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Yield Assessment of Tree Resources Outside the Forest Using Sector Sampling: A Case Study of a Public Park, Bangkok Metropolis, Thailand

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ABSTRACT

The objectives of this study were to determine a suitable sector angle for a sector sampling inventory of trees outside the forest (TROF), and yield assessment of volume, diversity, biomass, and carbon storage at Wachirabenchatat Park, Bangkok metropolis, Thailand. Three angle sizes of 5, 10, and 15 ° were examined. In each angle size, eight sectors were randomly selected within the same study area, emanating from the same pivot point but going in different directions. The results showed that an angle size of 5 ° was suitable for sector sampling because of the slightly lower relative standard errors (SE%) of the tree volume and similar diversity index estimates, when compared with the other sector angles. From a study of the coefficient of variation of tree volume, the suitable number of sample sectors was six (sample size), for sampling in a similar study area. The results of a yield assessment study in Wachirabenchatat Park using an angle of 5 ° included estimates of biodiversity, volume, biomass and carbon storage estimates of trees. Twenty nine unique species were identified, the total volume of tree stems was 910.72 m^3 (15.0 m^3/ha); the total tree biomass and carbon storage in this selected area were 559.58 and 279.79 tonnes, respectively.

Keywords: sector sampling, tree resources outside forest, yield assessment, Wachirabenchatat Park, Bangkok

INTRODUCTION

Trees in urban parks are a part of trees outside the forest (TROF). According to the United Nations Food and Agriculture Organization (FAO), TROF refers to trees on land not defined as forest and other wooded land. This may include agricultural land, including meadows and pasture, built-on land (including settlements and infrastructure) and barren land (including sand dunes and rocky outcroppings). It may also include trees on land that fulfils the requirements of a forest or other wooded land except that: 1) the area is less than 0.5 ha, 2) the trees are able to reach a height of at least 5 m at maturity in situ but the stocking level is below 5%, 3) the trees are not able to reach a height of 5 m at maturity in situ where the stocking level is below 10% and 4) the trees are in shelterbelts and riparian buffers of less than 20 m width and less than 0.5 ha (FAO, 2002).

In Thailand, TROF are not specifically defined, but could be interpreted to mean trees in

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areas outside conservation and production forests. TROF are an important resource in Thailand for rural livelihood, for biodiversity conservation and for carbon sequestration. Thus, their assessment for volume, biodiversity and carbon content is important.

The most widely used method of forest resource assessment or sampling in Thailand is fixed-area sampling such as a line-plot survey. However, in some cases this system is not suitable for TROF where there are irregularly shaped areas, boundaries are not defined and trees are typically very scattered which can include settlements and infrastructure. In 2006, a suitable technique called "sector sampling" was developed in British Columbia, Canada by Iles and Smith (2006). However, this technique has never been formally researched or operationally applied in Thailand.

The shape of a sector sampling plot is similar to the letter "*A*" in the English alphabet or to dovetailing one end from each of a pair of chopsticks to make an angle. The sector sampling method is applicable for small areas and areas with irregular or uneven boundaries. The sample plot shape depends on the area boundary shape. In tree selection, the equal probability principle is used. The principle of sector sampling based on Iles and Smith (2006) is as follows. From any pivot point inside or outside the polygon, establish a sector with angle size α selected with equal probability (θ_a) for any orientation (Figure 1). An object picked by the sector is sampled with probability equal to s/C, where s is the arc length within the sector and C is the circumference. In one complete revolution, the arc length, s, passes through the object for s/C of the total circumference. The pivot point can be located anywhere, based on operational convenience, since the probability of tree selection (s/C) depends only on · and not on r, where r is the distance from the pivot point to the tree (Iles and Smith, 2006).

The objectives of the present study were to determine a suitable sector angle for a sector sampling inventory of trees outside the forest (TROF) in Wachirabenchatat Park, Bangkok metropolis and to carry out yield assessment of the volume, biomass and carbon storage. Three angle sizes of 5, 10, and 15 ° were examined.

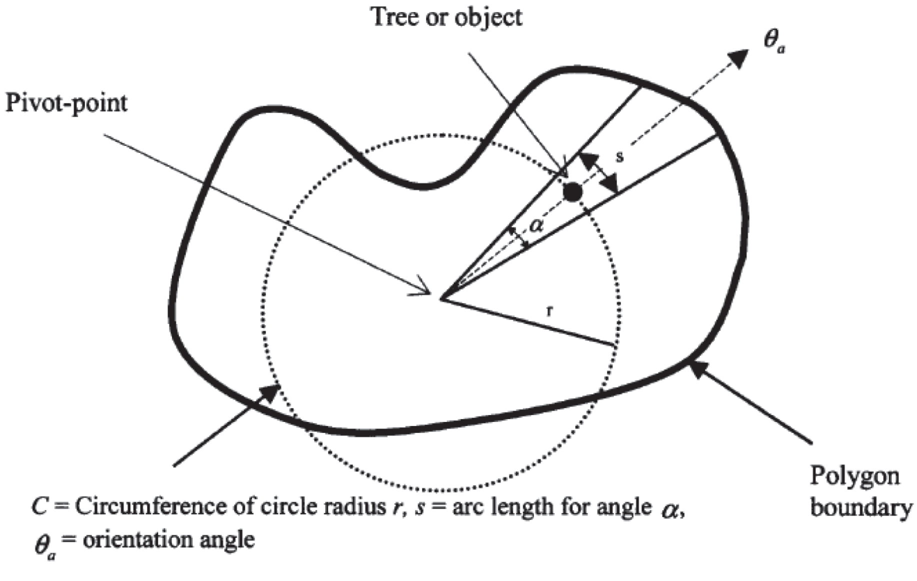

Figure 1 Sector sampling technique.
Source: Smith *et al.* (2008)

MATERIALS AND METHODS

Study area

The study area was in Wachirabenchatat Park (60.7 ha), which is located in Chatuchak District, Bangkok metropolis. In 1991, the Wachirabenchatat Park was established through a donation of land by the State Railway of Thailand. It is the biggest and the newest park in the Bangkok metropolis. The Wachirabenchatat Park is well known as the State Railway Public Park or Suan Rot Fai. On July 2002, the name was changed to honor HRH crown Prince Maha Vajiralongkorn's 50th birthday anniversary (Public Park Office, 2007).

Fieldwork

A survey was conducted in Wachirabenchatat Park using the sector sampling technique involving three angle sizes: 5, 10, and 15 °. For each angle size, eight sectors were randomly selected in the study area in eight compass directions (north, northeast, east, southeast, south, southwest, west and northwest), all emanating from one subjectively selected pivot point. The tool for measuring the angles and establishing the sector plot was the Suunto KB-14. All trees inside the sector plot were measured and tree species, diameter at breast height and total height were recorded. For accurate volume and biomass determination, each tree total height was divided into logs of 2 m in length and the last log was measured as the actual remaining length. A pentaprism was used to measure the tree diameter at three points on each log, at the base, middle and top.

Data analysis

Data analysis was conducted using the following steps. Firstly, log volume was determined using Newton's formula (Prasomsin and Duangsathaporn, 2005) and converted into an estimate of tree total volume. Secondly, total tree volume for the Park was estimated based on the volume of the study area using the formula of Iles and Smith (2006), including the estimated standard deviation, standard error and coefficient of variation for the volume estimate. Thirdly, tree biomass was estimated indirectly as trees were not allowed to be destructively sampled by cutting. Relationships between the biomass, specific gravity values and trees volume were used. The biomass was estimated by multiplying the specific gravity values by the tree volume. Fourthly, carbon storage assessment was calculated as 0.5 multiplied by the biomass (Dixon *et al.*, 1994; Brown, 1997). Finally, the diversity index was calculated based on the Shannon-Wiener's index diversity formula (Shannon and Weaver, 1964).

Further details of the volume, biomass, carbon content and species diversity calculations are outlined below.

Volume

The basic statistics for the calculations of sector sampling are:

1) Tree volume assessment per sector (V_s), and in the case of more than one sector, use average volumes ($\hat{V}$) in Equation 1:

$$V_s = [(\sum_{t=1}^{n} V_t)*(360°/\text{sector angle})] = (\sum_{t=1}^{n} [\frac{V_t}{P_t}]) \quad (1)$$

where: V_s = total tree volume in the study area, assessed by sector s

V_t = a tree volume

P_t = probability of tree selection

sector angle = angle used for sampling sector s (5, 10 or 15 °)

n = number of tree 1, 2, 3, …, n

2) Tree volume assessment for the total area, for more than one sector was calculated using Equation 2:

$$\hat{V} = \frac{\sum_{s=1}^{ns} V_s}{n_s} \quad (2)$$

3) The sector tree volumes were used to calculate the total volume standard deviation, standard error and coefficient of variation using the usual statistical formulas for simple random sampling.

Biomass

Biomass refers to the amount of organic matter in the living parts of plants both aboveground and underground. Biomass can be measured using the fresh weight or the dry weight; with dry weight measurement, the value is more constant because moisture is removed. The unit of biomass is tonnes per area. Biomass can be measured using three methods:

1) cut all plants in the area and determine their fresh weight, then remove the moisture by determining the oven-dry weight and then compare the fresh and dry weight to determine the actual biomass. This method is complicated and uses a lot of labor, time and budget, but the result is more accurate.

2) cutting selection by finding the mean tree. This is appropriate for a pure stand and a young forest.

3) weigh some samples then calculate a relationship between parts of the plant. This method is known as the allometric method. However, trees are not allowed to be cut in Wachirabenchatat Park. Thus none of these methods were appropriate.

Hence, the biomass was calculated using the relationship between specific gravity values and tree volume. The specific gravity values of trees from reference books were used (Viriyabuncha, 2003; Forest Research and Development Bureau, 2005). The specific gravity value is defined as the wood dry weight divided by the water weight equal to the volume of the fresh or dry tree (Chunwarin, 1990). The biomass was estimated using the specific gravity values multiplied by the tree volume.

Carbon

Forests play an important role in the global carbon cycle (Fukuda *et al*., 2003; Masera *et al*., 2003; Jandl *et al*., 2006) and approximately one-half of a tree's biomass (dry weight) is carbon. Therefore, when the tree grows, carbon storage increases in the tree roots, stems, branches and leaves through the process of photosynthesis and carbon dioxide fixation from the air into the tree's biomass (Pumijumnong, 2004).

The amount of carbon storage in trees can be estimated by assuming that carbon is approximately 50% of the biomass (Dixon *et al*., 1994; Brown, 1997). Therefore, the carbon storage was determined as 0.5 multiplied by the biomass.

Tree diversity

Species diversity was determined using Shannon-Wiener's index of diversity which combines species abundance and species distribution, so that the index equation has two components being the number of species and the distribution of trees. If the species are more variable, the diversity is also more variable. Moreover, if each species is regularly distributed in the area, the diversity will also be high. The Shannon-Wiener's formula (Shannon and Weaver, 1964) is provided by Equation 3:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad (3)$$

where: H' = diversity index

s = number of species

p_i = the proportion of trees in each species (i = species; i = 1, 2, 3, …, s)

ln = natural logarithm

RESULTS AND DISCUSSION

Yield assessment of tree volume, biomass and carbon storage

The results of the sector sampling using angles of 5, 10 and 15 ° to estimate the total tree volume in the study area, along with the relative standard error (%) and coefficient of variation (%) are given in Table 1.

This study showed that sector sampling using a 5 ° angle had the highest total volume compared to that using an angle of 10 or 15 °. Sector sampling using a 10 ° angle gave the highest biomass and carbon storage estimates. The results showed that biomass and carbon storage in a tree were not consistent with total volume; an angle of 5 ° produced the greatest total volume, followed by 10 ° and the lowest was 15 °, but the angle of 10 ° had the largest biomass and carbon storage, second was the angle of 5 ° and the lowest was the angle of 15 °. This was due to the fact that the biomass formula uses specific gravity values multiplied by the tree volume, with some trees having high volume but low specific gravity, resulting in low biomass and low carbon storage.

The results showed that the angle of 5 ° had the lowest standard error (SE%) and coefficient of variation (CV%) of volume, compared to the larger angles, although the differences in SE% among the angles were very small. The 5 ° angle resulted in a smaller sample size and variance of trees than in sampling using angle sizes of 10 and 15 °. Note that the distribution of trees in Wachirabenchatat Park was highly variable or not stable.

Species diversity index

The sector sampling using angles of 5, 10 and 15 ° resulted in a variable number of species (29, 36 and 39, respectively), number of trees (411, 757 and 1048, respectively) and diversity index (2.45, 2.56 and 2.57, respectively) as shown in Table 2.

The angle of 5 ° produced the top five species as *Pterocarpus macrocarpus*, *Tabebuia rosea*, *Acacia auriculaeformis*, *Alstonia scholaris* and *Streblus asper* and the number of trees was 110, 74, 53, 26 and 25, respectively. The angle of 10 ∞ produced similar species as the angle of 5 °, but found seven more species: *Spathodea campanulata*, *Barringtonia macrostachya*, *Dalbergia cochinchinensis*, *Lagerstroemia speciosa*, *Spondias pinnata*, *Eucalyptus camaldulensis* and *Artocarpus heterophyllus*. For the sector sampling using an angle of 10 °, the top five species were the same as for the angle of 5 ° but the number of trees was 179, 143, 91, 61 and 44, respectively. Finally, the sector sampling using an angle of 15 ° found more species than the other two angles, with an additional three species: *Senna*

Table 1 Total volume standard error, coefficient of variation, biomass and carbon storage estimates in Wachirabenchatat Park, Bangkok metropolis using sector sampling with different angle sizes.

Angle (°)	Total volume (m^3)	Relative standard error of volume (%)	Coefficient of variation of volume (%)	Biomass (tonne)	Carbon storage (tonne)
5	910.72	33.30	94.20	559.58	279.79
10	891.34	33.72	95.38	569.86	284.93
15	830.53	34.48	97.54	520.54	260.27

Table 2 Shannon-Wiener diversity index from sector sampling using different angles at Wachirabenchatat Park, Bangkok metropolis.

Angle (°)	Number of unique species	Number of trees	Shannon-Wiener's diversity index	Standard deviation	Relative coefficient of variation (CV%)	Relative standard error (SE%)
5	29	411	2.45	0.09	0.02	0.02
10	36	757	2.56	0.08	0.01	0.01
15	39	1,048	2.57	0.09	0.01	0.01

siamea, Peltophorum dasyrachis, and Moringa oleifera. For the angle of 15 °, the top five species were *Pterocarpus macrocarpus*, *Tabebuia rosea*, *Acacia auriculaeformis*, *Alstonia scholaris*, and *Peltophorum pterocarpum* and the number of trees was 236, 193, 119, 92 and 85, respectively. From these results, it appeared that increasing the angle size increased the likelihood of additional unique species being found in the study area.

The Shannon-Wiener diversity index values (H') are shown in Table 2. This index value typically ranges from 0 to about 4.6. A value near 0 would indicate that every species in the sample is the same. A value near 4.6 would indicate that the number of individual are evenly distributed between all the species. This study produced Shannon-Wiener diversity index estimates with middle values within the range 2.45–2.57 (Table 2), which means that every species in the sample was the same. The sector sampling using an angle of 5 ° had slightly lower Shannon-Wiener diversity index values, but the values were similar to those from sampling using larger angles.

Suitable angle for sector sampling

The relative standard errors (%) of the total volume from using sector sampling with angles of 5, 10, and 15 ° are shown in Table 1. The criteria for a suitable angle include a low standard error of the total volume and the diversity index. From Table 1, sector sampling using an angle of 5 ° had the lowest standard error of the volume, although the differences between angles were very small. In addition, although 5 ° had the lowest diversity index estimate, its values were similar to those obtained using 15 °. Consequently, sector sampling using an angle of 5 ° was more suitable since it had a low or comparable standard error of the volume and provided a similar diversity index value.

Suitable number of sectors for sector sampling

The suitable number of sectors for sampling in the study area was investigated using the relationship between the relative coefficient of variation (CV%) of the volume and the number of sample sectors. A plot of the graph between the CV% of the volume and the cumulative number of sectors for each angle is shown in Figure 2 which indicates that the CV% gradually increased as the number of sectors increased up to six sectors, after which it stabilized and became relatively constant. Thus, the suitable number of sectors was six, since using the additional sectors (7 or 8) did

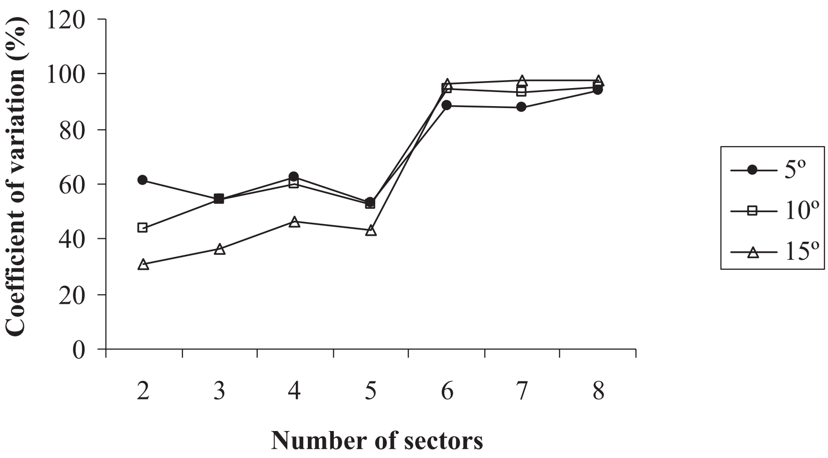

Figure 2 Coefficient of variation of volume determined by sector sampling using various angle sizes versus cumulative number of sectors at Wachirabenchatat Park, Bangkok metropolis.

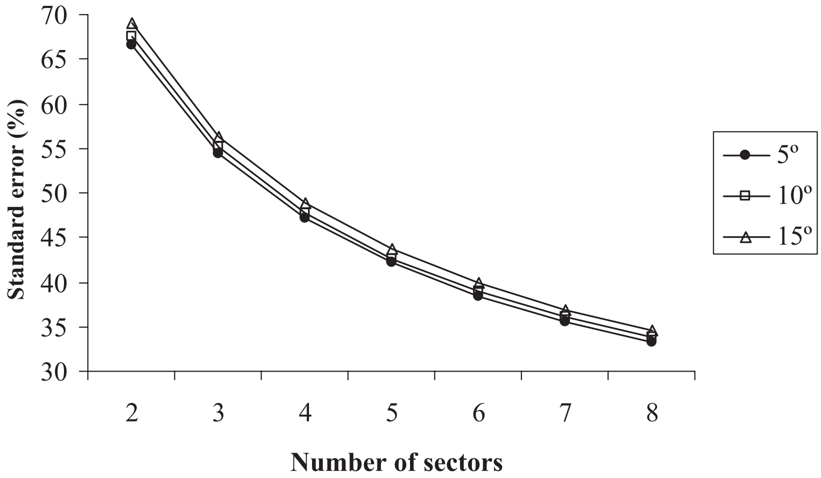

Figure 3 Standard error of sector sampling by angle size variation and use number of sector variation, at Wachirabenchatat Park, Bangkok metropolis.

not result in much change in the CV%. The number of sample sectors could be increased if a lower allowable SE% were desired.

The suitable number of sectors for sampling in the study area was also investigated using the relationship between the relative standard error of the volume (SE%) and the number of sample sectors. A plot of the graph between SE% and the number of sectors for each angle is shown in Figure 3 which indicates that the SE% decreased sharply initially and then more gradually as the number of sample sectors increased. The rate of decrease in SE% seemed to stabilize also around six sectors, so that an increase in the number of sectors above six did not reduce the SE% appreciably. Thus, again, it appears that the suitable number of sample sectors was six.

CONCLUSION

The results showed that the suitable angle for sector sampling in Wachirabenchatat Park was 5 ° because it resulted in the lowest standard error of the total volume estimate, although the estimate of the tree diversity index was slightly lower than that based on the angles of 10 and 15 °.

The appropriate number of sectors was six because the estimate of the coefficient of variation of total volume stabilized or was relatively constant for a greater number of sectors than six.

Using sector sampling and a 5 ° angle, the yield assessment study provided estimates of total volume, biomass and carbon storage in Wachirabenchatat Park of 910.72 m^3, 559.58 tonne and 279.79 tonne, respectively.

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