Presentation of Two New Empirical Equations for Point-Centered Quarter Method for Estimating Trees Density in the Forest

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Research

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Posted Date: August 5th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-46899/v1>

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Presentation of Two New Empirical Equations for Point-centered quarter Method for
Estimating Trees Density in the Forest

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Abstract

Background and objectives: The point-centered quarter(PCQ) method is one of the distance sampling methods. Previously, researchers such as Cottam and Curtis (1954), Pollard(1971), and Haidari *et al.* (2008) introduced three equations to the estimation of plant density using the above method. The objective of this research includes developing two new formula for the estimation of tree density with the PCQ method, which is not biased toward the tree distribution pattern.

Materials and methods: In this study, 40 circular sample plots (1000 m² as the real state) and PCQ method were measured via a systematic random sampling design (100 m × 100 m) in the educational research forest at Razi University in Dalahoo Mountain in Kermanshah province. Later, through the mentioned formulas, forest stand density was calculated. Then, the obtained density with different formulas of the PCQ method with the circular plot in the spatial pattern of various types (uniform, random, and cluster) was compared in terms of accuracy and precision.

Results: The results showed that two new empirical equations for estimating the density of trees in forest stand were more appropriate than the previous equations in terms of accuracy and precision.

Conclusion: The new equations have the following important characteristics: Firstly, they are less dependence on the tree distribution pattern than other equations are, and secondly, the number of trees per area unit can be calculated for each sampling point like

the equation used for the sample plot methods. Finally, it is suggested to use the new equations for other forests and also other vegetation, such as the grasslands and scrublands.

Key words: density, distance methods, new formulas, Oak, PCQ method, Zagros.

Introduction

Density is one of the most remarkable vegetation traits (Bonham, 2013). Sampling methods with plot-based and plot-less (distance methods) are used to estimate the density of the trees. The main objective of sampling is to develop an accurate and precise survey of plant communities' characteristics in ecological studies (Borges Silva *et al.* 2017). Distance sampling methods have been used to measure plant density since the 1950s (Bonham, 2013). Most distance sampling methods have more than one empirical formula. The development of non-dimensions and fixed shapes is aimed at increasing inventory speed, reducing sampling time and thus keeping running costs low and achieving correct accuracy (Namiranian, 2010). Spatial patterns are influenced by vegetation density estimation using distance sampling methods. While the density estimation by distance methods is not biased if plants and animals have a random distribution pattern, it will be biased if the plants and animals have a cluster pattern. Therefore, the distribution pattern of individuals should be determined using distance methods before estimating population density (Krebs 1989). The bias is dependent on the plan (inventory network, number of points, etc.) or the estimator. When the distance among sample points and trees or the distance between the trees is low, formulas provide more estimates of quantitative parameters. This can be a significant obstacle to determining the quantitative parameters in low-density forests (Askari *et al.* 2013).

The point-centered quarter method is one of the distance sampling methods. Stearns (1949) indicated that making the first surveys of government land, the point-centered quarter method, which was used by surveyors in the mid-nineteenth century, dates back to at least 150 years ago (Mitchell 2007). Cottam and Curtis (1954) compared the point-centered quarter method to quadrat sampling and empirically derived a formula that could be used to estimate population density from the distance data collected. Cottam and Curtis (1954), Pollard (1971), and Haidari *et al.* (2008) introduced equations to estimate the density of trees using the above method (Haidari 2008).

The studies revealed that the equations introduced by the above researchers would bias the estimated density in most cases, especially when the distribution pattern of trees was arranged or cumulative. Engeman *et al.* (1994) compared some distance methods together using the Monte Carlo simulation program and found the result biased with Cottam and Curtis (1954) and Pollard (1971) estimators for the PCQ method (Engeman *et al.* 1994).

Haidari's study (2008) indicated that the estimation of trees through the equation introduced by Cottam and Curtis (1954) and Pollard (1971) in the clumped distribution pattern was biased (Haidari *et al.* 2008). Kiani *et al.* (2013) also compared some distance methods in *Haloxylon ammodendron* lands of Siahkooh in Yazd, Iran, and found that the equation presented by Cottam and Curtis (1954) and Pollard (1971) estimated the density of shrubs erroneously (Kiani *et al.* 2013).

The objective of this study was to present new empirical equations for the point-centered quarter method with less dependence on the plant distribution pattern than previous equations had.

Materials and Methods

The studied area: The area was in the educational research forest at Razi University of Kermanshah in Dalahoo Mountain between Kerend-e Gharb and Sarpol-e Zahab cities in

76 Kermanshah, Iran (Figure 1).

77 The area of the forest was 16000 hectares. The west, north, east, and south of the forest
78 respectively adjoined Habibvand village, DalahooMountains, Sarmil village, and Kuh-e Nava
79 Mountain. The area is geographically located between latitudes of 34° 16' and 34° 30' north
80 and longitudes of 45° 55' and 46° 7' east. In terms of the topography, the area is mountainous
81 and 760-2400 meters above the sea level. The vegetation of the area is of *Quercetumpersicum*,
82 and *Quercuspersica* constituted the dominant species of the forest (Haidari 2006).

83 Methods: Firstly, a 40-hectare area was specified in the educational research forest at Razi
84 University of Kermanshah. Then, 40 sampling points (here 40 samples) were marked and
85 numbered on the ground among the studied community using the statistical record network of
86 100×100 m and the systematic random recording design.

87 Data calculation

88 On each sampling point, a 10-ar circle sample plot was marked on the ground, and the trees
89 inside the circular plot were counted and recorded. Simultaneous to recording each circle
90 sample plot, another sample was recorded using the point-centered quarter method in a way
91 that its starting point (the sampling point) was the center of the circle sample plot (Figure 2).

92 Point-centered quarter method

93 In this sampling method, four distances were measured (Figure 3). Each sampling point is
94 considered the center of the four quarters (quadrants), with orientation given by the compass
95 line of the traverse. At each point, the closest tree to the point in each of the four quarters
96 around the point is chosen as the sample. Distances are measured from the point to each of the
97 four trees recorded. Once the data were collected, all the data collected in the statistical record
98 forms were fed into the computer, and the following calculations were carried out using SPSS,
99 Excel, and Ecological Methodology (Krebs 2001) software programs.

100 Counting trees per hectare

101 Firstly, the number of trees per unit of area, hectare, and variance in the number of trees were
102 calculated for circle samples, and the dot diagram of the number of trees per area unit of the
103 circle samples was drawn. In the next step, the density of trees in the 40 samples was calculated
104 using different equations of the point-centered quarter method (table 1).

105 A-Equation suggested by Cottam and Curtis 1954 (reference: Cottam and Curtis 1954)

106 B-Equation suggested by Pollard 1971(reference: Pollard 1971)

107 C- Equation suggested by Haidari *et al.* 2006(reference: Haidari *et al.* 2008)

108 D-New Empirical Equations suggested by the author (dalahoo1 and dalahoo2)

109 Calculation of the tree distribution pattern

110 There were various indices to quantify the distribution of natural populations. In this study,
111 the variance/mean ratio ($S^2/\bar{x}$) was used to determine the tree distribution pattern in the area
112 because the circle samples were considered as the control (base). If the ratio equals one, the
113 spatial distribution will be random; the ratio greater than one will indicate a clumped
114 distribution pattern; and the ratio less than one will show a uniform distribution pattern
115 (Moghadam, 2001). The reason that the circle sample plot method was considered as the base
116 was primarily that the circle method is one of the common methods used for Zagros forests,
117 and secondly that all the trees of 40 samples recorded through the point-centered quarter
118 method were inside the circle samples.

119 Rest of calculations

120 To examine the effect of the tree distribution pattern on the results obtained from estimating
121 the density of trees through different equations of the point-centered quarter (equations of
122 Cottam and Curtis (1954), Pollard(1971), Haidari *et al.* 2008 and also the new equations) after
123 drawing the dot diagram for the 40 samples in the circle sample method, one sample that had
124 the highest deviation from the mean data was eliminated. For the remaining 39 samples, firstly,
125 the spatial distribution pattern (variance/mean ratio) and, then, the number of trees per hectare

126 and also the equations of the point-centered quarter method were. The calculation continued
127 until the distribution pattern changed from the clumped pattern (the variance/mean ratio was
128 2.150 for all the 40 samples) to the random pattern (the variance/mean ratio was 1.02 for 30
129 samples) followed by the uniform pattern (the variance/mean ratio was zero for four samples).
130 In short, the calculations in A and B steps were carried out for 40, 39, and 38 samples in order
131 followed by 4 sample plots with zero variance/mean ratio (the uniform distribution pattern).
132 Finally, the density calculated with different equations of the point-point method was
133 compared to the one obtained from the 10-ar circle samples as the control (base) regarding the
134 paired t-test and the accuracy(A) criterion ($A\% = \pm 100[(Estimated - True)/True]$) (Southwood &
135 Henderson, 2000). A summary of the calculations was provided in the result section.

136

137 Results

138 Tree distribution

139 As shown in Table 2, the trees in the studied area had a clumped distribution pattern because
140 the variance/mean ratio for the 40 circle samples was 2.150. The tree distribution pattern was
141 also determined for 4-39 samples regarding their variance/mean ratio, and the relevant results
142 are shown in Table 2.

143 Number of trees per hectare

144 Table 2 and Figure 4 show the number of trees estimated per hectare using the circle method
145 and different equations of the point-centered quarter method in different tree distribution
146 patterns (with variance/mean ratio of zero, 1, and 2.150 respectively for the uniform, random,
147 and clumped patterns).

148 A. Regarding the number of samples (4-40 samples in Table 2), values obtained from
149 different equations of the point-centered quarter method for different tree distribution
150 patterns were compared to those obtained from the circle method (the control) using

paired *t-test* (Table 3).

B. Values obtained from different equations of the point-centered quarter method were compared to those obtained from the circle method (4-40 samples) regarding the accuracy criterion ($A\% = \pm 100[(Estimated - True)/True]$) (Table 2 & Figure 5).

Discussions

The results (Table 2) showed that the trees of the studied forest followed the clumped distribution pattern. This result conformed to that of the studies conducted in relation to Zagros forests by other researchers, such as Haidari (2006), Haidari *et al.* (2007), Safari (2010), and Askari *et al.* (2013). As shown in Table 2 and Figure 4, the different equations of the point-centered quarter method produced different estimates of the number of trees per hectare, which was due to the nature of the equations estimating density (estimators). According to Askari *et al.* (2013), bias depended on the design (the statistical record network, number of points, etc.) or the estimator. In this study, the statistical record network and the number of points were identical for all equations, and only the estimators (equations) were different. Moreover, Krebs (1998) pointed out the evident effect of tree distribution patterns on the results of different equations used for density estimation.

According to Figure 4, Haidari *et al.*'s equation (2008) provided a lower estimate for the density of trees in the clumped, random, and uniform distribution patterns than the circle method (the control) did. Thus, Pollard equation (1971) provided a lower estimate for the density of trees in all kinds of distribution patterns than the circle method did. However, based on Table 2 and Figure 4, the equations introduced by Cottam and Curtis (1954) and new equations (dalahoo1 and dalahoo2) provided values for the density estimated in all patterns (clumped, random, and uniform) similar to those obtained in the circle method (the control), but the best formulas seem to be dalahoo1 and dalahoo2. This was well confirmed by the results of the statistical test, namely the paired *t-test* (Table 3), and calculation of the acceptable

accuracy (Figure 4). According to Table 2, the equations that were not highly affected by the changes in the distribution pattern were the dalahoo1 and dalahoo2 equations. Furthermore, according to Southwood *et al.* (1999), an equation with ± 10 accuracy could be used in research procedures (Southwood & Henderson 2000). Table 2 and Figure 5 also show the estimated density of trees in the range of -5.94 to +4.55 using the dalahoo2 equation against the 10-ar circle method. In this respect, it could be argued that the dalahoo2 equation provided acceptable results in terms of the accuracy criterion.

Based on the equations presented in this study, it appears that the point-centered quarter technique of the distance sampling method can be used for Zagros forests instead of the 10-ar circle sample plot method based on the results of this study; characteristics of Zagros protected forests (that are mountainous in terms of topography and usually with a low density of trees); the point that “when sampling of a piece of land is difficult or too costly (in mountainous lands or forests with low density), distance sampling methods are more appropriate (Shale *et al.* 2003; Picard *et al.* 2005; & Kiani *et al.* 2013)”; and the tree distribution pattern in the studied area that is usually clumped according to the studies conducted in these forests. The reason is that the point-centered quarter method is performed faster than the circle method and takes a much shorter time. The point-centered quarter method using the new equations can largely reduce the costs of statistical recording in forests. The new equations have the following important characteristics:

Firstly, they are less dependent on the tree distribution pattern than other equations, and secondly, the number of trees per area unit can be measured for each sampling point like the equation used for the sample plot methods.

Declarations

201 Acknowledgments

202 I thank research deputy of the Razi University for assistance in the field.

203 Funding

204 This study was funded by the research deputy of the Razi University.

205 Availability of data and materials

206 The datasets used and analyzed during the current study are available from the
207 corresponding author on reasonable request.

208 Ethics approval and consent to participate

209 This research was performed in accordance with the laws, guidelines and ethical
210 standards of Iran, where the research was performed.

211 Author's contributions

212 RHH is the sole author. He carried out all analyses and drafted the manuscript. The
213 author read and approved the final manuscript.

214 Consent for publication

215 Not applicable.

216 Competing interests

217 The author declares that they have no competing interests

218

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266 Table 1. All Equations for estimating tree density with point-centered quarter method

Equations	sign	Estimated density in each sample point(trees/m ²)	Mean estimated density in <i>n</i> sample points(trees/m ²)	Reference
Cottam and Curtis	N _{CC}	-----	$\hat{N}_{cc} = 1/[(\sum r_{ij}/4n)^2]$	Cottam and Curtis, 1954
Pollard	N _P	-----	$\hat{N}_p = [4(4n - 1)]/[\pi * (\sum r_{ij}^2)]$	Pollard, 1971
Haidari et al.	N _H	$\hat{\lambda}_i = [(r_{i1}r_{i2}r_{i3}r_{i4})^2]/[(\sum r_{ij}/4)^{10}]$	$\hat{N}_H = \sum \hat{\lambda}_i/n$	Haidari et al. 2008
Dalahoo1(New)	N _{D1}	$\hat{\lambda}_i = 3.092/[\pi * (\sum r_{ij}/4)^2]$	$\hat{N}_{D1} = \sum \hat{\lambda}_i/n$	New
Dalahoo2(New)	N _{D2}	$\hat{\lambda}_i = 0.50255/\sum r_{ij}$	$\hat{N}_{D2} = \sum \hat{\lambda}_i/n$	New

Where N_{cc}, N_p, N_H, N_{D1} and N_{D2} : Number per unit area by Cottam, G & Curtis, JT (1954), Pollard, JH (1971), Haidari *et al.*(2007) and new formulas respectively. $\hat{\lambda}_i$: density in each sample point(trees/unite area), r_{ij} =

distance(m) from pt to nearest individual trees in sampling point(i)and in quadratej (j = 1, 2, 3 and4):
 $\hat{N}_{trees/ha} = 10000 * \hat{N}_i$, $\hat{N}_i = \hat{N}_{cc}, \hat{N}_p, \hat{N}_H, \hat{N}_{D1}$ and $\hat{N}_{D2}$

n = sample size

267

268 Table 2. Results of statistical recording

Size of sample s	Index of spatial pattern (variance/mean)	Circle plot density	Tree density estimation by different formulas of point-centered quarter method					Accuracy(%) = 100 * ($\frac{\text{Estimated} - \text{True}}{\text{True}}$)				
			Pollar	Cotta	Haida	Dalahoo	Dalahoo	Pollar	Cotta	Haida	Dalahoo	Dalahoo
			d	m	ri	1	2	d	m	ri	1	2
4	0	180	158.5	190.3	103.0	187.4	186.8	-	5.731	-42.81	4.11	3.80
								11.95				
								7				
5	0.011	182	173.6	199.6	105.9	196.5	188.7	-	9.644	-41.80	7.97	3.70
								4.625				
6	0.015	183.3	187.8	208.1	119.4	204.9	191.0	2.417	13.49	-34.90	11.76	4.21
		3							6			
7	0.016	184.2	174.8	188.3	111.5	185.5	182.8	-	2.197	-39.49	0.63	-0.79
		8						5.146				
8	0.057	187.5	177.9	192.1	105.3	189.1	183.3	-	2.427	-43.85	0.86	-2.22
								5.111				
9	0.079	190	175.2	184.6	101.2	181.8	179.4	-	-2.817	-46.72	-4.30	-5.59
								7.785				
10	0.09	192	187.5	197.3	120.9	194.2	186.7	-	2.740	-37.03	1.17	-2.74
								2.367				
11	0.096	193.6	177.5	187.1	112.9	184.2	182.1	-	-3.391	-41.69	-4.87	-5.94
		3						8.329				

12	0.112	191.6	188.2	198.4	134.0	195.4	188.9	-	3.511	-30.07	1.93	-1.44
		7						1.798				
13	0.145	189.2	174.7	189.1	124.6	186.2	184.7	-	-0.088	-34.18	-1.62	-2.39
		3						7.683				
14	0.168	187.1	180.5	194.9	125.0	191.9	187.2	-	4.144	-33.21	2.55	0.01
		4						3.573				
15	0.208	184.6	165.3	176.7	120.0	174.0	181.3	-	-4.339	-35.04	-5.80	-1.80
		7						10.51				
								3				
16	0.216	183.1	170.6	182.0	118.0	179.2	183.7	-	-0.606	-35.57	-2.13	0.31
		3						6.848				
17	0.244	185.2	171.0	181.5	114.2	178.7	182.6	-	-2.039	-38.37	-3.54	-1.43
		9						7.737				
18	0.295	182.7	175.6	186.4	114.7	183.6	184.8	-	1.998	-37.24	0.44	1.13
		8						3.924				
19	0.335	180.5	175.8	184.8	113.6	182.0	183.5	-	2.384	-37.08	0.82	1.62
		3						2.635				
20	0.367	178.5	179.5	187.4	117.8	184.6	184.2	0.560	4.998	-34.03	3.39	3.19
21	0.414	180.9	185.7	194.9	122.9	191.9	189.2	2.624	7.683	-32.09	6.04	4.55
		5										
22	0.465	178.6	173.7	183.4	118.8	180.6	185.3	-	2.694	-33.52	1.12	3.76
		3						2.759				
23	0.559	181.7	173.7	182.6	117.1	179.8	184.3	-	0.476	-35.58	-1.06	1.42
		4						4.447				
24	0.631	184.5	175.8	184.2	115.5	181.4	184.6	-	-0.183	-37.44	-1.71	-0.01
		8						4.778				
25	0.677	182.4	174.4	183.5	111.6	180.7	183.7	-	0.607	-38.84	-0.93	0.70
								4.380				
26	0.765	185.3	174.8	183.7	108.5	180.9	183.2	-	-0.915	-41.47	-2.43	-1.16
		8						5.683				
27	0.834	188.1	180.0	190.1	123.4	187.2	188.1	-	1.027	-34.42	-0.52	-0.03
		5						4.315				
28	0.903	185.7	179.6	188.7	121.7	185.8	187.0	-	1.602	-34.47	0.05	0.68
		1						3.298				
29	0.96	183.4	174.4	182.7	119.3	179.9	184.6	-	-0.394	-34.99	-1.92	0.62
		5						4.940				
30	1.05	186.3	178.9	188.9	120.2	186.0	189.5	-	1.355	-35.49	-0.19	1.73
		3						4.006				
31	1.15	189.3	181.9	192.0	120.3	189.0	190.9	-	1.373	-36.46	-0.18	0.80
		5						3.963				
32	1.2	191.8	185.3	195.1	127.5	192.1	192.2	-	1.679	-33.58	0.12	0.19
		8						3.426				
33	1.27	194.5	184.2	192.9	125.7	190.0	190.9	-	-0.822	-35.39	-2.34	-1.87
		5						5.303				
34	1.35	197.3	188.2	197.6	135.7	194.5	193.8	-	0.104	-31.24	-1.43	-1.78
		5						4.613				
35	1.44	200.2	191.9	201.5	142.7	198.4	196.0	-	0.618	-28.74	-0.92	-2.13
		6						4.177				
36	1.56	197.5	190.6	200.8	139.2	197.7	195.2	-	1.658	-29.51	0.10	-1.16
								3.517				

37	1.73	194.3	182.8	191.8	137.0	188.9	192.5	-	-1.274	-29.49	-2.78	-0.92
		2						5.936				
38	1.84	197.3	187.2	198.2	165.3	195.2	199.4	-	0.431	-16.27	-1.10	1.02
		6						5.157				
39	1.96	200.5	188.8	199.6	162.6	196.6	199.5	-	-0.442	-18.90	-1.96	-0.49
		1						5.859				
40	2.15	197.2	187.6	197.8	159.6	194.8	198.3	-	0.266	-19.08	-1.27	0.52
		5						4.899				

269

270

Table3. Comparison results of different formulas of point-centered quarter method with circle plot

271

(precision criteria)

Pair	Paired Differences							Sig. (2-tailed)
	95% Confidence					t	df	
	Mean	Std. Deviation	Std. Error	Interval of the Difference				
				Lower	Upper			
Circle - Pollard	8.655	5.342	0.878	6.874	10.436	9.856	36	.000**
Circle - Cottam	-2.842	6.329	1.04	-4.952	-0.732	-2.731	36	.010**
Circle - Haidari	64.788	11.353	1.866	61.003	68.574	34.711	36	.000**
Circle - Dalahoo1	0.075	6.269	1.031	-2.015	2.165	0.073	36	.942 ^{ns}
Circle - Dalahoo2	0.083	4.517	0.743	-1.423	1.589	0.111	36	.912 ^{ns}
Pollard - Cottam	-11.497	4.858	0.799	-13.117	-9.877	-14.396	36	.000**
Pollard -Haidari	-56.133	11.403	1.875	-59.935	-52.331	-29.942	36	.000**
Pollard -Dalahoo1	8.58	4.829	0.794	6.97	10.19	10.808	36	.000**
Pollard - Dalahoo2	-8.573	4.967	0.817	-10.229	-6.917	-10.498	36	.000**
Cottam -Haidari	-67.63	12.894	2.12	-71.929	-63.331	-31.906	36	.000**
Cottam -Dalahoo1	-2.917	0.108	0.018	-2.953	-2.881	-163.876	36	.000**
Cottam - Dalahoo2	2.925	4.478	0.736	1.432	4.418	3.973	36	.000**
Haidari - Dalahoo1	-64.713	12.903	2.121	-69.015	-60.411	-30.506	36	.000**
Haidari - Dalahoo2	-64.706	10.978	1.805	-68.366	-61.045	-35.851	36	.000**
Dalahoo1 - Dalahoo2	-							
Dalahoo2	0.007	4.405	0.724	-1.461	1.476	0.01	36	.992 ^{ns}

* * p-value=1%

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273 Fig1-location of study area (Dalahoo County in Kermanshah province).

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Fig. 2. Position of point-centered quarter method in the circle plot

Fig. 3. point-centered quarter method

Fig. 4. The relationship between variance/mean ratio and estimated number of trees per hectare using different equations

Fig. 5. The relationship between the Index of spatial pattern(variance/mean) with accuracy of estimate the number of trees per hectare with different formulas

Figures

Figure 1

location of study area (Dalahoo County in Kermanshah province).

Figure 2

Position of point-centered quarter method in the circle plot

Figure 3

point-centered quarter method

Figure 4

The relationship between variance/mean ratio and estimated number of trees per hectare using different equations

Figure 5

The relationship between the Index of spatial pattern (variance/mean) with accuracy of estimate the number of trees per hectare with different formulas