Hydrobiologia (2008) 598:123–130
DOI 10.1007/s10750-007-9144-8

PRIMARY RESEARCH PAPER

A comparison of line-intercept and census techniques for assessing large wood volume in streams

Dana Richard Warren · William S. Keeton · Clifford E. Kraft

Received: 5 October 2006 / Revised: 14 August 2007 / Accepted: 20 August 2007 / Published online: 12 September 2007

Abstract Most surveys of large wood in streams are conducted by counting and measuring every piece of large wood within a reach, a technique that is effective but time-consuming. In this study we evaluated an alternative method that takes less time and can be employed in studies in which an estimate of total large wood volume along a stream reach is the primary metric of interest. In first- through third-order streams we estimated in-stream large wood volume and large wood frequency, comparing large wood census estimates to those from a modified a line-intercept technique that has been commonly used in terrestrial forest surveys. Estimates of large wood volume from line transects located in the geographic center of the stream (parallel to stream axis and equidistant from bankfull margins) were highly correlated with those from the wood census ($P < 0.001$, $r^2 = 0.88$, Pearson's $r = 0.935$), but produced slightly greater estimates of large wood volume (regression slope = 1.28, SE = 0.16). Line-intercept estimates of large wood frequency (number per 100 m of stream) were significantly correlated to the wood census counts, but the line-intercept method underestimated frequency by about 50% ($P = 0.016$). Differences in the estimated large wood volume between line-intercept and wood census surveys were associated with variability in the diameter of the large wood, but unrelated to stream bankfull width, for the range of stream sizes evaluated in this study ($\approx$ 2 to 11 m). Our results suggest that in small constrained streams, line-intercept surveys are an effective method for estimating in-stream large wood volume and that these estimates better approximate results from whole-stream census techniques where the diameter of in-stream wood is relatively consistent.

Keywords Large wood · Large woody debris · Line-intercept · Wood census · Wood volume · Stream assessment

Handling editor: K. Martens

D. R. Warren (✉) · C. E. Kraft
Department of Natural Resources, Cornell University,
Ithaca, NY 14853, USA
e-mail: drw23@cornell.edu

W. S. Keeton
Rubenstein School of Environment and Natural
Resources, University of Vermont, 343 Aiken Center,
Burlington, VT 05405, USA

Introduction

Large wood has been established as an important physical and ecological feature in many stream ecosystems, and studies of stream habitat frequently quantify the amount of in-stream wood by estimating large wood volume (Bilby, 1981; Montgomery et al., 1995; Roni & Quinn, 2001; Gregory et al., 2003). In addition to providing a measure of stream wood that can be associated with ecosystem processes, the expanding number of studies reporting large wood volume presents an opportunity to compare wood characteristics in specific study areas throughout the world (Meleason et al., 2005). In this study, we evaluated the ability of the line-intercept method of wood volume estimation (VanWagner, 1968)—a method developed and commonly applied in forest surveys—to accurately estimate wood volume in stream ecosystems. We compared line-intercept estimates to estimates from the more common large wood census method, in which in-stream large wood volume is estimated by counting and measuring the diameter and length of every piece of wood within a given section of stream. The objectives of this study were to (1) determine whether or not the line-intercept survey method provided wood volume estimates comparable to those derived from a full wood census and (2) identify factors influencing accuracy of line-intercept estimates of stream wood volume (e.g., stream bankfull width, reach length, wood diameter, or wood abundance).

Most studies that report estimates of stream wood volume also include other information relevant to wood characteristics within a stream channel, such as orientation, species, decay class, geomorphic function, etc. In the process of collecting these data researchers typically evaluate and measure all wood present within the bankfull channel of a stream reach, then calculate the total estimated wood volume within that reach by summing the estimated volume of each individual piece of large wood (usually calculated as a cylinder). Estimating wood volume with this method requires considerable time and effort (Gippel et al., 1996; Young et al., 2006).

The line-intercept technique provides a rapid assessment tool for estimating the volume of wood along a transect (VanWagner, 1968). This method was first used in streams by Wallace and Benke (1984), who established a series of transects perpendicular to the stream to quantify wood volume in a blackwater river channel. Subsequent studies have used a similar modification of the line-intercept technique (O'Connor, 1992; Gippel et al., 1996; Baillie et al., 1999; Thevenet & Statzner, 1999), but the broad application of this approach in stream studies has been limited. Latterell et al. (2006) used a different modification of the line-intercept method, employing multiple short transects within a sample area for a largeflood plain river system. An alterative application of the line-intercept method in small headwater streams has been to estimate wood volume by running a transect through the stream thalweg rather than along multiple perpendicular transects (Valett et al., 2002). The accuracy of the line-intercept technique has been frequently evaluated in terrestrial settings (Kaiser, 1983; Bate et al., 2004; Woldendorp et al., 2004), but we are aware of only one study that has evaluated the line-intercept method as an approach for estimating total wood volume within stream ecosystems. Gippel et al. (1996) found that a series of line-intercept transects oriented perpendicular to the stream bank over-estimated wood volume relative to both a wood census and aerial surveys in a large, low gradient Australian stream. No studies have evaluated the accuracy of the line-intercept method in other streams settings or when applied as a transect through the center of a stream.

The line-intercept survey, as initially developed for estimating the volume of downed woody debris within a forest, requires the use of a straight line transect (Warren & Olsen, 1964). The diameters of all downed logs greater than a minimum threshold (e.g., 10 cm) crossed by the transect line are recorded during the survey at the point of each intersection with the transect line (Warren & Olsen, 1964). The transect length and wood diameter for each surveyed piece of large wood are then used to estimate the volume of wood within a given area, typically reported in units of cubic meters per hectare (VanWagner, 1968). Multiple transects within a study site can be used to decrease potential error and to estimate a variance for the forest woody debris volume estimates (VanWagner, 1968; Woldendorp et al., 2004).

The line-intercept technique relies on the assumption that wood is randomly distributed and arranged along the surface being evaluated (VanWagner 1968). In streams, however, wood is often aggregated in debris dams (Keim et al., 2000; Kraft & Warren, 2003) and exhibits a non-random orientation (Bisson et al., 1987; Nakamura & Swanson, 1994). Bisson et al. (1987) suggested that wood tends to be randomly arranged in small streams, but is more likely to be oriented parallel to the direction of flow in larger streams. Similarly, Chen et al. (2006), working in forested British Columbia streams, found that logs in small streams <3 m bankfull width were most often oriented perpendicular to the stream flow, whereas in larger streams >7 m bankfull width wood was often oriented parallel to stream flow. In our study, we evaluated wood volume in first- to third-order streams ranging from 2.2 to 10.9 m bankfull width (Table 1).

We evaluated the line-intercept method as applied using a transect within a stream reach. We expected that line-intercept survey estimates in smaller streams would be either similar to the wood census estimates or would overestimate wood volume relative to the wood census. An overestimate could occur if a majority of pieces were oriented perpendicular to the stream, leading to a greater number of intersections of large wood by the transect in comparison to circumstances in which wood was randomly oriented within the stream channel. In contrast, in larger streams where stream energy is greater and wood transport is more common, large wood is more likely to be oriented parallel to the stream flow or to be located near the stream edge where it it is less likely to be intercepted by a transect established through the center of the stream (Nakamura and Swanson 1994; Chen et al. 2006). In such instances, line-intercept estimates would be expected to underestimate wood volume.

Materials and methods

Wood surveys were conducted in 11 streams in the western Adirondack region of New York State in northeastern North America. The riparian forests were representative of the mixed hardwood–conifer forests typical of this region (Keeton et al., 2007). Dominant riparian trees included *Betula alleghaniensis* (yellow birch), *Fagus grandifolia* (American beech), *Picea rubens* (red spruce), and *Tsuga canadensis* (eastern hemlock). All streams had constrained channels, and stream gradients ranged from ~1% to ~8%. The average age of dominant canopy trees ranged from approximately 100 to 315 years based on extensive tree coring (Keeton et al., 2007). Stream reaches ranged in length from approximately 120 to 250 m and from 23 to 90 times the width of the bankfull channel (Table 1). The second growth forests studied here were recovering from historic logging and, in some cases, subsequent fires rather than other types of natural disturbances or agriculture. Mean height of dominant riparian trees ranged from 22 to 34 m

Assessment of large wood volume using wood census methods followed procedures similar to those used in previous stream studies (Richmond & Fausch,

Table 1 Stream and large wood (LW) characteristics for the 11 western Adirondack streams evaluated in this study

Site	Mean bankfull (m)	Reach length (m)	*Wood census* LW volume estimate (m^3 ha^{-1})	*Line-intercept* LW volume estimate (m^3 ha^{-1})	*Wood census* LW frequency estimate (No. 100 m^{-1})	*Line-intercept* LW frequency estimate (No. 100 m^{-1})	Mean LW diameter (m)	Coefficient of variation of LW diameter from wood census surveys
Combs Brook	4.2	210	37.3	41.4	18	7	0.21	44.1
Darby Brook	3.2	120	67.4	45.7	33	15	0.19	55.1
Witchopple 2	3.4	150	19.5	14.6	11	4	0.15	38.7
Witchopple 1	6.6	200	92.7	151.1	53	30	0.21	38.9
Clearlake 2	2.5	120	236.9	327.4	43	38	0.21	59.3
Clearlake outlet	8.0	190	186.6	216.9	63	23	0.22	45.9
Panther trail trib.	2.2	200	150.0	106.2	17	13	0.24	46.4
Constable inlet	5.9	150	97.6	162.8	42	19	0.19	50.1
Canachaguala Brook	10.9	250	9.0	4.5	8	1	0.18	43.8
Beth's Brook	3.7	150	32.0	38.3	25	12	0.14	35.1
Pico Creek	8.0	200	39.2	30.5	48	7	0.17	36.1

1995; Young et al., 2006). We recorded the length and diameter of all large wood contained within the bankfull channel. "Large wood" was defined as dead wood lying within the bankfull channel that was at least 1 m in length and had a diameter of at least 10 cm at one point (excluding knots and branch extensions). The length of wood within the stream channel was estimated to the nearest 0.5 m using a 1.5 m wading staff (with 0.5 m increments delineated), and wood diameter was measured with an accuracy of 0.01 m using a meter stick. Pieces of wood with a diameter greater than 10 cm at only one location were considered to be 1 m in length; the length of all other pieces were based on the length of wood with a diameter of at least 10 cm. For the first 5–10 pieces encountered in each stream, measurements of wood length and diameter were corroborated using tape measures and diameter tapes in order to ensure accurate estimates. Wood volume was calculated for each piece assuming a simple cylindrical shape (Meleason et al., 2005; Young et al., 2006). We summed all individual wood volumes to determine the total estimated volume of wood contained within a reach, and reach area was estimated based on the length of the reach and the mean bankfull width for each stream. The overall wood volume was converted to cubic meters per hectare for comparison with the line-intercept method estimates. Calculating log volume from a diameter measurement can introduce error to the wood census method. The wood census also requires that every piece of wood is noted and measured and missing a piece can also lead to error in census estimates.

The line-intercept surveys were conducted using a transect along the length of each reach that was placed in the center of the bankfull channel (the approximate center of the stream was estimated visually). The survey transect was placed through the center of the stream channel rather than along the thalweg to reduce bias, especially in larger streams where stream flow through the thalweg is likely to dislodge wood. The diameter at the intercept with the transect was recorded for each piece of large wood encountered. To calculate the volume of wood per hectare, we used the equation developed by Warren and Olsen (1964) and Van Wagner (1968), as modified by Shivers and Borders (1996):

$$X = \left(\frac{\pi^2}{8L}\right)\sum d_i^2 \tag{1}$$

where X = the estimated wood volume in cubic meters per hectare, L = transect length in meters, and d = log diameter in centimeters. Results from the line-intercept surveys are also reported in Keeton et al. (2007).

We also evaluated line-intercept estimates of large wood frequency (number of pieces of large wood per 100 m) in each stream by comparing the number of pieces of large wood encountered per 100 m from each of the two methods.

In comparing estimates of large wood volume, we first conducted a Pearson correlation analysis to determine the coefficient of correlation between estimates from the two methods. Although some error is associated with the volume estimate for each individual log in the wood census, we assumed that wood census estimates provided the most accurate estimate of wood volume. All data evaluated in this study were normally distributed based on an Anderson-Darling goodness-of-fit test ($\alpha > 0.05$) (MINITAB® Release 14.20, 2005). After conducting the correlation analysis, we regressed wood census volume estimates against the line-intercept estimates and compared the best fit line to the one-to-one relationship expected for identical estimates. To evaluate the potential influence of stream characteristics on the line-intercept estimates of wood volume, we plotted mean bankfull width, stream reach length and the total number of pieces of large wood against: (1) the differences between the two estimates and (2) the ratio of the two estimates (wood census/line-intercept). Finally, to determine whether estimates were more accurate in streams with more uniform wood size, we plotted the coefficient of variation of wood diameter against the magnitude of the difference between the two estimates (both normally distributed). With greater variability in large wood diameters, the line-intercept method may over- or under-estimate wood volume relative to the census method due to the greater chance of including or excluding large pieces of wood.

Results

Estimates of stream wood volume using the line-intercept and wood census techniques were highly correlated (Pearson's $r = 0.935$, $P < 0.001$; Fig. 1). The line-intercept method appeared to slightly

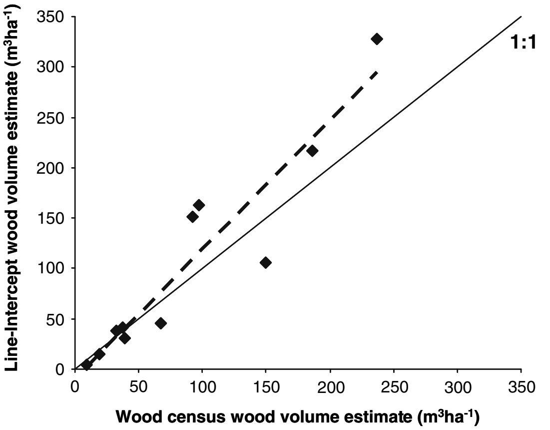

Fig. 1 Large wood volume estimate comparison between a complete wood census and the line-intercept survey for 11 streams in the western Adirondack Mountains, NY. The dotted line represents the best fit line for a regression between the two estimates ($P < 0.001$, $r^2 = 0.87$, line-intercept estimate = (census estimate) × 1.3–9.3); the solid line represents the 1:1 line

overestimate wood volume, particularly as the amount of wood in the stream increased ($P < 0.001$, $r^2 = 0.88$; Fig. 1). The equation for the best fit line relating these two estimate methods is as follows:

$$\text{line} - \text{intercept estimate} = (\text{census estimate}) \times 1.28 - 9.34 \tag{2}$$

Although the slope is slightly greater than we had hypothesized, it is not significantly different from one (95% CI = 0.928, 1.638). Using the slope of 1.28 from the best fit line in this analysis, the line-intercept method overestimated large wood volume relative to the census by about 9% for a system with 50 m^3 ha^{-1} of large wood, by about 16% for a system with 100 m^3 ha^{-1} of large wood, and by about 20% for a system with 250 m^3 ha^{-1} of large wood. Differences between the two estimates increased with variability in large wood diameters ($P = 0.038$, $r^2 = 0.40$; Fig. 2), a result consistent with terrestrial studies in which greater variability in large wood diameter—particularly infrequent large logs—resulted in greater error (Bate et al., 2004). In contrast to our expectations, stream bankfull width did not have a consistent influence on the relative accuracy of the line-intercept estimate in predicting stream wood volume for the range of stream sizes evaluated in this study (Fig. 3).

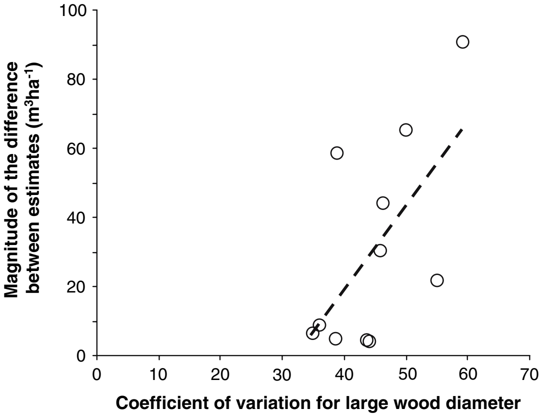

Fig. 2 Regression of the magnitude of the difference between estimates from the best fit line against the coefficient of variation of wood diameter for each stream surveyed. Dotted line represents best fit line of the regression ($P = 0.038$, $r^2 = 0.40$, Magnitude of error = 2.4 × (coefficient of variation of diameter) – 78.5)

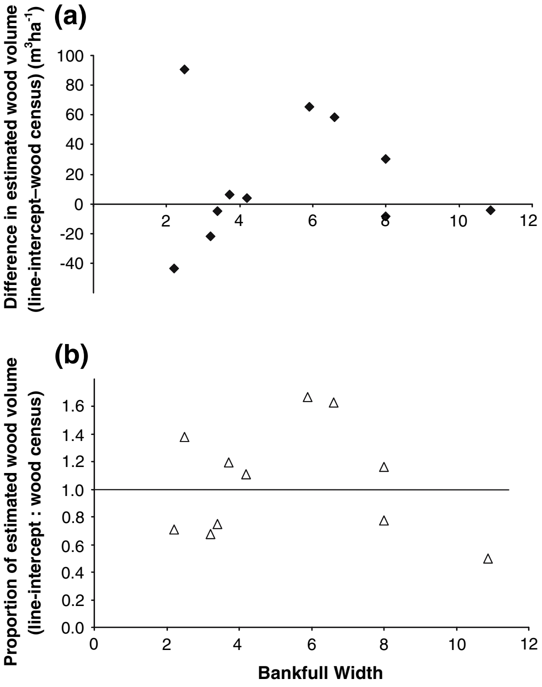

Fig. 3 Differences (**a**) and ratios (**b**) between line-intercept and wood census estimates plotted against stream bankfull widths for the 11 study streams. In Fig. 3a, negative values indicate greater estimated volume from the wood census and positive values indicate greater estimated wood volume from the line-intercept method. In Fig. 3b, values less than one indicate greater values in the wood census estimate and values greater than one indicate greater values in the line-intercept method

Similarly, reach length and the total number of pieces of large wood in a reach were also not significantly related to the magnitude or ratio of error between the two estimates, although there was a non-significant trend toward greater estimated large wood volume using the line-intercept method in streams containing more wood ($P > 0.1$ for all).

Although line-intercept estimates of large wood frequency (number of pieces per 100 m of stream) were significantly related to the wood census frequency estimates ($P = 0.016$), the predictive power of the relationship was weaker than for estimates of wood volume ($r^2 = 0.49$). Overall, the line-intercept estimate of large wood frequency was slightly less than 50% of the wood census estimate (slope of the best fit line = 0.43, SE = 0.15; Fig. 4). Unlike wood volume, proportional differences between the two estimates of wood frequency were significantly related to stream bankfull width ($P = 0.007$, $r^2 = 0.58$). Multiple regression using both the line-intercept estimate and the mean bankfull width as independent variables improved the potential to accurately predict large wood frequency ($P = 0.015$, $r^2 = 0.65$; Large wood frequency = (line-intercept frequency estimate) $\times$ 0.48 +(bankfull) $\times$ −1.69 + 8.468).

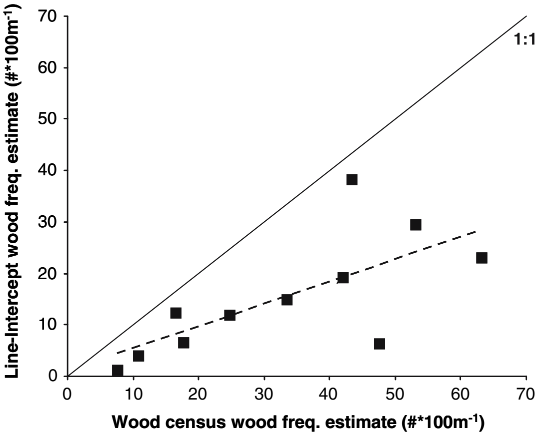

Fig. 4 Estimated large wood frequency from complete wood census and line-intercept surveys for 11 streams in the western Adirondack Mountains, NY. The dotted line represents the best fit line for a regression between the two estimates ($P < 0.016$, $r^2 = 0.49$, line-intercept estimate = (census estimate) $\times$ 0.43 + 1.15); the solid line represents the 1:1 line

Discussion

Line-intercept estimates of large wood volume were relatively consistent with volume estimates from wood census with surprisingly little systematic bias associated with stream size for the range of bankfull widths evaluated in this study. Although we expected the line-intercept method to overestimate large wood volume in the smaller streams relative to the wood census estimates—due to the increased probability of intersecting wood oriented perpendicular to the stream in small channels that do not sustain large flows—this hypothesis was not supported. Instead, no trend was observed, and we found that error associated with variability in large wood size exerted a greater influence on the line-intercept estimates of in-stream wood volume.

The line-intercept estimates of large wood volume were expected to systematically underestimate large wood volume in larger streams relative to the wood census estimates. This hypothesis was based upon the expectation that a transect would not intersect wood that had been pushed to the edge of the stream channel by large flow events. Results from the sole study stream with a bankfull width >10 m (Canachagala Brook) were consistent with this expectation, but the next two largest streams did not correspond to this result. It is relevant to note that although the proportional difference between the two methods was greater in Canachagala Brook than any other study stream, the absolute error between estimates was relatively low by comparison with the other streams because Canachagala Brook had low overall amounts of large wood (Fig. 3). The small number of streams with bankfull width >10 m is likely to have influenced our observations, and no streams in this study exceeded the height of the dominant canopy trees. We expect that systematic underestimates would be more likely to occur in streams in which bankfull width exceeds the height of dominant riparian trees. For the range of stream sizes evaluated in this study, our results suggest that establishing transects through the geographic center of the stream bankfull channel effectively provided an un-biased sampling method. We believe that this transect location helped encompass wood accumulations that did not span the channel, as well as portions of the thalweg devoid of wood in larger and mid-sized streams.

Table 2 Stream, reach and large wood (LW) features evaluated in this study for their potential contributions to bias in line-intercept survey (LIS) estimates of large wood volume in streams

Stream and LW characteristics	Influence on line-intercept survey estimates of LW volume
Bankfull width	No clear bias (for streams up to at least 8 m)
Reach length	No clear bias (all reaches were at least 120 m in length)
LW diameter	High variability in LW diameter can increase differences between LIS and census wood volume estimates
Wood orientation	No clear bias as applied in these streams
No. of LW pieces in the study reach	Non-significant trend toward greater estimated volume from LIS as wood frequency increases

We also initially expected that the orientation of wood might result in relatively low line-intercept large wood estimates in larger streams. It appears, however, that wood orientation relative to the stream channel did not produce a substantial amount of error in estimated wood volume from line-intercept transects placed through the center of the stream channel. Specifically, wood volume was not consistently underestimated in larger channels, suggesting that the transects were sufficiently random (relative to wood location) to be unbiased. In contrast to the systems studied by Chen et al. (2006) in which most wood in streams >7 m bankfull width was oriented parallel to the stream channel, we did not observe a clear trend in orientation while conducting our surveys (personal observation). Consistent with these observations, in a quantitative survey of an eastern Adirondack stream with an 8 m bankfull width, we found that only 11% of wood pieces were oriented parallel to stream flow (Warren unpublished data). Other transect locations (e.g., through thalweg or perpendicular to the stream) were not evaluated in our study and may be subject to greater error associated with wood orientation.

Overall, our study results indicate that employing a line-intercept survey with a transect through the center of a stream channel can produce stream wood volume estimates with minimal bias in small constrained, mid-gradient streams (see Table 2 for a list of the potential sources of bias evaluated here and whether or not they had systematic influences on line-intercept wood volume estimates relative to wood census surveys). We caution, however, that this method is not always a suitable substitute for a complete wood census, especially when additional information regarding individual in-stream wood characteristics is desirable. Further evaluation of this technique will be required for application within larger streams, but our results suggest that stream size does not influence the accuracy of the line-intercept estimates for streams up to 8 m bankfull width. Given that line-intercept estimates are subject to greater error as variability in stream wood diameter increases, we suggest that variability in wood diameter should be included in future publications reporting wood volume estimates derived from line-intercept surveys.

Acknowledgements We would like to thank field crews from both Cornell University and the University of Vermont for help in woody debris surveys. We thank Marissa Weiss and Bethany Boisvert for helpful comments on earlier drafts of this manuscript. Funding for this research was provided by the USDA Forest Service, McIntire-Stennis Forest Research Program; and the Cornell Biogeochemistry and Environmental Biocomplexity NSF IGERT grant (NSF DGE-0221658).

References

Baillie, B. R., T. L. Cummins & M. O. Kimberley, 1999. Measuring woody debris in the small streams of New Zealand's pine plantations. New Zealand Journal of Marine and Freshwater Research 33: 87–97.

Bate, L. J., T. R. Torgersen, M. J. Wisdom & E. O. Garton, 2004. Performance of sampling methods to estimate log characteristics for wildlife. Forest Ecology and Management 199: 83–102.

Bilby, R. E., 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62: 1234–1243.

Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dolloff, G. B. Grette, R. A. House, M. L. Murphy, K. V. Koski & J. R. Sedell, 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, future. In Salo, E. O. & T. W. Cundy (eds), Streamside management: forestry and fishery interactions. University of Washington. Seattle, pp 143–190.

Chen, X. Y., X. H. Wei, R. Scherer, C. Luider & W. Darlington, 2006. A watershed scale assessment of in-stream large woody debris patterns in the southern interior of British Columbia. Forest Ecology and Management 229: 50–62.

Gippel, C. J., B. L. Finlayson & I. C. ONeill, 1996. Distribution and hydraulic significance of large woody debris in a lowland Australian river. Hydrobiologia 318: 179–194.

Gregory, S., K. Boyer, A. Gurnell (eds), 2003. The ecology and management of wood in world rivers. American Fisheries Society, Bethesda, MD, p 431.

Kaiser, L., 1983. Unbiased estimation in line-intercept sampling. Biometrics 39: 965–976.

Keeton, W. S., C. E. Kraft & D. R. Warren, 2007. Mature and old-growth riparian forests: structure, dynamics, and effects on Adirondack stream habitats. Ecological Applications 17: 852–868.

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

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

Latterell, J. J., J. S. Bechtold, T. C. O'Keefe, R. Van Pelt & R. J. Naiman, 2006. Dynamic patch mosaics and channel movement in an unconfined river valley of the Olympic Mountains. Freshwater Biology 51: 523–544.

Meleason, M. A., R. Davies-Colley, A. Wright-Stow, J. Horrox & K. Costley, 2005. Characteristics and geomorphic effect of wood in New Zealand's native forest streams. International Review of Hydrobiology 90: 466–485.

MINITAB® Release 14.20. 2005. Minitab Inc. State College, PA.

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

Nakamura, F. & F. J. Swanson, 1994. Distribution of coarse woody debris in a mountain stream, western cascade range, Oregon. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 24: 2395–2403.

O'Connor, N. A., 1992. Quantification of submerged wood in a lowland Australian stream system. Freshwater Biology 27: 387–395.

Richmond, A. D. & K. D. Fausch, 1995. Characteristics and function of large woody debris in subalpine Rocky Mountain streams in northern Colorado. Canadian Journal of Fisheries and Aquatic Science 52: 1789–1802.

Roni, P. & T. P. Quinn, 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Science 58: 282–292.

Shivers, B. D. & B. E. Borders, 1996. Sampling techniques for forest inventory. John Wiley and Sons, New York, USA. p 356.

Thevenet, A. & B. Statzner, 1999. Linking fluvial fish community to physical habitat in lary wood debris: sampling effort, accuracy and precision. Archives of Hydrobiology 145: 57–77.

Valett, H. M., C. L. Crenshaw & P. F. Wagner, 2002. Stream nutrient uptake, forest succession, and biogeochemical theory. Ecology 83: 2888–2901.

VanWagner, C., 1968. Line intersect method in forest fuel sampling. Forest Science 14: 20–26.

Wallace, J. B. & A. C. Benke, 1984. Quantification of wood habitat in sub-tropical coastal-plain streams. Canadian Journal of Fisheries and Aquatic Sciences 41: 1643–1652.

Warren, W. G. & P. F. Olsen, 1964. A line intersect technique for assessing logging waste. Forest Science 13: 267–276.

Woldendorp, G., R. J. Keenan, S. Barry & R. D. Spencer, 2004. Analysis of sampling methods for coarse woody debris. Forest Ecology and Management 198: 133–148.

Young, M. K., E. A. Mace, E. T. Ziegler & E. K. Sutherland, 2006. Characterizing and contrasting instream and riparian coarse wood in western Montana basins. Forest Ecology and Management 226: 26–40.