Spatial Distribution and Composition of Trees in an Aging Coppice Forest in Japan

Stanko Trifković*

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Abstract: The importance of studying the ecology of coppice forests in Japan has risen recently amid growing demands to reestablish utilization of their tangible resources. The objective of the paper is to assess whether the spatial distribution of trees at an undisturbed aging-coppice follows some common pattern and how its composition changes with time. Coppice forests in Japan usually grow on steep lands and conventionally used forest inventory methods and methods used in ecological studies are time-consuming. Therefore, a rapid sampling approach based on measurements of angles and distances was used to achieve the objectives of this study. The field survey was conducted at coppice stands harvested 48, 60 and 77 years ago. Results suggest that distribution of the trees at aging-coppices shifts toward a regular spatial pattern. However, the process toward this regularity is slow and the distributions of individual trees were still not significantly different from a random pattern. Use of the combined angle-distance methodology is rapid and the data collected can be useful for planning ecologically-friendly management of coppice forests.

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* Kyoto University, Japan
1. Introduction

Forests in Japan were heavily harvested in the past and large parts have been regenerated by applying coppicing practices. Coppices extensively supported the early industrial development of the country. Exploited resources include wood used to produce charcoal to heat dwellings during cold winters or to support early developing industries such as smelting or pottery (Totman, 1989). Practices to clear-cut the trees in 10 to 20 years rotations were aimed at maintaining coppicing ability and also at keeping small stem diameters for the sake of easy harvest and transport. Rapid industrialization in the years following the end of the World War II and fast economic growth, supported generously by other available sources of energy, created market conditions which did not favor coppicing practices and Japanese forestry overall (Komaki, 1993). This led to the abandonment of coppicing practices and conversion of many coppice forests into forest plantations; mainly coniferous and mono-species stands (Iwai, 2002). At present, forests cover an impressive 69% of Japan’s land; the share of primary forests in the total forest area is approximately 19%, forest plantations cover approximately 41%, and the rest, approximately 40%, is regarded by FAO as “other naturally regenerated forest” (FAO, 2010). Among the “other naturally regenerated forest” are many coppice stands which were not converted into forest plantations and were left to grow almost without any artificial disturbance. However, the extent of old-growth coppices in Japan’s forests is still not known precisely. Apparently because the low market value of their tangible products did not call for a comprehensive inventory. The importance of studying these coppices has risen recently amid growing demands to reestablish utilization of their tangible resources.

One useful and rapid method for forest inventory is c-tree sampling—also referred to as n-tree distance sampling (Lessard et al., 1994;
Lynch and Rusydi, 1999; Lessard et al., 2002; Lynch and Wittwer, 2003), density-adapted sampling (Jonsson et al., 1992), \(k\)-tree sampling (Kleinn and Viško, 2006) or plotless ordered distance sampling (Engeman et al., 1994). The advantage of using \(c\)-tree sampling is mostly in its simple design and its ability to reduce the cost of field surveys when compared with conventional methods used in forestry (Jonsson et al., 1992; Lessard et al., 1994; Lynch and Rusydi, 1999; Husch et al., 2002). C-tree sampling is a statistical method based on measurements of distances from sampling points to their second, third, etc. closest tree. The ordered number of neighboring trees from sampling points is constant and it is necessary to set it prior to the survey. For instance, 2-tree sampling requires the measurement of distances from sampling points to their second nearest trees, which we can also use to draw circular sampling plots (Figure 1).

![Figure 1. Two sampling plots of a variable circular size defined by distances from sampling points (+) to second nearest individuals (black dots); \(c = 2\) sampling.](image-url)
The development of density estimators derived for c-tree sampling has taken two major paths in the past. One approach takes into consideration variable-plot-areas (Eberhardt, 1967) and the other the distances themselves (Pollard, 1971). Research in the past has suggested that density estimates with c-tree sampling can be biased and that the bias depends on spatial pattern distributions of measured populations and the type of density estimator used (Payandeh and Ek, 1986; Engeman et al., 1994; Lynch and Rusydi, 1999; Picard et al., 2005). Density estimators which account for the distances are usually applicable to estimating relative density of only uniformly random populations (Pollard, 1971). On the other hand, density estimators which accounts for variable-plot-areas are more robust in regard to exhibited spatial patterns. One of the most studied robust density estimators which accounts for variable-plot-areas is the \((c-1)\) estimator proposed by Eberhardt (1967). Because of its robustness, the \((c-1)\) estimator has been recommended in the past for the use in forest inventories (Payandeh and Ek, 1986; Jonsson et al., 1992; Lessard et al., 1994).

In addition to its applicability to estimating density of randomly distributed trees, the \((c-1)\) estimator can also be used in forest stands with individual trees exhibiting clustered spatial patterns (Eberhardt, 1967) while the GM estimator (Trifković and Yamamoto, 2010) can be used to estimate the density of regularly distributed trees. However, density estimators which accounts for variable-plot-areas are burdened with a higher variance (Lessard et al., 2002).

Various aspects need to be understood prior to setting any concrete measures and managerial goals to predict and model the development of aging coppices. Among these is whether the spatial distribution of trees at abandoned coppices follows some common pattern and how its composition changes over time. Spatial patterns of trees are among the most important issues in ecology (Levin, 1992) and thus highly impor-
tant to consider in management planning. It is known that competition between trees is a strong driving force toward regularity (Moeur, 1993) while disturbances can turn spatial distributions of trees back toward clustering. It is also clear that the spatial distribution of trees plays a crucial role in whether to use c-tree sampling and which estimator to choose. Numerous methods have been proposed over the years to index spatial patterns of individual trees. Conventional methodologies applied in ecological research require the mapping of the trees (Moeur, 1993) which is time consuming. Moreover, it is recognized that “all tests have their weaknesses” (Perry et al., 2006), but the information provided is usually a valuable indicator of ecological processes. Other methods are mostly designed to minimize field effort. The fixed-area plot method, which is the conventional method used in forest inventories, can be used to index spatial patterns but such information is influenced by the size of the fixed-plot area (Pielou, 1959; Moeur, 1993). Methods which require measurement of distances from chosen individual trees to their nearest neighbors, such as the plant-to-plant method (Clark and Evans, 1954), are often criticized for the difficulty regarding a random selection of the trees. On the other hand, the point-to-plant method proposed by Pielou (1959) requires firstly estimating the tree density. Many other methods can be found in the literature (Nishikawa, 1996; Pommerening, 2002; Liu, 2001) but the mean-of-angles method (Assunção, 1994) is one of the most-practical choices since the sample of angles can be easily obtained in the field and its ability to distinguish between regular and clustered populations or to assign a degree of regularity or clustering is also very straightforward (Trifković and Yamamoto, 2008).

Coppice forests in Japan are generally left to grow on steep lands and conventionally used forest inventory methods and methods used in ecological studies are thus very expensive to apply. Therefore, using a
faster and cheaper (but still reliable) methodology to assess the current state of the coppices is necessary. This paper aims to assess changes in spatial distribution and composition of trees by using a rapid field sampling approach at an “undisturbed” old-growth coppice with regard to the time span since the latest harvest of the trees.

2. Methods

Tokyo University Forest in Chiba, located in the south-east of Tokyo was chosen to serve as an example of “undisturbed” old-growth coppice since it offers highly valuable records to support a choice of study sites. A field study was conducted at coppice stands harvested 48, 60 and 77 years ago. A 5 m buffer-zone was settled-out to exclude the crests of the hills and streams from the examination area, so that only the trees growing on slopes were considered.

Ten transect lines, each 30 meters long, were placed on slopes at each of these three stands. 30 transect lines were placed in total and 10 sampling points were chosen randomly along each of the transect lines; in total 300 sampling points. The horizontal distances “l_i” to the second nearest individual trees from sampling points were measured (Figure 2) and numbers of stems (stems whose DBH exceeds 5cm ) arises from individual trees were counted and their DBH measured. The tree species were identified by their morphological features (Amakawa and Osada, 1988). Measurement of angles (α_i) between lines of sight to nearest two neighboring individual trees from each sampling point was also conducted (Figure 2).

3. Results

A slight shift from a clustered toward a regular spatial pattern can be observed in the distributions of measured angles; the means in the distributions of angles at the 60-year-old coppice and at the 77-year-
old coppice have higher values than the means at the 48-year-old coppice (Figure 3). The bootstrap estimates of confidence intervals also give us a visual impression of a slight shift toward higher means (Figure 4). The confidence interval estimates also indicate that aging in coppice forests results in a reduced variance in measured angles (Figure 4) which coincides with a shift of spatial arrangement of trees toward a regular spatial pattern. However, each of the three samples were not significantly different from a uniform frequency distribution (Kolmogorov-Smirnov test), neither were they significantly different from samples of angles measured at theoretically random populations (Two-sample Kolmogorov-Smirnov test). A significant difference was revealed only between samples of angular measurements in the 48-year-old and 77-year-old coppice stands (Two-sample Kolmogorov-Smirnov test, \( p = 0.02 \)).
Figure 3. Cumulative frequency distributions of measured angles at the 48-year-old, the 60-year-old and the 77-year-old coppice stand respectively.

Each of the three samples of point-to-second-nearest-neighbor-tree distances was not significantly different from a gamma frequency distribution (Kolmogorov-Smirnov test) (Figure 5) which was also the case in simulated random point populations. The sample of distances from the 60-year-old coppice was also not significantly different from a normal distribution (Shapiro-Wilk normality test). The difference between the samples of the distances measured at the 60-year-old and 77-year-old coppices was not significant (Two-sample Kolmogorov-Smirnov test)
Figure 4. Bootstrap estimates of confidence intervals involved in the samples of angles applying 10,000 replications.

Neither are there significant differences in their means (Wilcoxon-Rank-Sum test) and variances (F test). On the other hand, the same tests strongly suggest that the sample of the distances at the 48-year-old coppice is significantly different from samples at the 60-year-old and the 77-year-old coppices. Since spatial distributions of individual trees at the old-growth coppice were not significantly different from completely random pattern, the maximum-likelihood estimator was used to estimate densities of individual trees: estimated density at the 48-year-old coppice was 1,927 trees/ha, at the 60-year-old coppice was
1,409 trees/ha and at the 77-year-old coppice was 1,403 trees/ha.

Figure 5. Frequency of point-to-second-nearest-neighbor-tree distances at the 48-year-old, the 60-year-old and the 77-year-old old coppice and their Quantile-Quantile plots fitted to a gamma frequency distribution.

In total, 24 dominant tree species were indentified: Abies firma, Acer amoenum, Acer mono, Castanopsis cuspidata, Cinnamomum japonicum, Euptelea polyandra, Ilex integra, Ilex rotunda, Litsea coreana, Magnolia obovata, Mallotus japonicas, Machilus thunbergii, Neolitsea sericea, Prunus jamasakura, Styrax japonica, Swida controversa, Swida macrophylla, Torreya nucifera, Quercus acuta, Quercus glauca, Quercus
myrsinacefolia, Quercus salicina, Quercus serrata and Zelkova serrata. Only 6 species belong to the Fagaceae family and 2 were coniferous species. Also 16 co-dominant tree and shrub species were identified: Aucuba japonica, Callicarpa japonica, Camellia japonica, Carpinus turchzaninovii (tschonoskii), Cephalotaxus harringtonia, Cleyera japonica, Dendropanax trifidus, Diospyros sp., Eurya japonica, Ficus erectas, Illicium anisatum, Osmanthus heterophyllus, Pourthiaea villosa var. laevis, Rhus succedanea, Sapium japonicum and Zanthoxylum ailanthoides. Three species couldn’t be identified by their morphological features.

Medians of stem-counts at the three populations were not significantly different (Kruskal-Wallis test). Also the means between the counts were not significantly different (Mann-Whitney U test). The majority of the dominant tree species had only one stem per individual tree; 79% at the 48-year-old, 84% at the 60-year-old and 75% at the 77-year-old coppice stand. The count of additional stems at the 48-year-old coppice stand was not significantly different from a negative-binomial distribution. The count of additional stems at the 60-year-old coppice stand can also be explained by a negative-binomial distribution but the fit was not as high ($p = 0.054$), while at the 77-year-old coppice stand the difference can be regarded as significant ($p = 0.034$, Goodness-of-fit test). The medians (Kruskal-Wallis test) and the means (Wilcoxon rank sum test) between the numbers of stems were not significantly different.

At the 48-year-old and the 60-year-old coppice stands, tree species which belong to the Fagaceae family share 48% of the total number of dominant trees. That share was 61% at the 77-year-old coppice stand. DBH of tree species which belong to the Fagaceae family with only one stem per individual tree exhibited an “L-shaped” frequency distribution, a characteristic of a successive (climax) species pattern, although
they did not fit to any widely applied theoretical frequency distribution. Numbers of *Abies firma* and *Torreya nucifera* trees were not high enough to draw any conclusions about their ingrowth patterns but the large majority were in their juvenile stage (Figure 6). DBH distributions of other one-stem dominant *Angiospermae* (tree species excluding those which belong to the *Fagaceae* family and the two conifer species) were not significantly different from a gamma frequency distribution.

Figure 6a. Distribution of stem-DBH at the 48-year-old coppice at the Tokyo University Forest in Chiba.
4. Discussion

The applied survey design was relatively fast in the field and measurements were conducted with considerable ease even though the terrain conditions at Tokyo University Forest in Chiba are steep in general; the field survey was completed in six working days by two crew-members. Also, the methodology revealed that spatial patterns of individual trees at the study sites were not significantly different from a complete spatially random distribution and that the trees are uniformly distributed. The c-tree sampling method can be used to provide a reliable esti-
Figure 6c. Distribution of stem-DBH at the 77-year-old coppice at the Tokyo University Forest in Chiba.

The method was also able to indicate that the distribution of trees is uniform. The Mean of Angles method was useful to find that the distribution of individual trees is random and its use also indicated the presence of an evolution in tree spatial distributions; it can be hypothesized that competition between the trees and the future growth of young naturally-regenerated trees at aged coppice forests may result in a shift in spatial distributions of trees toward a regular pattern but coppices at the Tokyo University Forest in Chiba are still rela-
tively young to confirm this hypothesis. Even though the conducted analyses of measured angles and bootstrap estimates of confidence intervals (Figure 4) have confirmed the relatively low statistical power of the Mean of Angles method (Assunção, 1994), the method was still highly practical and simple to use to test for randomness or to reveal the presence of clustering or regularity. Combining the methodologies we can improve the amount of extracted information while still being able to retain methodology practicality. The results have shown that even such a simple and practical methodology can yield ecologically important data.

The methodology was able to reveal that aging of coppice stands induce a change in distribution of individual trees toward a regular spatial pattern. However, the shift toward regularity is slow and this research cannot say whether the distribution of trees at the studied coppice will reach the regular state. It is also unknown whether future disturbances will significantly drive spatial distribution of the trees toward clustering. On the other hand, the data presented in this paper may serve as a starting point for future spatial analysis and ecological studies of aging coppice forests in Japan.

We can highly rely on c-tree sampling to estimate density of the trees at the aging coppice in Japan since the individual trees are distributed randomly. That also implies that each individual tree will have an equal probability to be selected, so other important parameters can be assessed; the tree-stems growing inside and on the outskirts of the clusters will have the same probability of selection. Moreover, forest stands composed by trees being uniformly distributed at random can be easily simulated and spatial modeling becomes much easier to conduct. Furthermore, the difference in the distribution of tree-stems is not highly significant and spatial models assuming a negative-binomial distribution will not be far from the reality.
The survey at the coppice forest in Chiba peninsular suggests that the preservation of once heavily harvested coppices favors tree species from the *Fagaceae* family. An absence of major disturbances is likely to benefit to *Fagaceae* tree species and further suppresses opportunistic (pioneer) tree species. The *Fagaceae* is a family whose tree species, such as *Castanopsis cuspidata* (Hirayama *et al*., 2010), are largely regarded in Japan as successive and competitive in shaded conditions. The current state is also suitable for regeneration of the two coniferous species (*Abies firma* and *Torreya nucifera*), whose juvenile stage is likely to be relatively highly tolerant to shade (Figure 6). The pioneer tree species will likely not benefit the current state of old-growth coppices; inferiority of the pioneer tree species is likely to remain until some larger-scale disturbances increase their chances to compete (Yamamoto, 1996; Perry *et al*., 2008).

5. Conclusions

The Mean-of-Angles method was proved as simple, rapid and useful in obtaining information regarding the spatial distribution of individual trees. Spatial distribution of individual trees in an aging coppice in Chiba peninsular of Japan was not significantly different from a completely random distribution. Also, a shift toward a regular spatial pattern is present but it is not statistically significant. The c-tree sampling method was also useful and it revealed that the density of the individual trees at aged-coppices is uniformly distributed. We also can highly rely on c-tree sampling to estimate density of the trees at the aging coppice in Japan since the individual trees are distributed randomly. The data collected is useful for planning an ecologically-friendly management of coppice forests and may serve as a starting point for future spatial analysis and ecological studies of aging coppices in Japan.
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References


