Assessment of coarse woody debris following selective logging in Caspian forests: implications for conservation and management

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ABSTRACT: Information on the amount, distribution, and characteristics of coarse woody debris (CWD) in forest ecosystems is highly demanded by wildlife biologists, fire specialists and ecologists. Owing to its important role in wildlife habitats, fuel loading, forest productivity, and carbon sequestration, coarse woody debris is an indicator of forest health. Two sampling methods including fixed-area plot and line intersect sampling were compared for accuracy and efficiency in measuring CWD. Data were selected from mature beech stands following selective logging in Caspian forests. Line intersect sampling consistently provided estimates similar to the results of a 100% survey (high accuracy). This method also took the least amount of time and effort to map the layout and field line location (high efficiency). Finally, line intersect sampling as an easy and fast survey method is suggested to monitor coarse woody debris (CWD) in Caspian forests.

Keywords: line intersect method; fixed-area plot; beech forest

Coarse woody debris (CWD) is widely recognized as an extremely important structural and functional component of forest communities (Harmon et al. 1986; Muller, Liu 1991; McCarthy, Bailey 1994; Ducey et al. 2012). It includes whole fallen trees and branches, and pieces of fragmented wood, stumps, standing dead trees (snags) and logging residues. CWD plays a crucial role in many aspects of ecosystem functioning (Bertz, Dobbertin 1996), both in aquatic and on-land systems while the latter includes habitats for wildlife and fungi, nursery sites for seedling establishment, nutrient cycling, and soil stability (Cobb et al. 2011). Stocks of CWD vary widely between forests, related to variation in forest structure, disturbance history, and environmental factors such as soil fertility. Some researchers proved that CWD masses in pathogen invaded stands are greater than those in pathogen uninvaded stands, which can alter the ecosystem function (Cobb et al. 2011). This study focuses on sampling strategies for forest floor CWD (i.e. stumps and snags are excluded) and it is referred to as CWD throughout this paper. From practitioners trying to realize management goals it is obviously required to obtain efficient and reliable estimation of CWD. Diverse sampling designs have been used until now for quantifying CWD in particular countries (e.g. Brown 1971; Delisle et al. 1988; Stewart, Burrows 1994; Gove et al. 1999; McKenzie et al. 2000); but there have been few systematic analyses of these alternative approaches. The most widely used method for sampling CWD is the line intersect method (Warren, Olsen 1964; Van Wagner 1968) when diameter of CWD is measured at the point of intersection along a transect of a given length but no width. The design options associated with the line intersect method are transect length, transect layout and number of replicates. Regardless of the importance of logs for wildlife survival, little work has been carried out to develop test methods for sample logs from the aspect of meeting wildlife needs. Brown (1974) adapted the line intersect method (LIM) to estimate the volume and weight of logs for management of fuels and prediction of fire behaviour. The line intersect technique based on Brown's sampling method was developed by Van Wagner (1968), who elaborated the technique using matchsticks of equal length and diameter. Hazard and Pickford (1986) further elaborated Van Wagner's line intersect method using computer-simulated log populations. Simulations were drawn from a population of logs that were tapered and variable in length based on data collected from clearcut stands. Hazard and Pickford (1986) found out that sampling needs to achieve the same precision as in Van Wagner's (1968) study that was increased six times when logs of variable length and shape were used. Hazard and Pickford (1986), however, verified that the LIM produced unbiased estimation of coarse woody debris when sampled using random location and orientation of line transects. Because the LIM was developed to estimate important log characteristics for fuel management, namely volume and weight; in fact, all important structural characteristics for log-dependent wildlife are not measured by conventional application of this method. For example, the percent cover of logs that is not measured for purposes of fuel management was positively correlated with the abundance of small vertebrates and their forage base in recent studies (Tallmon, Mills 1994; Carey, Johnson 1995). Log density, large-end diameter and length, none of which are outputs of Brown's line intersect method, were documented as important variables in defining the foraging habitat for the pileated woodpecker (Bull, Holthausen 1993; Torgersen, Bull 1995). The British Columbia Ministry of Forests uses a triangle with 30 m sides for determination of fuel loading prior to a prescribed burn, while an L shape with two 24 m lines is used in their Vegetation Resources Inventory (Marshall et al. 2000). A transect layout recommended in the sampling protocols by McKenzie et al. (2000) for quantifying the carbon amount in Australian ecosystems is a variation on the L arrangement. McKenzie et al. (2000) recommended sampling downed CWD >2.5 cm in diameter using two 10 m transects arranged at right angles to each other, when >10 pieces of CWD occur in a 25 × 25 m plot. Starting from a random point in the plot, the first 10 m transect is laid out in a random direction. If the plot boundary is intersected before the full 10 m, the second transect starts at right angles to the first. This is continued (turning at right angles whenever the plot boundary is intersected) until a total of 10 m in both directions is reached. Smelko and Merganic (2008) quantified deadwood volume in Slovakia in sample plots. The volume of deadwood was calculated by Smalian's method. The stumps from felled or dead trees were recorded if their diameter was 7 cm or more. Hegetschweiler et al. (2009) used the line intersect method to estimate woody debris in northwestern Swiss forests. The results indicated that total woody debris volume reached median values of 0.3 cm^3 per meter transect length in disturbed plots and 1.7 cm^3 per meter in control plots. Merganicova and Merganic (2010) calculated coarse woody debris in spruce virgin forests by establishing 57 permanent circular sample plots. The results revealed that as the elevation increased, CWD decreased. Miehs et al. (2010) compared the efficiency of the line intersect and strip plot methods in order to sample properties of downed coarse woody debris (DCWD) at woodland sites of Victoria, Australia. The results indicated that the line intersect method performs faster and locates individual pieces of DCWD more easily than the strip plot method. Ducey et al. (2012) proposed a modified method which was called distance-limited PDS. The new method is compared with line intersect sampling (LIS) and PDS in a field trial in the northeastern United States. The results of the field trial showed that this new method requires as little as one-tenth of the sampling effort of LIS in order to achieve comparable variance of the estimates.

This study investigated alternative methods for quantifying CWD in Caspian forest conditions for the first time in Iran with a focus on developed methodologies for wildlife research purposes. In this paper, procedures and preliminary results of testing the performance of two sampling methods were described to estimate the volume, density, and projected area (percent cover) of CWD considered valuable for wildlife. Specifically, two approaches were compared: the line intersect sampling method and fixed-area plot method. Each method was compared in terms of precision, bias, and efficiency under a variety of field conditions.

MATERIAL

Sampling was carried out in the Caspian forests, a 107 ha tract of northern hardwood located in Guilan province during the summer season in 2006. Forest composition is a typical Caspian hardwood type of Iran with mature stand dominated by beech (*Fagus orientalis*), alder (*Alnus subcordata*), maple (*Acer velotinum*), hornbeam (*Carpinus betolus*) and elm (*Ulmus glabra*). Three compartments (211, 216, and 217) were used in this study (Table 1). Forests were dominated at all sites by beech (*Fagus orientalis*) characteristic of approximately 90% of Caspian forests. In each study area, lines and plots were selected by systematic random sampling.

METHODS

To evaluate sampling methods against known parameters, within each stand, at first a complete count (census) of all pieces that had a large-end diameter of 10 cm or greater and a length of 1 m at least was conducted. Trees which had fallen and broken were tallied as two pieces if the pieces were not touching; otherwise, each fallen tree was considered one piece. Only pieces whose central axis lay above the ground were tallied (Brown 1974). For a suspended log, only a portion of log that was about 1.8 m of the ground was tallied. A piece was considered down if it lay about 45 degrees of the ground. In the text below, pieces of these dimensions and characteristics are referred to as qualifying pieces. Each piece was painted at both its large and small ends where the diameter measurements were taken using 1 m-long callipers. Diameters were measured to the nearest millimetre. Lengths of pieces were measured to the nearest diameter between the painted diameter marks. For large logs with their root systems still attached, the large-end diameter was measured just above the butt swell, whereas the length was measured along the entire bole from the root wad out to the 2 cm small-end diameter.

After finishing the complete count of pieces, a total of 99 sampling points were located in 3 compartments selected to include a range of conditions frequently encountered by practitioners in regional forests (Table 1). In each stand, a systematic series of sampling points was located for the inventory of CWD. At each sampling point (start point), line intersect sampling (LIS) was performed with a line length of 100 m with random orientation of sample lines and also circular fixed-area sampling (FAS) (with 0.04 ha). The central point of fixed-area plots and the start point in line intersect sampling were common. For FAS and LIS, the slope correction procedure outline was followed according to Stahl et al. (2002). The order of implementation was randomly determined at each sampling point, and the first employed method was timed with a stopwatch. Subsequent methods performed at each sampling point were not timed to avoid a potential underestimation of the time requirement for the method because of foreknowledge of the location and characteristics of pieces of already tallied CWD. All sampling was performed using a three-person crew. All pieces of CWD with a 10 cm large-end diameter were included in the inventory. With FAS, a piece of CWD was tallied and its entire length was measured if the pith of its large end was located within the plot boundaries. For each piece tallied, large and small end diameters were measured using tree callipers and total length using a standard distance tape. Estimations of piece number per hectare (indd·ha^{-1}), volume per hectare (m^3·ha^{-1}), projected area per hectare (m^2·ha^{-1}), and sample standard errors were calculated for each method and stand. Volume of individual pieces, projected area, and number of pieces per hectare were calculated using formulas (1), (2), and (3).

$$Y_i = \frac{\pi^2}{8L} \times \sum_{j=1}^{m_i} \frac{d_{ij}^2}{\cos\lambda_{ij}} \tag{1}$$

where:

Y_i – volume per hectare based on line transect i (m^3·ha^{-1}),

π – consonant amount (3.14),

L – length of line transect (m),

d_{ij} – diameter of CWD piece j crossed by line transect i (m),

λ_{ij} – acute angle from the horizontal of CWD piece j crossed by line transect i (degrees).

$$Y_i = \frac{50\pi}{L} \times \sum_{j=1}^{m_i} \frac{d_{ij}}{\cos\lambda_{ij}} \tag{2}$$

where:

Y_i – projected area per hectare by CWD based on line transect i (m^3·ha^{-1}),

π – consonant amount (3.14),

L – length of line transect (m),

d_{ij} – diameter of CWD piece j crossed by line transect i (m),

λ_{ij} – acute angle from the horizontal of CWD piece j crossed by line transect i (degrees).

Table 1. A description of the compartments used in the study

Compartment	Area (ha)	Plot type	Plot size (ha)	Transect length (m)	No. of samples
211	36				32
216	32	fixed-radius transect	0.04	100	30
217	39				36

$$Y_i = \frac{10{,}000\pi}{2 \times L} \times \sum_{j=1}^{m_i} \frac{1}{(l_{ij} \times \cos\lambda_{ij})} \quad (3)$$

where:

Y_i – number of pieces per hectare based on line transect i (indd·ha^{-1}),

π – consonant amount (3.14),

L – length of line transect (m),

l_{ij} – length of piece j in line transect i,

λ_{ij} – acute angle from the horizontal of CWD piece j crossed by line transect i (degrees).

Testing for bias in the estimations was performed relative to 100% census. Therefore, bias in field implementation with 100% census was assumed to be zero. Usually, testing for bias in the estimates of volume per hectare, number of pieces per hectare, and projected area per hectare would be determined by a parametric paired-sample t-test. Also, standard error for volume per hectare, number of pieces per hectare, and projected area per hectare was calculated for each method and stand. Standard error was calculated as follows:

$$\text{Standard error} = s_x^2 + bias^2 \quad (4)$$

where:

s_x^2 – sampling variance of an estimate,

$bias^2$ – difference between sampling method estimates and 100% census to the second power

$$s_x^2 = \frac{(X_i - X)^2}{(n-1)} \quad (5)$$

where:

X_i – amounts of 100% census and sampling methods,

X – the average amount of 100% census and sampling methods,

n – sample size.

And $bias^2$ was calculated as

$$Bias = X_{100\%} - X_s \quad (6)$$

where:

$X_{100\%}$, X_s – amounts of 100% census and sampling methods, respectively.

Relative efficiency (E) for all methods was calculated as

$$E = \frac{t_1 \times s_x^{2\,2}}{t_2 \times s_x^{2\,2}} \quad (7)$$

where:

t – indicates the mean of required time per sample point for one of the two sampling methods,

s_x^2 – sampling variance of the estimates.

Relative efficiency (E) is the required time to achieve any specified confidence limit width using one method, expressed as a fraction of the time required to achieve the same confidence limit width using the other method. LIS and FAS were compared related to 100% inventory (E = 1). Thus when E > 1, 100% census is more efficient than the method compared with. When E < 1, 100% census is less efficient than the method compared with. Because the times were not obtained for all methods at each sampling point, the mean time requirement for each method was estimated by regressing the time requirement on the number of pieces tallied at each sampling point for all methods in each stand. The resulting linear regression was applied for the mean number of pieces tallied using each method in each stand.

RESULTS AND DISCUSSION

Estimates for the number of pieces per hectare, volume per hectare, and projected area per hectare are given for each method and stand in Tables 2–4. Summarized statistics are given for estimates of each variable and for each method and stand in Tables 2–4. There were some differences between the estimates of LIS and FAS that were found to be statistically significant using the boot strap paired-sample t-test, indicating a potential difference in bias in field implementation of the two sampling methods in some stands. Wherever bias in field implementation relative to the census was measured, it was usually observed in underestimates for each variable, method, and stand. If estimates obtained with LIS are accepted as the true measure of accuracy, this result suggests that bias in field implementation is similar to the result of non-detection errors on the part of the search-based methods.

The mean time requirement as a function of the number of pieces of CWD tallied per sampling location in LIS and FAS method over all stands is shown in Fig. 1. The mean time requirement per plot or line tallied (min) was 22.5 and 59.4 min for LIS and FAS, respectively. This result suggests that the mean time requirement per sampling location is influenced by other factors as well as by the number of pieces of CWD tallied. For LIS, the mean time requirement per sampling location was partially driven by line set-up and sloping topography in some stands, which necessitated the use of slope correction techniques to obtain accurate horizontal line lengths. The mean time requirement per sampling location with FAS was partially driven by time spent to search for can-

Table 2. Estimation of volume and summary statistics for each sampling method and compartment

Compartment	Sampling method	Volume ($m^3 \cdot ha^{-1}$)	Bias	Standard error	*P*-value
	100%	4.94			
211	LIS	5.98	–1.04	1.67	0.19
	FAS	7.11	–4.17	1.87	0.07
	100%	5.15			
216	LIS	6.70	–1.55	1.44	0.13
	FAS	8.99	–3.84	1.65	0.06
	100%	5.49			
217	LIS	6.71	–1.22	1.32	0.35
	FAS	8.13	–2.64	1.47	0.05

Table 3. Estimates of projected area and summary statistics for each sampling method and compartment

Compartment	Sampling method	Projected area ($m^2 \cdot ha^{-1}$)	Bias	Standard error	*P*-value
	100%	164.11			
211	LIS	229.51	–85.40	1.32	0.25
	FAS	322.32	–198.21	1.76	0.12
	100%	198.54			
216	LIS	297.34	–98.80	1.12	0.12
	FAS	401.25	–202.67	1.42	0.02
	100%	234.65			
217	LIS	277.43	–42.78	1.14	0.11
	FAS	201.22	33.43	1.23	0.06

didate pieces of CWD, which appears to increase as the theoretical area of inclusion of CWD pieces increases for a given method. Relative efficiency scores (E) are given for each of the three variables and for each method and stand in Table 5. As expected, E for each sampling method varied based on the variables of interest, size and distribution of CWD pieces and stand conditions. In general, a method was most efficient for sampling CWD where the variable of interest and the probability of selection an individual piece of CWD into the sample were coincident (Schreuder et al. 1993).

LIS was found to be an efficient method in the present study (Marshall et al. 2000; Hegetschweiler et al. 2009; Miehs et al. 2010) for estimating the total volume, total number of pieces and also projected area per hectare of coarse woody debris. The results indicate that LIS provides rela-

Table 4. Estimates and summary statistics for each sampling method and compartment

Compartment	Sampling method	Number of pieces ($indd \cdot ha^{-1}$)	Bias	Standard error	*P*-value
	100%	299.47			
211	LIS	330.76	–31.29	1.16	0.14
	FAS	400.12	–100.65	1.53	0.03
	100%	331.23			
216	LIS	398.43	–67.20	1.21	0.15
	FAS	330.66	–99.43	1.11	0.19
	100%	362.43			
217	LIS	412.25	–49.82	1.06	0.14
	FAS	622.67	–260.24	1.59	0.01

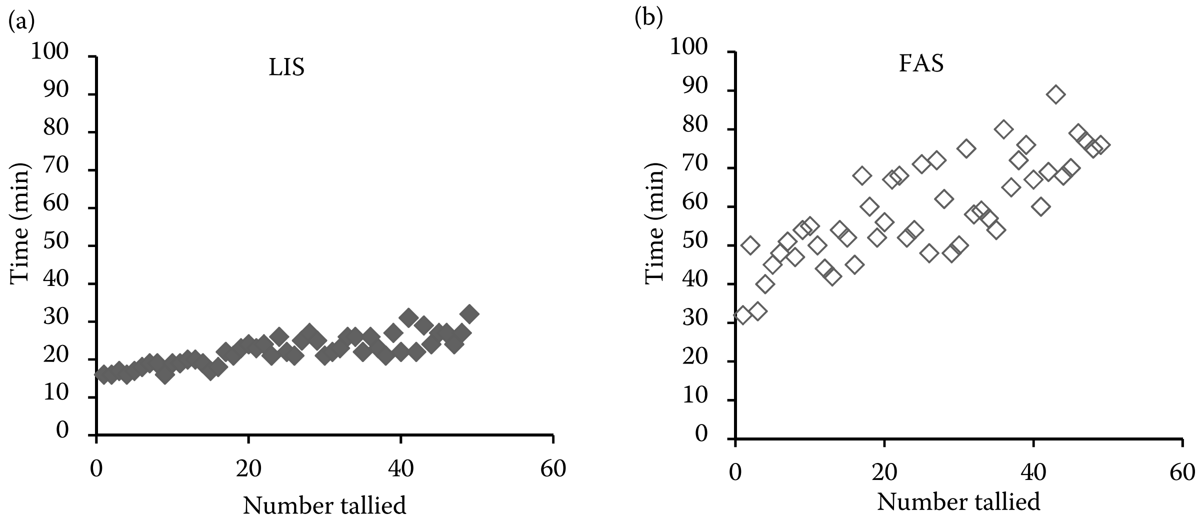

Fig. 1. Time requirement per sampling location: (a) LIS method (line intersect sampling), (b) FAS method (fixed-area sampling) compared in the field trial. The time shown does not include the travel time between sampling locations

tively unbiased and precise estimators of characteristics of most pieces in the conditions of testing (Marshall et al. 2000). However, an efficient method for estimating CWD may be different or similar in other forest areas; for example Ducey et al. (2012) applied distance-limited PDS. This new method is compared with line intersect sampling (LIS) and PDS in a field trial in the northeastern United States. The results of the field trial showed that this new method requires as little as one tenth of the sampling effort of LIS in order to achieve comparable variance of the estimates. In contrast, Hegetschweiler et al. (2009) used the line intersect method to estimate woody debris in northwestern Swiss forests as an efficient method.

Table 5. Relative efficiency score (E) for each sampling method and compartment

Variable per hectare	Compartment	Sampling method	
		LIS	FAS
Volume	211	0.86	1.54
	216	0.34	1.76
	217	0.32	2.37
Number of pieces	211	0.94	1.71
	216	0.23	1.01
	217	0.71	2.55
Projected area	211	1.08	0.86
	216	1.45	0.82
	217	2.05	0.41

E – 1.00 for 100% survey

In the estimation of density of pieces, LIS appeared to be more precise than FAS. In addition, compared to FAS, LIS was clearly more efficient in estimating the number of pieces, projected area (percent cover) or volume of pieces. Further analysis of the data will clarify merits of each method under a variety of conditions. The results also demonstrated that research and management of wildlife essentially involve different methods of sampling. Regardless of the relative sampling efficiency, LIS may be a preferred method in stands judged to have heavy amounts of CWD owing to a tendency to minimize non-detection errors. The relative sampling efficiency for each method was based on the measuring of each piece tallied for cubic volume. Measurements of large-end diameter, small-end diameter, and total length were done for each piece to be used in Smalian's method for cubic volume. The sampling efficiency and bias of each method were determined relative to 100% survey. Although this comparison is very meaningful for sampling efficiency, the comparison of bias in field implementation is subject to a number of limitations. Determination of the potential for bias in field implementation of these sampling methods could be established more firmly through field trials or controlled experiments where estimates obtained by each method can be directly compared to a true measure of accuracy.

CONCLUSIONS

It has been found that the bias estimates in all compartments with LIS were consistently lower than from FAS method. This suggests that LIS is suitable for use in Caspian forests. In order to preserve the ecological integrity of Caspian forests and for better planning and management in the region, the line intersect sampling method is suggested to estimate woody debris. The focus of this study has been on the examination of accuracy of the line intersect method for quantifying CWD as line intersect sampling strategies are as diverse as the forests in which the methods are implemented. The estimations with a desired level of accuracy can be achieved in most forest conditions, providing transect length, number of replicates and arrangement of transects that are appropriate for the forest condition. The line intersect method is efficient and gives a high degree of precision for less effort compared to FAS for CWD. The method is flexible, which enables the estimates by diameter and decay class and transect length can be varied for each diameter class. The importance of CWD as a substrate for tree establishment is widely recognized. It is also indicated that the spatial distribution, frequency and size of CWD pieces had a significant influence on the precision of estimation using the line intersect method. Orientation bias of CWD was negligible; therefore, the transect layout had a small effect on the CV. Transect length must be sufficiently long to account for these factors; this length should be 100 m or greater in conditions of Caspian forests stands. Single line transects (with an appropriate number of replicates across the forest) can estimate at an acceptable level of accuracy provided by the transect length spans and the spatial heterogeneity in CWD. Sampling approaches for CWD need to be effectively integrated with methods for assessment of other forest biomass pools such as life in overstorey and understorey biomass, leaf litter, and soil or other structural values.

Acknowledgments

The authors thank the governmental company of Shafaroud for their cooperation in this study.

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Received for publication November 17, 2012
Accepted after corrections February 22, 2013

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