Effect of quadrat shapes on measurement of tree density and basal area: a case study on Scots Pine (*Pinus silvestris* L.)

Iyan Robiansyah

Pusat Konservasi Tumbuhan Kebun Raya Bogor, LIPI
Jl. Ir. H. Juanda 13, Bogor 16003
Email: iyanrobiansyah@yahoo.com

Abstract

While quadrat shape of 10 x 10m has been commonly used in tree studies, the efficiency of this shape compared to the other shapes of size 100 m^2 has not been tested. In this study, effect of various shapes of 100 m^2 quadrat on measurement of Scots Pine (*Pinus silvestris* L.) density and basal area would be assessed. The aim was to assess the effect of quadrat shapes of 10 x 10m, 5 x 20m and 2 x 50m on the estimation of density and basal area of the pine in two woodlands in Norwich and to find the most efficient shape, statistically and with respect to sampling time. The results from all quadrat shapes similarly showed that the density and basal area of the Pines between two woodlands were significantly different. In site with lower pine density, the density and basal area measurement were not affected by variety of quadrat shapes. In site where the density of the Pine was higher, however, mean density and basal area measurement using 2x50m quadrat gave higher value than of the other two shapes. In term of efficiency, all shapes were not significantly different in statistical precision and sampling time. Shape of 5x20m, however, was more preferable as it required fewer samples before the mean of density and basal area always falls inside the 95% confidence interval of whole samples mean.

Key words: quadrat shapes, Scots pine, *Pinus silvestris*, tree density, tree basal area

Abstrak

Ukuran kuadrat 10 m x 10 m telah umum dipakai dalam studi ekologi, dan efisiensi dari bentuk ini dibandingkan bentuk lain dengan ukuran yang sama belum pernah diuji. Pada penelitian ini efek dari berbagai bentuk kuadrat 100 m^2 terhadap pengukuran kepadatan dan basal area dari Pinus Scots (*Pinus silvestris* L.) akan dikaji. Tujuannya adalah untuk melihat pengaruh bentuk kuadrat 10 m x 10 m, 5 m x 20 m dan 2 m x 50 m terhadap estimasi kepadatan dan basal area Pinus Scots di dua hutan di Norwich dan untuk menemukan bentuk quadrat yang paling efisien baik secara statistik maupun waktu pengambilan sampel. Hasil pengukuran dari seluruh bentuk kuadrat menunjukan bahwa kepadatan dan basal area Pinus Scots di dua hutan berbeda secara signifikan. Di hutan dengan kepadatan pinus yang rendah, pengukuran kepadatan dan basal area tidak dipengaruhi oleh bentuk kuadrat. Hasil yang berbeda ditujukan pada pengukuran di hutan dengan kepadatan pinus yang tinggi dimana kuadrat 2 m x 50 m memberikan rataan kepadatan dan basal area yang lebih tinggi dari dua bentuk yang lainnya. Dalam hal efisiensi, semua bentuk kuadrat tidak berbeda secara signifikan baik dalam hal presisi statistik maupun waktu pengambilan sampel. Akan tetapi, bentuk kuadrat 5 m x 20 m memerlukan jumlah sampel yang kurang sebelum rataan kepadatan dan basal area hasil pengukuran selalu berada pada rentang selang kepercayaan 95% dari rataan seluruh sampel.

Kata kunci: bentuk kuadrat, Pinus Scots, kepadatan, basal area

Introduction

The method of quadrat sampling is among the oldest techniques in ecology and was first introduced by Pound and Clements in 1898. The term quadrat is strictly defined as a 4-sided figure. In practice, however, this term usually refers to any sampling unit, whether circular, hexagonal, or even irregular in outline (Muller-Dombois and Ellenberg, 1974). The method has two basic requirements: the area is known and the organisms are relatively immobile during the counting period (Krebs, 1999). Due to these reasons, quadrat method has been used extensively on plants (Krebs, 1999; Sutherland, 2006).

Different vegetation types require different quadrat sizes. For the tree layers in temperate forests, a quadrat shape of 10 m x10 m (100m^2) is the most commonly used (Oosting, 1956; Krebs, 1999). Within this quadrat, various attributes can be measured, including density, cover, frequency and biomass (Sutherland, 2006). Ayres (2010) explained that the accuracy and precision of these measures can be affected by several factors, including measurement error, total area sampled, dispersion of the population, quadrat size and shape of quadrat.

This last factor has been tested mostly on grass vegetation (e.g. Wiegert, 1962; Van Dyne *et al.*, 1963; Klimes *et al.*, 2001) and crops (e.g. Brummer *et al.*, 1994). These studies found that in term of data variability, a circular quadrat, which has the least perimeter per unit area, is better than a rectangular, square, or strip one. Few studies have tested this for trees.

Since the shape of the quadrat can influence the accuracy and precision of the measurement results, we have to choose the best one. According to White (2010), the best quadrat can be defined in three ways: (1) statistically, as that quadrat shape giving the highest statistical precision. Dixon & Massey (1957) stated that a statistic which has a variance smaller than other estimates of the same population parameter is an "efficient" estimate; (2) ecologically, as that quadrat shape that are most efficient to answer the question being asked; and (3) logistically, as that quadrat size and shape that are easiest to establish in the field. In many cases, the statistical criterion and the ecological criterion are the same.

In this study, effect of various shapes of 100 m quadrat on density and basal area of Scots Pine (*Pinus silvestris* L.) were assessed. The aim was to address the following two questions: (1) What is the effect of quadrat shape on the estimation of density and basal area of the pine, and (2) Which shape of quadrat is the most efficient in estimating the measures, statistically and with respect to sampling time.

Methods

Study site and species

The study was carried out in two woodlands near the University of East Anglia, Norwich, UK. Covering area of 31,875 m^2, the first woodland are dominated by Oak (*Quercus sp.*), Birch (*Betula sp.*) and Scots Pine (*Pinus silvestris* L.). The second woodland is 27,968 m^2 in size and dominated by Scots Pine. Scots Pine is one of the world's most widespread conifers (Earle, 2010). The species is commonly sold as a Christmas tree in North America and Britain, and an important timber species throughout much of its range (Earle, 2010).

Sampling procedure

Three shapes with area of 100 m^2 were used in this study are 10 m x 10 m, 5 m x 20 m and 2 m x 50 m. Within the selected two sites, 15 quadrats of each shape were randomly placed. This was done by placing randomly 15 points on Google Earth (www.earth.google.co.uk) and then recording the coordinates of each point. The points were generated using RANDBETWEEN function in Microsoft Excel (2007). In the woodlands, those points were located by means of GPS (Garmin eTrex H) and then the three shapes of quadrat were placed with those points as starting line (Figure 1). The pines inside the quadrat were counted and the diameters of the trunks at 1.3 m were measured. The trees on the edge of the quadrat were included if 50% or more of the trunk were inside. In addition, the time needed to complete each quadrat was also recorded.

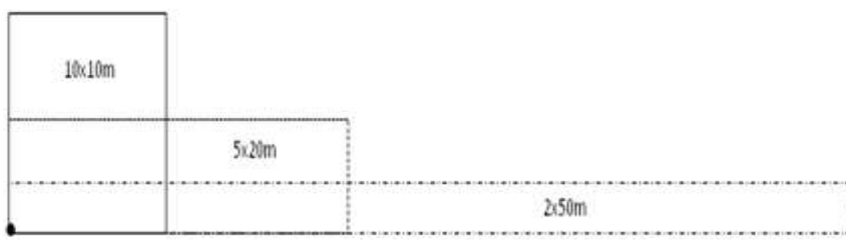

Figure 1 Schematic of placing the quadrat shapes using one point as a starting line. Black point at the bottom left is the point with GPS coordinates

Data analysis

The normality of the distribution and equality of variance of the data were verified with One-Sample Kolmogorov-Smirnov test and Levene's test, respectively. Within each site an ANOVA (or Kruskal-Wallis if the data was not normally distributed) was used to test the difference of sampling time, density and basal area of the pine between quadrat shapes. Further, to test the difference of those parameters between sites for each quadrat shape, a t-test (or Mann-Whitney test for non-normal distributed data) was performed. All the analyses are performed using PASW Statistic 18.

Results

All data were normally distributed except in site 1 for density measurement of 10x10 m^2 (Z= 1.39, n=15, P=0.042) and 2x50 m^2 (Z= 1.45, n=15, P=0.03) quadrat and for sampling time of 10x10 m^2 (Z= 1.56, n=15, P=0.015).

Density and basal area

Quadrat shapes did not affect the density measurement of the Pine in site 1 as the mean density between shapes and were not significantly different (Kruskal-Wallis Test, X^2_1=0.202, P=0.653) (Figure 2). Similarly, in site 2 the densities were not significantly different ($F_{2,42}$=2.595, P=0.087) although the density of 2x50m quadrat was much higher than of the other shapes. A similar pattern was also observed for basal area measurement. In site 1 the mean did not differ significantly ($F_{2,42}$=0.476, P=0.625). In site 2, however, basal area from 2x50 m quadrat shape was significantly higher that of the other shapes ($F_{2,42}$=4.082, P=0.024). Figure 3 also shows clearly that density and basal area of the pine in site 1 was lower that of in site 2 for all quadrat shapes (confirmed by t-test and Mann-Whitney Test, Table 1).

Relative efficiency

Quadrat shape efficiency was determined from the perspective of statistics and sampling time.

In site 1, three data dispersion (i.e. standard error mean, standard deviation and variance) of density and basal area data for the 5x20 m^2 shape were lower than of the other shapes (Table 2). While the dispersion of basal area data were almost the same for every quadrat shapes, data dispersion of density for 2x50 m^2 shape had lower values than of the others in site 2 (Table 2). Test of homogeneity of variance using Leven's test, however, showed that in both sites the variance of density ($F_{2,24}$=0.006, P=0.99 and $F_{2,24}$=1.46, P=0.24 for site 1 and 2, respectively) and basal area ($F_{2,24}$=0.017, P=0.98 and $F_{2,24}$=0.12, P=0.88 for site 1 and 2, respectively) were equal across all the shapes. Since all three types of data dispersion were related each other, this indicated that all shapes had similar efficiency in term of statistical precision.

The second aspect of efficiency was sampling time. The Kruskal-Wallis Test for sampling time in site 1 (X^2_1=1.065, P=0.302) and ANOVA one way for site 2 ($F_{2,42}$=0.231, P=0.795) showed that sampling time for each quadrat shape did not differ significantly in both sites.

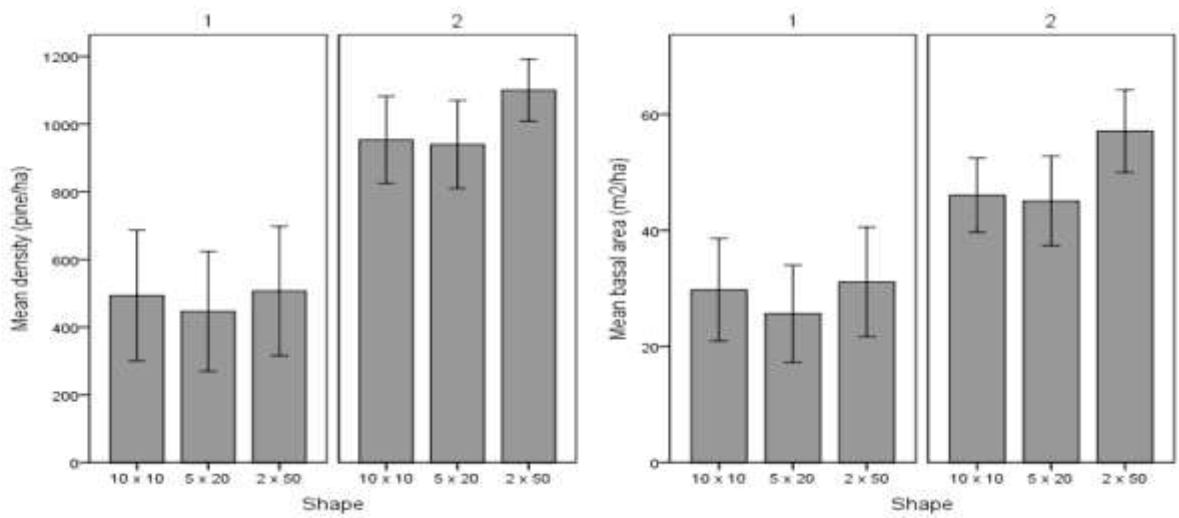

Figure 2 Mean density and basal area of Scots Pine in the two study sites. Numbers at top and below of the graphs represent sites and quadrat shapes (m), respectively. Error bars represent 95% confidence interval

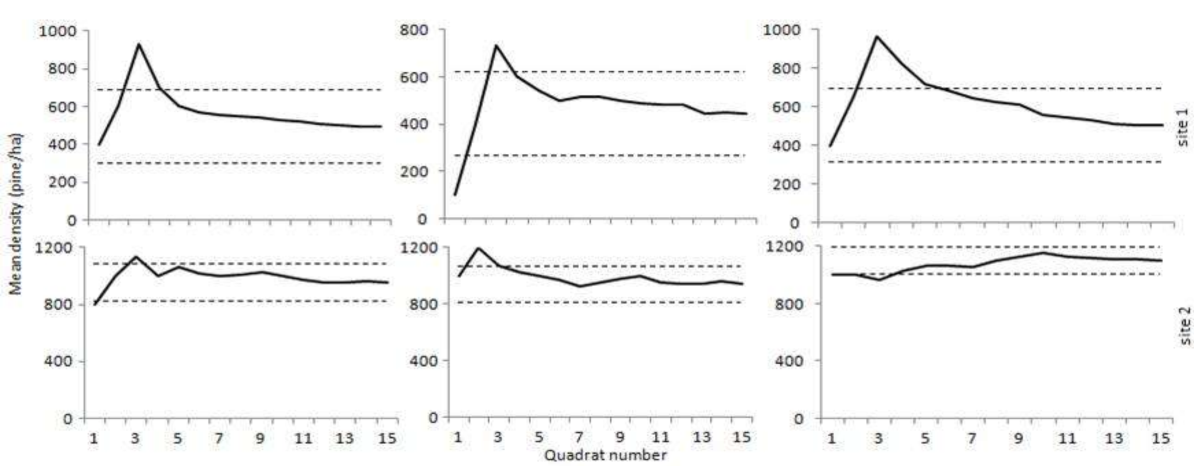

Figure 3 Mean density of Scots Pine in every quadrat number. Dashed lines are 95% confidence interval of the all samples. From left to the right is shape 10x10m, 5x20m and 2x50m, respectively.

Table 1 Test for difference of density and basal area of Scots Pine between two study sites

Shape	Density		Basal area	
	Statistic	P	Statistic	P
10x10m	$U_{15,15}$=19.5	<0.0001	t_{28}= -3.211	0.003
5x20m	t_{28}= -4.805	<0.0001	t_{28}= -3.662	<0.001
2x50m	$U_{15,15}$= 16	<0.0001	t_{28}= -4.724	<0.001

In addition to data dispersion and sampling time, efficiency could be also assessed by determining how many samples for each shape are required before the mean reach the stability. By the 'stability' I mean the condition where the mean of the collected samples always falls inside the 95% confidence interval of whole samples mean. For density in site 1, shape 10x10 m^2, 5x20 m^2 and 2x50 m quadrat required 5, 4 and 6 samples, respectively, while in site 2 they required 4, 3 and 4 samples before the mean became stable (Figure 3).

The mean of basal area in site 1 became stable for 10x10 m^2, 5x20 m^2 and 2x50 m^2 shapes after collecting 5, 3 and 9 samples, respectively (Figure 4). In site 2, number sample of 4, 3 and 5 are required before the mean became stable. From all the results, it appeared that quadrat shape of 5x20 m^2 required fewer samples in order to reach mean stability.

Table 2 Data dispersion of density (pine/ha) and basal area (m^2/ha) measurement for each quadrat shape in two study sites

Measures	Data dispersion	Site 1			Site 2		
		10x10	5x20	2X50	10x10	5x20	2X50
Density	Standard error of mean	90.22	82.73	89.16	60.05	60.79	42.54
	Standard deviation	349.42	320.42	345.31	233.58	235.43	164.75
	Variance	122.095	102.666	119.238	54.095	55.428	27.142
Basal area	Standard error of mean	4.12	3.91	4.39	2.98	3.59	3.31
	Standard deviation	15.94	15.16	17.02	11.54	13.91	12.82
	Variance	254.07	229.87	289.72	133.1	193.5	164.31

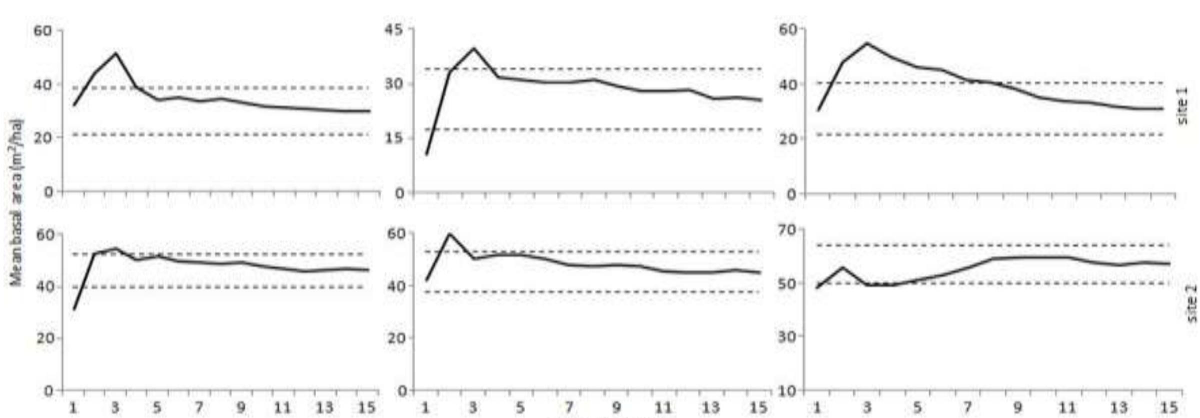

Figure 4 Mean basal area of Scots Pine in every quadrat number. Dashed lines are 95% confidence interval of the all samples mean. From left to the right is shape 10x10m, 5x20m and 2x50m, respectively.

Discussion

This study showed that in a site with low Scots Pine density, the density and basal area measurement of were not affected by quadrat shape for a given quadrat size. In site where the density of the trees was higher, however, mean density and basal area measurement using 2x50 m quadrat were higher than for the other two shapes. In terms of efficiency, shapes did not differ for statistical precision and sampling time. The shape of 5x20 m^2, however, required fewer samples before the mean density and basal area to always fall the 95% confidence interval.

Shape effect on mean density and basal area

Since choice of quadrat shape is not about biased measurements but is about narrower confidence limit and higher accuracy (White, 2010), we expected that all shapes of a given area would give the same mean density and basal area value. The results of this study followed this expectation except for the higher density and basal area measurement using 2x50 m quadrat in site with high density of the pine, which might indicates the presence of edge effects. Edge effects are important because they lead to possible counting errors. They often produce positive biases because observers tend to include individuals that lie on the quadrat boundary (Sutherland, 2006; White, 2010). Moore & Chapman (1986) explained that the greater the length/breadth ratio the greater will be the edge effect. In this study, the ratio of length/breadth in 2x50m quadrat was the highest compared to the other shapes which might lead to produce positive bias as showed on the results. As study of herbage yield on the Red Bluff Ranch in Montana by Van Dyne *et al.* (1963) showed a similar pattern to this study. The authors found that the mean yield of plot 8x18 inches was significantly higher than of plot 12x24 inches. As the first plot had approximately 38% more perimeter per unit area than the second one, the authors concluded that this difference was due to edge effects. Similarly, the study of shape effects on estimates of herbage yield by Burlison (1949) in Idaho Palouse grassland also showed that plot with higher perimeter per unit area had significantly higher yield estimates.

Relative efficiency

Our study found that all shapes had no difference in data dispersion and sampling time. In both sites, however, the shape of 5 m x 20 m needed fewer samples before its mean estimation of density and basal area became always within the confidence limit of all samples. This could be an indication that this shape is more efficient than others in estimating density and basal area of Scots Pine in these woodlands. In comparison to the other two shapes, 5 m x 20 m may have a lower probability of edge effects than 2 m x 50 m due to its lower length/breadth ratio. Compared to the 10 m x 10 m shape, however, it had enough length to capture more of the habitat variability that might exist in the field. This might be the reason why 5 m x 20 m shape required fewer samples to reach mean density and basal area stability.

Previous studies concerning quadrat shape efficiency showed variable results. One study concluded that long, thin quadrats were the most efficient while another study showed that the compact quadrat was the best one. For instance, the study by Van Dyne *et al.* (1963) found that less variable yield data per unit area were obtained with circular than with rectangular, square, or strip plots. In this case, the circular plots had the lowest length/breadth ratio compared to the rest of the shapes. Thus, the observer had fewer decisions about whether to include or exclude the individual, which lead to more consistence measurement. This result was different to the study of Clapham (1932) who counted the number of self-heal (*Prunella vulgaris*) plants in 1 m^2 of 2 shapes: 1m x 1m (square) and 4 m x 0.25 m (rectangle). His results showed that a rectangle shape had lower standard error mean and narrower confidence interval and hence was better and more efficient than a square one. A similar result to Clapham's study was also showed by Bormann (1953) who measured basal area of trees in an oak-hickory forest in North Carolina using several quadrat

shapes. He found that long, thin quadrats obtained the highest precision (lowest standard error mean). Both authors argued that long quadrats cross more patches and thus capture more of the habitat variability, leading to more consistence measurement.

Implication for practice

All the issues encountered in this study have to be considered when using small number of samples and few sampling sites. Nevertheless, it shows that the choice of the most widely used 10 x 10 m quadrant may not always be best for vegetation analysis, and for this reason each population should be analyzed independently. For Scots Pine in our sample forests, this study showed that the 5x20m quadrat was preferable.

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