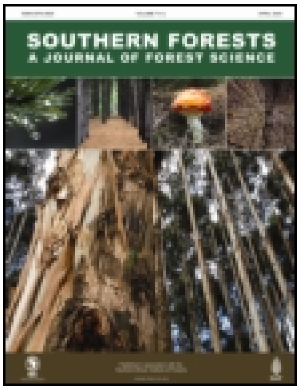


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# Efficiency of inventory plot patterns in quantitative analysis of vegetation: a case study of tropical woodland and dense forest in Benin

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**The main issue in forest inventory is the reliability of data collected, which depends on the shape and size of inventoried plots. There is also a need for harmonisation of inventoried plot patterns in West Africa. This study focused on the impact of plot patterns on the quantitative analysis of two vegetation types of West Africa based on case studies from Benin. Twenty and fifteen plots of 1 ha each were demarcated in dense forest and woodland, respectively. Each 1 ha plot was divided into 100 quadrats of 100 m$^2$ each and diameter at breast height (dbh) of trees was recorded in each quadrat. The required time to measuring trees diameter in each 1 ha plot was also recorded to compute the mean inventory effort. From the 100 quadrats in each 1 ha plot, 14 subplots of different shapes and sizes were considered by grouping together adjacent quadrats. The basal area of each subplot was computed and the relationship between estimation bias of the basal area and the size of subplots was modeled using Smith's Law (Smith 1938). The mean absolute error of the shape parameter *c* of Weibull distribution was computed for each of the subplot shape, size and direction. The direction and shape of subplots did not influence significantly ($P > 0.05$) the precision of the quantitative analysis of vegetation. However, square subplots were suitable in practice. On the contrary, plot size was significantly ($P < 0.05$) and inversely correlated to estimation efficiency. The optimal plot size for quantitative analysis of vegetation was 1 800 and 2 000 m$^2$ with an inventory effort of 0.51 and 0.85 man-days per subplot in woodland and dense forest, respectively. It is concluded that use of standard sample sizes will help to harmonise a forestry database and to carry out comparisons at regional level.**

**Keywords:** efficiency, forest inventory, plot patterns, structure, tropical vegetation types

## Introduction

In forest ecology and management, forest inventory is an important tool in decision-making (Fonweban 1995, Rondeux 1999, Kangas and Maltamo 2007). Given the large extent of forests, inventory data is often based on sampling instead of an exhaustive inventory being carried out (Picard 2006, van Laar and Akça 2007). The reduction in sampling errors is therefore essential to ensure a greater reliability of the collected data. It means that a particular emphasis must be put on the features of sampling unit, which is a major factor in sampling error.

The area of the sampling unit (plot or relevé) is an important characteristic in the reduction of the estimation bias and the increased precision of the measured parameters. Several investigators have examined the relationship between the statistical precision of sample estimates and plot size (Kenkel and Podani 1991, Shiver and Borders 1995, Jyrki et al. 1998, Magnussen 1999, Nath et al. 2009, Whittle 2009). These authors recommend using the largest plots possible considering the constraints of sampling effort. In fact, according to these studies, the precision of estimation of the structural parameters of vegetation can be improved by increasing plot size. However, the size of plot that can give accurate estimation with minimum effort still constitute an important issue because plot size cannot be increased indefinitely. Previous studies have failed to propose a standard sample size for a given vegetation type. This might somewhat explain the great variability of plot sizes that is often observed even for the same vegetation type.

Apart from the plot size, another important criterion in the reliability of forest inventories is the plot shape (Philip 2002). Plot shapes can be circular, square or rectangular (Kenkel and Podani 1991, Rondeux 1999, Kangas and Maltamo 2007). Circular plots represent the geometrical figure of lowest perimeter for a given size. Hence, they reduce the number of edge trees compared with other plot shapes of the same size (Kangas and Maltamo 2007). They are, however, notoriously difficult to establish under field conditions, particularly in tropical forests. That is the reason why square or rectangular plots are reported to be suitable in tropical forests (van Laar and Akça 2007).

In a given area, rectangular plots often include more species than other plot shapes (Jyrki et al. 1998). Furthermore, in the case of rectangular plots, an important

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question is the direction of the length of the plot. In fact, a gradient of any factor can influence estimation efficiency according to the direction of rectangular plots (Rondeux 1999). In riparian forests, for example, the rectangular plots whose length runs parallel to the bed of the river are suitable (Natta 2003). Moreover, Kangas and Maltamo (2007) showed that external factors of degradation (e.g. logging) could imply differences of estimation accuracy according to direction. Thus, for a given plot size, the direction (north–south, east–west or slope direction) of rectangular plots could have a significant effect in terms of efficiency of estimate of the vegetation structural parameters.

In addition, the sampling of plant communities is a compromise between the precision of estimates of the parameters and the inventory effort (Jyrki et al. 1998). However, very few studies have documented the time necessary for data collection (Kenkel and Podani 1991), which is a major component of inventory effort (Nath et al. 2009) because the cost of the inventory depends on it.

In Africa and especially in West Africa, size and shape of plots are often chosen according to the experience of foresters and not through analytical means. This leads to a high diversity of size and shape of plots in the same country and also for the same vegetation type. For example, in Benin, plot sizes between 500 $m^2$ and 1 500 $m^2$ of various shapes are considered in the inventory of deciduous dense forest (Ganglo and de Foucault 2006, Bonou et al. 2009, Glèlè Kakaï and Sinsin 2009). This high diversity of size and shape of plots does not allow for comparisons of structural patterns of forests at regional level. Therefore, harmonisation of techniques of forest inventory is necessary.

The present study was set up to identify the most suitable sizes and shapes of inventoried plots for structural characterisation of tree-species populations in dense forests and woodlands. Dense forests and woodlands were selected in this study because of lack of scientific data on the appropriate plot direction, shape and size for their dendrometric analysis. In addition, they are increasingly vulnerable vegetation types because they are being converted into savanna as a result of human influence (Bamba et al. 2008). As such, there is an urgent need to set up effective management strategies that in part should be based on reliable inventory data.

## Materials and methods

### *Study areas*

The study was conducted in the Lama Forest Reserve (a tropical dense forest) and in the Béllèfoungou Forest Reserve (a tropical woodland).

### *Lama Forest Reserve*

The Lama Forest Reserve is located in southern Benin in the Dahomey Gap between 6°55′ to 7°00′ N and 2°04′ to 2°12′ E. The total area of the forest is estimated at 16 250 ha. The original vegetation was a dense semideciduous forest established on 4 777 ha composed of 292 ha of *Tectona grandis* and *Gmelina arborea* plantations, 1 900 ha of dense forest dominated by *Dialium guineense* and *Diospyros mespiliformis*, with the remaining area (2 685 ha) being fallow (Emrich et al. 1999). Rainfall regime in the reserve is bimodal from April to June and from September to November, with a mean annual rainfall of 1 200 mm. Mean temperature varies between 25 and 29 °C and relative humidity between 69 and 97%. The vegetation in the forest has been strongly affected since the mid-1970s by various agricultural activities and now forms a mosaic of cultivated lands and small relic forest patches (Kassa 2001). Since 1988 the forest has been subjected to a participative management plan, one of the most successful in Benin. Four vegetation groups have been identified in the forest by Bonou et al. (2009): the young preforest fallow, the old preforest fallow, the degraded dense forest and the typical non-degraded dense forest. The typical non-degraded dense forest was selected for this study.

### *Béllèfoungou Forest Reserve*

The Béllèfoungou Forest Reserve is located in the Sudano-Guinean transition zone referred to as 'Sudanian woodland zone with abundant *Isoberlinia* spp.' after White (1983). In Benin, this zone is located between 9°46′ to 9°49′ N and 1°42′ to 1°45′ E. The total area of this forest is estimated at 709 ha. The native vegetation of this zone is characterised by species such as *Isoberlinia doka*, *Isoberlinia tomentosa*, *Anogeissus leiocarpa*, *Pterocarpus erinaceus*, *Vitellaria paradoxa*, *Burkea africana*, *Prosopis africana*, *Pericopsis laxiflora*, *Afzelia africana* and *Kaempferia aethiopica*. The rainfall regime is unimodal with an annual rainfall of 1 000–1 200 mm and the soils are mainly ferruginous (Adomou 2005).

### *Forest inventory design and data collection*

Data were collected through forest inventory. Sampling units were laid out in the forest following a random sampling scheme. Overall the investigation covered 20 ha of dense forest representing 1.05% of the total surface covered by the typical dense forest of Lama and 15 ha representing 2.12% of the total surface covered by the Béllèfoungou woodland. Each 1 ha plot was divided into 10 lines and 10 columns so as to obtain 100 quadrats of 10 m × 10 m each (Figure 1). To identify each quadrat easily, the lines were labeled from zero to nine and the columns also from zero to nine (Figure 1). Moreover, each 1 ha plot was oriented as indicated in the figure. Species and diameter at breast height (dbh) of all trees of dbh ≥ 10 cm were recorded in each quadrat and the required time to measure dbh of trees in each 1 ha plot and five random quadrats from each plot of 1 ha were also recorded.

### *Structural characterisation of vegetation types*

Structural characteristics of each investigated vegetation type were assessed by calculating the tree-density (*N*), the basal area of the stand (*G*), the mean diameter of trees (*D*), the species richness (*S*), the Shannon diversity index (*H*) and the Pielou evenness (Eq).

Apart from the ecological parameters that were computed for the whole stand of each of the vegetation types, the mean and coefficient of variation of the other parameters were computed for dense forest and woodland. Moreover, for each vegetation type, the stem diameter structure was established by fitting the observed dbh values using the flexible three-parameter Weibull distribution, with density

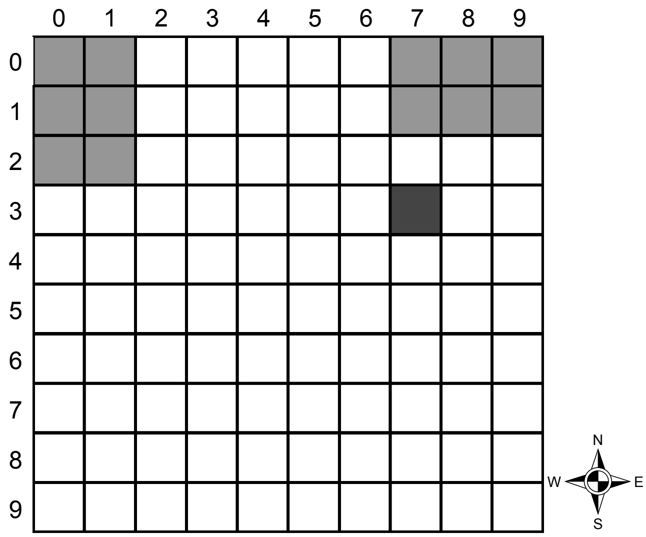


**Figure 1:** Sampling units within a 1 ha plot consisting of 100 quadrats each of 100 m². Plot 37 is indicated in dark grey. Shaded regions in the top left and right corners are examples of the plot sizes and shapes considered in the analysis (see Table 1)

function f for a random variable *x* (Johnson and Kotz 1970):

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]; \quad (1)$$

where parameter *a* is the location parameter, *b* is the scale parameter, *c* is the shape parameter, and exp [ ] is the exponential function. The random variable *x* is stem diameter at breast height. For each vegetation type, diameters of trees were used to estimate the parameters *b* and *c* based on the maximum likelihood method (Johnson and Kotz 1970). The log-linear analysis (Caswell 2001) was performed in R software (R Development Core Team 2009) for each case to test the adequacy of the observed structure to the Weibull distribution.

### *Types of subplots considered*

Subplots were obtained from the 100 quadrats in each 1 ha plot, by grouping together adjacent quadrats of 100 m². Rectangular subplots were considered in two directions, north–south and east–west, to test the impact of subplot direction on estimation accuracy. Each type of inventory subplot was replicated a number of times in each 1 ha plot (see values in parentheses in Table 1). In total, 14 types of inventoried subplots were considered (Table 1).

Figure 1 shows an illustration of a replicate of rectangular subplots of 600 m² (20 m × 30 m) oriented north–south (00, 01, 10, 11, 20 and 21) and a replicate of the same subplot oriented east–west (07, 08, 09, 17, 18 and 19).

### *Assessing the efficiency of plots patterns in the dendrometric characterisation of the vegetation*

*Computation of the estimation error of the basal area from subplots*

For each type of subplot, the basal area was computed. This parameter was selected because it integrates other dendrometric parameters, such as the density and the mean diameter of the trees. Moreover, it constitutes a simple and reliable criterion considered in the directives of forest management (Bary-Lenger et al. 1988). For each of the 100 quadrats of each 1 ha plot, the mean basal area of trees was computed. This parameter was also computed for each replication of the 14 subplots in each 1 ha plot. The mean square error of the basal area for quadrats of 100 m² ($\sigma_1^2$) was computed through analysis of variance (ANOVA). This ANOVA compared the 20 square 1 ha plots (dense forest) or the 15 square 1 ha plots (woodland) using the 100 replications of the quadrats of 100 m². Similarly, for a given type of subplot of $n \times 100$ m², the mean square error ($\sigma_n^2$) of the estimation of the basal area was computed through ANOVA comparing the 20 squared 1 ha plots (dense forest) or the 15 squared 1 ha plots (woodland) with the *m* replications of the subplots. The relationship between the mean square error of the estimation of the mean basal area and the size of the subplots was then modeled using Smith's Law (Smith 1938):

$$\sigma_n^2 = \sigma_1^2 / n^{\beta} \quad (2)$$

where $\sigma_1^2$ is the mean square error linked to subplots of 100 m², and $\beta$ is a parameter that measures the degree of dependence of the quadrats within a 1 ha plot; it varies between 0 and 1. If $\beta = 0$, the dependence is complete; if $\beta = 1$, Equation 2 becomes the formula of the mean of a parameter computed from a random sample for which there is no dependence between the observations. Then, for $\beta = 1$, both the shape and direction of the subplots do not impact the mean square error of the basal area. To estimate $\beta$, weighted regression was used after logarithmic transformation applied to Equation 2; the weights were considered as the numbers of replications of the different types of subplots.

*Assessing the efficiency of plot patterns in the analysis of stem diameter structure*

For each vegetation type, the stem diameter structure was established for each shape and size of subplots (Table 1). Diameters of trees found in all the 1 ha plots (15 in woodland and 20 in dense forest) were considered to compute the shape parameter $c_{1ha}$ of the Weibull distribution. Log-linear analysis was performed to test the adequacy of the observed structure to the Weibull distribution.

To compute the estimated value $c_k$ of subplot *k*, replication *i* (*i* = 1 to *m*) of a type *k* (*k* = 1 to 14) of inventory subplots in a 1 ha plot. A replication *i* of a subplot *k* corresponds to a given location of this subplot in each 1 ha plot.

The mean absolute error, MAE$c_k$ of the estimation of *c* from subplot *k* was then computed with regard to $c_{1ha}$ (from the 1 ha plots) as follow:

$$\mathrm{MAE}\, c_k = \frac{1}{m}\sum_{i=1}^{m}\left|c_i - c_{1ha}\right| \quad (3)$$

### *Computation of the mean sampling effort*

For a given subplot of size $n \times 100$ m², the mean sampling effort ($W_{n \times 100\,m^2}$) for a team of three experienced foresters was computed as:

$$W_{n \times 100\,m^2} = n \times W_{1\,ha}/100 \times \omega \quad (4)$$

where $W_{1\,ha}$ is the mean sampling effort (in man-days) of the 1 ha plots, computed by adding the time of establishment of the plots and the time required to measure dbh of trees and then converted in man-days using Norman tables (Norman 1973); and $\omega$ is a coefficient of lengthening of time ($\omega = \bar{t}_{rc}/\alpha$). It was considered to take into account the lengthening of the human sampling effort during a day. $\bar{t}_{rc}$ is the sampling time per quadrat, using the time of inventory of the five random quadrats selected; $\alpha$ is the mean sampling time of a quadrat from the 1 ha plot (i.e. $\alpha$ = inventory time of 1 ha/100).

## Results

### *Structural characteristics of the vegetation types*

The structural parameters of the two vegetation types (Table 2) showed that the woodland is more diversified in species than the dense forest. However, the dense forest presented higher values of the dendrometric parameters considered.

The stem diameter structure of the two vegetation types (Figure 2) showed an inverse 'J' shape, characteristic of stable multispecific populations ($c < 1$). The log-linear analysis applied revealed a good adjustment of the observed distribution to the Weibull distribution ($p > 0.05$). The 10 to 50 cm dbh classes were the best represented in dense forest, whereas in woodland trees of dbh between 10 and 40 cm were the most common. In addition, individuals with dbh higher than 150 cm and 70 cm were very scarce in dense forest and woodland, respectively.

### *Efficiency of shape and size of subplots in the dendrometric characterisation of vegetation*

*Effect of subplot patterns on the estimation error of the mean basal area*

Results from the weighted regression to model the relationship between the estimation error of the basal area and subplot size provided the following equations:

$$\sigma_n^2 = (2856.9/n^{1.010}) \text{ (dense forest)}$$
$$\sigma_n^2 = (230.4/n^{0.998}) \text{ (woodland)} \quad (5)$$

From Equation 5, it can be noticed that $\beta$ is close to 1 for the two vegetation types and thus indicates no dependence between the quadrats of 100 m². This implies that the shape and direction of subplots did not affect the mean square error of the basal area contrary to the size that was revealed to be significantly and inversely proportional to the basal area error (Equation 5). The relationship between the mean square error of the basal area, the sampling effort and the size of the subplots is illustrated by Figure 3. It revealed that beyond 2 000 m² and 1 800 m² for dense forest and woodland, respectively, the gain of precision in the estimation of the basal area of the vegetation does not significantly increase. In addition, the inventory effort for such plot size was

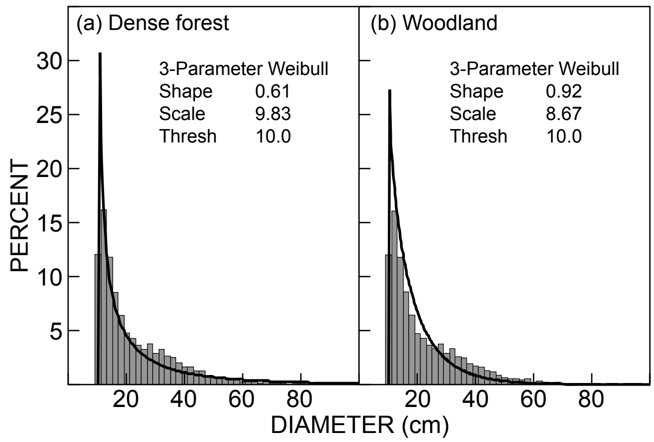


**Figure 2:** Stem diameter structure of (a) dense forest and (b) woodland

**Table 1:** Types of subplots inventoried. Values in parentheses are the number of replications of each type of subplot in the two directions in a 1 ha plot. $L$ = Length of the subplot, $\ell$ = width of the subplot

| Squared | Shape: Rectangular ($L/\ell = 3/2$) | Rectangular ($L/\ell = 2$) | Rectangular ($L/\ell = 3$) |
|---|---|---|---|
| 20 m × 20 m (50) | 30 m × 20 m (30) | 20 m × 10 m (100) | 30 m × 10 m (60) |
| 30 m × 30 m (18) | 60 m × 40 m (4) | 40 m × 20 m (20) | 60 m × 20 m (10) |
| 40 m × 40 m (8) | 90 m × 60 m (2) | 60 m × 30 m (6) | 90 m × 30 m (6) |
| 50 m × 50 m (8) | – | 80 m × 40 m (4) | – |

**Table 2:** Structural parameters of the vegetation types: mean and coefficient of variation (CV) of ecological and dendrometric parameters

| Structural parameter | Dense forest | | Woodland | |
|---|---|---|---|---|
| | Mean | CV (%) | Mean | CV (%) |
| **Ecological parameters** | | | | |
| Species richness ($S$; no. of species) | 42 | – | 57 | – |
| Shannon index ($H$) | 2.94 | – | 4.42 | – |
| Pielou's evenness (Eq) | 0.55 | – | 0.76 | – |
| **Dendrometric parameters** | | | | |
| Mean diameter (Dg; cm) | 27.32 | 8.70 | 20.76 | 7.63 |
| Tree density ($N$; stems ha$^{-1}$) | 433.60 | 16.58 | 321.40 | 2.34 |
| Basal area ($G$; m² ha$^{-1}$) | 25.21 | 15.08 | 10.83 | 25.87 |

0.85 and 0.51 man-days subplot$^{-1}$ for dense forest and woodland, respectively.

### *Effect of directions and subplot patterns in the analysis of stem diameter structure of vegetation types*

*Effect of rectangular subplot directions on the MAE*c

The results of covariance analyses (direction and shape as factors and subplot size as covariate) showed that the north–south and east–west directions and the various rectangular shape ($L/\ell = 3/2$, $L/\ell = 2$ and $L/\ell = 3$) of subplots did not significantly influence ($p > 0.05$) the MAE*c* of the shape parameter *c* of the Weibull distribution (Table 3). This analysis indicated, however, that the size of rectangular subplots highly influenced ($p < 0.001$) the estimation bias of this parameter, meaning that the stem diameter structure of stands did not depend on the direction and the rectangular shape of subplots but rather on their size.

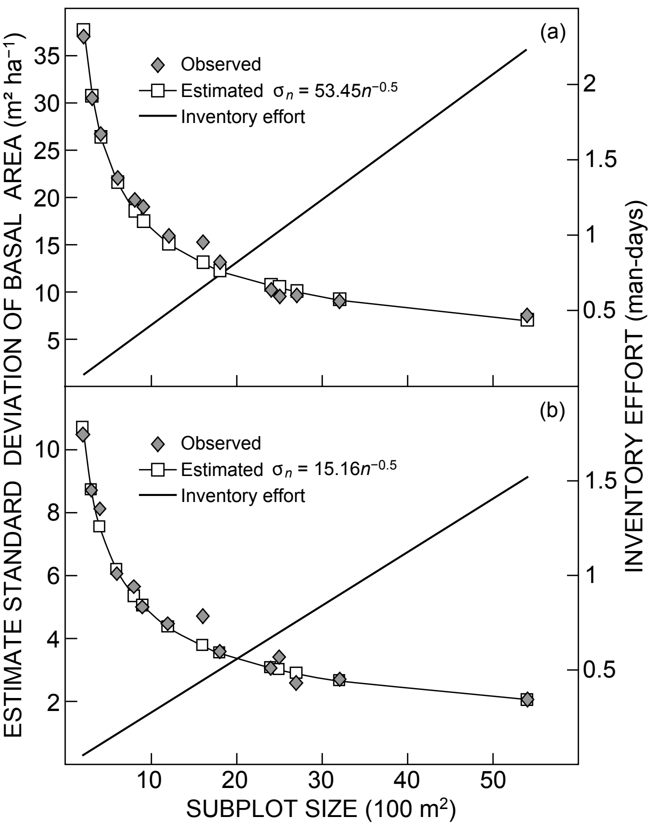


**Figure 3:** Relationship between the mean square error $\sigma_n^2$ of the basal area, the subplot size and sampling effort in (a) dense forest and (b) woodland

*Effect of subplot shapes and sizes on MAE*c

The results of the covariance analyses applied to the estimation bias of the shape parameter *c*, with the subplot size as covariate (Table 3), indicated that in dense forest the subplot shapes influenced significantly ($p < 0.05$) the estimation bias of the shape parameter *c*, whereas it was not the case in woodland ($p > 0.05$). However, the effect of the size was highly significant ($p < 0.01$) in both vegetation types. Figure 4 shows that, in dense forest, the decrease of MAE*c* according to plot size was more obvious for rectangular than for square shapes. In the case of woodland, the decrease of MAE*c* was more important than for the dense forest.

## Discussion

Plot patterns (direction, shape and size) are of great importance for estimation efficiency in forest inventory (Økland 1990, Rondeux 1999, Kangas and Maltamo 2007), particularly in quantitative analysis of the vegetation. Pursuing a goal of harmonisation of forest inventory techniques in West Africa, we examined the efficiency of inventoried plot patterns on dendrometric characterisation and the analysis of stem diameter structure of its vegetation types. Using study cases from Benin, we focused on tropical woodland and dense forest, which are among the most common woody vegetation types in West Africa.

Plot direction is only important when the parameters under study vary significantly with direction (Rondeux 1999). Our results showed that the estimation efficiency of both the basal area and the shape parameter *c* of the Weibull distribution (for the stem diameter structure) were not influenced by direction. Previous studies have also reported direction to be less important in forestry estimation efficiency, unless it concerns riparian forests (Natta 2003, Picard 2006). Such findings are consistent with a random distribution of trees within the two studied vegetation types (Dagnelie 1956). This first suggests the absence of a significant ecological gradient within the two forests and, second, the two vegetation types to be relatively homogeneous with low anthropogenic pressure. In fact, Kangas and Maltamo (2007) showed that external factors of degradation such as felling could result in differences of estimation accuracy according to direction.

As for plot shape, square and three rectangular shapes ($L/\ell = 1$, $L/\ell = 3/2$, $L/\ell = 2$ and $L/\ell = 3$) were examined in this

**Table 3:** Effect of rectangular subplots direction on the MAE*c*: results of covariance analysis (covariate = size). Adj-MS = Adjusted mean square, Prob. = probability

| Source | Dense forest | | | | Woodland | | |
|---|---|---|---|---|---|---|---|
| | df | Adj-MS | *F*-value | Prob. | Adj-MS | *F*-value | Prob. |
| Direction | 1 | 0.000 | 0.05 | 0.825 | 0.005 | 1.21 | 0.272 |
| Shape | 2 | 0.002 | 1.48 | 0.229 | 0.004 | 1.16 | 0.315 |
| Size | 1 | 0.027 | 16.51 | 0.000 | 0.092 | 23.98 | 0.000 |
| Direction × Shape | 2 | 0.001 | 0.78 | 0.458 | 0.001 | 0.18 | 0.833 |
| Error | 235 | 0.002 | – | – | 0.004 | – | – |

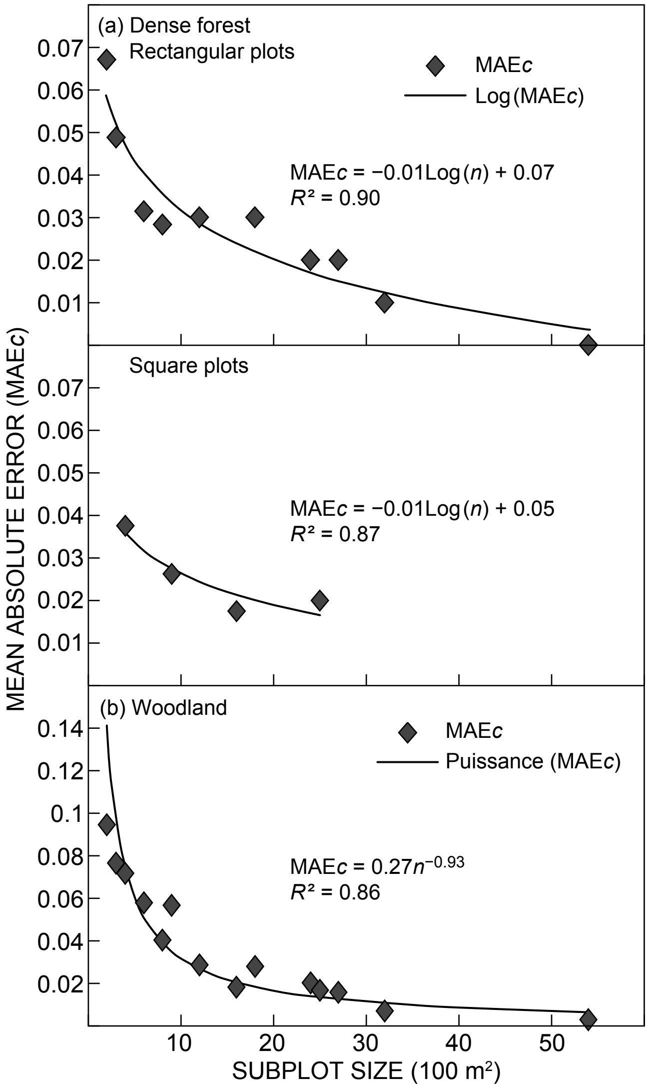


**Figure 4:** Relationship between the estimation bias of parameter *c* and subplots patterns in (a) dense forest and (b) woodland



study. Overall, results also indicated that the shape of plots did not influence the estimation efficiency of both dendrometric parameters and the diameter size class distribution. This is congruent with findings of Kulow (1966), Grayet (1977) and Picard (2006), who showed that plot shape only slightly influences estimation accuracy. However, results were slightly different between the vegetation types. In fact, whereas in woodland the plots shapes performed equally (no significant difference), in dense forest square plots were more efficient for the analysis of stem diameter class distribution. According to Jyrki et al. (1998), rectangular plots are suitable for forest communities with a strongly clustered spatial pattern of species. Rondeux (1999) added that the choice of the shape of plots should be made according to the easiness of establishment, the type of stand and the perimeter of the stand inventoried.

Contrary to direction and shape, the size of the plots highly influenced estimation efficiency for both basal area and the shape parameter *c* of the Weibull distribution. Actually, estimation efficiency in community-level studies can always be improved by increasing plot size (Kenkel and Podani 1991, Jyrki et al. 1998, Nath et al. 2009). Although large increases in estimation efficiency occur at small plot sizes, only slight increases in estimation efficiency were observed at larger plot sizes (see Figure 3). Given that there is a plot size beyond which the gain of accuracy is offset by substantial increases in inventory effort (Jyrki et al. 1998), the optimisation of the plot size should aim for a plot size that minimises the inventory effort for a given estimation precision (Johnson and Hixon 1952, Bormann 1953, Savage 1956, Zeide 1980, Gambill et al. 1985, Hebert et al. 1988, Grenier et al. 1991, Schreuder et al. 1993). In this study, it was noticed that plots of 2 000 $m^2$ in dense forest and 1 800 $m^2$ in woodland allowed an accurate quantitative analysis of vegetation with a minimum inventory effort of 0.85 man-days $plot^{-1}$ and 0.51 man-days $plot^{-1}$ in dense forest and woodland, respectively. This implies that a team of three experienced foresters could realise dendrometric inventory of three plots of 2 000 $m^2$ or five plots of 1 800 $m^2$ per day in dense forest or woodland, respectively. Taking into account these observations, we then deduced that square plots of 2 000 and 1 800 $m^2$ would allow efficient estimation of the dendrometric parameters of vegetation in dense forest and woodland, respectively. The obtained efficient plots sizes are larger than the ones often used (≤1 500 $m^2$; see Ganglo and de Foucault 2006, Thiombiano 2008, Bonou et al. 2009, Glèlè Kakaï and Sinsin 2009) in forest inventory, suggesting the latter to be less efficient than the ones found in this study.

Given that the choice of an appropriate plot size and shape is also ruled by the field and vegetation features (van Laar and Akça 2007), inventory effort (per plot size) could change, provided that vegetation features are not strictly the same for a given vegetation type. In addition, following Jyrki et al. (1998), rectangular plots are suitable for forest communities with a strongly clustered spatial pattern of species. This suggests the vegetation pattern to also affect estimation efficiency of subplot patterns (Picard 2006). Thus, examining the combined effect of spatial distribution of trees and inventory plot patterns in efficient estimation of dendrometric parameters could provide insights in efficient forest inventory design for the two studied vegetation types.

## Conclusion

The shape and size are important characteristics of the inventory plots in the reduction of the estimation error. Given that our findings suggest a random distribution of the tree species and an isotropic pattern of environmental factors (Dagnelie 1956) in the two studied vegetation types, we concluded that square subplots of 2 000 $m^2$ and 1 800 $m^2$ were suitable in the dendrometric characterisation and in the analysis of stem diameter structure for tropical dense forest and woodland. Further studies should focus on the remaining vegetation types (e.g. woody savanna and riparian forests). In addition, they should address regeneration, which is a major component of forest management, as well as how factors such as spatial pattern of trees could affect estimation efficiency of plot shape and size in inventories of tropical forests.

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