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Comparison of Plot Sizes for Forest Inventory in Natural Deciduous Forest in Korea

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Abstract : The plot design influences the budgets and the precision of forest inventory results. The objective of this study is to determine the efficiency of estimating forest variables such as tree density, basal area, volume, and species richness based on various plot sizes using fixed-area plot sampling in the natural deciduous forest of Pyeong-Chang County, Gang-won Province, Korea. In this study, 108 reference plots were established with a fixed plot size and shape of 0.09 ha (30 m×30 m). In order to determine the optimal plot size for the interest of variables, each sample plot was established using different shapes (square, circle, and rectangle) and was divided into different plot sizes from 100 to 900 m^2. The mean relative difference (MRD) for the sum of the basal area and volume, and tree density per hectare decreased as plot size increased. But the MRD for three variables were only below 13% at the plot size of 500 m^2. Species richness for each reference stand observed ranging from 2 to 15 species, demonstrated highly positive significant relationships with plot size. The minimum plot size for the estimation of tree density, the sum of the BA and volume was determined to be about 400 m^2, whereas the estimation of species richness required a minimum plot size of 500 m^2.

Key words **:** *forest sampling, mean relative difference, species richness, tree density*

Introduction

Data and information about forest resources, including the state and changes of forest, are required by various users including forest owners, forest managers, politicians, environmental organizations and research institutes, and at different scales such as local, provincial, national, and global level with the objective of ensuring the sustainable management of the natural resource. Forest inventories are an effective means for providing this information to the interested parties.

In South Korea, a national forest inventory (NFI) system exists, which was developed in the 1960s and is being implemented currently. Already the NFI implemented its fourth phase (1996-2005) with the coordination of KFRI (Korea Forest Research Institute). The inventory system used a stratified sampling with clusters of sub-plots. Initially, aerial photos were observed to classify the forest cover type. Ground measurement of the field plots was identified by the forest cover type for stratification (KFRI, 1996). In the 4th NFI the 500 m^2 plot size with a circular shape was empirically applied for estimating of the growing stock. However, the source from NFI should not provide various information of forest resource to various users, exclusively for national politicians, because plot design for the NFI has not changed. The aim of the NFI in Korea was to provide information only for timber production and not for ecosystem assessment and sustainable management of forest resources (KFS, 2002; Shin *et al.*, 2002).

Plot size plays an important role in all sampling techniques for conducting forest inventories (Zeide, 1980). The budget and the precision of inventory are influenced by plot size. In general, large plots require a smaller number of plots to describe the population parameters, but the average time needed to measure those plots is greater than that required by small plots. Furthermore, larger plots are more difficult to search out thoroughly than the smaller plots. In addition, an efficient plot size differs according to the variables of interest, which might be tree diameter and height (Lee and Han, 1984; Lynch, 2003; Grey, 2003), basal area and volume (Brooks and McGill, 2004), forest biomass (Spetich and Parker, 1998), species richness (Park, 1994; Standen, 2000), regeneration (Corona *et al.*, 1998), budworm and mortality (Lynch, 2003) etc. For instance, in a compar-

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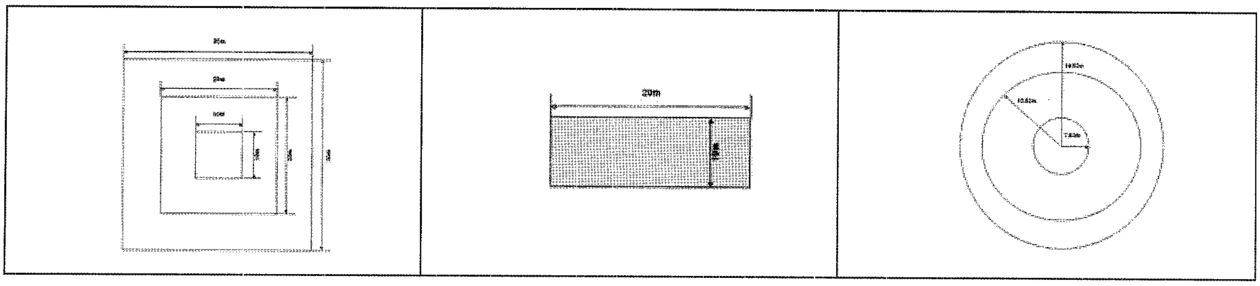

S1: 10*10 = 100 m^2, S2 : 20*20 = 400 m^2, S3 : 30*30 = 900 m^2, R : 20*10 = 200 m^2 C1 : r = 5.64m ≈ 99.9 m^2, C2 : r = 12.62m ≈ 500 m^2, C3 : r = 14.93m ≈ 700 m^2

Figure 1. Plot design simulation for forest inventory in natural deciduous forest in Korea.

ison of 144 sampling designs in forest inventory, Kulow (1966) found that sampling precision and accuracy were proportionate to the size of the sampling unit. He also determined that the plot size of 0.04ha (400 m^2) and 0.08 ha (800 m^2) resulted in significantly better results than smaller sampling units by greatly reducing the difference between the true mean and the estimated mean. In general, in forest inventory the plot size is determined based on the criterion of tree density, with a mean of 15 to 25 trees per plot (Akça, 2000; Šmelko, 1968).

The optimal plot design produces a high level of precision at a low cost. Many researchers have conducted studies for optimal plot design (Freese, 1960; Zeide, 1980; melko and Saborowski 1999), but the previous studies in Korea could not provide enough information about an efficient plot design for the natural deciduous forests(Kim, 1965; Lee and Han, 1984; Byun and Yoo, 1988). Therefore, the objective of this study is to determine the efficiency of estimating the variables of interest based on a variety of plot designs using fixed-area plot sampling in natural deciduous forest stands in Korea.

Materials and Methods

1. Study site

The study site selected was a natural deciduous forest within a national management forest in Pyeong-Chang county, Gang-won province, South Korea. The study site is located at 37°25'~30' of east longitude and at 128°30'~35' of north latitude, in the northeast region of South Korea. The study site area is approximately 2,400 ha. The altitude ranges from 550 m to 1,500 m and the mean altitude is about 1,000 m in a rugged mountain range. The climate at the study site is mild, averaging a maximum temperature of about 11.1°C and a minimum of about 1.7°C. The relative humidity averages 74%. The parent rocks consist of gneiss or limestone; the forest soil is a fertile brown (KFS, 1990).

2. Field methods

At the study site, 108 numbers of plots were established having a fixed plot size of 0.09ha (30 m×30 m). At each sample plot, all trees with a diameter greater than 6cm at DBH (1.2 m) were measured. The data recorded included number of tree species, DBH, height, and the coordination (x, y) of each individual tree (Shin *et al.*, 2001).

In order to determine the optimal shape and size for the plots, each sample plot was distinguished by its different shape that could be square (S1, S2, S3), circular (C1, C2, C3), and rectangular (R). Also, each sample plot was divided into different sizes ranging from 100 to 900 m^2 (Figure 1).

3. Data analysis

The different fixed-area plot sampling designs for estimating tree density, basal area, volume, and species richness as number of species were assessed. The plot sizes that were compared included square plots of 100, 400, and 900 m^2, circle plots measuring 99.9, 500, and 700 m^2, and rectangle plot of 200 m^2. The various plot sizes were compared on the basis of the coefficient of variation (CV) and standard error of mean per plot, and the error of estimation between a plot size and a reference plot size.

In order to evaluate the error of estimation for tree density, the sum of the basal area and volume, relative difference was used. The relative difference was computed between the estimate for each plot size and the actual value of the reference stand area, 900 m^2, used for analysis:

$$\text{Relative difference} = \frac{\text{abs}(x_{ik} - \mu_k)}{\mu_k} \times 100 \quad \text{or}$$

$$\text{Difference} = \text{abs}(x_{ik} - \mu_k)$$

where is an estimated mean for the variables by plot size i in stand k, and μ_k is the actual mean in stand k. The difference used for species richness was absolute, not relative, because the absolute difference was more readily interpretable (Gray, 2003).

Results and Discussion

1. DBH and height

The mean coefficient of variation(MCV) for DBH and height varied from 40% to 46% and from 23% to 27%, respectively (Figure 2). The variation of the MCV for DBH and height were determined to be similar in even-aged Korean pine plantation (Lee and Han, 1984). Lee and Han recommended the plot sizes of at least 400m^2 and 800m^2, for DBH and height, respectively. The MCV was nearly constant over the plot size of 200 m^2.

In contrast with the MCV, the mean percent standard error (MPE, %) decreased with increasing plot size because the standard error depended on the tree density by plot size in reference stands but stabilized at plot sizes greater than 400 m^2, where the MPEs were 8% (±1.32 cm) and 5% (±0.59 m), respectively.

2. Basal area and Volume

The MCV for basal area (BA) and volume per plot for each plot size is depicted in Figure 2. As plot size increased the MCV increased. Variation of the MCV for BA and volume converged for plot sizes greater than 400 m^2, that is, differences among the MCV were similar for plot sizes greater than 400 m^2 whenever plot size is increased. In general, the CV for BA and volume in a managed plantation may be about 40%, while in a natural or native forest the CV may exceed 100%. In our case, the MCV ranged from 77% to 97% for BA and from 84% to 107% for volume. At a plot size of 400 m^2, the MCV for BA and volume were 93% and 102%, respectively. The MPE for BA and volume ranged from 30% (±0.008 m^2) to 12% (±0.003 m^2) and from 32% (±0.047 m^3) to 13% (±0.018 m^3), respectively. The MPE decreased with increasing plot size as well. This means that as plot size increased confidence limits of actual mean for each reference stand decreased.

However, the mean relative difference (MRD) for the sum of the BA and volume per hectare decreased as plot size increased (Figure 3). In other words, the error of estimation decreased with increasing plot size. The MRD ranged from 10% to 39% for the sum of the BA and from 11% to 41% for the sum of volume. But the MRD only differed 11% and 13% between plot sizes of 500 m^2 and 900 m^2, respectively.

3. Tree density

The optimal plot size is determined by the criterion of

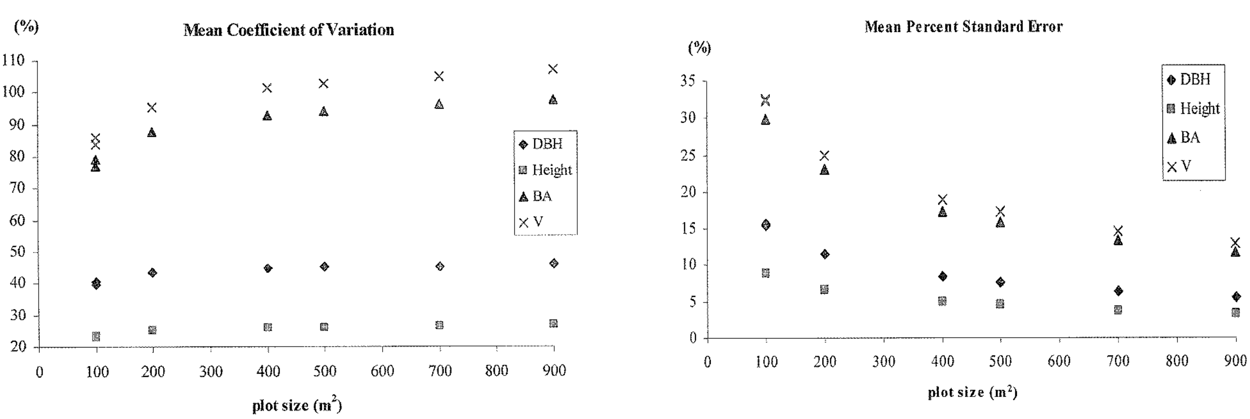

Figure 2. Mean coefficient of variation and mean percent standard error for DBH, height, volume and basal area by plot size in natural deciduous forest in Korea.

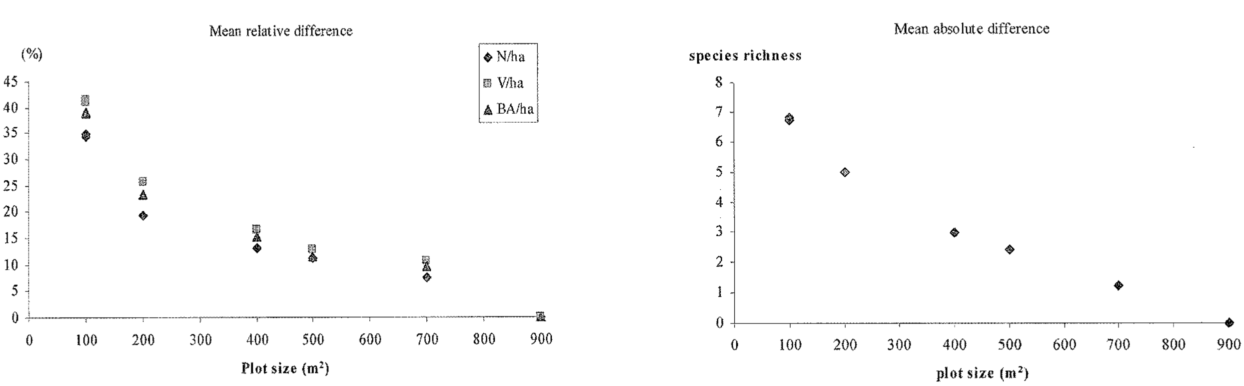

Figure 3. Mean relative differences for tree density, sum of the basal area and volume per hectare and difference for species richness per plots by plot size in the natural deciduous forest in Korea.

Table 1. Mean tree density and tree species richness per plot by plot size in the natural deciduous forest in Korea.

Variable		Plot size (m^2)						
		99.9	100	200	400	500	700	900
Tree density	Mean	8	8	16	31	38	54	73
	Max.	22	23	36	70	90	112	140
	Min.	1	1	4	10	15	21	31
Species richness	Mean	3	3	5	7	8	9	10
	Max.	8	9	10	13	14	15	15
	Min.	1	1	1	1	1	1	2

tree density, with a mean of 15 to 25 trees per plot (Akça, 2000; Ŝmelko, 1968). In this study, the tree density averaged approximately 16 trees per plot at plot sizes of 200 m^2, while plot sizes greater than 400 m^2 contained more than 30 trees. At a plot size of 100 m^2, less than 10 trees were identified. If only tree density is considered to determine an optimal plot size, the optimal plot size in this study would be between 200 m^2 and 400 m^2. However, tree density in natural forests is variable because most natural deciduous forests are composed of trees of various ages and sizes (DBH) as a result of natural regeneration. In this study, tree densities for each reference stand were observed ranging from 31 to 140 trees. With respect to evaluation for stand density per hectare, Shin *et al.* (2001) recommended that the stand density for natural forests could be a more efficient indicator for the sum of the basal area than for number of trees per hectare.

For tree density, the MRD declined exponentially with increasing plot size (Figure 3). This result was similar to a study conducted for mature and old growth stands (Gray, 2003). In this study, the MRD ranged from 7% to 35% and the curve demonstrated that the slope was low for plot sizes greater than 400 m^2, in which the MRD was about 13%.

4. Species richness

Tree species richness in the different reference stands with the plot size of 900 m^2 ranged from 2 to 15 species (Table 1). The figure 4 illustrates the mean species richness by plot size. The species-area curves produced highly positive significant linear relationships. The species-area curves demonstrated the effect of plot size on species richness. This observation is one of the few ecological relationships that approaches the status of a 'law' (Weiner, 1999; Pickett *et al.*, 1994).

In this study, species richness increased with increased plot size up to the given maximum plot size. Therefore, a greater plot size is required to investigate species richness. In relation to species diversity, Park (1994) concluded that the minimum plot size required for investigating a forest community structure was generally

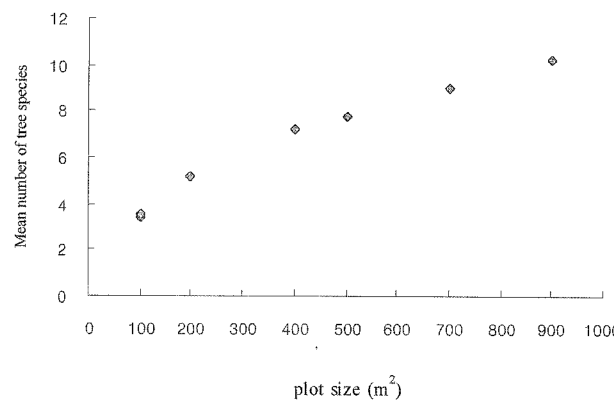

Figure 4. Mean species richness by plot size in the natural deciduous forest in Korea.

about 500 m^2, and if more accuracy is required, an area of approximately 1,000 m^2 is needed. The mean difference computed ranged from 1 to 7 species (Figure 3) and decreased as plot size increased.

Conclusion

With growing interest in environmental issues, the need for information on forest management is increasing. However, the budget for conducting forest inventories is decreasing.

The size of the plot plays an important role in all sampling techniques measured for a forest inventory. Plot size influenced not only the time and costs required but also the precision of the results of the inventory. If a forest stand structure has homogeneous characters, the precision did not improve with larger plot size. With a small plot size, the cost and time required for conducting the inventory decreased. However, if the plot size is too small the precision is very low, and the cost increased with increased plot size. Thus, this study evaluated the individual plot-level error of estimation for different sizes and shapes of plots for the variables of interest.

In order to compare the sample error for DBH, height, basal area and volume by plot size in each reference stand, the mean coefficient of variation and percent standard error were computed. The MCV for four variables increased as plot size increased, but showed little difference at the plot size of 200 m^2 for DBH and height, and 400 m^2 for BA and volume. In contrast, the mean percent standard error decreased with increasing plot size due to tree density by plot size and converged for plot sizes greater than 400 m^2. The relative or absolute difference was calculated to evaluate the error of estimation for tree density, the sum of the basal area and volume, and species richness. The mean relative difference for sum of basal area and volume and tree density per hectare decreased as plot size increased. But the MRD was only below 13% at the plot size 500 m^2. The tree density should be applied to determine an optimal plot size, with the optimal plot size in this study determined to be a plot size between 200 m^2 and 400 m^2. However, the determination for tree density in this study is unsuitable for determining the plot size in natural forests due to the fact that natural forests are composed of trees having various ages and sizes. The species richness for each reference stand ranged from 2 to 15 species. The minimum plot size for estimation of tree density, the sum of the BA and volume, was determined to be about 400 m^2, whereas the estimation of species richness required a minimum plot size of 500 m^2.

To determine the optimal plot size, information about various plot designs and consideration of time and costs according to each plot design are required (Zeide, 1980, Lynch, 2003; Byun and Yoo, 1988). In the future, time and cost requirement should be investigated by plot design.

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