Research Article

Turk J Agric For
36 (2012) 389-398
© TÜBİTAK
doi:10.3906/tar-1103-45

Two-stage sampling to estimate individual tree biomass

Ramazan ÖZÇELİK[1,*], Tuncay ERASLAN[2]

[1]Faculty of Forestry, Süleyman Demirel University, East Campus, 32260 Isparta - TURKEY

[2]Forest Engineering, Eğirdir Forest Enterprise, Isparta Regional Forest District - TURKEY

Received: 17.03.2011

Abstract: The accurate estimation of tree biomass is crucial for the efficient management of forest resources. In this study, we used a subsampling method for unbiased estimates of above-ground tree biomass. The method consists of 2 stages: the first stage consists of randomized branch sampling (RBS) and the second stage uses importance sampling (IS). RBS is used to select a path from the butt of an object branch to a terminal segment. IS is used for selecting a disk that produces unbiased estimates of the fresh biomass of tree. In this study, the subsampling method was tested on 14 black pine sample trees (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) in order to estimate the trees' biomass quickly and easily. The results showed a wide range of sampling error per tree, ranging from 2.51% to 22.63%. However, the sampling error for the total biomass of the 14 trees tested was only 2.65%. The proposed 2-stage sampling method generally performed better for the bole biomass than the branch biomass. These results indicated that the proposed 2-stage sampling method is effective and might overcome many of the identified constraints in biomass estimation. It is a viable alternative to the current methods used in Turkey.

Key words: Biomass, black pine, importance sampling, randomized branch sampling, subsampling

Ağaç biyokütlesini tahmin için iki aşamalı örnekleme

Özet: Ağaç biyokütlesinin gerçeğe yakın olarak tahmini, orman kaynaklarının etkin yönetimi için büyük önem taşımaktadır. Bu çalışmada; bir ağacın toprak üstü biyokütle miktarının tarafsız olarak tahmini için bir alt örnekleme yöntemi kullanılmıştır. Yöntem, tesadüfî dal örneklemesi (RBS) ve önem örneklemesi (IS) olmak üzere 2 aşamadan oluşmuştur. RBS, dipten uç tomurcuğa kadar uzanan bir yol seçimi yardımıyla dal biyokütlesinin tahmini için; IS ise ağaç gövdesinin yaş ağırlığının tahmini amacıyla gövde kesiti seçimi için kullanılmaktadır. Bu çalışmada önerilen yöntem, toplam ağaç biyokütlesinin hızlı ve gerçeğe daha yakın tahmin edilmesi amacıyla 14 karaçam (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe) örnek ağacı üzerinde test edilmiştir. Sonuçlar; örnekleme hatasının % 2.51 ile % 22.63 arasında geniş bir aralıkta değiştiğini göstermiştir. Bununla birlikte 14 ağacın toplam biyokütle tahmininin örnekleme hatası ise yalnızca % 2.65 bulunmuştur. Önerilen 2 aşamalı örnekleme metodu, özellikle ağaç gövdesinin biyokütle miktarının tahmininde, dal biyokütlesinin tahminine göre daha başarılı olmuştur. Sonuç olarak; önerilen 2 aşamalı örnekleme metodu, Türkiye'de halen kullanılmakta olan biyokütle tahmin yöntemlerine bir alternatif olarak değerlendirilebilir.

Anahtar sözcükler: Alt örnekleme, biyokütle, karaçam, önem örneklemesi, tesadüfî dal örneklemesi

* E-mail: ramazanozcelik@sdu.edu.tr

Introduction

Forest ecosystems play a very important role in the global carbon cycle, storing about 80% of all above-ground and 40% of all below-ground terrestrial organic carbon (IPCC 2001). During the productive season, CO_2 from the atmosphere is taken up by vegetation and stored as plant biomass (Losi et al. 2003). For this reason, the United Nations Framework Convention on Climate Change and its Kyoto Protocol recognized the role of forests in carbon sequestration and storage (Brown 2002).

There is considerable interest today in estimating the biomass of forests for both practical forestry issues and scientific purposes. Forest biomass is important for commercial uses and national development planning, as well as for scientific studies of ecosystem productivity and energy and nutrient flows, and for assessing the contribution of changes in forestlands to the global carbon cycle (Parresol 1999). Trees are important components of forest ecosystems, and the quantification of various aspects of trees is necessary for an adequate description and understanding of such systems. Thus, during the past 5 decades, sampling strategies have been designed to estimate an individual tree's above-ground woody biomass as well as other characteristics such as mineral content and foliage biomass. These sampling strategies are quite distinct from the more common method of relating a particular characteristic of a tree to combinations of easily measured size characteristics by means of regression models. There are a number of probability sampling strategies, particularly applicable to tree characteristics, that have been used only scantly in ecological field studies (Gregoire and Valentine 1996). Generally, 2 kinds of methods are available for measuring sample tree biomass: nondestructive and destructive. A nondestructive method is when the biomass of a tree is estimated without felling the tree itself (Montes et al. 2000). This method is mainly applied when the species of interest are rare or protected and cannot be destructively sampled to determine the allometric relationship (Brown 1997; Montes et al. 2000). The destructive method is done by felling the sample tree and then weighing it. Direct weighing can only be done for small trees; for larger trees, sectioning is necessary in order to use the weighing scales. In other cases, subsamples are collected and used to estimate the tree's fresh weight, dry weight, and volume (Montes et al. 2000).

The most common method for estimating tree biomass is through the use of regression analysis. Equations are developed by weighing entire trees or their components and relating weight to easily measured tree dimensions such as the diameter at breast height (dbh) and height. Biomass equations have been developed in Turkey for some coniferous and hardwood trees such as Scotch pine (Uğurlu et al. 1976; Tolunay 2009), Brutian pine (Sun et al. 1980; Ünsal 2007; Durkaya et al. 2009), Oriental spruce (Özkaya 2004), black pine (Çakıl 2008), Oriental beech (Saraçoğlu 1998), common alder (Saraçoğlu 2000), oak (Durkaya 1998), and chestnut (İkinci 2000). However, as Tolunay observed previously (2011), all of these studies in Turkey have been conducted on a local or regional basis.

A sampling procedure was developed by Valentine et al. (1984) for estimating the above-ground biomass of trees. Although destructive, this method is found to be cost-effective and it overcomes many of the constraints identified in biomass measurements (De Gier 1989, 2003). This method employs randomized branch sampling (RBS) (Jessen 1955; Valentine and Hilton 1977) and the importance sampling (IS) technique of Monte Carlo integration (Rubinstein 1981) based on probabilities proportional to size (Williams 1989). RBS can be used alone or can be combined with importance sampling (IS) in a way that permits researchers to estimate the above-ground woody components of a tree from measurements taken on a single disk (Valentine et al. 1984). This method should prove useful in any forest sampling in which estimates of the biomass components are needed for individual trees. This procedure permits larger first-stage samples, thereby increasing the precision of the inventory (Gregoire and Valentine 1996). RBS was developed originally by Jessen (1955) to estimate fruit counts on individual orchard trees, although this technique can be used to obtain estimates of many different attributes of orchard, forest, and shade trees and other branched plants. RBS could also be applied to other branched structures such as corals and river systems. Researchers have used RBS to estimate fruit production (Jessen 1955); insect densities (Furness 1976); foliage area, mass, and leaf count (Valentine and Hilton 1977); tree weight (Valentine et al. 1984; Williams 1989); total foliar area (Gregoire and Valentine 1996; Hietz et al. 2009); stem length and surface area (Gregoire and Valentine 1996); needle mass (Gaffrey and Sabarowski 1999; Raulier et al. 2002); tree biomass (De Gier 1989, 2003; Good et al. 2001; Mabowe 2006; Deo 2008); coarse woody debris (Gove et al. 2002); floral distribution (Chen et al. 2003); and insect populations in entire tree crowns (Evans and Gregoire 2006).

The primary objective of this study was to predict the green weight outside bark for black pine (*Pinus nigra* Arnold subsp. *pallasiana* (Lamb) Holmboe) trees in Turkey using RBS and IS for tree biomass estimation.

Materials and methods

Data were collected for black pines from Eğirdir Forest Enterprises in Turkey, on lands owned by the Forest Service. Sample trees were selected from both the dominant and codominant crown class in even-aged stands. Trees possessing multiple stems, broken tops, obvious cankers, or crooked boles were not included in the sample. Each tree was cut from a 0.30-m stump and total height was measured to the nearest 0.05 m. The diameter outside bark (dob) at breast height (1.3 m) was measured and recorded to the nearest 0.2 cm. After each tree was felled, the randomized branch and importance sampling methods were employed with 1 or 2 sampling paths determined for each tree. The actual fresh weights of the tree components (bole, living and dead branches, and barks) were weighed to the nearest 0.1 kg on platform scales while in the field. Summary statistics for the data sets are shown in Table 1.

Randomized branch sampling (RBS)

RBS is used to select a path from the butt of a felled sample tree to a terminal bud. The path is a series of connected branch segments or internodes (Valentine et al. 1984). "Branch" is defined as the entire stem system that develops from a single bud, whereas a branch segment, or segment, is a part of a branch between 2 consecutive nodes (Gregoire et al. 1995). This method does not distinguish between a stem and a branch. At every node of branching, a decision has to be made about the continuation of the path.

The first segment of the path extends from the butt of the object branch, which is defined as the first node, to the second node (the first whorl of the live branch). By convention, the first segment of the path has a selection probability of $q_1 = 1$. To determine a path, a selection probability is assigned to each branch emanating from the second node and one is chosen at random. The choice of this branch, with selection probability q_2, fixes the second segment of the path (Valentine et al. 1984; Gregoire and Valentine 1996). The second segment of the path to a node is followed and a branch is selected by RBS with the probability q_3 and so on, until a terminal shoot is reached with probability q_R (Gregoire et al. 1995). The selection probabilities assigned to various branches emanating from each node must add up to 1. This continuation

Table 1. Summary statistics for sample trees.

Tree number	Diameter (cm)	Tree height (m)	Tree number	Diameter (cm)	Tree height (m)
1	26	15.70	8	34	12.00
2	22	11.60	9	34	12.00
3	30	12.90	10	38	16.70
4	42	17.30	11	46	15.50
5	42	15.10	12	58	17.80
6	42	14.95	13	50	15.00
7	34	14.50	14	54	15.80

is selected with probability proportional to size (PPS). Different probabilities may be assigned for different purposes. When the objective is to estimate the woody biomass, wood volume, or total biomass of the tree, as suggested by Valentine et al. (1984), this is determined as the product of the squared diameter and length; this quantity is related to the volumes and weights of the branches.

A random number between 0 and 1 was used to determine which branch emanating from the node would be selected. The first branch to be considered at each node was the main stem. The remaining branches were considered in a clockwise direction around the node, beginning with the branch protruding from the node on the left side of the main stem, facing the top of the tree. If the selection probability of the main stem was greater than that of a random number, the path continued along the main stem; it was terminated when a main-stem diameter of 5 cm was reached (Williams 1989). If the selection probability of the main stem was less than the random number, the selection probability of the second branch at the node was added to the first. If this sum was greater than the random number, then the second branch was selected for sampling. If the sum of the selection probabilities of the first 2 branches was not greater than the random number, the selection probability of the third branch was added, and so on, until a branch was selected at a node. If one of the whorl branches at a node was selected, the path was terminated with the selection of the branch. This branch was flagged and labeled when selected, and the process of determining a second path began (Williams 1989).

The selection probability assigned to a branch is the conditional probability of selecting that branch given that the path has reached the node at which the branch arises. The unconditional probability of selection for the kth segment included in the path is:

$$Q_k = \prod_{r=1}^{k} q_r \tag{1}$$

where q_r is the selection probability of the selected branch at the r^{th} node whose path has a total of k segments. An inflated branch weight was determined for each path by dividing the actual weight of the branch selected from that path by Q_k. This inflated branch weight is an estimate of the weight of the tree from the node at which the branch is attached to the top of tree (Gregoire et al. 1995).

The biomass of all of the above-ground components of a tree can be estimated from a single path. However, at least 2 paths are needed to estimate within-tree standard errors. Therefore, the estimated fresh weight of a tree can be calculated as follows:

$$\widehat{b} = \sum_{k=1}^{n} \mathrm{b}_k / \mathrm{Q}_k \tag{2}$$

where Q_k is the unconditional selection probability for the k^{th} segment of the path and b_k is the weight of the k^{th} segment.

After the path selection was completed, branches not at a whorl (epicormic) that occurred in the path were removed and weighted. The inflated weight of the epicormic branches was determined by dividing the actual weight by the Q_k of the path segment in which they occurred. Dead branches were not considered in path selection and were removed and weighted separately.

Importance sampling (IS)

Importance sampling is based on a technique of Monte Carlo integration, which is a continuous analog of sampling with PPS. The method uses IS, leading to the removal of only one randomly located disk for the purpose of estimating the weight of the tree up to the node where the sample branch was severed.

IS begins by measuring the diameter of the tree at numerous points along the path from the butt to the location of the severed sample branch. Along the path, points are located where a change of taper occurs. The diameter is measured at each of these points and the distance to the butt is recorded. From the latter, the distance between any 2 successive points can be calculated. The inflated cross-sectional area of the stem at each measured diameter and the inflated woody volume of the path were calculated using Eqs. (3) and (4), respectively (Valentine et al. 1984; Gregoire et al. 1996; Parresol 1999).

$$A(L_s) = D(L_s)^2 / Q_k \tag{3}$$

$$V(\lambda) = \int_0^{\lambda} S(L)\,dL \quad (4)$$

A point, θ, for cutting a disk is randomly selected with probability proportional to $S(L)$. The point is chosen that satisfies $V(\theta) = u^*V(\lambda)$, where u is a random number from a uniform (0,1) distribution. Next, the fresh weight per unit thickness (Valentine et al. (1984) used 10-cm-thick disks) of the disk cut at $L = \theta$ must be determined as $B(\theta)$. The inflated weight per unit thickness of the disk is:

$$B^*(\theta) = B(\theta) / Q_k, \quad (5)$$

where k is the index of the path segment in which θ occurs. Finally, the unbiased estimate of the true woody fresh weight of the tree is computed as follows:

$$\widehat{w} = B^*(\theta) * V(\lambda)/S(\theta) \quad (6)$$

The estimated total weight of the tree, $\hat{b}$, is $\hat{w}$ plus the inflated weight of the terminal branch and inflated weights of all small shoots and foliage attached to the path (Gregoire and Valentine 2007). Thus:

$$\widehat{b} = \widehat{w} + b_j/Q_j + \sum_{k=1}^{j=1} e_k/Q_k \quad (7)$$

where b_j is the weight of the terminal branch and e_k is the weight of the small shoots and foliage attached to the kth segment of the path (Valentine et al. 1984).

For further details on and examples of RBS and IS, see the literature published by Valentine et al. (1984), Gregoire et al. (1995), and Gregoire and Valentine (2007).

Results

A numerical example and step-by-step description of this procedure follows for the tree diagrammed in Figure 1. Selection probabilities proportional to the product of the diameter squared and the branch length were used in this study. The diameters and lengths of the branches and their selection probabilities are listed in Table 2. All calculations summarized in Table 2 indicate that branch ***b*** was selected with the probability $q_3 = 0.60$. At this point, the path was terminated and branch ***b*** was cut off and weighed. The fresh weight was 27 kg and the unconditional probability of reaching branch ***b*** was calculated from Eq. (1) as $Q_3 = 1.0 \times 0.77 \times 0.60 = 0.462$. The inflated weight was 58.44 kg. After the path selection was completed, all of the epicormic branches on the path were removed and weighed. In this tree, there were no epicormic shoots or dead branches on the path.

IS begins with the measurement of diameter at numerous points along the path from the butt to the cut tip, as shown in Figure 2. The diameter is measured at each of these points and the distance to the butt is recorded. From the latter, the distance between any 2 successive points can be calculated. Measurements are taken close together where butt swell or rapid taper occur. The data for sample tree 7 are presented in Table 3, along with the calculated values of $A(L)$ from Eq. (3) and $\Delta V(L)$ and V(L) from related equations (Valentine et al. 1984).

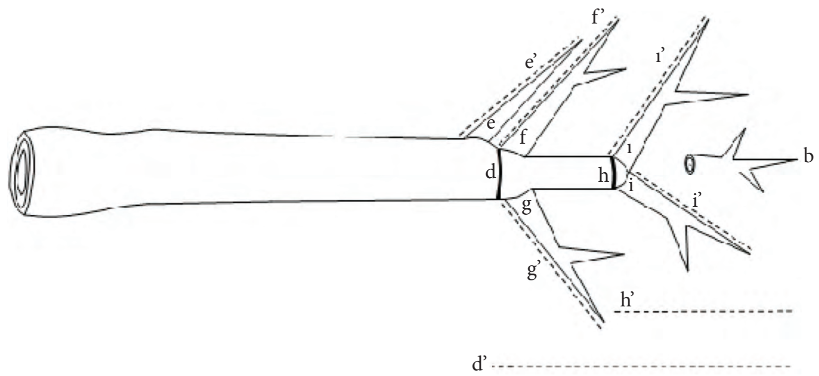

Figure 1. Identification of tree branches for selecting a path according to RBS.

Table 2. Data from randomized branch sampling.

k	Branch	Diameter (D, cm)	Height (L, m)	D^2L	$\sum D^2L$	Selection probability	u	Selection branch	q_k	Q_k
1	bole					1.00		bole	1.00	1.000
2	**d**	0.15	5.30	0.119		0.77	0.41	d	0.77	0.770
	e	0.06	3.55	0.013		0.08				
	f	0.07	3.25	0.016		0.10				
	g	0.06	2.15	0.008	0.156	0.05				
3	**h**	0.09	3.40	0.028		0.60	**0.14**	h	**0.60**	0.462
	ı	0.06	2.55	0.009		0.20				
	i	0.06	2.60	0.009		0.20				

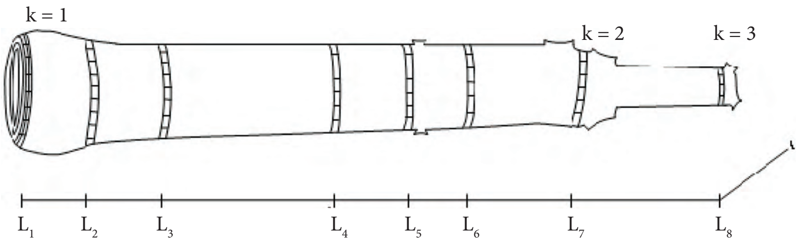

Figure 2. Locations of diameter measurements for IS of the path

Table 3. Data from the importance sampling of the path.

	(L)	*D(L)*	*k*	Q_k	*A(L)*	*ΔV(L)*	*V(L)*
L1	0	0.39	1	1	0.152	0	0
L2	0.80	0.37	1	1	0.137	0.1156	0.1156
L3	1.50	0.32	1	1	0.102	0.0838	0.1994
L4	3.30	0.28	1	1	0.078	0.1627	0.3621
L5	5.80	0.25	1	1	0.063	0.1761	0.5382
L6	7.40	0.22	1	1	0.048	0.0887	0.6269
L7	8.00	0.20	1	1	0.040	0.0265	0.6534
L8	9.20	0.15	2	0.77	0.029	0.0415	0.6950
λ	11.10	0.09	3	0.462	0.018	0.0444	**0.7400**

The location of the sample disk was determined by the equations of Valentine et al. (1984), and a disk 15 cm in length was cut and weighted. The weight of the disk was 16.3 kg and its inflated weight was 108.67 kg m^{-1}.

Eq. (6) was used to estimate the woody weight of the tree from the butt up to the point where branch was severed:

$$\hat{w} = 108.67\ kg / m * 0.74\ m^3 / 0.1342\ m^2 = 598.63\ kg.$$

The estimated total fresh weight of the tree from each path was determined by summing the inflated branch weight, the estimated weight of the tree up to the sample branch, the inflated epicormic branch weight, and the dead wood weight.

$$\hat{b} = 598.63 + 58.44 = 657.07\ kg$$

After the completion of all sampling and weighing, the remaining portions of the tree were cut into manageable lengths and weighed. This weight was added to the recorded weights of the sample branches and disks to attain the actual total fresh tree weight. The total fresh tree weight of this sample tree was 641 kg. The above-ground biomass is given separately in Table 4 for branches and bole using a combination of RBS with IS. The results for the estimation of the total fresh above-ground biomass for the 14 black pine trees are given in Table 5 using a combination of RBS and IS. Sampling errors were found to range from 2.51% to 22.63% of the actual fresh weight.

Discussion

A statistical evaluation of our results is provided in Table 5. These results show a wide range of sampling error per tree, ranging from 2.51% to 22.63%, although the sampling error of the total biomass of all of the tested trees was only 2.65%. When above-ground biomass is estimated from only a single path, the sampling error per tree ranges from 2.51% to 9.33%. Valentine et al. (1984) tested their sampling procedure on 8 hardwood trees of 6 species for an estimation of the total fresh above-ground biomass and produced sampling errors ranging from 4.9% to 14.4% of the actual fresh weights of the individual trees and 4.9% for the total sample. Later, Williams (1989) tested RBS and IS to estimate the softwood biomass of 5 Loblolly pine trees in order to estimate the total fresh above-ground biomass. Williams' (1989) study also showed a wide range of sampling error per tree, ranging from 5.3% to 28.9%. However, the sampling error for the total biomass of the 5 trees tested was only 3.3%. Our results are smaller than the sampling errors found in results of similar studies

Table 4. Above-ground biomass for branches and bole using a combination of RBS and IS.

Tree number	Dead branches and epicormic shoots (kg)	Branch biomass (kg)	Bole (woody) biomass (kg)	Total* (kg)
1	40	135.13	457.42	632.55
2	9	53.76	225.89	288.65
3	0	122.70	401.45	524.15
4	14	227.56	1044.96	1286.52
5	51	345.63	1045.32	1441.95
6	0	300.86	1133.43	1434.29
7	0	58.44	598.63	657.07
8	13	86.43	486.95	568.37
9	0	64.20	539.95	604.16
10	0	147.48	983.26	1130.73
11	40	398.71	1286.68	1725.39
12	0	841.79	2141.50	2983.28
13	147	175.81	1261.79	1584.60
14	170	231.62	1903.56	2305.18
Total	484	31 93.98	13 510.79	17 168.5

*Estimated fresh weight from path estimations.

Table 5. Test results for the 14 trees.

Dbh (cm)	Number of paths	Actual fresh weight (kg)	Estimated fresh weight (kg)[a]	Root mean square error (RMSE)	Percent error[b]
26	1	610	632.55	22.55	3.69
22	2	292	288.65	66.08	22.63
30	1	571	524.15	46.85	8.20
42	2	1422	1286.52	266.90	18.77
42	1	1340	1441.95	101.95	7.61
42	2	1310	1434.29	164.66	12.57
34	1	641	657.07	16.07	2.51
34	2	622	568.37	77.54	12.47
34	2	572	604.16	122.30	21.38
38	2	1223	1130.73	145.89	11.93
46	1	1903	1725.39	177.61	9.33
58	2	3085	2983.28	223.49	7.24
50	2	1749	1584.60	164.59	14.11
54	2	2588	2305.18	494.07	19.09
Total		17 928.0	17 168.5	475.09	2.65

[a]Estimated fresh weight from path estimations.
[b]Percentage of error calculated as 100% rmse / actual fresh weight.

in the United States for total biomass. This sampling procedure therefore appears to be reliable and efficient for obtaining precise estimates of the total fresh weight of black pine trees in the Mediterranean region of Turkey.

As suggested for the estimation of woody biomass, woody volume, or total biomass of the tree by Valentine et al. (1984), we used selection probabilities proportional to the product of the diameter squared and length. This quantity should be related to the volumes and weights of the branches. Generally, the selection probability assigned to each branch should ideally equal the fraction of the total fresh weight beyond the node and contained in the branch (Gregoire and Valentine 2007). However, if the selection probabilities do not accurately reflect the component of branch biomass as compared to the woody biomass of the tree, the use of this procedure may produce large within-tree errors in biomass estimates for softwoods.

In this study, the proposed 2-stage sampling method generally performed better for the woody biomass than the branch biomass, and the combination of RBS and IS was useful in consistently obtaining close predictions of the woody biomass. Our results obtained using a combination of RBS and IS are fairly similar to the actual woody biomass and are in accordance with the results of Good et al. (2001). Branch biomass produced the greatest sampling error per tree. Selection probabilities may not adequately reflect the proper fraction of the biomass contained in the branch. RBS produced more overestimates than the actual fresh branch biomass, while the combination of RBS and IS generally underestimated the biomass of the tree. The application of RBS with IS was fairly variable in the estimation of the weight of branches.

The combination of RBS and IS for estimating tree biomass is quick and reduces the laborious work required to weigh whole trees or tree components

(Gregoire et al. 1995). As Williams (1989) reported, however, the use of this procedure may produce large within-tree errors in the biomass estimates for some intolerant softwood if the selection probabilities do not accurately reflect the fraction of the biomass contained in the branch as compared to the remainder of tree. There are 3 ways to avoid large sampling errors. First, small epicormic branches or spurs should be ignored during the path selection. The RBS should be confined to those branches that constitute the main architecture of the tree. The ignored shoots or small branches are ultimately treated as part of the segments to which they are attached. Second, the stratification of a tree into subpopulations of relatively homogeneous units is perhaps the foremost means of reducing the variance of estimation (Gregoire et al. 1995). For this purpose, each tree crown may be stratified into 2 or 3 equal-length sections, and the method may be conducted separately in each stratum. As reported by Gregoire and Valentine (1996), one advantage of stratification is that the sampling effort could be allocated between strata in a way that optimally utilizes within-stratum variability and cost of sampling. Finally, this problem may be overcome by selecting more paths and perhaps more disks per path within each tree. However, this tends to defeat the objective of this procedure to reduce time and effort in the collection of biomass data (Williams 1989). Both practical and acceptable statistical considerations should be taken into account when choosing a tree biomass estimation method for operational applications. Thus, the usefulness and reliability of this method will depend upon the purposes of the sampling.

As recommended by Gregoire and Valentine (2007), the selection of a path is best performed by 2 people, the first to man the field computer and the second to measure the branches and mark the path. We used 2 people in the field to conduct RBS and IS research, and 1 sample tree took approximately 30 min. The calculations required for RBS and IS can be easily and quickly handled in the field by a programmable pocket calculator.

Acknowledgments

We thank Dr Harry V. Wiant Jr and Dr Yılmaz Balcı for their valuable comments on the earlier drafts of the manuscript and for revising the English grammar of the text.

References

Brown S (1997) Estimating Biomass and Biomass Change of Tropical Forests: A Primer. FAO Forestry Paper 134. FAO, Rome.

Brown S (2002) Measuring carbon in forests: current status and future challenges. Environmental Pollution 116: 363-372.

Chen B, Da LJ, Song YC (2003) Flowering phenology and floral distribution of *Castanopsis fargesii* in Tiantong, Zhejiang Province. Zhiwu Shengtai Xuebao 27: 249-255.

Çakıl E (2008) Zonguldak Orman Bölge Müdürlüğü Karaçam Biyokütle Tablolarının Düzenlenmesi. Yüksek Lisans Tezi. Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, p. 167.

De Gier A (1989) Woody Biomass for Fuel: Estimating the Supply in Natural Woodlands and Shrublands. Albert Ludwigs University, Freiburg, Germany.

De Gier A (2003) A new approach to woody biomass assessment in woodlands and shrublands. In: Geoinformatics for Tropical Ecosystems (Ed. P Roy). Bishen Singh Mahendra Pal Singh, India, pp. 161-198.

Deo RK (2008) Modeling and Mapping of Above-Ground Biomass and Carbon Sequestration in the Cool Temperate Forest of North-East China. MS Thesis, International Institute for Geo-Information Science and Earth Observation, Enschede, Netherlands, p. 78.

Durkaya A, Durkaya B, Ünsal A (2009) Predicting the above-ground biomass of calabrian pine (*Pinus brutia* Ten.) stands in Turkey. Afr J Biotechnol 8: 2483-2488.

Durkaya B (1998) Zonguldak Orman Bölge Müdürlüğü Meşe Meşcerelerinin Biyokütle Tablolarının Düzenlenmesi. Yüksek Lisans Tezi. Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, p. 110.

Evans AM, Gregoire TG (2006) The tree crown distribution of hemlock woolly adelgid, *Adelges tsugae* (Hem., Adelgidae) from randomized branch sampling. J Appl Entomol 131: 26-33.

Furness GO (1976) The dispersal age structure and natural enemies of the long-tailed mealybug (*Pseudococcus longispinus*) in relation to sampling and control. Aust J Zool 24: 237-247.

Gaffrey D, Sabarowski J (1999) RBS, a multistage inventory method for estimating tree characteristics. I. Estimating needle and branch dry mass of 66-year-old Douglas fir trees. Allgemeine Forst und Jagdzeitung 170: 177-183.

Good NM, Paterson M, Brack C, Mengersen K (2001) Estimating tree component biomass using variable probability sampling methods. J Agric Biol Environ Stat 6: 258-267.

Gove JH, Ducey MJ, Valentine HT, Dibble AC (2002) Multistage point relascope and randomized branch sampling downed coarse woody debris estimation. For Ecol Manage 155: 153-162.

Gregoire TG, Valentine HT (1996) Sampling methods to estimate stem length and surface area of tropical tree species. For Ecol Manage 83: 229-235.

Gregoire TG, Valentine HT (2007) Sampling Strategies for Natural Resources and the Environment. Chapman & Hall/CRC Applied Environmental Statistics, New York.

Gregoire TG, Valentine HT, Furnival GM (1995) Sampling methods to estimate foliage and other characteristics of individual trees. Ecology 76: 1181-1194.

Hietz P, Eckmüllner O, Sterba H (2009) Leaf area of beech (*Fagus sylvatica* L.) from different stands in eastern Austria studied by randomized branch sampling. Eur J For Res 129: 401-408.

Intergovernmental Panel on Climate Change (IPCC) (2001) Climate Change 2001: Working Group 1: The Scientific Basis. Cambridge University Press, New York.

İkinci O (2000) Zonguldak Orman Bölge Müdürlüğü Kestane Meşcerelerinin Biyokütle Tablolarının Düzenlenmesi. Yüksek Lisans Tezi. Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, p. 86.

Jessen RJ (1955) Determining the fruit count on a tree by randomized branch sampling. Biometrics 11: 99-109.

Losi CJ, Siccama TG, Condit R, Morales JE (2003) Analysis of alternative methods for estimating carbon stock in young tropical plantations. For Ecol Manage 184: 355-368.

Mabowe BR (2006) Aboveground Woody Biomass Assessment in Serowe Woodlands, Botswana. MS Thesis. International Institute for Geo-Information Science and Earth Observation, Enschede, Netherlands, p. 82.

Montes N, Gauquelin T, Badri W, Bertaudiere V, Zaoui EH (2000) A non-destructive method for estimating above-ground forest biomass in threatened woodlands. For Ecol Manage 130: 37-46.

Özkaya S (2004) Artvin-Genya Dağı Yötesi Doğu Ladini (*Picea orientalis* (L.) Link.) Ormanlarında Toprak Üstü Biyokütlennin Belirlenmesi. Yüksek Lisans Tezi. Kafkas Üniversitesi, Fen Bilimleri Enstitüsü, p. 62.

Parresol BR (1999) Assessing tree and stand biomass: a review with examples and critical comparisons. For Sci 45: 573-593.

Raulier F, Bernier PY, Ung CH, Boutin R (2002) Structural differences and functional similarities between two sugar maple (*Acer saccharum* Marsh) stands. Tree Physiol 22: 1147-1156.

Rubinstein RY (1981) Simulation and the Monte Carlo Method. Wiley, New York.

Saraçoğlu N (1998) Kayın (*Fagus orientalis* Lipsky) biyokütle tabloları. Turk J Agric For 22: 93-100.

Saraçoğlu N (2000) Sakallı Kızılağaç (*Alnus glutinosa* (L.) Gaertn subsp. Barbata (C.A. Mey.) Yalt.) biyokütle tabloları. Turk J Agric For 24: 147-156.

Sun O, Uğurlu S, Özer E (1980) Kızılçam (*Pinus brutia* Ten.) türüne ait biyolojik kütlenin saptanması. Ormancılık Araştırma Enstitüsü Teknik Bülteni, Teknik Bülten Serisi No: 104, p. 32.

Tolunay D (2009) Carbon concentrations of tree components, forest floor and understorey in young *Pinus sylvestris* stands in north-western Turkey. Scan J For Res 24: 394-402.

Tolunay D (2011) Total carbon stocks and carbon accumulation in living tree biomass in forest ecosystems of Turkey. Turk J Agric For 35: 265-279.

Uğurlu S, Araslı B, Sun O (1976) Stebe geçiş yörelerindeki sarıçam meşcerelerinde biyolojik kütlenin saptanması. Ormancılık Araştırma Enstitüsü Yayınları, Teknik Bülten Serisi, p. 48.

Ünsal A (2007) Adana Orman Bölge Müdürlüğü Karaisalı Orman İşletme Müdürlüğü Kızılçam Biyokütle Tablolarının Düzenlenmesi. Yüksek Lisans Tezi. Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, p. 51.

Valentine HT, Hilton SJ (1977) Sampling oak foliage by the randomized-branch method. Can J For Res 7: 295-298.

Valentine HT, Tritton LM, Furnival GM (1984) Subsampling trees for biomass, volume, or mineral content. For Sci 30: 673-681.

Williams RA (1989) Use of randomized branch and importance sampling to estimate Loblolly pine biomass. South J Appl For 13: 181-184.