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Distance sampling technique in vegetation studies: A critical review

Gbènakpon Aubin Y. G. Amagnide, Ceptime Ahlonsou, and Romain Glele Kakaï

Laboratoire de Biomathématiques et d'Estimations Forestières, Faculté des Sciences Agronomiques,
04 BP 1525 Cotonou, Benin

ABSTRACT: Plotless sampling techniques, linear recordings of distances among random trees or points and trees were developed to overcome some limitations of plot-based or quadrat methods by reducing time consuming, sampling effort, etc. However, research works proved that some points need to be clarified in order to provide a more useful guidelines for ecologists. The main objective of this study is to make a critical review of literature on plotless sampling techniques in vegetation studies. For this purpose, most original studies published and focused on plotless techniques in plant communities were identified via Keywords searching on scientific database websites and additional references from retrieved articles. Thereafter, about hundred papers were sampled in this review through careful reading of the abstract, methods and results. This study revealed that plotless sampling methods are mainly used to estimate population density. Furthermore, this study showed that among the plotless sampling methods that were described, some remains slightly documented in ecology to date. Results obtained also showed that the spatial distribution of organisms impacted the performance of these methods. All plotless sampling methods recorded their best performance when the population is randomly distributed. When the population is uniformly or contagiously (clump) distributed, most of them produced the largest bias of density estimate. However, over all spatial patterns, distance measurements at least to the third nearest neighbour were the best preferred methods. Therefore, further research works need to control this bias, to continue some investigations on those methods mainly on measurement errors and detection process.

KEYWORDS: Sampling, plotless techniques, quadrat methods, density estimation, plant community.

1 INTRODUCTION

Sampling consists of techniques for selecting a sample from a large population with techniques for efficient and accurate estimating of some parameters of that entire population from measurements made on the sample [1]. Before 1980, in quantitative ecology, sampling techniques were one of the least well understood tools [2]. Many research works have been focussed on sampling techniques in vegetation since quantitative data are fundamental to an appropriate characterization of vegetation. Thus, sampling is a basic but an important step for quantitative analysis in plant community research. It is known that sampling techniques are linked with whether the study outcomes can reveal the community pattern [3]. Indeed, in vegetation study with a large number of trees, a census which technically means a survey for which the intended sample is the entire study area is impracticable due to manpower, material resources, and time constraints. In ecological research, an accurate assessment of the size and composition of plant in communities is required to design more effective conservation actions and develop appropriate strategies for restoration purposes (e.g. see [4], [5]). For instance, when assessing the size of a plant community, the parameter of interest is density which expresses the number of individuals per unit of area. The most useful method to estimate density is tree counting. However, counting all individuals in plant community is very time consuming and generally impracticable [6] and when possible, the information obtained would not be useful and reliable than those derived from an adequate sampling schemes ([7], [8]). From ecological literature, two main sampling techniques can be distinguished: Plot-based or quadrat methods and Plotless or distance sampling methods. Plot-based methods are traditional sampling techniques used by ecologists to measure the abundance (count, cover, density, frequency) of a given species [9]. These methods are based on plots with fixed defined areas in which counting and measurements on individuals are made ([8], [10]). Plot pattern (size, shape and direction) constitutes an important issue for ecologists to survey plant community ([11], [12]). [13] and [14] showed that characteristics of quadrats greatly affect density estimates and spatial pattern of individuals from non-random populations. Therefore, plot-based methods become impracticable in some situations where plants in community are sparsely or unevenly distributed, or when it is too hard to draw quadrats borders in dense vegetation (e.g. plants arranged in clump distribution) ([15], [16]). To overcome the limitations of plot-based sampling methods, plotless sampling techniques were developed by replacing quadrat measurements with linear recordings of distances among random trees or points and trees. The starting point of these techniques development coincided with the description of Pairs of Randomly Selected Trees method in forest survey [17]. Thus, sampling unit is reduced into a point, avoiding problems of size and shape of quadrat. According to [2], plotless sampling techniques are more advantageous than common plot ones, by allowing a low sampling effort to collect relevant data. For instance, [18] reported savings of at least 90 per cent in sampling time to obtain the same results in vegetation studies. However, these techniques were developed assuming a random spatial pattern as tree population distribution in community. Thus, many studies were designed to assess their robustness in case of non-random distribution of plants within a community ([19], [20], [21], [22], [23], [24]). Plotless sampling techniques were initially used to estimate population density (see [17], [25], [26]) based on distance measurements from two main schemes: (i) tree-to-tree/plant-to-plant approach wherein individuals are selected randomly from the population and from each of them, distance to nearest neighbour is measured and (ii) point-to-tree/point-to-plant approach wherein random points are located in the study area from which distance to the nearest or nth nearest individuals is measured. Moreover, many others investigations (e.g. see [27], [28], [29], [30]) focused on the use of distance in plant communities to determine spatial pattern of plant individuals. Plotless sampling techniques can be summarized in the following methods: variable area transect, closest individual, point-centered quarter, T-square sampling, nearest neighbour, random pairs, quartered neighbour method, angle-order method, ordered distance, N-tree method and triangle method. However, there exists more than twenty density estimators based on these techniques. A survey of ecological literature suggests that there are many points needed to be clarified in order to provide a more useful guideline for ecologists when using plotless sampling techniques. Indeed, according to several authors ([23], [31], [32]), some problems are also associated with these sampling techniques. To date, there is no published study which makes a comprehensive Abstract of plotless sampling techniques. Therefore, the current study aims at making a synthesis of literature on these sampling techniques by (i) describing the principles of plotless sampling techniques and (ii) comparing the two main sampling techniques (Plot-based versus Plotless methods).

2 MATERIEL ET METHODES

The study material is constituted of articles and books. They were identified via keyword searching (sampling, plotless techniques, density estimation, quadrat methods, and so on) on scientific database websites (Googlescholar, Sci-hub.cc) and additional references from retrieved articles. The main inclusion criterion used for studies was the scope of papers (papers published and focused on sampling methods in particular on plotless techniques in vegetation studies most specifically in plant communities). A census through careful reading of the abstract, methods, and results was made to select papers that meet considered criteria. Thereafter, a total of 88 papers were sampled in this literature review, mainly from following journals: Ecology, PloS ONE, Environmetrics, Ecological Modelling, Journal of Plant Ecology, Journal of Applied Ecology, Forest Ecology and Management, Canadian Journal of Forest Research and Conservation biology. Papers considered allowed us to (i) describe plotless sampling techniques (point-to-tree and tree-to-tree approaches), (ii) summarize comparison already made between plot-based and plotless methods and (iii) assess optimality conditions and relative efficiency of plotless sampling techniques.

3 RESULTATS

A literature review provides the description and the principles of plotless sampling methods, emphasizing studies that dealt specifically with plotless methods, comparison between plot-based and plotless methods or between plotless methods, introduced new concepts.

3.1 PLOTLESS SAMPLING TECHNIQUES

Sampling plants with fixed area plots is not the only alternative to mark-recapture estimation of abundance. Quadrats are not natural sampling units and one must always decide what size and shape of plot to use. One alternative is to use plotless sampling procedures. These techniques have been developed by plant ecologists and have been applied recently by animal ecologists. Plotless methods provide a third general class of methods for estimating abundance in plant community, and in addition to mark-recapture and quadrat counts provide an important tool for the field ecologist. The plotless sampling techniques can be summarized in the following methods: variable area transect, closest individual, point-centered quarter, T-square sampling, nearest neighbour, random pairs, angle-order, ordered distance, N-tree, quartered neighbour and triangle methods.

3.1.1 POINT-TO-TREE TECHNIQUES

3.1.1.1 POINT-CENTERED QUARTER METHOD

Also called quadrant method, Point-centered quarter method (PCQ) is a very old distance one applied in ecological sampling. Based on point-to-tree sampling approach, it has been firstly described by [25]. At each random point, the area around it is divided into 90° quadrants and the distance to the nearest tree is measured in each of the four quadrants according to the orientation given by the search direction. From [25] and [18], the average of the four distances measured is the square root of the mean area occupied by a single plant. The main advantage of PCQ is that the method does not require any correction factor in estimating population abundance or density [18]. In addition, PCQ provides more information on tree species per sampling point and is least susceptible to subjective bias. Contrasting to previous noticed advantages, the method produces misleading results in the case of non-random spatial distribution of plant community and requires more time per sampling point ([32], [33]).

3.1.1.2 CLOSEST INDIVIDUAL METHOD

Here, a set of random points is selected and at each point, the closest plant is identified and its distance from the point is measured. Closest individual is the most simple of the point-to-tree sampling approach. Easiness in implementation is the main advantage of closest individual method. However, the average distance from point to closest individual required multiplication by a correction factor of 2 in order to obtain the mean of distances [18]. The disadvantages are the unreliability of the method when the spatial pattern deviates from random distribution of plant community and the variability of the parameters estimated [34].

3.1.1.3 RANDOM PAIRS METHOD

As firstly described by [35], the random pairs method is based on the principle of angle of exclusion to select some pairs of plant individuals for vegetation sampling. First of all, the closest individual to each of the sampling points is selected. Then, an exclusion angle is established on each side of the line between the sampling point and the closest individual. The technique state that the nearest individual to the first individual (second tree of the random pair), must be selected outside of this angle of exclusion [36]. 160° exclusion angle was firstly suggested by [35], and later, [36] recommended 180° exclusion angle for convenience in field. According to [36], the correct distance is obtained after multiplication by a factor of 0.80. It is known that random pairs method produces less variable results and is more accurate, even if the mathematical theory behind the method has not been succeeded [35].

3.1.1.4 VARIABLE AREA TRANSECT METHOD

Variable area transect (VAT) can be considered as a combination of distance and quadrat methods where a fixed transect width or strip is searched from a random point until the g-th individual is encountered in the strip [23]. It has been developed by [37] in order to overcome some issues about closest individual, nearest neighbours and point centered quarter methods (see [31] for details). In this method, the length of transect is measured from the random point to point at which the g-th individual occurred [37]. Thus, the area covered to encounter the g-th from a given point vary from one sample point to another implying the name variable area transect. The number of individual sampled should be small (<5) in order to keep the method practical and efficient [38]. When a population exhibits a special case of aggregation, [39] proposes an unbiased version of the density estimator. VAT is an appropriate sampling method that would be quick and easy to implement across a wide range of habitat types [38]. It is less time consuming implementation and outperforms even if plant communities are spatially clumped [19]. However, the method become impracticable when distance from the sampling point to the g-th individual is too long [19].

3.1.1.5 T-SQUARE SAMPLING

This method is developed in order to cancel the bias due to non-randomness in distribution pattern associated with the nearest neighbour distance measurement [40]. T-square sampling scheme involves the measurement of two distances: one from random point (O) to nearest individual (I) and another from the nearest individual to its nearest neighbour (N). However, the angle OIN must be more than 90°. When the nearest neighbour is not within OIN, the next closest individual is considered until the researcher find one that satisfies the angle assumption. The method is known to control the bias due to non-randomness in distribution pattern.

3.1.1.6 Angle-Order Method

This method which derived from PCQ, has been developed by [39] in order to overcome the problem of non-randomly distributed individuals. Angle-order method (AOM) consists in dividing the area around the random sample point into k equiangular sectors where the individuals are arranged randomly and then the distance to the g-th closest individual in each sector at each sample point is measured (g is considered as the number of individuals to be located in each sector) [39]. considered k = 4 and g = 3 as practical. In particular, let r (g) ij denotes the distance from the i-th sample point to the g-th closest individual in the j-th sector [39]. proposed in addition two unbiased estimates of the density when populations are not randomly distributed. This consists to divide the total area into subplots with areas sufficiently small so that no further aggregation exists in each. Within each subplot, either the population is distributed randomly, possibly with different densities for each subplot; or uniformly, again possibly with different densities for each subplot. AOM can be applied in plant or herbaceous community (shrubs, forbs, grass, etc.) or in animal surveys. AOM is flexible, less biased in random distribution and not affected by small sizes. One drawback of this method is that it is more onerous to perform.

3.1.1.7 Ordered Distance Method

This plotless sampling procedure was first derived by [39] and further developed by [41]. It involves measuring the distance from the random sampling point to the g-th closest individual (hence the ordering). It is one of the most practical plotless sampling methods [23] [41]. and [23] demonstrated in their study that the accuracy of this method performed when $g \leq 3$ both in random and clumped patterns. Beyond this value, this method may be impracticable in the field. One main advantage of this estimator is the simplicity both of the sampling scheme and of computation [42].

3.1.1.8 N-Tree Method

This method has taken place during the past decade under the constraints of terrain, vegetation and realization conditions in developing countries [43]. It is based on selection of the n trees (generally comprised between 1 and 7) closest to a sampling point located in a given plant population. Then, we draw a plot of circular shape of radius from sampling point to the centre of the n-th tree closest to the point. All n trees inside the plot are measured [44]. The radius of plot can be measured to mid diameter of n-th tree (usual method) or to half distance between trees n and n+1 (adjusted method). It is suggested by [45] and [46] for application in forest management inventories with n=6. N-tree method has several advantages. On the one hand, it requires only a 2-man crew. On the other hand, it is easy to measure trees selected at sampling points, and the area of the sample varies with the stand density. Furthermore, this method is attractive since the number of trees measured per plot is constant ([47], [48]). However, it requires more time and labor efficient [48]. This method has been used by [19] in comparison to other sampling methods in saxaul shrub-land and proved as being the best performing methods overall to estimate density and cover. It has also been applied in natural forests of northern Iran by [49] where it showed a weak performance due to clumped pattern.

3.1.1.9 Nearest Neighbours Method

Reviews of the literature suggest that [50] was the first to suggest the use of nearest neighbours (NN) measurements to characterize the spatial patterns in plant populations. In this method, two distance measurements are made: one from random points to the closest individual in the population and another from closest individuals to their nearest neighbour. An additional measurement is made from the nearest neighbour to its nearest neighbour called second nearest neighbour. As used by [25], NN is the average distance from each individual in the population to its closest neighbours. NN involves multiplication of observed distances by a correction factor of 1.67 instead of the theoretical 2.0, to obtain the correct square root of the mean area. This method can be used in grassland vegetation, in saxaul shrub land or in phytosociological sampling. NN is very simple, provides less variable results and unbiased results in random pattern [18]. It has been shown by [27] that the distance to nearest neighbour can be used in the detection of nonrandomness in spatial pattern. This method is sometimes labour intensive and yield biased results in non-random pattern.

3.1.1.10 Quartered Neighbour Method

This method constitutes a new plotless density estimator which has received little attention [3]. It is a combination of the point-centered quarter method and nearest neighbour's method. This method is just like the point centered quarter method and consists in dividing the area around the sampling point (considered to the centre) into four quadrants. The distance from the closest individual in each quadrant to its closest neighbour in the same quadrant is measured.

3.1.1.11 TRIANGLE METHOD

This plotless sampling method is developed recently to improve the precision of plotless sampling method [51]. It is based on the random selection of sampling point. At each sampling point, the closest individual is determined and the distance from this individual to its closest neighbour (t1), the secondly closest neighbour (t2) and the thirdly closest neighbour (t3) are measured respectively. Then, the average of them is computed and the tree density is estimated according to [51]. One attractive feature of this method is its goodness and the easiness of the sampling in forest survey work [51].

3.2 PLOT-BASED VERSUS PLOTLESS SAMPLING TECHNIQUES

Plot-based and plotless methods constitute the two broad categories of sampling techniques used to survey vegetation in order to estimate some key parameters such as population density, basal area, biomass, etc. Among studies on these techniques, fifteen focused on comparison of the two kinds of sampling techniques. Quadrat methods constitute the oldest sampling methods used by most ecologists and based on plots establishment within plant communities. Quadrat pattern is important issue in its use, since quadrat can be of any size or shape (square, rectangular or circular). However, it is known that increasing plot size improve estimation while circular plots seem to be more accurate than rectangular or square ones [52]. In contrast, plotless methods involve measuring distances either from a random point to its i-th nearest tree or from a random tree to its nearest neighbour assuming a random spatial distribution for the study population ([17], [25], [26], [27], [53]). The development of these distance sampling techniques reduced the sample unit into a point, avoiding constraints of quadrat pattern. Some of the studies that we considered found that quadrat sampling is simple and estimates vegetation parameters accurately with a minimum effort ([6], [25], [54]). Furthermore, it is found that this method is more consistent when the density is low and performs well under regular, random and aggregate distributions ([20], [37]). Moreover, some authors concluded at the end of their study that in spite of the simplicity of this method, the size and shape of quadrat affect its estimation [55]. In addition, [25] added in their study that this method is time consuming and tedious. Beside the studies mentioned above, most of the authors opt for plotless sampling techniques. Then their choice may be justified by the fact that the plotless methods are more efficient in term of time consuming, require less effort, more economical than quadrat methods ([7], [20], [25], [37], [56], [57]). It is also found that they are more flexible and faster. Indeed, [38] compared variable area transect and fixed area plot with field datasets and simulation test. They found out that in the field, variable area transect was significantly more efficient than fixed area plot and perform well under random distribution. In addition, they added that there is no difference between plot-based and plotless sampling methods in term of vegetation parameters estimates. According to other authors, they can be considered as an alternative sampling method to quadrat methods when organism is randomly distributed and supplement quadrat in the case of low abundance ([37], [56]). Furthermore, plotless sampling techniques are useful in some cases where quadrat methods are impracticable in other words when vegetation are sparse or unevenly distributed [7]. It has been proved that the plotless sampling techniques gave more satisfactory results than plot ones [32] [58]. as for them investigated on two new density estimators for distance sampling and found that the plotless methods were more accurate than fixed area plot. However, it is noteworthy through our review that the plotless sampling techniques are unreliable for aggregated spatial pattern and that their accuracy depend on the number of individuals sampled ([20], [25]). They recommend the use of quadrat methods or a large sample in order to produce satisfactory results for plotless methods [38]. studied comparative efficiency and accuracy of variable area transect versus square plots for sampling tree diversity and density. Indeed, they found that the plotless sampling techniques are biased under non-random spatial distribution. In the same point of view, [59] found that distance sampling using the nonparametric estimator was severely biased contrary to quadrat sampling which yielded unbiased estimates of density and recommended a particular attention on using multiple distances as described by [22] [60]. in their study have taken into account this suggestion. They compared this method with plot-based belt transect using point simulations and field studies of snags and shrub stems and found that Batcheler-corrected point distance (BCPD) performed well under a range of clustered and random dispersion patterns. In addition, the BCPD was cost-effective relative to belt transect. According to [32], he found that none of these methods could be useful for field ecology even if they gave acceptable accuracy and precision. So, he suggested that the sample points be related to each method. Indeed, we can notice that almost all the authors suggest the usefulness of plotless methods in a wide range of vegetation ([38], [57]). On the other hand, other studies suggest the use of quadrat methods with the condition that an appropriate quadrat size be used ([20], [55]). One study recommends that further investigations be done in order to continue the analysis [7]. According to [54], optimal methods for the quantitative habitat description of grassland, desert, edge and town situations will be recommended in a later paper.

3.3 OPTIMALITY OF PLOTLESS SAMPLING TECHNIQUES

Among the papers reviewed, 29 showed the different studies conducted by some authors on certain methods. One can notice that most of the studies focused on point-centered quarter ([8], [41], [56], [61], [62], [63], [64]) and variable area transect ([38],

[31], [37], [65], [66], [67]). Most of the studies that examined point-centered quarter found that this method perform well in random spatial pattern, very fast and easy to implement. This method requires also more time because four distances are measured at each sample point. Five of the seven studies found that some difficulties arise when using this method ([41], [56], [61], [62], [63]). The main problem of this density estimator is that the aggregation and small sample size biase its performance. It has been proved by [8] that point-centered quarter produced exaggerated mean basal area values in most New Zealand forest types. These errors are related to the wide range of size classes where individual species span only a part of the total range. They recommend then that further field be made in order to test the method both in New Zealand forests and abroad [62]. as for them showed that one limitation of point-centered quarter is the selection of any tree twice and recommended that more research effort should be made in order to evaluate the effect of considering an individual more than once in point-centered quarter [41]. has proved that it is difficult to decide in which quadrant a certain tree belongs in point-centered quarter and proposed a considerable care if this method should be used at all [63]. found some discrepancies which occur in distance measurements in the method. Furthermore, [3] have proved that although point-centered quarter is one of the best plotless methods, there is still a lack in distance measurement. In other words, the distance is measured from a point to a plant while the sample point is not chosen objectively from an existing individual but subjectively. Then, they proposed a new method called "Quatered neighbour method" for forest communities which is a combination of the quarter method and nearest neighbour's method. This method aims at improving the precision of sampling on the condition of no more workload. They suggest that further investigation be done to demonstrate whether the new method is applicable in all kinds of population spatial distribution patterns. Regarding variable area transect, three of the six studies found that this method is more suitable, speed, more efficient in term of man hour under random distribution and improve more estimation with g greater than 3 ([38], [37], [66]). On the other hand, the three remaining studies found that the transect width constitutes the main factor which affects the quality of density estimates and the relative bias of this estimator ([31], [65], [67]). Like all plotless sampling methods, the main difficulty with this method is its unreliability in non-random spatial pattern ([38], [66]). In other words, the density estimation by variable area transect is biased under aggregated and regular distribution. Some difficulties can also arise in determining transect boundaries, or in cases where the density is low ([37], [65]). In addition, it has been found that the precision and accuracy of plotless sampling in general and of variable area transect in particular depend on the number of samples and the number of measurement in each sample [31]. Some suggestions have been done in order to overcome these difficulties. Indeed, the use of this method is almost recommended as an alternative approach of Quadrat by the authors under random distribution because of its speed, efficiency and its reliability. Other study suggests that further studies are necessary in order to compare the implementation of variable area transect sampling with Quadrat [31]. Only two studies of the same authors investigated on random pairs. They found that this estimator is less labour intensive and requires little equipment [35]. Difficulty arised in the choice of angle of exclusion. More angle of exclusion increases, more distance measurement increases [36]. They recommended the use of 180° angle of exclusion because of its simplicity and satisfactory results, and a particular attention to this method for others appropriate correction. Only two studies investigated on angle-order method and only one study on T-square sampling and nearest neighbour [34]. showed that angle-order method is more accurate, applicable across all kind of spatial patterns and that there is no penalty for using it when trees are random [39]. came to the similar results and found that this method is one of plotless methods with greatest accuracy. They recommended both the practical use of this method unless the distribution within the aggregate is completely uniform [68]. as for them, showed in their study that the corrected T-square sampling is inaccurate for dispersed nests population and accurate for clustered nests population. This means that the accuracy of T-square sampling is influenced by the spatial pattern. Then, they suggest that an analysis should be done prior to determining the appropriate method in order to improve the accuracy of the population estimates. Regarding nearest neighbour, [30] showed that the distance to nearest neighbours constitutes a measure of the spacing between individual in a population of known density and also permits to detect the non-randomness in spatial pattern. Further to that, the distance between nearest neighbours is equal to one-half the square root of the mean area in a randomly distributed population. Some difficulties occur in the distance measurements when a given individual appears outside of specified area or when in some cases, some selected individuals are so closer to one another than any other individual. They suggested the use of this method in some populations where it is considered impracticable if the true density is known. Two studies of the twenty-nine literature reviews investigated on ordered distance and only one on closest individual [42] [34]. consider these two methods as one of the simplest plotless sampling methods both of the sampling scheme and of computation. But, despite its simplicity, some difficulty arise in closest individual from determining which individual is considered as closest and in non-random distribution where the performance of the method is biased. While [69] and [42] found that ordered distance produced low bias for random and dispersed distributions and higher bias for clustered distributions. Then the usefulness of a robust estimator is recommended like angle-order method or ordered distance of rank 3. Besides the reviewed studies on the distance methods mentioned above, five studies investigated on N-tree sampling technique. Indeed, [49] in his study on tree sampling in natural forests of Northern Iran found that N-tree sampling technique is not appropriate for this region and underestimate (negative bias) the true population parameter for each of the 6-,7-,8- and 9-tree. This bias may be due to clumped structure of natural forests or the insufficiency of the number of sample plots [43]. and [48] in their study came to similar results. They found that the statistical performance of N-tree sampling technique remains a problem despite its practicality and ease of implementation under many field condition. Its

performance depends considerably on spatial pattern of the population. Yet, according to [45], this method has potential for forest management and requires approximately 4 to 6 sampling point per hectare for the 6-tree sampling system which is not practicable for the natural forests of Northern Iran. The reason for which the statistical performance of this method remains a problem is because it leads to variable sample plot areas [47]. So, to remedy that shortcoming, they suggest a new density estimator based on point pattern reconstruction which differ slightly from N-tree sampling technique because it requires the coordinates of all n trees. They found that this new density estimator with n=6 is empirically superior in term of bias and relative root mean square error. Moreover, [70] proposed a new method denominated an adaptive composite estimator for N-tree sampling in order to lessen the sensitivity to the amount of extra Poisson variance. They found that this estimator performed well in terms of bias when n is at least 5. In addition, the performance appears too variable to be useful in practice. Then, ongoing researches need to continue some investigations on this method and apply it to other forest populations. In addition, to counterbalance the error introduced in point-distance estimates, [22] in his study suggested to employ a combination of distances between the nearest individual and its nearest neighbours in a linear function [60]. as for them, have taken into account in their study the suggestion done by [22] and considered this method as Batcheler-corrected point distance (BCPD). They found that BCPD performed well under a range of clustered and random dispersion patterns in reducing errors and was cost-effective. But, the measurement to the third object appears to be sensitive to measurement errors. In the studies that we reviewed, only the study of [51] investigated on triangle method. This method is an improved method of plotless sampling for forest communities aiming to improve the precision of sampling methods. They found that this method is a very good method, adequate and easy to use in wood engineering and forest survey work. But it has not been demonstrated in theory. Therefore, further investigations are required in order to demonstrate whether this method is applicable in all kinds of the population spatial distribution pattern.

3.4 Comparison Of Plotless Sampling Techniques

Thirteen of the 113 papers reviewed focused on the comparison of some plotless sampling methods. There are several important conclusions that can be drawn from these papers. For example, we can notice that relatively few studies are based both on real datasets and simulated datasets ([16], [20], [23], [24], [71]). These two datasets complement one another because real datasets should be used to test the results obtained with the simulated datasets [18]. compared closest individual, nearest neighbour, random pairs and point-centered quarter and concluded that all these methods performed well in random distribution but the adequate sample size in order to obtain accurate results vary with the methods. They found that point-centered quarter is superior to other distance methods [72]. also compared these methods and concluded that point-centered quarter is the most accurate for estimating density and relative frequency than the other plotless sampling methods [71]. compared these methods in addition to 3rd nearest, closest individual in 2 sectors, 3rd nearest in 2 sectors and T-square sampling and concluded that the distance methods to the third nearest were less biased than other plotless methods [18]. recommended the use of point-centered quarter because it is least susceptible to subjective bias and requires no correction factor whereas [71] preferred Quadrat because it gives unbiased estimates across all type of vegetation [25]. compared closest individual, random pairs and point-centered quarter and found that random pairs is similar to point-centered quarter but differ from it in that the number of individuals in each subsample is constant. Moreover, point-centered quarter always measures 4 individuals at each point but random pairs measures 2 individuals while closest individual produces interesting and consistency results in term of density per unit area. They suggest that a larger sample be used in order to produce satisfactory results. This was true regardless of sampling method and could be achieved by increasing either the number or the size of the sampling units. In a study of [73], they compared closest individual, point-centered quarter, angle-order method and corrected-point distance which is equivalent to nearest neighbour and came to that angle-order method to the third nearest gives a reasonable good estimates of density. They proposed that additional theoretical work is necessary on the angle-order method [23]. compared 25 estimators that were grouped into subsections. They concluded that the distance methods to the third nearest neighbour (angle-order method, variable area transect and ordered distance) perform well over all spatial patterns. The same study has also been conducted by [16] but with slight differences about the simulation design and the distance estimators compared. They found that a compound of the basic distance estimator was more robust across all spatial patterns for sample size greater than 25. Despite of this slight difference, the two studies recommend the use of these methods in particular angle-order method in the field or in clumped pattern. For a general recommendation, it is not assumed that the investigator would be able to clearly define what sort of spatial pattern is followed by the population to be sample [23]. However, [24] compared point-centered quarter, nearest neighbour, Basic distances, ordered distance and variable area transect and found that none of these methods produced accurate results across all field. In addition, these methods are unreliable in aggregative spatial pattern. But they recommend firstly, to reconsider plot-based methods, by making a large scale comparison both on accuracy obtained and feasibility and secondly, to make a deeper investigation into the relation between the combinations of spatial patterns and the accuracy for each method [3]. as for them compared quartered neighbour method and point-centered quarter and concluded that quartered neighbour method is more robust and more precise than the oldest method point-centered quarter. In addition, they suggest that further investigation be made to demonstrate whether the new method quartered neighbour method is applicable in all kinds of population spatial distribution patterns [37]. in comparing variable area transect, closest individual found that variable area transect is more useful and constitutes an alternative to others plotless sampling but these two methods provide an unbiased estimates of density with equal variances. They recommend the use of variable area transect in a wide range of biological sampling problems [19]. also come to the same conclusion in comparing point-centered quarter, joint-point method (JP), random pairs, T-square sampling and quartered neighbour method beside fixed area plot (FAP), N-tree and variable area transect and concluded that considering relative bias and time consuming, variable area transect and point-centered quarter appear to be the best methods respectively in clumped and random pattern and recommend the use of variable area transect where the spatial pattern of the population sampled is not clearly defined [20]. compared variable area transect, ordered distance and Byth's T-square sampling and concluded that for one sample study, all the three methods are very similar in random spatial pattern, but for an aggregated spatial pattern, the tree methods underestimate the density. In addition, T-square performed better than the two others. On the other hand, they found that for two sample study, no plotless sampling methods were robust. They advised plant ecologists to avoid those methods and to use Quadrat methods. Moreover, [51] have proposed a new method (Triangle method) aiming to improve the precision of plotless sampling method in forest communities. In their study, they compared this method with the old one (point-centred quarter method) and found that this method is adequate and easy to use in wood engineering and forest survey work. In addition, it is more accurate and precise than the old one. But, it is noteworthy that this new method has not been theoretically demonstrated. So, further investigations are required in order to demonstrate whether this method is applicable in all kinds of the population spatial distribution pattern. From the informations above, we can notice that each estimator has been developed to work better under the assumptions defined by a specific population. In other words, an estimator is just a function of the data, and whether it is biased, precise or accurate, that depends on what the researcher aims to estimate. Overall, the distance methods to the 3rd nearest neighbour like ordered distance, angle-order method are better than others plotless sampling methods in term of bias, followed by variable area transect.

4 Discussion

4.1 Plotless Sampling Methods

Sampling constitutes a basic step in ecological research. Plotless sampling techniques is one of the main group of sampling methods used by researchers when surveying vegetation. From the surveyed papers, closest individual (CIM), nearest neighbours (NN), random pairs (RPM) and point-centered quarter (PCQ) are basic distance methods. It is known that others techniques are derived from the first four methods. Indeed, according to [16] and [23], basic distance estimators involve distance measurements either from random points to the closest individual or from individuals to their nearest neighbours (sometimes from the nearest neighbour to its nearest neighbour). Surveyed papers revealed that point-centered quarter method was the most used technique by researchers in their ecological investigations ([3], [6], [7], [8], [18], [19], [24], [25], [32], [33], [41], [54], [56], [61], [62], [63], [64], [71], [72], [73]). Indeed, the technique seems very simple in term of implementation ([41], [62], [64]). However, point-centered quarter method as well as others plotless techniques assumes a random spatial pattern of trees (measurements taken are closed to those used to determine indices of aggregation) [21] and it is well known that these methods do not perform well when the spatial pattern deviates from random ([23], [69], [41]). To handle limitations about spatial pattern, many studies were done to assess the robustness of these methods in case of non-random distribution of plants within a community. For instance, [39] developed the first distance estimators for non-randomly spaced populations. Then, he extended the estimation principle to angle-order and ordered methods mainly developed by [41] later [34]. used the ordered distance method to study some sampling characteristics of a series of aggregated populations. From their study, ordered distance method is simple for both sampling scheme and computation aspect. On its asymptotic limit, [42] found that the method produced lower bias for random and dispersed distributions and higher bias for clustered ones. Apart from previous sampling techniques (point-centered quarter, angle-order and ordered distance methods), another ones were developed in order to reduce the bias due to non-randomness in distribution. These techniques combine point-to-plant and plant-to-plant distance measurement (for example, see T-square sampling and variable area transect for more details). However, [3] reported that even if these methods could improve accuracy and precision of parameters estimates, they make distance measurements too complicated. Moreover, some of plotless methods remains slightly documented in ecology to date. For instance, according to [31], variable area transect method has received little attention in ecology despite having robust estimation properties. It is only from 2000 year that the method has been more used in the vegetation studies. It is known that the method presents a good performance compared to other methods since it is a combination of distance and quadrat methods ([23], [66], [67]) [37]. and [38] reported that VAT is more useful and constitutes an alternative to other plotless sampling, mainly in clumped pattern of trees. Nevertheless results from techniques like VAT remain unsatisfactory [56]. Thus, more recent methods (see N-tree method and triangle method for example), were introduced to accommodate field conditions and to improve the precision of plotless sampling techniques. Moreover, [3] noticed some weaknesses regarding choice criteria of random sampling point and conclud that sampling points were subjectively considered. To overcome this issue, the quartered neighbour method [3] has been proposed as being a more precise method than the classical quarter method even if its theoretical aspects are not yet proved. The subjective choice of random point in this method can lead to measurement errors or to the variability of data obtained. This means that the results from repeated sampling of the same stand with different investigators can substantially differ.

4.2 Comparison Of Plotless Sampling Techniques And Factors Affecting Their Performance

Plotless sampling methods reduce sampling unit into a point, avoiding issues that arise with size, shape and orientation of quadrat [74]. and [7] recorded that plotless methods require less effort and reduce sampling time than plot-based ones. They provide an accurate and rapid estimation of tree densities [18]. On the one hand, the results of these techniques can provide important information about interaction relationships between species (inter or intra) in plant communities and on the other hand help to determine spatial pattern of plants ([19], [24], [39]).

Contrary to [7], [18], [19], [24], [39] and [74], [54] reported that quadrat methods provide a maximum of accuracy and a minimum effort for vegetation parameter estimates. However, they pointed out that the size of the plot and the amount of field effort expended impact results obtained to an unexpected degree. Similarly to quadrat methods, it has been proved that the sample size (i.e. number of sampling points) impacts the performance of plotless sampling methods ([20], [25], [32]). By increasing the sample size, more accurate parameters estimates from plotless sampling methods. This is consistent with [25] results on the comparison three plotless methods (random pairs, point-centered quarter and closest individual) with quadrat method. According to [20], they observed that the accuracy of estimations from plotless sampling methods depends mainly on the sample size. For instance, they found out that the quality of density estimation increased with sample size. Nonetheless, increasing sample size does not always guarantee a good accuracy. According to [32] in surveying a shrub community, some plotless sampling methods did not produce accurate results whichever the sample size considered. It has been shown by [25] that a minimum of 30 sample is necessary before any statement can be made on a vegetation. However, the same authors in 1956 indicated that the size of an adequate sample varies with the sampling method. According to our field experience, the type of vegetation (savannah, mangrove forest, dense forest, gallery forest, etc.) can also help in the choice of a given plotless technique. Most of studied papers in this literature review did not provide an appropriate sample size that can improve the performance of plotless sampling methods. Another factor that affect the performance of plotless sampling methods is the degree of randomness (i.e. spatial pattern) of plant communities [24]. reported that for almost all methods, the sign of error (under or overestimation) depends on spatial pattern of the population (aggregation or regular pattern). So, when vegetation has a high degree of non-randomness, they gave the largest bias. This strongly justifies the main assumption of random spatial distribution for populations of plotless sampling techniques (see [35], [41], [13]). Because a random spatial pattern of populations rarely occurs in nature, some attempts have been made to modify plotless estimators in order to improve their robustness in case of non-random spatial patterns. For instance, [39] proposed angle-order method for estimating density in population of unknown distribution while [75] suggested some correction factors according to the degree of aggregation of populations [23]. and [16] noticed that estimations from plotless methods involving distance measurements from the starting step (a random point or a random tree) to 3rd nearest plant (see angle-order method, variable area transect and ordered distance for example) are less biased than the other plotless sampling methods. Furthermore, from surveyed studies, one notice that some issues occur with the transect width in variable area transect method. Only few studies have investigated the effects of varying transect width in variable area transect method on its density estimates and the easiness of implementation in field. For instance, [31] and [65] revealed that the transect width affect significantly the quality (accuracy and precision) of density estimates when using this technique. Also, [23] noticed that distance from each starting point to the third nearest neighbours (g=3) is more useful whereas [67] suggested to setup g at 5. From these two studies, one need to study more on variable area transect optimization (for example, optimal transect width and g value). Therefore, it is clear that the plotless sampling methods perform differently according to spatial patterns of communities. For [32], no technique of plotless sampling is particularly desirable. So, most specific studies must be done to provide guidelines to ecologists in their vegetation investigations.

4.3 Limitations Of Surveyed Studies

Our discussion of plotless sampling methods up to this step assume optimal conditions of practical aspects. Many studies were designed to assess the robustness of plotless sampling methods in case of non-random distribution of plants within a community (see [19], [20], [21], [22], [23], [24]) without interesting to sources of bias which occurs in this case. Only very few studies investigated sources of bias that can occur when using these methods. This bias could be due to measurement errors. For instance, [76], [77] and [78] reported that although the distances are well measured and known in practice, there are often errors in measurement, but there is little research on this problem because the effect of measurement errors was unknown and methods for correcting these errors didn't exist. As noticed by [79], there are no exact measurement, there exists always some kind of error (additive error). Such errors can lead to potential impact on the bias and the precision of these estimators which cannot be reduced by increasing survey effort ([76], [77], [78], [80]) [76]. found out that measurement errors can cause underestimation of the abundance. Moreover, [8] and [73] link the bias to the structure of the stands examined. For [18], the occurrence of this error can be due to two different sources. The first will be the fact that the distance must be squared before density may be computed and the second is the extreme variability by multiplying the number of trees per acre by basal area per tree at each point. The idea developed by these authors have not been investigated in other studies. They added that this bias is relatively unimportant and will influence the data obtained. Otherwise, the occurrence of these errors may be related to the measurement instrument and sampling ([81], [82]) [82]. reported that measurements to the tree in place of the center of the tree trunk may lead to errors of estimations. Nevertheless, some estimators have been proposed to remove this error in order to correct the bias. For instance, [81] proposed one approach for using simulation extrapolation estimation (SIMEX) to reduce measurement errors. They found out that SIMEX allows to reduce measurement error bias through an useful method. On the other hand, [76] proposed the nonparametric approach in particular methods of moments which require knowledge of error distribution. But this estimator has been proved insufficient to remove the bias in all cases [76]. It is therefore important for researchers to develop a technique for correcting the bias of distance sampling methods by including distance measurements either from point to plant or plant to plant. Moreover, the majority of studies that we reviewed used plotless sampling methods to estimate population density. Otherwise, these studies are more orientated to population density and minimize other parameters which are also of great importance in quantitative analysis in ecology. Indeed, [64] showed that there exists a wide variety of ecological attributes such as basal cover, species composition, inter-species association, species richness (number of species occurring in a particular community), etc. It has been proved by [83] and [84] that species richness and occurrence are also basic step in studying community ecology. According to [85], species richness is the most parameter widely used in biodiversity metric. Besides, plotless sampling methods can help to determine spatial patterns of plant. For instance, [27] revealed that the distance between individual and its nearest neighbour might be used to study randomness through a comparison of the observed distribution of such distances with those expected from theory. In the same idea, [28] used distance between nearest neighbours with the average distance between random points and closest individuals for measuring aggregation. So, researchers may be interested in how plotless sampling methods perform on other ecological parameters. Furthermore, it is well known that in plant community, not all individual present in sample area are detected; some of them will be overlooked and remain unobserved. Otherwise, the observer may be unable to detect the presence of the species ([86], [87], [88], [34]). According to these authors, it is a common sampling problem of imperfect detection. It is noteworthy that this problem has not been mentioned in the studies reviewed. Yet, it has been proved by [86] and [34] that this problem may lead to bias in estimating plant population size. According to [87], this may be related to observer error, species, lack of visibility at the time of the survey or environmental conditions (rain, temperature, etc.) [88]. came to similar results and found that this sampling problem arised when the population size is small and individuals are difficult to sample or sampling effort is limited. Therefore, we hope that our findings prompt more ecologists to consider carefully the detection process in the future researches.

5 CONCLUSION

This study has made a critical review of literature on plotless sampling techniques in vegetation studies. This study based on a careful examination of the literature, showed that there are several plotless sampling techniques in ecological studies and some of them have received little attention or have not theoretically demonstrated. Moreover, the performance of these methods depend on the type of spatial distribution of organism and the sighted objectives by researchers. The study has shown that plotless sampling methods have a good performance (unbiased) when the population is randomly distributed but when the population is uniformly or contagiously (clump) distributed, these methods produce the largest bias of density estimate in spite of all efforts done by some researchers in order to improve their robustness. We conclude this study by giving our opinions, based on the study results presented here, as to what plotless sampling technique we would consider when designing a field study. Then, in most situations, variable area transect is the best preferred method overall and one of the most practical plotless sampling methods because of its easiness. So, researchers need to do whatever they can to control this bias. It is therefore impossible to summarize all present and possible future developments, and we ask for forgiveness if we left out some promising research that we did not know about. We hope that this review will show what has already been achieved and point the way to more sophisticated studies of plotless sampling techniques. The outcomes of this study provide ample suggestions for future research. It is suggested that before implementing the plotless sampling methods, the vegetation study should be examined in order to detect the spatial pattern of plant communities and to prescribe the best method. The research should also be extended to control the bias, to continue some investigations on those methods mainly on measurement errors, detection process and to evaluate their performance on other parameters in plant community (for example, the species richness). We suggest that similar study be done to determine the best plotless sampling method that can answer the three basis criteria.

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