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TRANSECT SAMPLING METHOD WITH *K*-TREE FIXED NUMBER: A FAST AND ACCURATE METHOD TO ESTIMATE QUANTITATIVE VARIABLES IN OPEN FORESTS

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Abstract

In this study, we investigated line transect sampling methods with *k*-fixed trees (k = 2, 3, 4 and 5) to estimate quantitative variables in Zagros open forests in the west of Iran. Accurate measuring and commercial benefits are two aspects of sampling methods that are important for forest managers. The results of full callipering inventory indicated that density above 12.5 cm DBH, basal area and canopy were 68.04 trees·ha^{-1}, 15.16 m^2·ha^{-1} and 35.71 % ha^{-1} respectively. Based on ANOVA test, mean of measured variables in the line transect sampling methods with k = 2, 3, 4 and 5 were statistical different (P = 0.00). The results of study showed that the mean of density, basal area and canopy variables using transect sampling with k = 5 trees were closest to actual means derived from full callipering inventory. Our findings showed that line transect sampling method with k = 5 fixed trees had reliable results and was statistically reliable, efficient and practical method to estimate of the quantitative characteristics in Zagros open forest area.

Key words: forest inventory, line transect sampling, *Quercus brantii* var. *persica*, Zagros forest.

Introduction

Sampling method is useful to obtain stand information in a large forest area (Bonyad 2015). Line transect sampling method with 2, 3, 4, 5 trees may be applied in forest inventories and ecological surveys in open forests. The best sampling design should provide accurate and representative information about the population, while being geometrically compact and requiring the least amount of field effort. In forest sampling, suitable survey design is a crucial prerequisite for reliable results. In the past studies, in forest inventory researchers have mostly used random and systematic plot sampling methods. These methods were important for forest managers in two aspects: accurate measuring and commercial benefits. Sampling distance method has a survey design engine, with a built-in geographic information system, that allows examining the properties of different proposed designs via simulation, and generating of survey plans (Thomas et al. 2010). The line transects and distance sampling, also known as plot less sampling, has a long history in forest inventory. The line transects and distance sampling are often faster than the fixed-area plot sampling (Hall 1991, Lessard et al. 2002, Sheil et al. 2003, Picard et al. 2005, Kleinn and Vilčko 2006). In the natural populations characterized by an irregular, possibly clustered distribution of trees, the precision of a density estimate from distance sampling can be better than the precision obtained with fixed area plot sampling (Lessard et al. 2002). Some stand elements can be difficult to detect and missed objects will lead to an underestimation of the true density. In order to be sure that all objects in a strip will be detected, the strip width must be small, leading to high variability in estimates. In this situation, line transect sampling can be an alternative to strip surveys (Burnham et al. 1985). Line transect sampling methods have been used since 1930s to estimate the abundance of many biological populations, such as animal, bird, and plant species, and even non-living things. It was used for estimating densities of wildlife populations and can be a useful alternative to the traditional methods (Buckland et al. 1993, Ringvall et al. 2000, Buckland et al. 2001). The study of quantitative variables in forest stands had an important role in evaluation of stand growth and production (Burnham 2002, Zheng and Zhou 2010, Lu et al. 2003). Hermandez (1997) showed that transect sampling method is the best for estimation of density and canopy variables in coniferous forests.

To survey the open forest characteristics required sampling methods with low cost and acceptable accuracy. The open forests are mixtures of trees, shrubs and herbaceous species in which, unlike closed forests, the tree canopies do not form a continuous closed cover (Norvell et al. 2003, Somershoe et al. 2006, Newson et al. 2008, Ronconi and Burger 2009). The open-canopy forests tend to be better coupled to the atmosphere than closed-canopy and the results were differences in climate and conductance of water vapour (Jarvis 1985). Tree cover in open forests is typically more diffuse and variable than in closed forests. The line intersect sampling method for assessing coarse woody debris was tested by using 11 surveyors in four old conifer stands in northern Sweden (Ringvall and Stahl 1999). The study did not indicate any systematic differences between surveyors in their way of performing the inventory, although for the surveyors as a group a negative bias was found. Beasom and Haucke (1975) compared four distance sampling methods: closet individual, nearest neighbours, random pairs, and point centred quarter with 100 % inventory, to obtain density of oak forests in southern Texas. The random pairs and point centred quarter methods were closest to actual density. Sparks and Masters (2002) compared six sampling methods in fixed plots with 3.64 and 5.64 m radii, square plots with a central point, variable plots, transect, and 10 m × 10 m square plots in three forest stands in the southeast regions of Oklahoma. The line transect sampling techniques were useful for obtaining stand information in large open forest area (Krebs 1999, Newton 2007, Sutherland 2008). However, Zagros forest stands were non-timber forests with low density and important for protection purposes. Zagros mountain forests covered 5 million hectares with low density. The natural regeneration virtually did not exist, soil erosion was severe, with exposed bedrock (Marvi-Mohajer 2007). In this study, we investigated line transect sampling method with *k*-fixed trees (k = 2, 3, 4 and 5) to estimate quantitative variables in Zagros open forests.

Material and Methods

Study area

This study was carried out at uneven-aged hardwood stands in Zagros open forests in the western part of Iran. Altitudinal range is from 1000 to 3000 m a.s.l. The study area was 37.2 ha located at 46°22´40˝ E and 46°23´30˝ E longitude and 33°42´05˝ and 33°42´40˝ latitude (Fig. 1). Climate in the region of study can be defined as semi-Mediterranean, with mean annual precipitation approximately 600 mm and mean annual temperature 10 °C. Zagros forests provide various non-timber products and services and had multiple socio-economic and ecological functions. They were classified as semi-arid and consist 40 % of Iran's forest areas. The original vegetation of this area consist of uneven-aged mixed forest dominated by *Quercus brantii* Lindl., mixed (*Q. brantii*, *Pistacia atlantica* Desf., *Acer cinerascens* Boiss.), and *Daphne mucronata* Royle, *Amygdalus orientalis* Mill. types. *Q. brantii* var. *persica* is the most abundant tree species in the study area.

Full callipering inventory (100 % survey)

In full callipering inventory, all trees with diameter at breast height (DBH) > 12.5 cm were measured, and number of trees, canopy, and basal area ($m^2 \cdot ha^{-1}$) were measured and recorded.

Line transect sampling method

In this study 37 line transect samples were measured. In each line transect sample, first 5 trees were measured in systematic perpendicular lines (Fig. 1), installed with a grid of 100 m × 100 m over the study area. The grid points of perpendicular lines were starting points of line transect samples. Diameter at breast height (DBH), basal area and diameters of crown (large and small diameters of tree crown) of selected trees were measured and recorded. Suunto compass was used to move along the line transect from starting point to fifth tree (Fig. 2). The equations 1 and 2 were used to calculate mean ($\bar{x}$) and variance (S2) of the line transect sampling methods:

$$\bar{x} = \frac{\sum x_i}{n} \quad (1),$$

$$S^2 = \frac{\sum x_i^2 - \frac{\sum (x_i)^2}{n}}{n-1} \quad (2),$$

where: $\bar{x}$ = mean, S^2 = variance, n = number of samples and x_i = quantitative value of measured variables in the line transect samples (i = 1, 2, …, 37).

The equations 3, 4 and 5 were used to calculate density of trees per ha (Zobeiri 2007, Bonyad 2015):

$$\bar{a} = \frac{(a_1 + a_2 + ... + a_n)}{d} \quad (3),$$

$$N = \frac{10000}{\bar{a}^2} \quad (4),$$

$$\bar{N} = \frac{\sum N}{n} \quad (5),$$

where: $\bar{a}$ is the mean distance between trees of each transect; d is the number of distance between trees; n is the number of trees per ha at each transect; $\bar{N}$

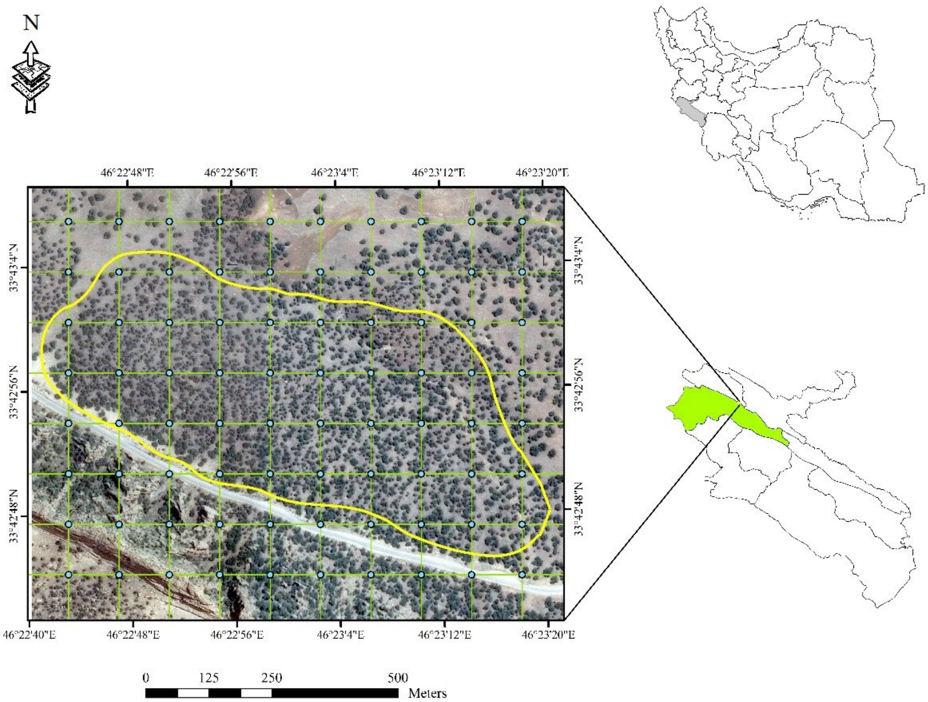

Fig. 1. Location of study area.

is the mean number of trees per ha for forest stand and *n* is the number of transects sampling. The equations 6, 7, 8 and 9 were used to calculate the basal area ($m^2 \cdot ha^{-1}$):

$$g = \frac{\pi}{4} d^2 \quad (6),$$

$$\overline{g} = \frac{\sum g}{n} \quad (7),$$

$$G = \overline{g} \cdot n \quad (8),$$

$$\overline{G} = \frac{\sum G}{n} \quad (9),$$

where: *g* is the basal area for a tree; *d* is the diameter at breast height; $\overline{g}$ is the mean of basal area at each transect; *G* is the basal area per ha, and $\overline{G}$ is the mean of basal area in forest stand. The equations 10, 11 and 12 were used to calculate canopy percent (ha^{-1}):

$$\overline{CA} = \frac{\pi \cdot \sum (CD_1 \times CD_2)}{4k} \quad (10),$$

$$CC = \frac{\overline{CA} \times 100}{\overline{a}^2} \quad (11),$$

$$\overline{CC} = \frac{\sum CC}{n} \quad (12),$$

where: CD_1 and CD_2 are small and large diameter of tree crown in meter; k is the number of tree in line transect; $\overline{CA}$ is the mean of tree's crown canopy in each transect; CC is the crown canopy of trees at each transect in percent; $\overline{CC}$ is the mean of crown canopy in forest stand in percent.

Statistical tests

Levene test was used to variance homogeneity of the line transect sampling methods with *k*-fixed trees (*k* = 2, 3, 4 and 5) in the SPSS. The density and characteristics (DBH, basal area and crown canopy) were compared using t-test and one-way ANOVA. The null hypothesis was that there is no significant difference among the means derived from the sampling methods with *k*-fixed trees. The standard deviation and confidence intervals of measured variables were compared with the ac-

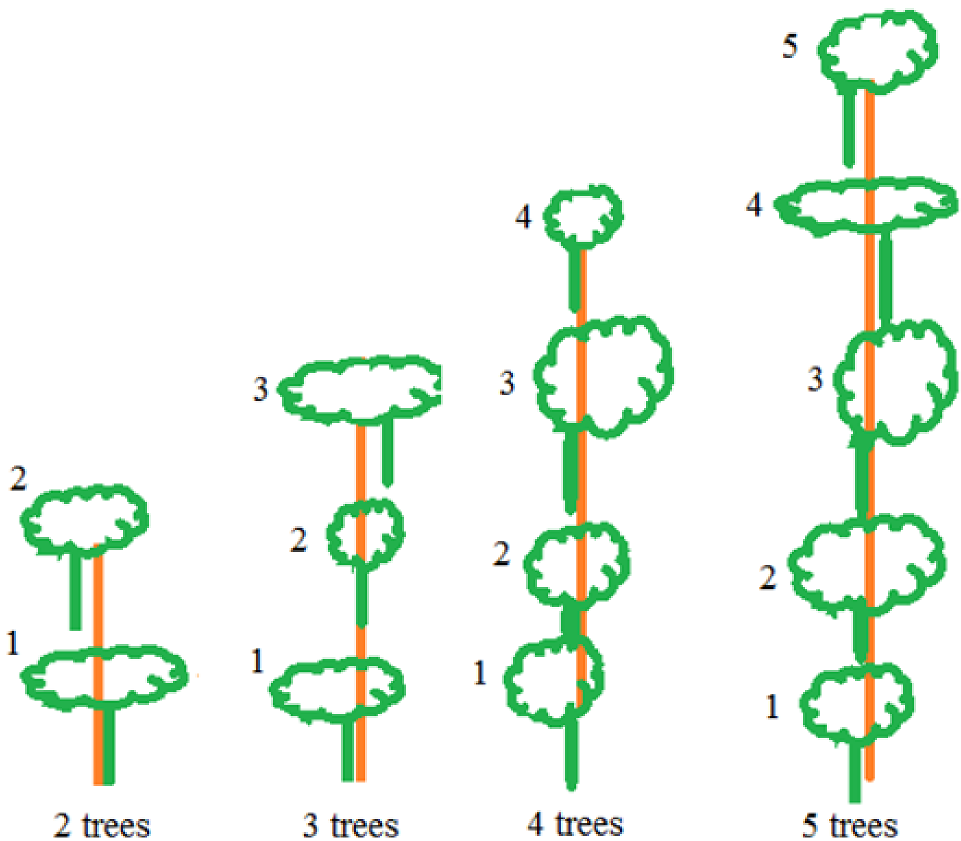

Fig. 2. Transect sampling method with k-fixed number of trees.

Table 1. Results of 100% inventory.

Characteristic	Actual mean	*SD*	*CV*, %
Density, ha^{-1}	68.04	±32.87	48.30
Basal area, $m^2 \cdot ha^{-1}$	15.16	±8.97	59.17
Crown canopy, %	35.71	±14.48	40.54

tual values derived from the full callipering inventory. Pairwise multivariate Hotelling's T^2 test was used to test means vectors of measured variables (Tatsouka 1988, Bonyad 2006).

Table 2. Statistical results for sampling methods.

Characteristic	*k*-fixed tree	Actual mean	$\bar{x}$	*SD*	$S_{\bar{x}}$	$\bar{x} \pm E$	*E*, %
Density, ha^{-1}	2 trees	68.04	61.63	±46.83	±7.70	61.63±12.93	20.99
	3 trees	68.04	77.36	±33.02	±5.43	77.36±9.17	11.86
	4 trees	68.04	78.17	±40.96	±6.73	78.17±11.37	14.54
	5 trees	68.04	74.17	±7.06	±1.16	74.17±1.96	2.64
Basal area, $m^2 \cdot ha^{-1}$	2 trees	15.16	12.7	±14.79	±2.43	12.7±4.08	32.17
	3 trees	15.16	14.39	±7.38	±1.21	14.39±2.04	14.21
	4 trees	15.16	15.01	±10.81	±1.77	15.01±2.99	19.92
	5 trees	15.16	13.9	±2.69	±0.44	13.9±0.74	5.34
Crown canopy, %	2 trees	35.71	25.17	±19.37	±3.18	25.17±5.35	21.26
	3 trees	35.71	31.46	±12.83	±2.11	31.46±3.56	11.33
	4 trees	35.71	29.02	±12.55	±2.06	29.02±3.48	11.99
	5 trees	35.71	35.25	±3.46	±0.56	35.25±0.94	2.68

Table 3. ANOVA test with *k*-fixed trees of line transect sampling methods.

Characteristic	Statistic	*df*	Mean Square	*P*-value
Density	Between Groups	3	2668182.147	0.00*
	Within Groups	144	54489.643	
	Total	147		
Basal area	Between Groups	3	40142.836	0.06
	Within Groups	144	9239.592	
	Total	147		
Crown canopy, %	Between Groups	3	116607.667	0.00*
	Within Groups	144	5213.688	
	Total	147		

Results

The results of full callipering inventory indicated that tree density above 12.5 cm DBH, basal area and crown canopy were 68.04 trees (ha^{-1}), 15.16 $m^2 \cdot ha^{-1}$ and 35.71 %, respectively (Table 1).

The results indicated that measured variables including: density of tree/ha, basal area and canopy using transect sampling with k = 5 trees were closest to actual values derived from the full callipering inventory. Also transect sampling with k = 5 trees has less statistical error (E, %) than other transect sampling (Table 2).

In ANOVA tests, the equality of variance of measured variables was a prerequisite. The results of variance equality tests indicated that the variance of measured variables in line transect sampling was not equal. Therefore, the results of ANOVA tests would be not robust. However, the analysis of variance was carried out to compare the means of measured variables with k-tree fixed (k = 2, 3, 4 and 5), and the results are shown in Table 3.

Based on Hotelling's T^2 test, the mean vectors of measured variables derived from transect with 2, 3, 4, 5 trees were compared with actual mean vectors derived from 100 % survey. In statistical terms, there was significant difference and results are shown in Table 4.

Table 4. Results of pair-wise test using multivariate Hotelling's T^2 test.

H_o	Num. df.	Den. df.	F_t	F_c	P-value
$\overline{X}^{(T_1)}$ and $\overline{X}^{(T_2)}$	3	73	2.74	54.04	0.00
$\overline{X}^{(T_1)}$ and $\overline{X}^{(T_3)}$	3	73	2.74	7.600	0.00
$\overline{X}^{(T_1)}$ and $\overline{X}^{(T_4)}$	3	73	2.74	82.61	0.00
$\overline{X}^{(T_1)}$ and $\overline{X}^{(T_5)}$	3	73	2.74	6.4676	0.00

Discussion

Two main peculiarities the sampling methods are important for forest managers: accurate measuring and commercial benefits. The quantitative variables of forest stands had important roles in forest survey and planning. The results of equality of variance tests showed that variances of measured variables derived from different lines transect sampling were not equal. The results of ANOVA test between mean of measured variables with fixed k-tree (k = 2, 3, 4 and 5) indicated that density and canopy % of study stands were significantly different (P = 0.00). This study showed that line transect sampling with k-5 trees, mean of density per ha, crown canopy and basal area were closest to actual means derived from 100 %. This result is important for forest inventory in the non-timber open forests with low density as Zagros forest area. The standard error and variance of measured variables with different k-tree fixed (k = 2, 3, 4 and 5) decreased with increasing number of fixed trees in the line transect sampling. The standard error in all measured variables (density, crown canopy and basal area) with k-5 fixed trees was closest to actual means derived from 100 % survey, and the variance of the transect sampling became more homogeneous with increasing the k from 2 to 5 fixed trees (Table 2). However, it should be noted that with increasing of k from 2 to 5 fixed trees requires geometrically compact and higher amount of measuring time, costs and field work. Our results were similar to the results of Buckland et al. (1993) and Ringvall et al. (2000), who reported that the line transect sampling was significant method to estimate densities of wildlife populations and can be a useful alternative to the traditional methods. Findings of our study concord with these obtained by other researchers. Hermandez (1997) showed that transect sampling method was the best for esti mation of density and canopy variables in conifer forests. Lessard et al. (2002) reported that the precision of a density estimate from distance sampling can be better than the precision obtained with fixed area plot sampling. Newson et al. (2008) and Ronconi and Burger (2009) suggested distance sampling method in large forest areas. Findings of our study indicated that line distance sampling method with $k = 5$ fixed trees had reliable result and was efficient sampling method in the open forests with low density as Zagros forests.

Conclusion

In a large forest area obtaining of stand information derived from full callipering inventory required higher amount of measuring time, costs and field work. Therefore, sampling method was considered useful in such areas. The best sampling design should provide accurate and representative information about the population and should require the least amount of field effort. The line distance sampling method with $k = 5$ fixed trees had reliable results and was efficient to obtain stand information in Zagros open forests. This sampling method with fixed trees was easy, and quick to estimate and monitor the quantitative variables in open forests.

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