



Comparison of fixed area and distance sampling methods in open forests: case study of Zagros Forest, Iran

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Abstract The main aim of this study was to evaluate methods for fixed area and distance sampling in the Zagros open forest area in western Iran. Basic forest management and planning required appropriate quantitative and qualitative information. Two sampling methods were compared on the basis of the actual means of characteristics derived from the 100 % survey. In total, 37 sampling plots were systematically installed with a grid of 100 m × 100 m in the study area. Density, crown canopy, and basal area of the stands were measured. The 100 % survey showed that tree density above 12.5 cm diameter at breast height was 68.04 stem ha⁻¹, basal area was 15.16 m² ha⁻¹ and crown canopy percentage was 35.71 % ha⁻¹. The values for the traits determined by the two sampling methods differed significantly ($P = 0.05$). When the time required for the methods was compared, transect sampling required less than systematic-random sampling. Therefore, the transect sampling method was the more economical method for the Zagros open forests. The transect sampling method was statistically defensible and practical for quantitating characteristics of the Zagros open forests.

Keywords Ilam · Systematic random sampling · Transect sampling · Zagros Forest

Introduction

The Zagros open forests in western Iran cover 5 million ha at low density. Natural regeneration is nearly non-existent, and severe soil erosion exposes the source rock (Marvi-Mohajer 2007). To survey stand characteristics of these forests, low-cost sampling methods with acceptable accuracy are needed. In most cases, the sampling method should accommodate the type of forest and suit the management aims for the forest (Bonyad 2015). Both data sampling and analysis need to be accurate enough to increase efficacy for a full-caliper inventory. The best sampling techniques provide accurate and representative information about the population studied, while being geometrically compact and requiring the least amount of field effort (Laycock and Batcheler 1975; Parker 1979; Scott and Gove 2002). Distance sampling methods, long used for forest inventories (Kleinn and Vilcko 2006; Bonyad 2015) are popular where plot (quadrat) sampling is difficult or too costly (Hall 1991; Lessard et al. 2002; Sheil et al. 2003; Picard et al. 2005). A fixed area square quadrat has traditionally been used for vegetation sampling (Clapham 1932). Other shapes of fixed area plots, such as rectangular or circular plots, and belt transects, have been used to improve habitat coverage and the ease of use (Barbour et al. 1987). Nimvari et al. (2004) compared systematic random sampling with circular plots and transect sampling methods in the Zagros Forest and the results showed that the transect method was more suitable for estimating density, crown canopy and basal area characteristics. When Pique et al. (2011) compared the accuracy of estimated means for basal area, stand density, and diameter class distribution in forest stand inventories, they found that the Bitterlich Relascope more accurately estimated basal area than density in stands with multiple strata

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and open structures, while the reverse was true for fixed radius plots. Evaluating the efficiency of the systematic random (rectangular plot), transect, strip, and stratification sampling methods in an oak forest in northern Iran, Fallah et al. (2012) found that the transect method was the most appropriate inventory method for this forest based on $(E\%)^2 \times T$, where $E\%$ is the percentage of sampling error and T is total inventory time. The main aim of this study was to evaluate the suitability of fixed area and distance sampling methods for an inventory of the Zagros open forest areas in western Iran to determine a statistically defensible and practical sampling method to quantitate stand characteristics of the Zagros open forests of Iran. For this purpose, the systematic random sampling method with fixed area and transect sampling method with a fixed number of trees were compared. The results of the two sampling methods were compared with the actual mean of these quantitative characteristics level derived from a 100 % survey. The concept of an easy and quick survey to obtain quantitative and qualitative information about the Zagros open forests is also proposed.

Materials and methods

Study area

The study area was 37.2 ha, located between $46^\circ 22' 40''$ E and $46^\circ 23' 30''$ E longitude and $33^\circ 42' 05''$ and $33^\circ 42' 40''$ latitude (Fig. 1). The original vegetation of the study area was an uneven-aged mixed forest dominated by *Quercus brantii*, mixed *Q. brantii*–*Pistacia atlantica*–*Acer*

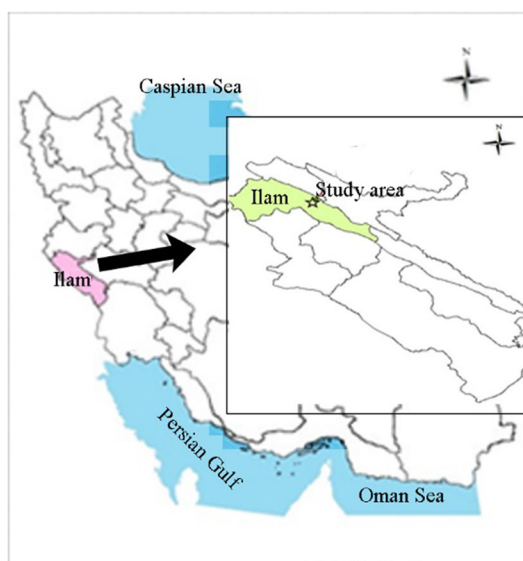


Fig. 1 Study area

cinerascens, and mixed *Daphne mucronata*–*Amygdalus orientalis* (Rostami and Heidari 2009). This area has a semi-humid cold climate based on the DeMartonne climate classification; the Emberger climate classification rates the climate as semi-arid (Rostami and Heidari 2009; Mirzaei and Bonyad 2014).

Methods

Full-caliper inventory (100 % survey) method

All trees in the forest stand with diameter at breast height (DBH) greater than 12.5 cm ($DBH > 12.5$ cm) were measured in a 100 % survey. To simplify the 100 % survey, the study area was divided into plots of 0.5 ha (100 m \times 50 m). Data for each plot was recorded separately, and variables for each tree were recorded: species, DBH, and diameters of canopy (maximum and minimum diameters).

Transect sampling method with fixed numbers of trees

A transect sampling method with fixed numbers of trees was used to estimate variables with low density in the Zagros open forest as recommended in different sources (Krebs 1999; Newton 2007; Sutherland 2008). The starting point of each transect, that is, the location of the first tree, was determined in the field, and species, DBH, and diameters of canopy (maximum and minimum diameters) of the first tree were measured. The same approach was used for each tree (crown or trunk) encountered on the transect, and the distance from the previous tree was also measured and recorded, until five trees in transect had been measured. In total, 37 sampling plots were systematically installed (a grid of 100 m \times 100 m) in the study area (Fig. 2). The equations used to calculate density per hectare, crown canopy (%), and basal area per hectare (Zobeiri 2007) are described in Table 1.

Systematic random sampling method

A systematic random sampling method within a fixed area (1000 m²) was also used. The grid of the systematic random sampling method was 100 m \times 100 m, and 37 rectangular plots (each 25 m \times 40 m) were established (Fig. 2). All tree characteristics were measured in each plot. The equations below were used to calculate statistical parameters for each variable measured (Zobeiri 2005; Bonyad 2015):

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

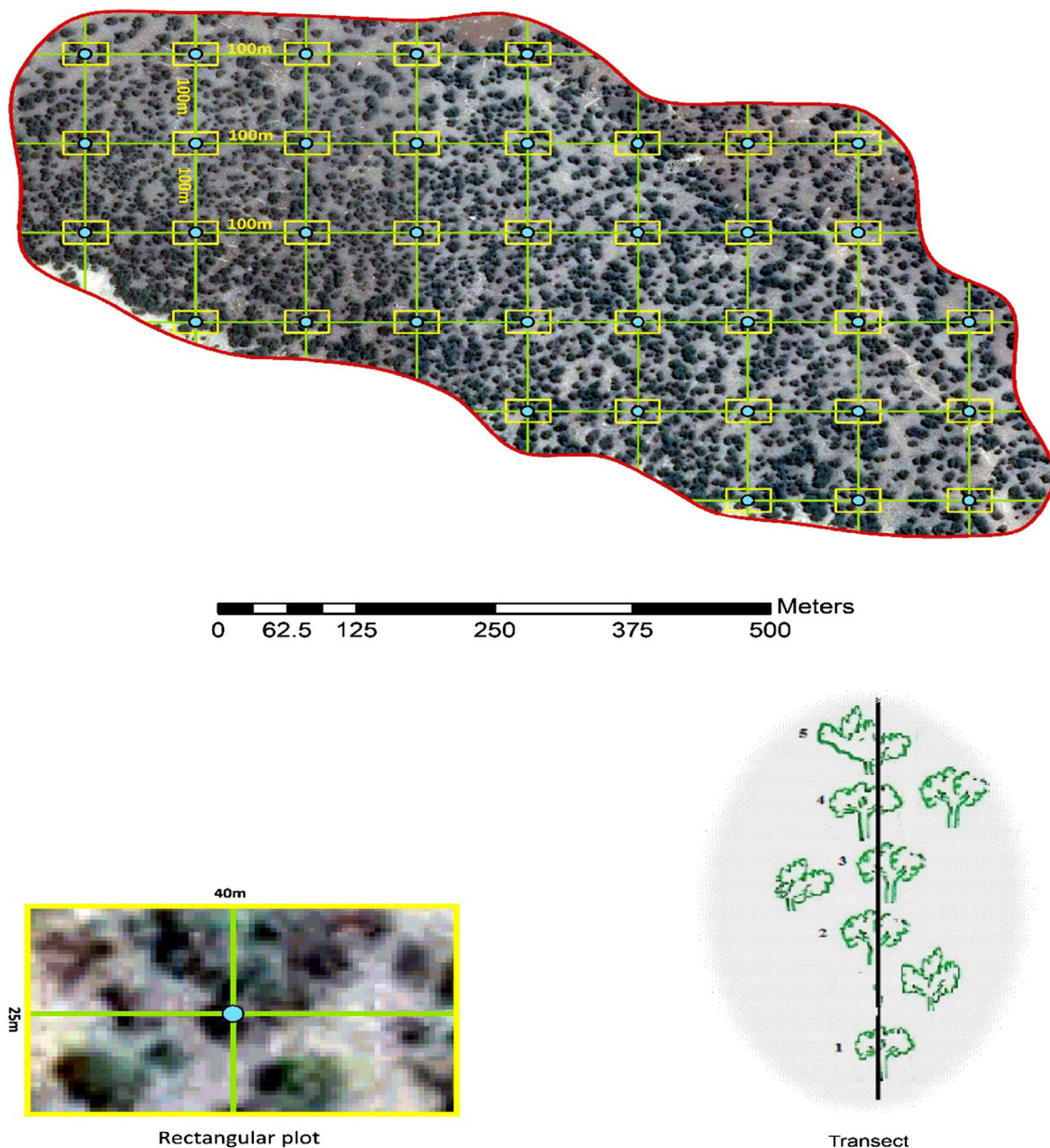


Fig. 2 Inventory network, rectangular plot and transect sampling

Table 1 Equations for calculation of characteristics

Characteristics	Equations
Density (per hectare)	$\bar{a} = \frac{(a_1+a_2+a_3+a_4)}{4}, N = \frac{10,000}{\bar{a}^2}, \bar{N} = \frac{\sum N}{n}$
Crown canopy (%)	$\overline{CA} = \frac{\pi \times \sum (CD_1 \times CD_2)}{5}, CC\% = \frac{\overline{CA} \times 100}{\bar{a}^2}, \overline{CC}\% = \frac{\sum CC\%}{n}$
Basal area (m ² ha ⁻¹)	$g = \frac{\pi}{4} d^2, \bar{g} = \frac{\sum g}{5}, G = \bar{g}N, \bar{G} = \frac{\sum G}{n}$

\bar{a} Mean distance between trees at each transect, N number of trees ha⁻¹ at each transect, \bar{N} mean number of trees ha⁻¹ in the forest stand, n number of transects measured, \overline{CA} mean of tree crown canopy on each transect, CD_1, CD_2 minimum and maximum diameter of tree crown (m), CC crown canopy trees at each transect (%), \overline{CC} mean of crown canopy in forest stand (%), g basal area for a tree, d diameter at breast height, \bar{g} mean of basal area at each transect, G basal area ha⁻¹, \bar{G} mean of basal area in forest stand

$$S_x = \sqrt{\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}}, \quad (2)$$

$$S_{\bar{x}} = \pm \frac{S_x}{\sqrt{n}}, \quad (3)$$

$$E = \pm t S_{\bar{x}}, \quad (4)$$

where \bar{x} is the mean of variable x , n is the number of plots, x_i is the value for i th tree, variables, S_x is the standard deviation (SD) of variables, $S_{\bar{x}}$ is the standard error, E is the sampling error and t -value is dependent to probability level and number of plot.

Kolmogorov–Smirnov test were used for the normality test of data. An analysis of variance and t test were used to compare statistical parameters for the different sampling methods. Excel ver. 2013 (Microsoft Office) and IBM SPSS Statistics ver. 22 software were used to compared differences between the measured data.

Time studies

Time studies are important in forest inventory (Heidari et al. 2009). The estimator $(E\%)^2 \times T$ for the sampling methods, was used to determine the most economical and fastest survey method for estimating stand variables (Loetsch et al. 1973; Husch et al. 1982). Thus, the method with the lowest $(E\%)^2 \times T$ is the most economical for ease and speed.

Results

The results of this study indicated that, the original vegetation in Zagros open forests area comprised uneven-aged mixed stands dominated by *Q. brantii* var. *persica* and *D. mucronata*–*A. orientalis*. The Kolmogorov–Smirnov test indicated that the data for the study area were consistent with a normal distribution. The results of the 100 % survey are shown in Table 2.

The stand variables for the 37 sample plots were measured and analyzed with systematic random sampling method with a fixed area (1000 m²) and transect sampling methods. The results of statistical parameters showed in Table 3.

Table 2 Results of the 100 % inventory

Characteristics	Actual mean	SD	CV (%)
Density (tree ha ⁻¹)	68.043	±32.807	48.215
Basal area (m ² ha ⁻¹)	15.108	±8.975	59.456
Crown canopy (%)	35.713	±14.481	40.548

CV coefficient of variation

The results indicated that the SD of DBH, basal area and crown canopy (%) in the transect sampling method was lower for each variable than in the systematic-random sampling method. The mean (\bar{x}) for the two sampling methods was compared using the paired t -test. The results showed that the values obtained by two sampling methods differed significantly different ($P = 0.05$; Table 4).

The mean DBH, basal area and crown canopy (%) derived from the systematic random sampling and transects sampling methods were compared with the actual mean of these variables derived from the 100 % inventory. The results indicated that two sampling methods differed significantly from the actual mean (Table 5).

When the two sampling methods were compared using the estimator $(E\%)^2 \times T$ the estimator $(E\%)^2 \times T$ for the transect sampling method was lower than for the systematic-random sampling method. Therefore, transect sampling method was more economical for the Zagros open forests (Table 6).

Discussion

The main advantages of the Zagros Forests that known as open forests are water supply, soil conservation, climate alternation and various intangible social benefits that are frequently termed as forest influence. For quantitating characteristics in these open forests, sampling methods need to be low cost with acceptable accuracy. The actual means of traits measured in the 100 % survey were used as the criteria for comparing values from the systematic random plot sampling with those from the transect sampling method, which was based on a fixed number of stems. The SD of DBH, basal area and crown canopy (%) in the transect sampling method were lower than for the systematic-random sampling perhaps due to variation within and between plots in the systematic-random sampling method because the forest stands of study area were open forests with very low density, basal area and crown canopy (%). Our results are consistent with those of Nimvari et al. (2004), in finding that the transect method was the most to measure open forest stand characteristics. The results of our study showed that the mean and variance of stand characteristics with transect sampling were near the actual mean and variance derived from the 100 % survey. The mean for crown canopy (%) in the transect method was not significantly different from the actual mean derived from 100 % survey ($P = 0.432$; Table 5). Also, the estimator $(E\%)^2 \times T$ or the transect sampling was lower than for the systematic-random sampling and thus more economical for the Zagros open forest (Table 6), consistent with results of other researchers. Hernandez (1997) showed that the transect sampling method was the best for estimating

Table 3 Statistical results of two sampling methods

Characteristics	Sampling methods	\bar{x}	SD	$S_{\bar{x}}$	E%
Density (tree ha ⁻¹)	Transect	70.182	±7.064	±1.161	2.808
	Systematic-random	61.078	±20.573	±3.382	9.397
Basal area (m ² ha ⁻¹)	Transect	14.911	±2.679	±0.440	5.007
	Systematic-random	9.847	±5.751	±0.945	16.286
Crown canopy (%)	Transect	35.246	±13.462	2.213	6.279
	Systematic-random	27.023	±18.643	±3.065	19.248

\bar{x} mean, SD standard deviation, $S_{\bar{x}}$ standard error, E% sampling error

Table 4 Comparison of results from the two sampling methods based on paired *t*-test

Characteristics	Transect	Systematic-random	<i>P</i>
Density (tree ha ⁻¹)	70.182	61.078	0.008*
Basal area (m ² ha ⁻¹)	14.911	9.847	0.000*
Crown canopy (%)	35.246	27.023	0.011*

* Values differed significantly at the 0.05 probability level

Table 5 Comparison of the two sampling methods with the actual means

Characteristics	Methods	<i>P</i>
Density (tree ha ⁻¹)	Transect	0.000*
	Systematic-random	0.000*
Basal area (m ² ha ⁻¹)	Transect	0.007*
	Systematic-random	0.000*
Crown canopy (%)	Transect	0.432
	Systematic-random	0.007*

* Values differed significantly at the 0.05 probability level

Table 6 Comparison of the two sampling methods based on $(E\%)^2 \times T$

Methods	Characteristics	$(E\%)^2$	<i>T</i>	$(E\%)^2 \times T$
Systematic-random	Density	125.57	248.35	31,186.23
	Basal area	371.71	332.42	123,563.83
	Canopy	523.49	412.23	215,798.28
Transect	Density	9.98	209.43	2090.11
	Basal area	41.08	243.09	9986.10
	Canopy	10.69	357.20	3818.40

E% accuracy of sampling methods, *T* total time of sampling methods (min)

density and crown canopy (%) in conifer forests. Alijanpour et al. (2004) estimated the number of trees ha⁻¹ and basal area using three sampling methods including circular, quadratic and transect methods in the Aras-baran forest in

Iran and showed that the transect sampling method was the most appropriate. However, when Lisa (2002) assessed the efficiency of strip and transect sampling methods for 17 conifer stands, there was no significant difference in the estimates from the two methods. The results of our study agreed with those of Salmanian Chafjiri (2004) and Fallah et al. (2012). The transect sampling method with a fixed number of trees was statistically defensible and practical for quantitating tree characteristics in an open forest such as the Zagros forest areas.

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