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Efficiency of inventory plot patterns for the estimation of woody vegetation recruit density in a tropical dense forest in Bénin

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Abstract

This study assessed the effectiveness of plot patterns for estimating recruit density of woody species in the dense forest of Lama Reserve (Bénin). The experimental design consisted of thirty 0.04 ha plots randomly settled in the forest and each subdivided into four hundred 1-m² quadrats. Within each quadrat, recruits (dbh ≤10 cm) were counted and saplings ($h \geq 2$ m and 2 cm ≤ dbh < 7 cm) and young trees ($h \geq 2$ m and 7 cm ≤ dbh < 10 cm) were measured in dbh. In each 0.04 ha plot, seven different plot shapes and sizes were considered by grouping adjacent 1-m^2 quadrats. Relationship between mean square error of the estimation of the density of recruitments and the plot sizes was modelled using the Smith law. Results obtained showed an average value of density of recruitments of 10.7 plants/m^2 with Green index value of 0.01. Shape and size of plots highly influenced the estimation of the density of recruitments. Rectangular plots of length/width = 2 and size of 72 m² (12 m × 6 m) were most efficient for the estimation of the density of recruitments in tropical dense forest with standard error of 0.79 plants/m^2.

Key words: Bénin, dense forest, efficiency, plot shape, plot size, recruitment density

Résumé

Cette étude a évalué la précision des caractéristiques des placettes d'inventaire dans l'estimation de la densité de régénération d'espèces ligneuses de la forêt dense de Lama au Bénin. Le dispositif expérimental était constitué de 30 placeaux de 0,04 ha installés au hasard dans la forêt et divisés chacune en 400 quadrats d'un mètre carré. Dans chaque quadrat, les recrus (dbh ≤ 10 cm) ont été dénombrés, et le diamètre des plants (h ≥ 2 m, et 2 cm ≤ dbh < 7 cm) et des jeunes arbres ($h \geq 2$ m, et 7 cm ≤ dbh < 10 cm) fut mesuré à hauteur de poitrine. Dans chaque placeau de 0.04 ha, sept formes et tailles de placettes furent définies en regroupant des quadrats adjacents d'un m². La relation entre l'erreur quadratique moyenne de l'estimation de la densité des recrus et la taille des placettes a été modélisée au moyen de la loi Smith. Les résultats obtenus ont indiqué une valeur moyenne pour la densité de régénération de 10,7 plants/m², avec un indice de Green d'une valeur de 0,01. La forme et la taille des placettes influençaient fortement l'estimation de la densité des recrus. Les placettes rectangulaires de rapport longueur/largeur égal à 2 et d'une surface de 72 m² (12 m × 6 m) étaient les plus efficaces pour l'estimation de la densité des recrus dans une forêt tropicale dense, avec une erreur-type de 0,79 plants/m².

Introduction

Understanding recruitment processes (all the stages from flowering to saplings) is fundamental in inferring forest dynamics and forecast sustainable forest management plans (Dessard & Bar-Hen, 2004). For example, low density of mature trees highly impacts the regeneration process, increases distance of crossed pollination and induces a high variation in the production of viable seeds and subsequent recruitment of new individuals (Murawski,

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Gunatilleke & Bawa, 1994; Ghazoul, Liston & Boyle, 1998). The study on natural regeneration of vegetation is therefore important for an objective evaluation of the functioning of forests. To assess natural regeneration of vegetation, forest inventory by means of plots is required (Rondeux, 1999). Forest inventory analysis units (plots) have to incorporate sight and sound surveys (rare flora and fauna, exotics, etc.) as they traverse into and out of sample locations to assist local managers in collecting 'incidence' data to facilitate locating sites for more intensive studies (Smith, 2002). In general, the efficiency of any ecological (forest) inventory can be maximized in two ways: either by optimizing sampling strategies and survey design, or by changing the field sample unit itself (Phillips *et al.*, 2003). Often, scientists use the minimal area which is the plot size beyond which the specific richness increases slowly or no more. While this method is widely used in vegetation studies, its relevance is however very questionable as far as estimation of structural parameters of woody vegetation is concerned (Roux & Rieux, 1981; Dietvorst, van der Maarel & van der Putten, 1982).

Inventories of forests and trees are highly sensitive to plot size (Dessard & Bar-Hen, 2004; Salako *et al.*, 2013). Many authors have suggested maximizing plot size to account for sampling effort as precision in vegetation parameters estimation increases as the plot size increases (Kenkel & Podani, 1991; Shiver & Borders, 1995; Jyrki, Vanha & Tina, 1998; Magnussen, 1999; Cheryl, Raphaël & Claude, 2009). Yet none of these investigations was able to recommend a minimum plot size, that is sampling effort which ensures an affordable degree of precision (Kangas & Maltamo, 2007). In natural recruitment studies, square and rectangular plots are the most commonly used (Rondeux, 1999; van Laar & Akça, 2007; Bonou *et al.*, 2009). The square plots were used to reduce the edge trees, but rectangular plots were used in case the characteristics studied vary following a given direction. It is then important to carry out a study on the efficient size and shape of inventory plots, following the community plants, which minimize the sampling bias.

Recent studies have been carried out to assess the impacts of plot patterns on quantitative characterization of natural vegetation. The authors reported an optimal plot size of 1800 and 2000 m^2 for dendrometric assessment of tropical woodland and dense forest, respectively (Salako *et al.*, 2013). In a similar manner, this study has explored the relationship between plot size and estimation efficiency using natural recruitments woody species' density following plot shape. The optimal plot shape and size that minimize sampling bias in natural recruitment density estimation in dense forest were determined.

Materials and methods

Study area

The study was carried out in Lama Forest reserve in Bénin (one of protected areas of the country since 1946) located in the South between latitudes 6.55′ and 7.00′ North and longitudes 2.04′ and 2.12′ East. The overall surface area of the forest is estimated at 16,250 ha. Four plant communities were identified in the core (Bonou *et al.*, 2009): the typical dense forest, the degraded dense forest, young and old fallows preforests. The study was undertaken in the typical dense forest. The climate is subequatorial with two dry seasons alternating with two rainy seasons. Rainfall regime is bimodal from April to June and from September to November, with a mean annual rainfall of 1200 mm. Mean temperature varies between 25°C and 29°C and relative humidity between 69% and 97%. Vegetation is pedoclimatic because it is characterized by a clay soil which maintains a favourable particular microclimate for species.

Sampling design and data collection

The sampling design of plots was simple and random. Data were collected within 30 square plots of 20 m × 20 m. Each inventory plot was divided in four hundred 1-m^2 quadrats. Figure 1 shows a 0.04 ha plot divided in four hundred 1-m^2 quadrats.

In each quadrat, woody recruitments' species (dbh < 10 cm) were identified. All recruits were counted and their diameters at breast height (dbh) measured. Regeneration here refers to installed regeneration as the sampled stems had heights higher than 1 m and diameter lower than 10 cm (Poorter *et al.*, 1996). This concerned especially dominant trees. All woody individuals smaller than 10 cm in dbh were counted during data collection. Regeneration of tree species was extracted from the entire data set according to species' morphology described in the flora of Benin (Akoegninou *et al.*, 2006). Three classes of regeneration (seedlings, saplings and young trees) were considered. For seedlings ($h < 2$ m and dbh < 2 cm), no diameter was considered; dbh was only considered for saplings ($h \geq 2$ m and 2 cm ≤ dbh < 7 cm) and young trees ($h \geq 2$ m and 7 cm ≤ dbh < 10 cm).

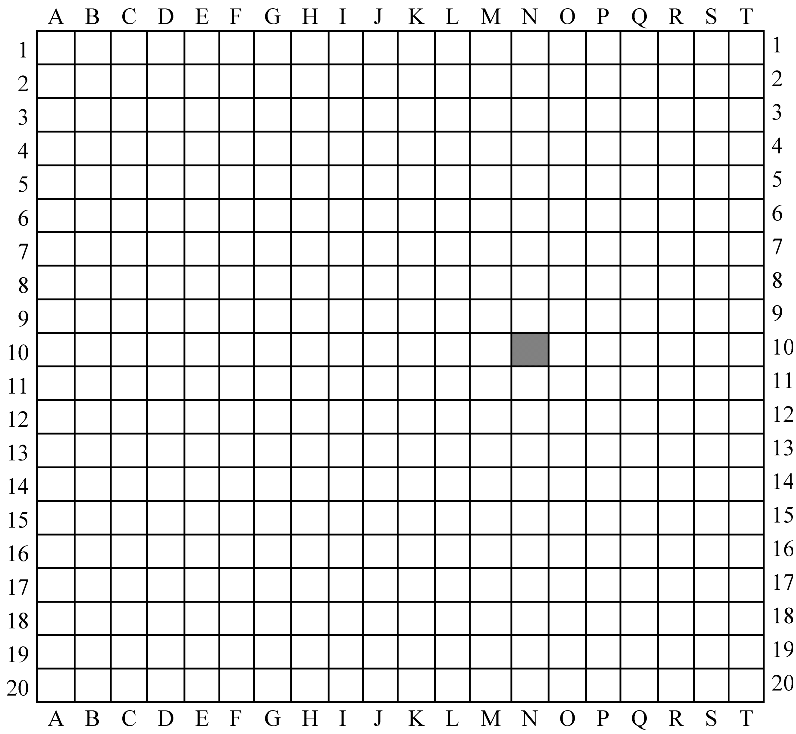

Fig 1 An illustration of 0.04 ha plot with the 400 one-meter-square quadrats. Each line was numbered from 1 to 20 and column from A to T. So, the N10 quadrat corresponds to the quadrat of column *N* and line 10

Structural characterization of the natural recruits

For each 0.04 ha plot, the following parameters were computed:

The density of recruits of the stand (*N*), that is the number of recruits (dbh < 10 cm) per sample plot expressed as plants per hectare:

$$N = \frac{n}{S} \tag{1}$$

n being the overall number of recruits in the main plot and *S* the unit area of the plot (*S* = 0.04 ha).

The Green index of the stand (GI) that gives a global view of spatial distribution of the scale of tree stand:

$$\mathrm{GI} = \frac{(\mathrm{BI} - 1)}{n - 1} \tag{2}$$

BI being the Blackman index and n defined as in (1). Blackman index was computed as follows:

$$\mathrm{BI} = \frac{V(N)}{m(N)} \tag{3}$$

where $V(N)$ and $m(N)$ are variance and mean of the density of recruitments computed from the thirty 0.04 ha plots.

Green index values ranging from −1 (regularity) to +1 (maximal aggregative distribution of regenerations) can be obtained, regardless of sample number, sample size or density. Values close to zero indicate random distribution of individuals.

The Shannon diversity index (*H*, in bits):

$$H = -\sum_{i=1}^{s} \frac{n_i}{n} \log_2 \frac{n_i}{n}, \tag{4}$$

n_i is the number of recruits per species *i*, *n* the total number of recruits inventoried in the 0.04 ha plots and *s* the species richness.

The Pielou evenness index (Eq) measures the diversity degree of a stand compared with the possible maximum and computed as follows:

$$\mathrm{Eq} = \frac{H}{\mathrm{Hmax}} \quad \text{with} \quad \mathrm{Hmax} = \log_2 s. \tag{5}$$

In (5), *H* represents the value of Shannon diversity index; Hmax is the maximum value of the diversity index and s defined as in (4). Pielou evenness varies from 0 (total dominance of one species) to 1 (equal abundance of species).

Diameter structure of recruits in the light of regeneration definition given in section (2.2.) above was established by fitting the observed values using the 3-parameter Weibull distribution, with density function f for a random variable x (Johnson & Kotz, 1970):

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1}\exp\left[-\left(\frac{x-a}{b}\right)^{c}\right] \quad (6)$$

In (6), parameter a is the location parameter (a = 2 cm), b the scale parameter, c the shape parameter, and exp [] is the exponential function. The random variable x is stem diameter at breast height of saplings and young trees. Diameters of recruitments were used to estimate the parameters b and c based on the maximum likelihood method (Johnson & Kotz, 1970).

Effect of inventory subplot size and shape on the estimation of density of recruitments

Types of subplots considered

Subplots were obtained from the 400 quadrats in each 0.04 ha plot by grouping together adjacent quadrats of 1 m^2 (Fig. 2).

Each type of inventory subplot was replicated as presented in Table 1, with the total number of replicates in brackets. In total, 7 types of subplots were considered (Fig. 2) so that for each of them, the total area taking into account all their replications equalled exactly 0.04 ha. This was necessary to compare different subplots that covered the same total area for the forest inventory (Table 1).

Table 1 Shape and size considered for the subplots

Shapes	Square (L/w = 1)	Rectangular (L/w = 2)
Size	2 m × 2 m (100)	1 m × 2 m (200)
	4 m × 4 m (25)	2 m × 4 m (50)
	5 m × 5 m (16)	5 m × 10 m (8)
	10 m × 10 m (4)	
	20 m × 20 m (main plot)	

L = length of subplots; w = width of subplot; values in bracket represented number of replications of same size of subplots that is possible to consider in a main 0.04 ha.

Computation of the estimation error of density of recruitments from subplots

The density of recruitments was estimated for each of the four hundred 1-m^2 quadrats, as well as for each of the seven subplots considered in Table 1 and the 0.04 ha plots. Mean square errors of the estimation of density of recruitments were used to establish relationship between the size of subplots and the estimation error of the density

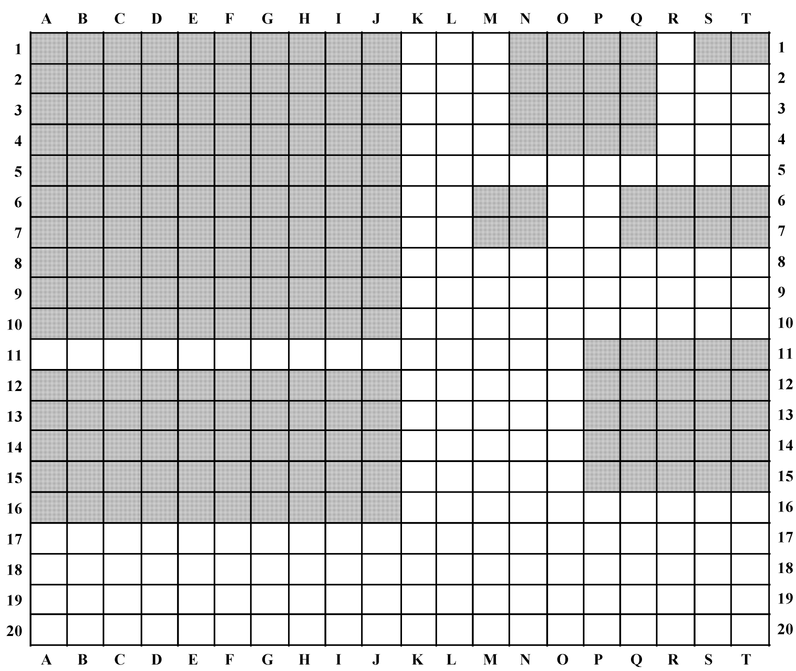

Fig 2 Illustration of seven types of subplots established from 0.04 ha plots. Each zone coloured in grey colour represents one subplot type. The first (left hand side) is 10 m × 10 m subplot. Just below, the one of 5 m × 10 m. In the right side of this, we have 5 m × 5 m subplot, etc

of recruitments for each subplot shape considered as in Salako *et al.* (2013). First of all, the thirty 0.04-ha plots were compared through one-way analysis of variance (ANOVA) based on their values of the density of recruitments in each 1-m^2 quadrat. This procedure helped to compute the mean square error, σ_1^2, based on the 0.04 ha plots. The same procedure was used to compute mean square error, σ_n^2, of the density of recruitments for each type of subplots of size *n*. This procedure was based on ANOVA applied to compare different subplots of same size based on the density of recruitments. Replicates in this model are number of times each type of subplot was considered in a 0.04 ha plot (values in brackets in Table 1).

The relationship between mean square error of the estimation of density of recruitments and subplot size was modelled using Smith law (Smith, 1938):

$$\sigma_n^2 = \frac{\sigma_1^2}{n^\beta} \quad (7)$$

In (7), σ_1^2 is the mean square error linked to 1-m^2 quadrats; β is a parameter that measures the degree of dependence of the quadrats within a 0.04-ha plot; it varies between 0 and 1. If $\beta = 0$, the dependence is complete; If $\beta = 1$, formula (7) becomes that of the mean of *a* parameter computed from a random sample for which there is no dependence between the observations. Then, for $\beta = 1$, the shape of the subplots does not impact the mean square error of the density of recruitments. To estimate β, weighted regression was used after logarithmic transformation applied to (7). The weights were considered as the numbers of replications of the different types of subplots.

Results

Structural patterns of recruits in Lama forest reserve

The structural patterns of recruits (Table 2) show a relatively higher density of seedlings (10.7 individuals/m^2) compared to the ones of saplings and young trees which are similar.

The value obtained for Green index indicates a random distribution of recruits for 0.5 m radius of observation. However, at larger scale, for example for 0.04-ha plots (10 m radius of observation), Green index value was 1, indicating a clumped distribution of recruits in the dense forest. Shannon diversity index and Pielou evenness are low, indicating a relatively selective stands with some dominant species like *Dialium guineense* Willd. (2979 plants/ha) and *Drypetes floribunda* Hutch. (1308 plants/ha).

Table 2 Structural parameters of recruitments in the Lama forest reserve

Structural parameters	m	s
Density of recruitments, *N* (individuals/m^2)	10.7	3.61
Density of seedlings, Nse (individuals/m^2)	5.05	1.73
Density of saplings, Nsp (individuals/m^2)	2.11	0.93
Density of young trees, Nyt (individuals/m^2)	2.90	0.91
Green index, GI	0.01	–
Diameter of saplings (cm)	3.39	1.3
Diameter of young trees (cm)	8.19	0.81
Species richness, s	28	
Shannon index, H (bits)	2.42	
Pielou evenness, Eq	0.50	

Stem diameter structure of recruitments (Fig. 3) reveals a 'J reverse' shape with the highest frequency of recruits in 2- to 2.5-cm-diameter class, indicating a good transition between different recruitments classes in the Lama forest reserve. The 2-2.5 class is dominated by *D. guineense*, *Diospyros mespiliformis* Hochst. ex A.DC. and *Afzelia africana* Sm.

Effectiveness of subplot shape and size on the density of recruitments

Results from the weighted regression to model the relationship between the estimation error of the density of recruitments and subplot size yielded the expression:

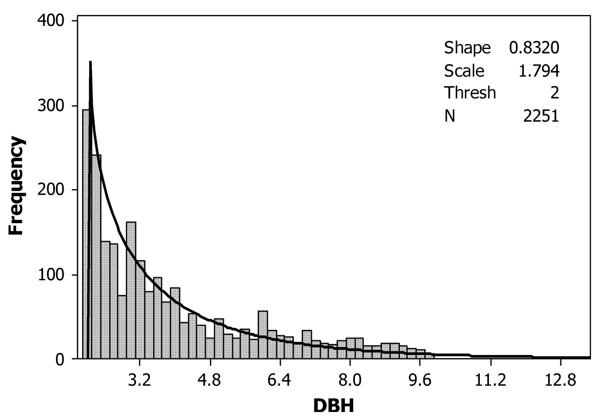

Fig 3 Stem diameter structure of recruitments in Lama Forest reserve

$$\sigma_n^2 = \frac{12.49}{n^{0.601}} \; (\sigma_n \text{ expressed as individuals/m}^2) \qquad (8)$$

From equation (8), it can be noticed that the degree of dependence is less than one ($\beta = 0.601$), suggesting a strong dependence between the four hundred 1-m^2 quadrats. Consequently, the size of subplots presents a significant effect on the estimation error of the density of recruitments in the Lama Forest reserve. Analysis of estimation error of the density of recruitments for each subplot shape (Fig. 4) revealed that the rectangular plots ($L/w = 2$) presented lower values of standard deviation of the density of recruitments as a function of plot size and thus gives more precision. It revealed that beyond 72 m^2 in dense forest, the gain of precision in the estimation of the density of recruitments of the vegetation failed to increase or increased only slightly. Provided a rectangular plot shape of ratio $L/w = 2$, plot size of 12 m × 6 m should give a good estimation of the density of recruitments in tropical dense forest with standard deviation of 0.79 plants/m^2.

Discussion

The study of regeneration of tree species in Lama Forest reserve was performed using random sampling scheme. The effect of plot patterns in the assessment of recruitments density of woody species was analysed using Smith law (Smith, 1938). Results from structural characterization of recruitments indicated that the Lama Forest reserve is selective with relatively low density of saplings and young trees in regard to the overall density of regeneration.

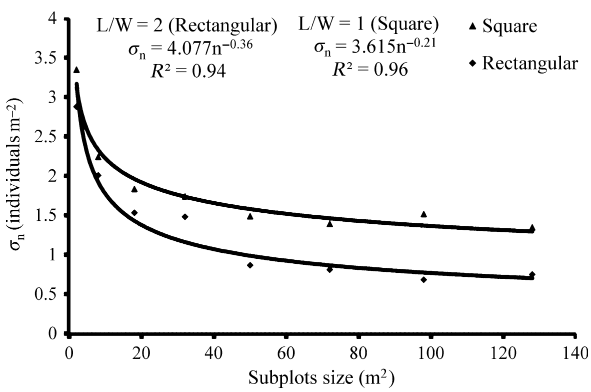

Fig 4 Evolution trend of the standard deviation of the density of recruitments in function of subplots size for different shapes. l = length; w = width

The most important factors explaining the trend of decreasing density of regeneration from seedling to young trees are abiotic factors mainly the type of soil of the forest reserve (clay soil) and intra- and interspecific competition of recruits in relation to nutrients (light and water) as reported by Fonton, Glele Kakaï & Rondeux (2002).

The shape and size of inventory plots constitute the main factors that impact accuracy of forest estimations (Rondeux, 1999; Kangas & Maltamo, 2007). Results from the assessment of the effect of plot patterns on the precision of the density of recruitments showed significant effect of plot shape. The more L/w ratio increases, the lower the standard deviation of the estimation of density of recruitments. Rectangular plots of L/w ratio equal to 2 gave the most accurate estimation of the density of recruitment (rapid decrease of the standard deviation as a function of subplot size). The rectangular shape was found to be more appropriate for the estimation of structural parameters of recruitments. This finding is consistent with that of Jyrki, Vanha & Tina (1998) according to which rectangular shape constitutes an effective alternative to circular plots in most varied habitats and topographic conditions. In fact, Lama Forest reserve varies in slope, light and water availability on soil. Consequently recruitments are abundant in open than closed areas. Moist zones gather more recruitments than dry zones. These results are also in accordance with those of Jyrki, Vanha & Tina (1998) and Kangas & Maltamo (2007) who reported that rectangular plots are more suitable in vegetation types where clumped distribution of regeneration occurs. Indeed, at equal size, rectangular plots help to take into account more individuals than other plot shapes in such vegetation communities (Podani, 1984; Condit *et al.*, 1996). But in general, square plots presented smaller perimeter and then relatively low sampling effort and reduced edge effect error (Picard, 2006; Kangas & Maltamo, 2007). Moreover, some studies concluded that square and rectangular plots did not differ significantly in the estimation of structural parameters for species with random distribution in the community (Cheryl, Raphaël & Claude, 2009).

Results from this study showed that plot size and shape highly impacted the standard deviation of the estimation of density of recruitments. Many studies came to the same conclusion and reported that the larger the plot, the higher the accuracy of the estimation from forest inventory (Jyrki, Vanha & Tina, 1998; Kangas & Maltamo, 2007). But this is not in favour of an indefinite increase of plot size. We need to take into account inventory cost. For rectangular plots of

L/w ratio equal to 2, we noticed that beyond 72 m^2 of plot size, standard deviation of the estimation of density of recruitments did not vary significantly and plots of 12 m × 6 m were the most effective in estimating density of recruitments in the tropical dense forest in Bénin.

In conclusion, the recruitment of woody species is very selective in the Lama Forest reserve. Plot shape and size significantly impact on the accuracy of recruitment density estimation. Rectangular plots of 72 m^2 (12 m × 6 m) are more suitable for tree recruitment species assessment. However, it is also possible that spatial distribution of recruitments species significantly impacts the precision of recruitments estimations in this forest. It would be useful for future researches to assess combined effect of plot patterns and spatial distribution on the accuracy of estimators.

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