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Research Application Summary

Effectiveness of inventory plot patterns and spatial distribution of trees and recruits in West African forest estimates: Recent findings and perspectives

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Abstract

Forest inventories constitute an important tool in decision-making by assessing quantitative and qualitative pattern of plant material and its evolution over time. Inventory techniques used in different countries in West Africa are numerous and diversified. This situation does not allow comparison of forest inventory results between different countries and decision making at regional level. Many studies have attempted to determine optimal inventory plot (shape and size) for different vegetations types. However, most of these studies have been undertaken outside Africa and did not take into account most common vegetation types of Africa. Recent studies in West Africa have focused on the comparison of inventory plot sizes and shapes and spatial pattern of trees and recruits on the floristic and dendrometric analysis of dense forest and woodland. From these studies, the direction and shape of inventory plots do not influence the precision of the quantitative analysis of vegetation. However, square plots were suitable in practice. On the contrary, plot size is significantly correlated with the precision of floristic analysis and estimation efficiency. Where trees tended to be aggregated, estimation error increases with degree of aggregation, and rectangular plots of 0.24 ha resulted in more precision. In terms of regeneration, shape and size of subplots highly influence the estimation of the density of recruits and rectangular subplots were most efficient for the estimation of the density of recruits in dense forest. As for stem diameter distribution of regeneration, only the plot size had a significant effect on the mean absolute error of the stem diameter structure. Further studies are required in order to cover all the vegetation types met in Africa.

Key words: Error, non-randomness, plot shape, plot size, plot structure, regeneration, vegetation

Résumé

Les inventaires forestiers constituent un outil important dans la prise de décision en évaluant le modèle quantitatif et qualitatif du matériel végétal et son évolution dans le temps. Les techniques d'inventaire utilisées dans différents pays d'Afrique de l'Ouest sont nombreuses et diversifiées. Cette situation ne permet pas de comparer les résultats d'inventaire forestier des différents pays et la prise de décision au niveau régional. De nombreuses études ont tenté de déterminer la placette (forme et taille) d'inventaire optimale pour différents types de végétations. Cependant, la plupart de ces études ont été entreprises hors de l'Afrique et n'ont pas tenu compte des types de végétation les plus populaires en Afrique. Des études récentes en Afrique de l'Ouest se sont concentrées sur la comparaison des tailles et des formes des placettes d'inventaire et la répartition spatiale des arbres et des recrues sur l'analyse floristique et dendrométrique des forêts denses et boisées. De ces études, la direction et la forme des placettes d'inventaire n'influencent pas la précision de l'analyse quantitative de la végétation. Cependant, des placettes carrées étaient en pratique appropriées. Au contraire, la taille de la parcelle est significativement corrélée à la précision de l'analyse floristique et de l'efficacité de l'estimation. Dans les endroits où les arbres ont une tendance à se regrouper, les erreurs d'estimation augmentent avec le degré d'agrégation, et les placettes rectangulaires de 0,24 ha ont donné lieu à plus de précision. En termes de régénération, la forme et la taille de l'unité parcellaire influent très fortement sur l'estimation de la densité des recrues et les unités parcellaires rectangulaires ont été les plus efficaces pour l'estimation de la densité des recrues dans une forêt dense. En ce qui concerne la distribution des diamètres de la tige de la régénération, seule la taille de la placette a un effet significatif sur l'erreur moyenne absolue de la structure du diamètre de la tige. D'autres études sont nécessaires afin de prendre en compte tous les types de végétation rencontrés en Afrique.

Mots clés: Erreur, non aléatoire, forme de la placette, taille de la placette, la structure de la parcelle, régénération, végétation

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.

During forest inventories, the unit of sampling often consists of plots whose shape and size vary according to the vegetation and the characteristics of the forest (Houeto *et al*., 2013). Accurate characterization of the vegetation structure partially depends on inventory plot size; it is inversely proportional to the estimation bias of investigated parameters (Kenkel and Podani, 1991; Shiver and Borders, 1996). Nevertheless, the larger the plot, the longer the time and the higher the sampling effort and the cost of inventory (Kangas and Maltamo, 2007). In practice, for floristic studies, vegetation scientists have traditionally used the minimal area approach when characterizing the structure of plant communities (Kenkel and Podani, 1991). Minimal area is generally defined as the plot size beyond which species richness fails to increase or increases only slightly. This minimal area is determined through an empirical pathway from the concept of species-area curve (Gounot, 1969). The use of the minimal area is straightforward. However, this approach has some problems (Barkman, 1989). In fact, it is based on presence–absence data rather than quantitative data (Roux and Rieux, 1981; Dietvorst *et al*., 1982).

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).

Vegetation spatial pattern is a potential variable governing the shape and size of inventory plots. Increasing plot size, probably, will catch more heterogeneities, but the effect of plot shape may act to define an optimal plot feature that minimizes the estimation error. Understanding the role of level of aggregation, combined with shape effects (square vs degree of rectangularity) in estimation of sampling error, is of incremental value for both ecology and forest fields.

Moreover, 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 (Thiombiano *et al*., 2016). This high diversity of size and shape of plots does not allow for comparisons of structural patterns of forests at regional level. Therefore, harmonization of techniques of forest inventory is necessary.

This paper therefore aimed at giving an overview of main conclusions linked to recent studies on the effect of inventory plots and tree spatial patterns on the structural characterization of vegetations by focusing on African tropical vegetation stands, mainly dense forests and woodlands.

Efficiency of plot patterns in the phytosociological characterization. Floristic characterization of vegetation constitutes a first step in the structural analysis of the vegetation; indeed, it aims at sorting species along a few axes in order to identify floristic communities in the vegetation. These axes must represent the main compositional gradients in the dataset using either abundance data or presence/abundance data (Økland, 1996; Salako *et al*., 2013). This analysis is however sensitive to plot patterns considered in collecting data. However, a recent study of Houeto *et al*. (2013) using Eigenanalysis showed that the phytosociological characterization of vegetation was not influenced by plot shape considering dense forest. Overall either square or rectangular plots resulted in similar relative loss of precision (Houeto *et al*., 2013).

The accuracy of phytosociological characterization can be improved by increasing plot size. The increase in the relative loss of precision is not very perceptible around 1500 m^2 (in dense forest) and 1000 m^2 (in woodland) suggesting that plots of 1500 m^2 and 1000 m^2 could provide a good accuracy of the phytosociological characterization of the vegetation with a minimum sampling effort of 0.35 man-days/plot and 0.2 man-days/plot, respectively, in dense forest and in woodland (Houeto *et al.*, 2013).

However, the design used did not consider circular plots, which are also used in the vegetation studies (Kangas and Maltamo, 2007; Van Laar and Akça, 2007). They are often considered for their ease of establishment with aid of optical devices (Husch *et al.*, 2003) and the reduction in borderline trees (Philip, 2002). They are also convenient when the studies are related to the planted forests (Van Laar and Akça, 2007). However, in developing countries, the lack of suitable facilities (e.g. optical devices) limits the use of circular plots in natural forests (Houeto *et al.*, 2013).

Efficiency of plot patterns in the quantitative analysis of vegetation. Quantitative analysis of vegetation takes into account computation of dendrometric parameters and stem diameter and/or height structure of the vegetation per community identified by the floristic analysis (Bonou *et al.*, 2009; Glele Kakaï and Sinsin, 2009; Houeto *et al.*, 2013). In most studies, basal area is considered to assess the precision of dendrometric parameters estimations. Indeed, basal area takes into account trees diameter and density and constitutes a simple and reliable criterion considered in the directives of forest management (Bary-Lenger *et al.*, 1988).

Salako *et al.* (2013) found in the computation of dendrometric parameters of the vegetation, that direction and shape of inventory plots did not influence significantly the precision of the parameters. However, square plots were suitable in practice. Previous studies have also reported direction to be less important in forestry estimation efficiency, unless it concerns riparian forests (Natta, 2003; Picard, 2006).

On the contrary, plot size was significantly and inversely correlated to estimation efficiency. Results obtain from Salako *et al.* (2013) indicated that in dense forest the plot shapes influenced significantly the estimation bias of the shape parameter of the Weibull distribution for the adjustment of the observed stem diameter distribution of trees. However, it was not the case in woodland where the estimation bias of the shape parameter gave slightly the same value. Moreover, effect of plot size was highly significant on the mean square error of the basal area in dense Forest and woodland (Salako *et al.*, 2013). The optimal plot size for quantitative analysis of vegetation was 1800 and 2000 m^2 with an inventory effort of 0.51 and 0.85 man-days per plot in woodland and dense forest, respectively (Salako *et al.*, 2013). Plot direction is only important when the parameters under study vary significantly with direction (Rondeux, 1999).

Effectiveness of plot patterns on the density of recruits. Understanding recruitment processes (all the stages from flowering to saplings) is fundamental in inferring forest dynamics and forecast sustainable forest management plans (Dessard and 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 and Bawa, 1994; Ghazoul *et al.*, 1998; Donou Hounsode *et al.*, 2015). 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).

For natural regeneration, plot size gives a significant effect on the estimation error of the density of recruits in dense forest (Donou Hounsode *et al.*, 2015). Analysis of estimation error of the density of recruits for each plot shape revealed that the more Length/width ratio increases, the lower the standard deviation of the estimation of density of recruits (Donou Hounsode *et al.*, 2015). Hence, rectangular plots of Length/width ratio equals 2 presented lower values of standard deviation of the density of recruits as a function of plot size and thus gives more precision (Donou Hounsode *et al.*, 2015). These authors also found that a rectangular plot shape of ratio L/w = 2, plot size of 12 m x 6 m should give a good estimation of the density of recruits in tropical dense forest with standard deviation of 0.79 plants/m^2.

According to Jyrki *et al.* (1998), rectangular shape constitutes an effective alternative to circular plots in most varied habitats and topographic conditions. 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 and Maltamo, 2007).

Accounting for tree and recruits spatial distribution in the determination of optimal plots

Overview of spatial patterns of vegetation. The error related to sampling design when assessing vegetation characteristics may also be explained by the spatial distribution of existing tree species (Mensah *et al.*, 2016). Tree spatial distribution could play a very significant role in the evolution of ecological models (Goreaud, 2000). At community and species levels, tree spatial distribution could play a central role in the efficiency of inventory plot size and shape. Some previous studies have highlighted that the relationship between the statistical precision of estimates and plot size may depend on the spatial distribution of trees (Kenkel *et al.*, 1989; Picard, 2006). Following Jyrki *et al.* (1998), a particular tree spatial distribution would require a particular sample size and plot for accuracy of estimates. Assuming that tree aggregation is the most encountered tree spatial pattern in nature (Wiegand *et al.*, 2007; Li *et al.*, 2009), particular features of inventory plot are expected to take into account this environmental heterogeneity (Mensah *et al.*, 2016).

Most such studies have focused on adult tree individuals (Kenkel and Podani 1991; Salako *et al.*, 2013), neglecting regeneration strata. The few studies that focused on the plot size influence on the regeneration assessment include Fröhlich and Quednau (1995), Dessard and Bar-Hen (2004) and Donou Hounsode *et al.* (2015), who respectively suggested plots of 12 m × 6 m, 2 m × 2 m, adjacent diagonal 10 m × 10 m plots for natural regeneration studies in tropical forests. Spatial structure of individuals is presumed to play an important role in the accuracy of regeneration estimates. Most studies from West Africa have failed in taking into account spatial distribution of regeneration when studying the population structures of woody species. Furthermore, it was shown that the relationship between the statistical precision of estimates and the plot size depends upon the spatial distribution of trees (Picard, 2006).

Vegetation-related effect of tree spatial distribution and the efficiency of plot size and shape. Precise estimation of structural parameters involves the use of suitable sampling design that should consider the plot shape, size and spatial distribution of tree species (Jyrki *et al*., 1998; Kangas and Maltamo, 2007). Mensah *et al*. (2016) found a significant interaction of vegetation type with plot size and degree of tree aggregation. In fact, species in woodland would exhibit structural and spatial patterns differently from species in dense forest (Houeto *et al*., 2013; Mensah *et al*., 2014), because of distinct inter- and intraspecific relationships across life stages. In woodland, Mensah *et al.* (2016) found that, where highest values of Green index were obtained, both plot shape and tree spatial distribution had significant effects on estimation error of basal area. On the contrary, plot shape and tree spatial distribution did not influence the estimation error in dense forest. In their study, Green index was used to assess the spatial distribution of trees and high values of this index reveal trees aggregation. According to Jyrki *et al*. (1998), a plant community would probably require a plot size with respect to its spatial pattern, for efficient analysis of vegetation parameters of enumerated species. Where spatial distribution had significant effect, Mensah *et al*. (2016) found that estimation error was proportional to the degree of tree aggregation. From this finding, it can be inferred that, for a given plot size, a random distribution likely results in more reliable estimation than an aggregative distribution. In other words, for a given precision (estimation error), a larger subplot size will be required for species with aggregative distribution than for species displaying a random distribution. Where spatial distribution had significant effect, these authors also found that rectangular subplots were more effective than square plots. In dense forest where there was no effect of tree spatial distribution, both rectangular and square plots performed equally. This is probably due to the low values of Green index that were recorded, in general, in that habitat. Such results however reveal that all vegetation types will not require the same form of plot, that is some will be indifferent to plot shapes while others will not.

Effect of the tree spatial distribution patterns, the plot size and shape on the estimation of the density of recruits. Recent study of Gnonlonfoun *et al*. (2015) showed that the standard deviation of the regeneration density is negatively affected by plot size whereas it was positively affected by the Green Index. Moreover, no significant additional accuracy was obtained above a plot size of 100 m² plot size. Their results showed that the spatial distribution pattern and the plot size significantly influenced the error of the regeneration density estimation. The estimation accuracy is improved by increasing plot size. However, very slight improvement was observed above 100 m² plot size. In contrast to the plot size, any increase in the Green index generates a loss of accuracy. This may suggest that for similar plot features, the random spatial distribution of individuals yields the most accurate estimation of regeneration density (Gnonlonfoun *et al*., 2015).

The plot shape significantly impacted the estimation accuracy of *Afzelia africana* Smith, *Dialium guineense* Willd and *Drypetes floribunda* Hutch stem density. These results confirm previous findings according to which rectangular plots are more appropriate for the assessment of vegetation communities with aggregated individuals (Jyrki *et al*., 1998; Kangas and Maltamo, 2007). Consistently with Van Laar and Akça (2007) and Rondeux (1999), the results for *D. guineense* and *D. floribunda* clearly suggest that square plots are more appropriate when the regeneration individuals are randomly distributed (Gnonlonfoun *et al*., 2015). The spatial pattern of regeneration did not affect the stem diameter distribution analysis whereas subplot size had a significant effect. Indeed, the shape of the stem diameter distribution of regeneration is a global characteristic of forest ecosystems and so is less linked to the spatial pattern of individual and subplot characteristics.

Findings from Gnonlonfoun *et al*. (2015) would suggest rectangular and square plots of 100 m², 14 m × 7 m and 10 m × 10 m to be suitable for estimating regeneration population of woody species. These shapes and sizes are applicable in dense semi-deciduous forests for aggregative and random distributions, respectively.

Conclusion

Precision in Forest estimations is closely linked to plots pattern considered and the availability of different plot sizes and plot shapes that can be used in forest inventory is undoubtedly an asset. However, this could also constitute a drawback in comparing for example results from successive inventories that use different plot sizes and shapes for the same vegetations. Therefore a harmonization of plot pattern is needed and this study considered results from recent papers to suggest a guideline for choosing plot size and shape in inventory of vegetation. From these recent studies, the following conclusions are derived;

(i) for floristic analysis of vegetation, square plot of 1500 m² is recommended in dense forest whereas square plot of 1000 m² is adequate in woodland (Houeto *et al*., 2014);

(ii) for dendrometric and stem diameter structure analysis of the whole vegetation, square plot of 2000 m² is required whereas in the case of woodland, square plot of 1800 m² constitutes the optimal plot (Salako *et al*., 2013);

(iii) for the dendrometric analysis of individual tree species, 2400 m² rectangular plot is required when aggregative pattern is noted and 2400 m² square plot is advised in the case of random pattern (Mensah *et al*., 2016);

(iv) in the case of regeneration studies, rectangular plots of 72 m² (12 m x 6 m) are optimal for the estimation of the density of recruits in dense forest (Donou Hounsode *et al*., 2015);

(v) In the case of aggregative distribution of recruits, 100 m² rectangular (» 14 m × 7 m) plot is optimal for aggregative distribution and 100 m² square (10 m × 10 m) plot for random distribution (Gnonlonfoun *et al*., 2015).

Further studies are still needed to cover all the vegetation types in Africa to able effective harmonization of forest inventory methods targeting plot patterns.

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References

Barkman, J.J. 1989. A critical evaluation of minimum area concepts. *Vegetatio* 85: 89-104.

Bary-Lenger, A., Evrard, R. and Gathy, P. 1988. *La forêt: Ecologie-Gestion, Economie-Conservation*. Editions du perron. Liège, 619p.

Bonou, W., Glèlè Kakaï, R., Assogbadjo, A.E., Fonton, H.N. and Sinsin, B. 2009. Characterisation of *Afzelia africana* Sm. habitat in the Lama forest reserve of Benin. *Forest Ecology and Management* 258:1084-1092.

Condit, R., Hubbell, S.P., Lafrankie, J.V., Sukumar, R., Manokaran, R., Foster, R.B. and Ashton, P.S. 1996. Species-area and species-individual relationships for tropical trees: a comparison of three 50-ha plots. *J Ecol.* 84: 549-562.

Dessard, H. and Bar-Hen, A. 2004. Experimental design for spatial sampling applied to the study of tropical forest recruitment. *Forest Research* 99: 1-13.

Dietvorst, P., Van Der Maarel, E. and Van Der Putten, H. 1982. A new approach to the minimal area of a plant community. *Vegetatio* 50: 77-91.

Donou Hounsode, M., Glèlè Kakaï, R., Azihou, F. and Ouedraogo, A. 2015. Efficiency of inventory plots patterns for the estimation of woody vegetation recruits density in a tropical dense forest. *African Journal of Ecology* 53: 355-361.

Fonweban, J.N. 1995. Modélisation de la production des peuplements forestiers : Application aux peuplements d'*Eucalyptus sativa* au Cameroun. Thèse de doctorat. ENGREF, Nancy: 197p.

Fröhlich, M. and Quednau, H.D. 1995. Statistical analysis of the distribution pattern of natural recruitment in forests. *Forest Ecology and Management* 73:45-57.

Ghazoul, J., Liston, K.A. and Boyle, T.J.B. 1998. Disturbance induced density dependent seed set in *Shorea siamensis* Dipterocarpaceae, a tropical forest tree. *J. Ecol.* 86:462-473.

Glèlè Kakaï, R. and Sinsin, B. 2009. Structural description of two *Isoberlinia* dominated communities in the Wari-Maro forest reserve (Benin). *South African Journal of Botany* 75 (1): 43-51.

Gnonlonfoun, I., Glèlè Kakaï, R., Salako, V.K., Assogbadjo, A.E. and Ouédraogo, A. 2015. Structural analysis of regeneration in tropical dense forest: combined effect of plot and spatial distribution patterns. *Acta Botanica Gallica* 162 (1):79-87.

Goreaud, F. 2000. Apports de la structure spatiale en forêt tempérée à l'étude et la modélisation des peuplements complexes. PhD dissertation, ENGREF, Nancy, France.

Gounot, M. 1969. Méthodes d'études quantitatives de la vegetation. Masson et Cie, Paris, France.

Houeto, G., Fandohan, B., Ouédraogo, A., Ago, E., Salako, V.K., Assogbadjo, A.E., Glele Kakaï, R. and Sinsin, B. 2013. Floristic and dendrometric analysis of woodlands in the Sudano-Guinean zone: A case study of Belléfoungou forest reserve in Benin. *Acta Botanica Gallica* 159 (4):387-394.

Houeto, G., Glèlè Kakaï, R., Salako, K.V., Assogbadjo, A., Fandohan, B., Sinsin, B. and Palm, R. 2013. Effect of inventory plot patterns in the floristic analysis of tropical woodland and dense forest. *African Journal of Ecology* 52:257-264.

Husch, B., Beers, T. and Kershaw, J.J.R. 2003. *Forest Mensuration*. (4th Ed). John Wiley & Sons, New Jersey.

Jyrki, J., Vanha, I. and Tina, T. 1998. Optimal sample and plot size for inventory of field and ground layer vegetation in a mature Myrtillus-type boreal spruce forest. *Ann. Bot. Fennici* 35:191-196.

Kangas, A. and Maltamo, M. 2007. Forest inventory: *methodology and applications*, Springer, Dordrecht.

Kenkel, N.C. and Podani, J. 1991. Plot size and estimation efficiency in plant community studies. *Journal of Vegetation Science* 2:539-544.

Kenkel, N.C., Juhasz-N_agy, P. and Podani, J. 1989. On sampling procedures in population and community ecology. *Vegetatio* 83:195-207.

Li, L., Huang, Z., Ye, W., Cao, H., Wei, S., Wang, Z., Lian, J., Sun, I.F., Ma, K. and He, F. 2009. Spatial distributions of tree species in a subtropical forest of China. *Oikos* 118: 495-502.

Mensah, S., Assogbadjo, A.E., Salako, V.K., Ago, E.E. and Glèlè Kakaï, R. 2016. Accounting for tree spatial distribution in a comparison of plot sizes and shapes in dense forest and woodland in Benin (West Africa). *African Journal of Ecology* 54 (1):87-94.

Murawski, A.D., Gunatilleke, N. and Bawa, K.S. 1994. The effects of selective logging on inbreeding in *Shorea megistophylla* (Dipterocarpaceae) from Sri Lanka. *Conserv. Biol*. 8:997-1002.

Natta, K.N. 2003. Ecological assessment of riparian forets in Benin: Phytodiversity, phytosociology, and spatial distribution of tree species. Thèse de Doctorat. University of Wagennigen, 226 p.

Økland, R.H. 1990. Vegetation ecology: theory, methods and applications with reference to Fennoscandia. *Sommerfeltia Supplement* 1:1-123.

Philip, M.S. 2002. *Measuring Trees and Forests*, 2nd Ed. CABI, London.

Picard, N. 2006. Méthode d'inventaire forestier. Projet de développement rural participatif dans le moyen Atlas central (projet Khénifra). *Cirad 00147247 version* 1:1-42.

Podani, J. 1984. Spatial processes in the study of vegetation: theory and review. *Acta Bot. Hung* 30:75-118.

Rondeux, J. 1999. *La mesure des peuplements forestiers*. Presses agronomiques de Gembloux, 2ème éd. Gembloux, 521p.

Roux, C. and Rieux, R. 1981. L'aire minimale des peuplements lichéniques saxicoles-calcicoles. *Vegetatio* 44: 65-76.

Salako, V. K., Glèlè Kakaï, R., Assogbadjo, A., Fandohan, B., Houinato, M. and Palm, R. 2013. Efficiency of inventory plot patterns in quantitative analysis of vegetation: A case study of tropical woodland and dense forest in Benin (West Africa). *Southern Forests* 75 (3):137-143.

Shiver, B.D. and Borders, B.E. 1995. Sampling techniques for forest resources inventory. John Wiley & Sons. 356p.

Thiombiano, A., Glèlè Kakaï, R., Bayen, P., Boussim, J.I. and Mahamane, A. 2016. Méthodes et dispositifs d'inventaires forestiers en Afrique de L'ouest: État des deux et propositions pour une harmonisation. 2016. *Annales des Sciences Agronomiques 20 - Spécial Projet Undesert-UE:* 15-31.

Van Laar, A. and Akça, A. 2007. *Forest mensuration*. Springer, Dordrecht.

Wiegand, T., Gunatilleke, S., Gunatilleke, N. and Okuda, T. 2007. Analyzing the spatial structure of a Sri Lankan tree species with multiple scales of clustering. *Ecology* 88: 3088-3102.