Khulna University
Life Science School
Forestry and Wood Technology Discipline

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Title: Relationship between degree of randomness in tree distribution in tree distribution and sampling efficiency: comparison between new Point-Centered Quarter Method (PCQM) and square plots

Supervisor(s): Dr. Md. Nabiul Islam Khan, Professor, Forestry and Wood Technology Discipline, Khulna University

Programme: Bachelor of Science in Forestry

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FORESTRY AND WOOD TECHNOLOGY DISCIPLINE

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DECLARATION

I, Mukta Biswas, declare that this thesis is the result of my own work; has been carried out under the direct supervision of Dr. Md. Nabiul Islam Khan, Professor, Forestry and Wood Technology Discipline and it has not been submitted or accepted for any degree to other university or institution.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for title and summary to be made available to outside organizations.

Signature

Mukta
08·03·18

Name: Mukta Biswas

APPROVAL

This is to certify that the present thesis work entitled **"Relationship between degree of randomness in Tree Distribution and sampling efficiency: comparison between new Point-Centred Quarter Method (PCQM) and square plots"** has been carried out by Mukta Biswas (Student Id: 130521) under my direct supervision at the Forestry and Wood Technology Discipline of Khulna University, Khulna-9208, Bangladesh.

I recommend that the content of the project report can be accepted in the partial fulfilment of the requirement for the Degree of B.Sc. (Hons) in Forestry.

Supervisor

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Dr. Md. Nabiul Islam Khan

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DEDICATED TO

MY

BELOVED PARENTS

ACKNOWLEDGEMENT

First of all, I would like to express with utmost my humble gratitude and infinite admirations to Almighty GOD who created me and has given me the opportunity to complete the thesis successfully. I want to express my sincere gratitude to my beloved parents who brought me to this earth and helped me in every step of my life.

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I am also thankful to my friends specially Md. Arifuzzaman Arif and Selina Khatun helping me in conducting this study.

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Abstract

In Point-Centred Quarter Method, the mean distance of first nearest trees in each quadrant of a number of a random sample point is converted to plant density. Different type of plant assemblages such as random, aggregated, regular spatial pattern were used for estimating plant density using new PCQM and square plots. The new PCQM estimators and square plot show the better result for random distribution. The new PCQM shows reasonable result for other plant assemblages. When the Clark and Evans aggregation index (R) is high the plant assemblages show strong regularity, the performance of PCQM estimators is not good. On the contrary, the square plot performance is better than the new PCQM estimators. Overall the accuracy of square plot is better than the new PCQM estimators for all vegetation method except aggregation pattern. The square plot is more efficient estimator of density than PCQM. At last, it is said that the accuracy of tree density estimation varies between new PCQM and square plot but also varies among vegetation spatial pattern. When the plant assemblages are random (R value is 1) and aggregated (R value is less than 1) new PCQM and the square plot are very near. The higher order PCQM (PCQM2, PCQM3) offers better density prediction for regular and aggregated pattern. The square plot shows higher accuracy in density estimation for all type of plant assemblages except aggregated distribution (R<1). The results of the study suggest that sampling efficiency not only depends on sampling methods (plotless or plot-based) but also varies among plant assemblages or vegetation spatial pattern.

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Chapter1: Introduction

1.1 Background and justification of the study:

Sampling techniques have a foremost importance to find out the precision of estimates greatly depend on it. Point Centered Quarter Method (PCQM) is a sampling technique was compared for tree density estimation. PCQM method gives the highest precision for tree density estimation (Kumarathunge et al. 2011). Since 1947, the methods of distance measuring of community study have all appeared, when the random pairs method used for sampling forest tree. With the use of distance either for the study of the randomness of dispersion of the population are the main concern of subsequent investigation. For the study of randomness the distance between each individual in the population and its nearest neighbor through a comparison of the observed distribution of such distance with those expected from theory might use. The Point Centered Quarter Method for measurement of density and a number of relative characteristics were used. The distance between random points, closet individuals which are plant to plant distance and of the distances between nearest neighbors which are plant to plant distance were also reported by them. The nearest neighbor distances in a study of aggregation were also used by Clark and Evans in 1954. All of the methods have been used for density estimation and some of them in addition have been applied for the study of randomness (Cottam and Curtis 1956). PCQM method is the best option which provides speedy sampling while requiring few logistics. Plant densities based on scattered points over a large geographic area is estimated by PCQM method. The main limitation of PCQM method is its bias and statistical uncertainty. The first work on PCQM (Cottam and Curtis 1956) which was further modified (Pollard 1971), which improved the statistical bias with PCQM estimator and later (Beasom and Haucke 1975). The first nearest plant's mean distance in each of four quadrants of a random sample point is converted to density in PCQM. The second order distance (PCQM2-distance of 2^{nd} nearest plant in each quadrant is measured) as well as third order distance (PCQM3-distance of 3^{rd} nearest plant in each quadrant is measured) have explored the accuracy of PCQM (Khan et al. 2016). It has been argued that higher order PCQM shows better accuracy of density estimation (Engeman et al. 1994, White et al. 2008)

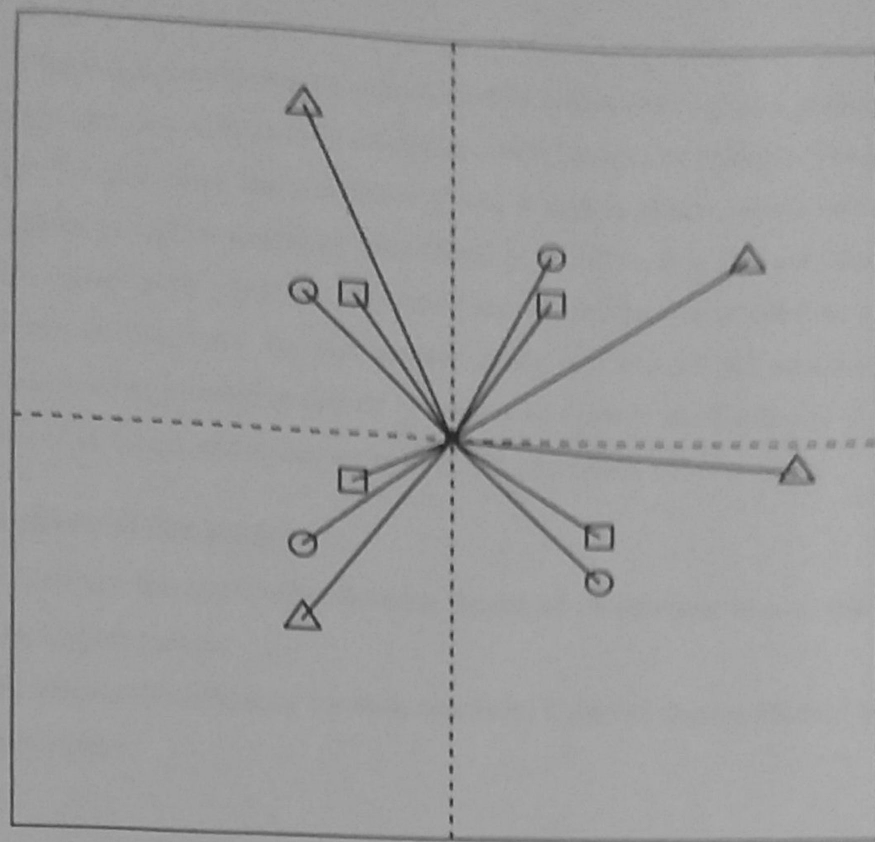

Figure 1: Schematic representation of a PCQM sample point with trees represented as circles, squares or triangle.

Based on the first order PCQM estimator and the concept of the k-th nearest plant in a circular distance from sample point has been described (Pollard 1971) and higher order PCQM density estimators has also been derived (Engeman et al. 2005) and where the performance of various plotless density estimators have been compared. Recently, Khan et al. (2016) proposed the more accurate equation of PCQM1, PCQM2 and PCQM3 as below:

$$\text{PCQM1}, \rho = 4(4N-1)\Big/\left(\pi\sum_{i=1}^{N}\sum_{j=1}^{4}R^2_{(1)ij}\right)$$

$$\text{PCQM2}, \rho = 4(8N-1)\Big/\left(\pi\sum_{i=1}^{N}\sum_{j=1}^{4}R^2_{(2)ij}\right)$$

$$\text{PCQM3}, \rho = 4(12N-1)\Big/\left(\pi\sum_{i=1}^{N}\sum_{j=1}^{4}R^2_{(3)ij}\right)$$

Although, these equations have been proved to offer higher accuracy as a plotless method, it is necessary to test their efficiency in comparison with square plot methods. The performance of PCQM is the best when the population shows a random spatial pattern and is moderate with aggregated or regular spatial patterns (Khan et al. 2016). It is also not known that how accurate the square plots when the population shows various spatial patterns. Therefore, in the framework of this study, the performance of the new PCQM and square plots will be evaluated considering population density as a response variable and the degree of randomness as measured with "Clark and Evans index R"(Clark and Evans 1954) as factor.

1.2 Objectives of the study:

I. To find out the relationship between degree of randomness in tree distribution and sampling efficiency.

II. To compare the efficiency between new Point Centered Quarter Method (PCQM) and square plots.

Chapter2: Literature Review

2.1 Random distribution:

A set of points on a given area, it is assumed that any point has had the same chance of occurring on any sub-area as any other point, that any sub-area of specified size has had the same chance of receiving a point as any other sub-area of that size and that the placement of each point has not been influenced by that of any other point which is called random distribution (Clark and Evans 1954). Each of the objects making up the population is located independently to all others, so that any object has an equal and independent chance of occurring at any locus is called Random Distribution. The objects are not located at fixed distances from one another nor is there a marked gradient from regions where it is rather sparse. So there is no fixed pattern. Two random populations will not be exactly alike, but all will have the above mentioned characteristics. The randomness of the population was checked by comparison with a Poisson distribution and by areal homogeneity test. Area sample and with exclusion angle methods that related methods behave similarly on random populations. The exclusion angle methods depend on the measurement of distance to arrive at density per unit area. There are a wide variety of these methods. Such as the point centered quadrant and the random pair methods. The quadrant method divides the area around the sampling point into four equal parts. At each point four distances and the species of the four individuals are obtained. Variations of this method include using the closest individual rather than the point as the center (Cottam 1953).

2.2 Sampling Efficiency:

Efficiency is a measure of quality of an estimator of an experimental design or of a hypothesis testing procedure. The sampling efficiency depends on the sample size available for the given procedure. Efficiencies are often defined using the variance or mean square error as the measure of desirability.

2.3 Clark and Evans Aggregation Index:

Distribution pattern of a plat population is a fundamental characteristic of that population. But it is very difficult to describe in precise and meaningful term. Many important concepts of phytosociology are based upon the impersonation that the individuals of most plant populations are distributed at random. A number of methods of demonstrating the occurrences of non-random distribution are available, but the degree of departure from random expectation is much more difficult to identify and the significance of differences in the distribution pattern of two or more populations is difficult to evaluate. A sets of points may be random regarding specified area but decidedly non-random regarding a large space which includes the specified area (Clark and Evans 1954).

If, in a population having a specified density ρ, the distance r from each individual to its nearest neighbor is measured, the mean observed distance may be represented as $r_A = \sum r/N$. The mean distance would be expected if this population were distributed at random, r_E. For measuring the degree to which the observed distribution approaches or departs from random expectation, the ratio $R = r_A/r_E$ can be used. When $R = 1$, it indicates random distribution. $R = 0$ indicates under conditions of maximum aggregation, since all of the individuals occupy the same locus and the distance to nearest neighbor is therefore 0. In an even hexagonal pattern and every individual (except those at the periphery of the population) will equidistant from six other individuals, individuals will be distributed under conditions of maximum spacing. In this case, the mean distance to nearest neighbor will be maximized. When these is the case, $R=2.1491$. R has a limited range which indicate perfectly uniform, random and completely aggregated patterns of distribution. In any given distribution, the mean observed distance to nearest neighbor is R times as greater that would be expected in a random distribution of the same density. $R = 0.5$ would indicate that nearest neighbors are, on the average, half expected under condition of departure of randomness. It should be of practical use in describing spatial relation (Clark and Evans 1954). So $R>1$ indicates regularity, $R<1$ indicates clustering, $R=1$ indicates randomness. The standard range is $0<R<2.1491$(Hijbeek et al. 2013).

2.4 Plotless density estimators:

To estimate the density of stationary objects is a basic problem in many fields of biology. For estimation of density many plotless density estimators (PDEs) have since been developed to offer efficient approaches for acquiring a sample. For assuming a random distribution for the sampled population, many plotless density estimators were developed. While this distributional impersonation promotes the development of theory, natural population tends to occur in aggregations pattern. Our study provides the field investigation with information concerning which estimators yield a reasonably accurate assessment of density, even if the population spatial pattern is known or unknown. We consider 25 methods for sampling and estimating density. Such as Basic distance (BD) estimators, Batcheler-Bell (BB) estimators, Nonparametric (NP) estimators, Kendall-Moran (KM) estimators, T-square (TS) estimators, the distribution pattern of two or more populations is difficult to evaluate. A sets of points may be random regarding specified area but decidedly non-random regarding a large space which includes the specified area (Clark and Evans 1954) .

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2.5 Simulation Study:

Simulation programming would become very difficult for 25 methods for sampling and estimating density. The behaviors of those methods were evaluated through a Monte Carlo simulation study. A simulation program was written in Microsoft FORTRA 77(Version 5.0, MS-DOS operating system), each run of which was designated by a specific combination of population spatial pattern, population density and sample size (of random sampling points). The uniform random-number generator used for placing population individuals and locating sampling points was the UNIF routine and VNORM routine was used to convert the uniform random numbers to normal random numbers. UNIF has been used for testing uniformity, independence and nonperiodicity and VNORM for accuracy. The density used in a particular run of program was specified by inputting the size of a rectangular area (the length of each dimension) and the number of individuals to reside in that area. The population simulated 6 spatial patterns as random, regular, triangular, aggregate-50, aggregate-15 and double clumped. The random pattern was simulated by generating the appropriate number of random coordination in the designated area. The regular spatial pattern was generated by dividing the area into a grid of rectangles, the same number as individuals in the population. The two aggregate patterns, the centers of a user-specified number of clumps were randomly located in the designated area. For the triangular patterns (sometimes referred to as a hexagonal pattern) were generated so that the population numbers were located at the vertices of a lattice of equilateral triangles(Engeman et al. 1994).

2.6 Evaluation of sampling techniques and PCQM:

Point-Centred Quarter method is likened with two conventional sampling techniques namely; Quadrate method and Transect method. The Quadrat method is the standard sampling method. A random point is considered as the sampling points for the PCQ method. The predetermined sampling points are located in the field with GPS (Global Positioning System). It has an accuracy of less than 5m at each sampling point. The area around is divided into 4 quadrants. The nearest tree to the sampling point having more than 5cm diameter at 1.3m above the tree base (DBH) in each quadrat is selected for sampling. Four trees are included in the sample at each selected tree. Tree DBH and tree height are measured using DBH tape and Clinometer. Species name of the trees are also recorded. PCQ method is the most precise technique to estimate the tree density since the standard error estimate was very small compared to the other methods. Considering the higher precision of estimates and the saving of time and money, the recommended effective sampling technique is PCQ method (Kumarathunge et al. 2011). The point-Centred Quarter Method (PCQM) is one of the plot-less methods which has been considered very efficient in characterizing vegetation, while minimizing damage to the forest understory. It yields quantative data by studying trees nearest to sample points as an estimate of number and distribution (Dahdouh-Guebas and Koedam 2006).

Chapter 3: Methods

3.1 Study site description:

For this study, fieldwork is conducted in Lawachara National Park, Moulabi Bazar District, Bangladesh ($24^0 30'$N and $091^0 37'$E) which is a tropical semi-evergreen forest. The Divisional Forest Officer, Wildlife & Nature Conservation Division, Moulabi Bazar under the Ministry of Environment and Forest, Bangladesh permitted a research and field work. Another set of data was obtained in Manko wetlands mangrove forest in Okinawa, Japan (Khan et al. 2016).

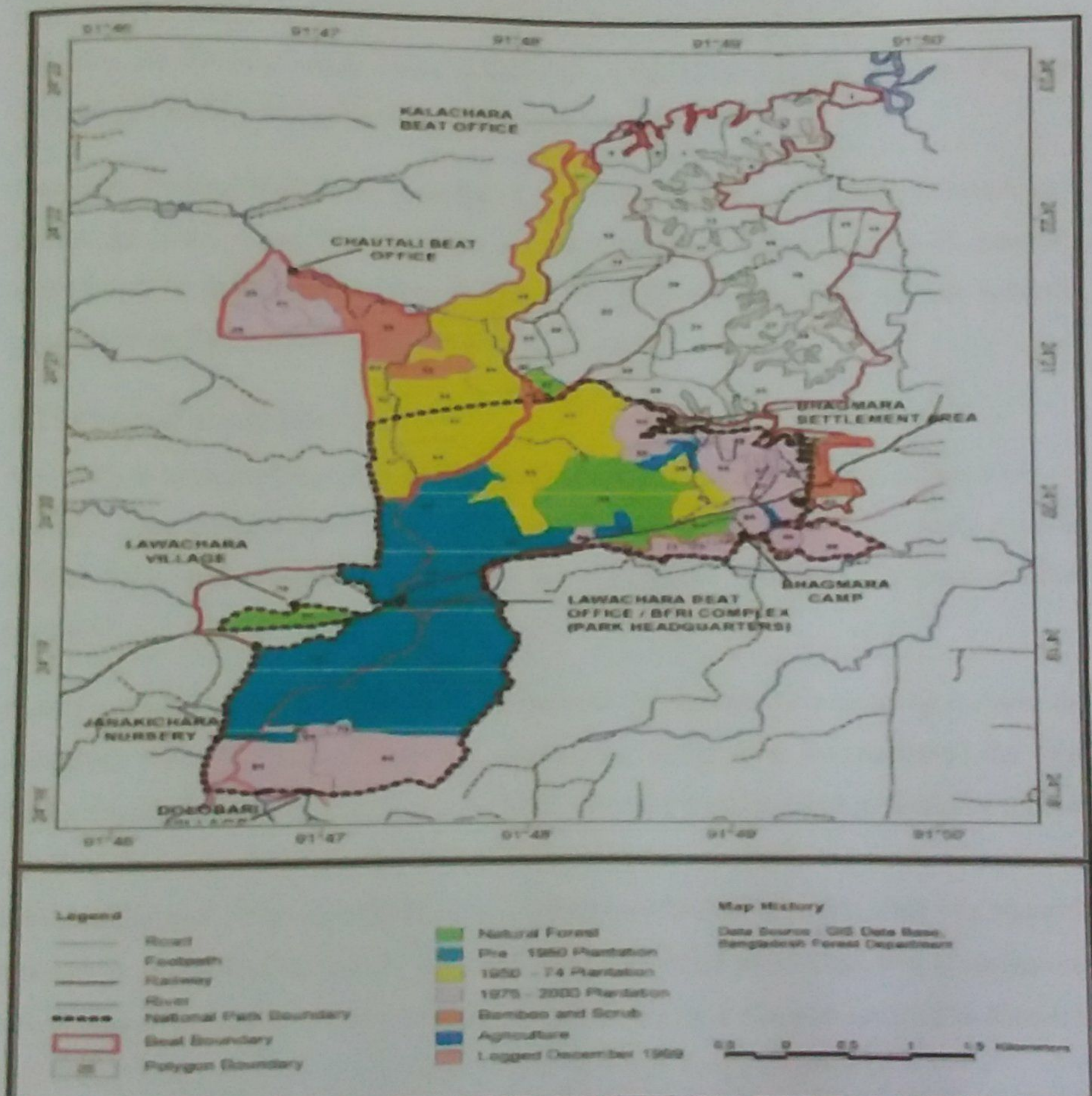

Figure 2: Map of study area (Lawachara National Park) with forest covers and land use patterns (source: Bangladesh Forest Department).

Lawachara is one of the major sanctuary in Bangladesh. Bangladesh Government declared it as a National Park in 1997. This forest was built by British. Its previous name was "West Bhanugan".

Lawachara is also a Bird Safari. Lawachara is under Kamalgonj Upazila of Moulabi Bazar District which is about 160 km north east of Dhaka, well connected by the national highway.

The area of the Park is 1250 ha and comprises forest of southern and eastern parts of West Bhanugach Reserve Forests within the Lawachara, Chautali and Kalachara Beats of Moulabi Bazar Range. The Park was notified in 1996 as per the wildlife Act of 1974. 15% of forest cover is completely lost and another 60% of its area thinned. Illegal logging and fuel wood collection are the main cause of the degradation of the forest. Roughly 80% wildlife has declined and another form of habitats has become extinct.

Lawachara National Park is full of biological diversity. There are 460 species of which 167 species are plants, 4 amphibian species, 6 reptile species, 246 bird species, 20 mammal species and 17 insect species. One of this is the critically endangered western hoolock gibbons of which only 62 individuals remain in the area.

3.2 Set up of study area:

This study is consists of several parts like; firstly an area might be selected in 100m×100m or 1ha plot. Then the plot was divided into 10m×10m and 5m×5m subplots. Secondly in each subplot trees were measured by using several instruments. The trees x-y position also measured.

At first we should know the true density to find out the accuracy of a sampling method. In Lawachara National Park counting and mapping all of the trees to established the true density. In summarizing the sampling data, point-to-first individual distance should be totaled for all species and all points, then averaged the distances and make the mean of point-to-individual distance. Then squared the mean of point-to-individual distance. This vale squared gives the mean area per individual. The mean area individual is the average area of surface on which one individual occurs. The total density of all species in the area sampled is obtained by dividing the mean area per individual into the unit area. So the equation is-

Total density of all species = Unit area / (mean point-to-individual distance)^2

We can reproduce the forest stands on a computer to test the plot less sampling methods as if they were applied in the field. In plot less sampling distances are measured between trees and therefore the tree location is variable here. We digitized all trees locations and developed an algorithm for each plot less sampling method. This allowed numerous repetitions of the density estimations and thus the calculation of the mean estimate and confined intervals for each sampling method measuring the distances from the trees to the grid borders.

3.3 Simulation-based study:

In order to find out the accuracy of PCQM density estimators on plant populations, simulation experiments were performed using the individual-based modeling platform NetLogo (Wilensky 1999). Appropriate codes are developed to perform experiments using the PCQM with simulated and imported real datasets on plant populations. Virtual plant assemblages having 'random', 'aggregated' and 'regular' patterns were created through simulation using NetLogo (Wilensky 1999) and the 'spatstat' package (Baddeley and Turner 2005) of R-software version 3.4.2(R Core Team 2017). Random patterns were created. The average radius of the clusters and the aggregation intensity (proportion of the population that appears in clusters) were needed for creating aggregation pattern. Repulsion distances (minimum distance among the neighbors) also needed for creating regular pattern. All the empirical and simulated datasets were accepted to have spatial isotropy and were not accepted to have spatial homogeneity. For expressing the spatial patterns of datasets which was used in a quantitative manner needed the aggregation index (R) of Clark and Evans(Clark and Evans 1954). Create different virtual forests with R-values of 1 ha area. 10m×10m and 5m×5m sample plot were used. Create random sample points (for sample size 50 and 100) within 1 ha area excluding 10 m and 5m all around. Measure distance data of PCQM for random point [1] to nearest tree. Also measure distance data for random point [2]. Quantify tree density at each random point use 5m×5m and 10m×10m sample plot. Record data by using computer-based system for further analysis.

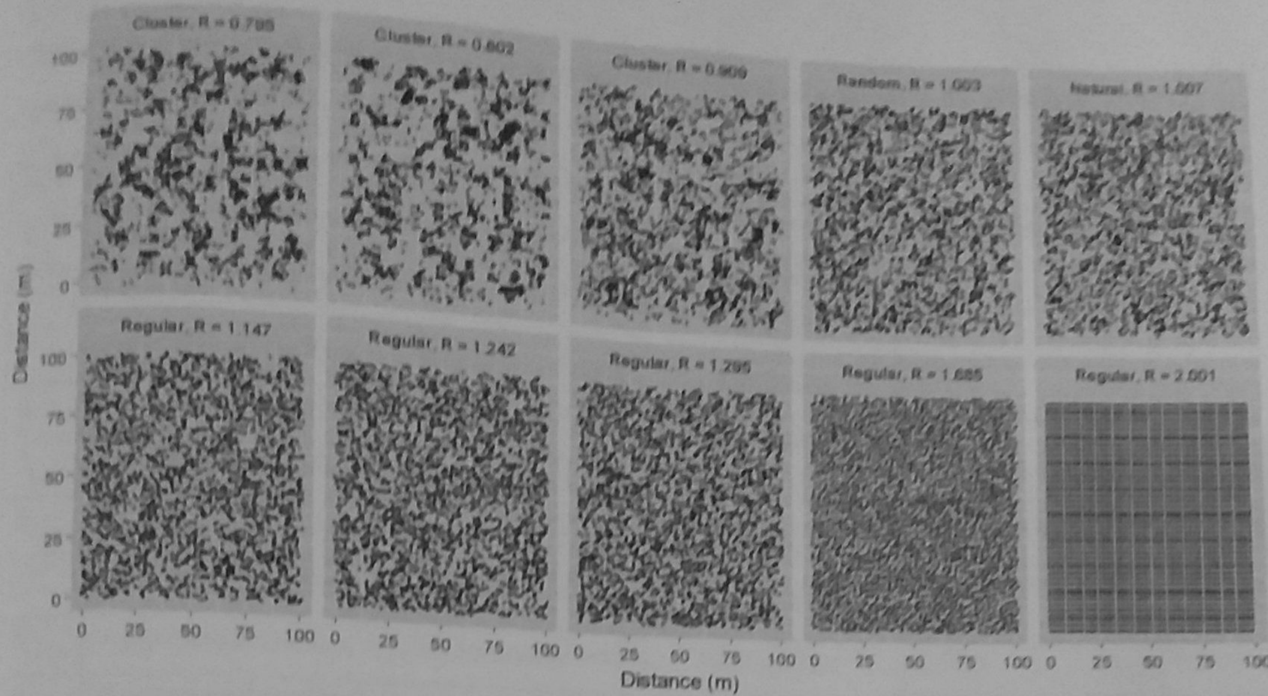

Figure 3: Different types of plan assemblages which represent the different Clark and Evans index R-values.

A 100m × 100m empirical datasets in a tropical semi-evergreen forest (trees >5cm D_{130}, diameter at 130 cm of tree height) in Lawachara National Park, Maulvibazar District, Bangladesh were used in the study. 10×10m and 5×5m sample plot were used. These datasets were imported into the NetLogo environment where trees are located identically to the real plot keeping the X-Y positions(Khan et al. 2016).

To estimate the performance of the corrected PCQM estimators, we applied virtual PCQM sampling to both empirical and simulated datasets according to the "virtual ecologist approach"(Grimm and Railsback 2005, Zurell et al. 2010). Random PCQM sample points(50 and 100 points per simulation) were generated inside the surveyed area excluding a boundary strip of 10% the length and width of the area, otherwise the bias associated with edge effects was not removed. Four quadrants were created at each sample point and the distance from the sample points to the desired nearest individual (Fig1) in each quadrants were estimated depending on PCQM order. The distance data were converted into an estimated density in relation to the "true" density related to either the empirical data set or the virtual assemblage simulated by the model as described above. "True density" (Table1) represents the one which has to be estimated by the sampling and the PCQM. A total of 100 simulations were performed for each sample size and each population(Khan et al. 2016).

3.4 Model description following the ODD protocol:

Description of individual based models (Grimm and Railsback 2005, Grimm et al. 2010) following the ODD (Overview, Design concepts, Details) protocol is provided NetLogo model codes are provided as supplementary information(Grimm and Railsback 2005, Grimm et al. 2010, Khan et al. 2016).

3.4.1 Overview:

3.4.1.1 Purpose of the model:

The purpose of this study was to revise the plotless density estimator Point-Centred Quarter Method (PCQM) based on simulated and empirical datasets for observing the accuracy of prediction in PCQM1, PCQM2, and PCQM3.

3.4.1.2 State variables and scales:

Individuals in the population are described primarily by the position (x-y coordinates). Plot size of the simulation area of 100m×100m and sample plot size 10m×10m and 5m×5m were used for this study. In each run population density 2,000 individuals ha^{-1}. Random PCQM sample points (50 and 100 points per simulation) were generated inside the simulation area. A total 100 simulations were performed for each sample size and each population.

3.4.1.3 Process overview and scheduling:

The following processes occurs each run: establishment of individuals, establishing a random PCQM sample point inside the NetLogo world, four quadrats were created with the sample point in the center, measuring the distance from the sample point to the desired nearest individual (depending on the PCQM order) in each of the four quadrants.

3.4.2 Design concepts:

3.4.2.1 Emergence:

Individuals emerge randomly, i.e., the spatial distribution of trees is completely random. There is no growth, mortality or any kind of dynamics in the population.

3.4.2.2 Interactions:

There is no interaction among the individuals in the population.

3.4.2.3 Sensing:

Individuals "sense" the distance of their neighbours.

3.4.2.4 Stochasticity:

Individuals establish randomly irrespective of any condition. PCQM points are obtained randomly but excluding a boundary strip of 10% the length and width of the area, otherwise the bias associated with edge effects is not removed.

3.4.2.5 Observations:

The model provides tracking of all state variables and derives parameters for all individuals.

3.4.3 Details:

3.4.3.1 Initialization:

The general settings of the settings of the simulation experiments are: (1) The NetLogo world to be initialized by simulated datasets of tree positions with varying densities based on x-coordinates and y-coordinates depending on spatial patterns; (2) The NetLogo world to be initialized by empirical datasets of trees located identically to the real field plot keeping the original x-y positions of tree (Table1).

3.4.3.2 Input:

There is no input in this model.

3.4.3.3 Submodels:

There is no submodel of NetLogo model.

3.4.3.4 Description of a single tree:

A tree is described by its x-y position only.

3.4.3.5 Tree density:

The model uses published and corrected PCQM estimators of density described in the section of Materials and Methods.

3.5 Statistical analysis:

The relative root mean square error (RRMSE) was used as the basis of comparisons between the different density estimator, where I is the number of simulation (100), $\rho^{\wedge}$ is the estimated density and ρ is the true density in the population, such that:

$$RRMSE = \sqrt{\frac{\Sigma(\hat{\rho} - \rho)^2}{I \cdot \rho^2}}$$

In order to detect the bias of the estimated density relative to the true density, the relative bias RBIAS was used, where I is the number of simulation (100), $\rho^{\wedge}$ is the estimated density and ρ is the true density in the population, such that:

$$RBIAS = \frac{(\Sigma\,\hat{\rho}/I) - \rho}{\rho}$$

Chapter4: Results and Discussion

4.1 Results:

Comparison of estimated density based on new PCQM estimators and square plot of populations having a wide range of spatial patterns and sample size. In plant populations having a random spatial pattern, the median values in the estimated densities by new PCQM estimators are very close to the true density (Fig.4). The PCQM1 shows an increasing deviation from true density with increasing Clark and Evans index (R) is more than 1 or less than 1. These deviations are low in PCQM2 and further low in PCQM3. In square plot the median value is close to the true density for R values of 1 and above (Fig.4), however, deviations are observed for R values less than 1. Within the square plots, the 10m×10m plot shows less deviation than 5m×5m plots. So for random spatial pattern, new PCQM estimators and square plot are very close.

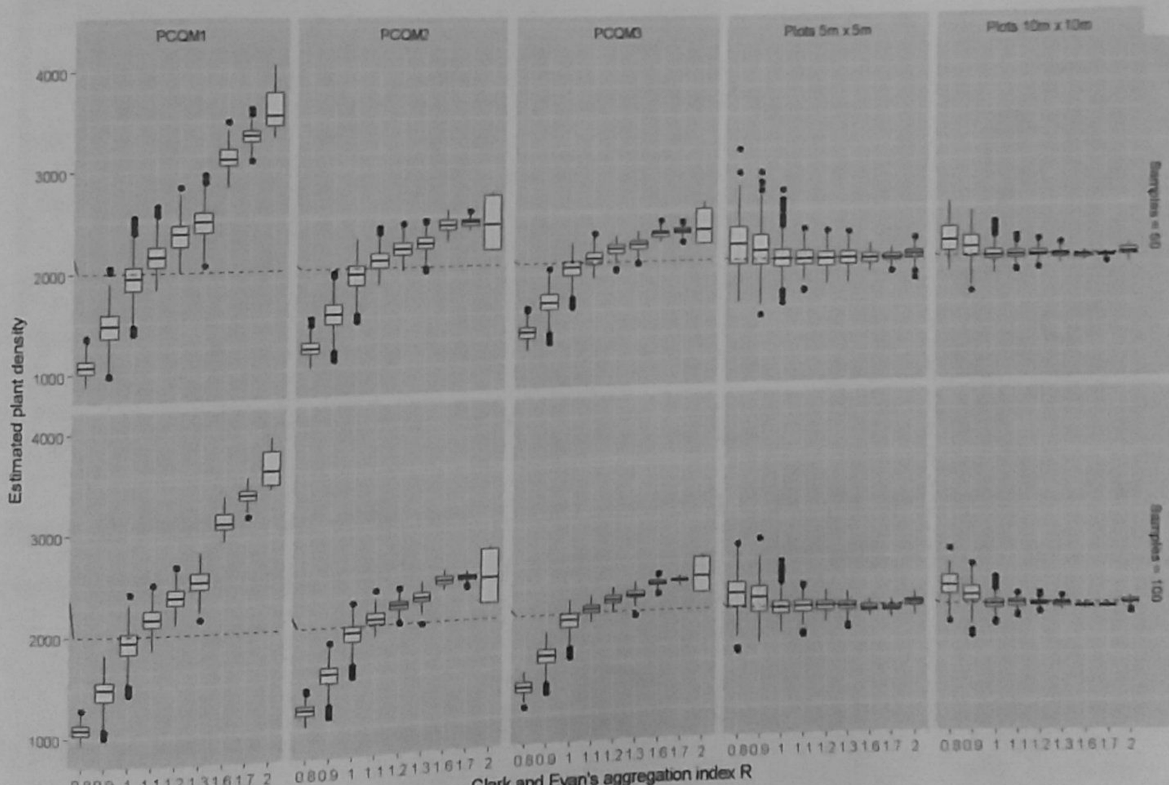

Figure 4: Boxplot of showing the performance of PCQM and square plots in plant density estimation in different populations having a wide range of spatial patterns. The dashed line indicates the true density.

In plant population having aggregated pattern, the median value of estimated densities by new PCQM estimators are very much lower than the true density (fig.4). These suggests under estimation of true density. But for square plot, the median value estimated densities are higher than the true density (Fig.4) that suggests the overestimation of true density.

At regular patter, the median values of estimated densities by new PCQM estimators are higher than the true density (Fig.4) which suggests overestimation of true density. In the square plot the median value of estimated densities are very close to true density (Fig.4). In strong regularity, the median value of estimated densities of square plot is also close to true density (Fig.4).

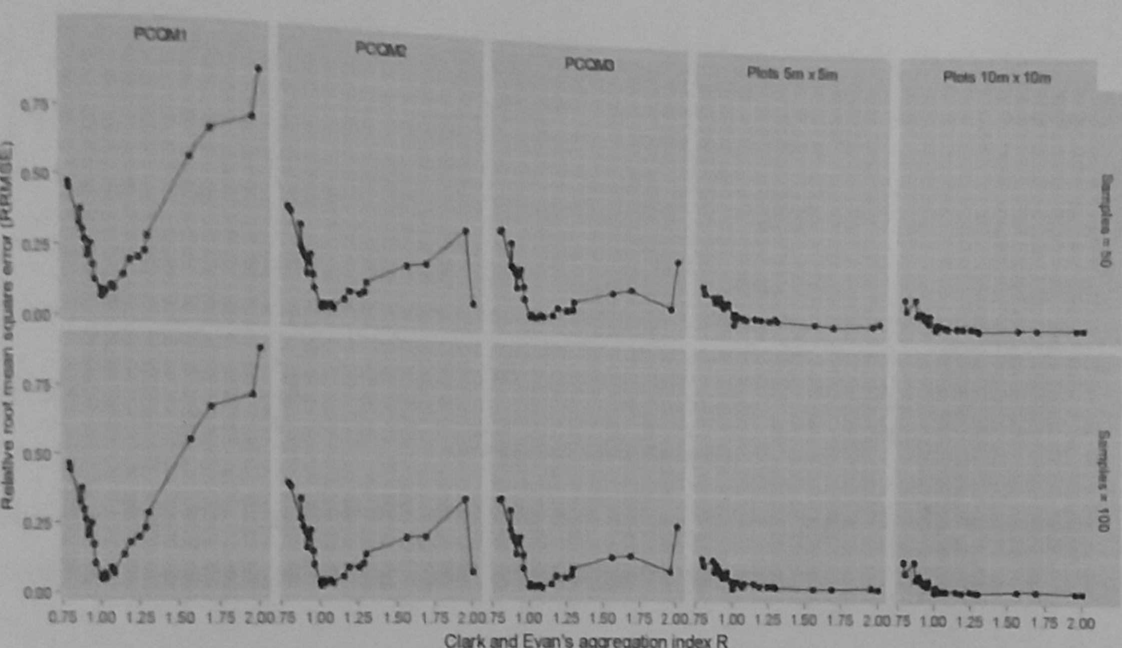

Figure 5: Relative root mean square error (RRMSE) of PCQM and square plots in plant density estimation in different populations having a wide range of spatial patterns.

In plants populations with 'random' spatial pattern the RRMSE and RBIAS values are very close to zero both for new PCQM estimators and square plots (Fig.5, Fig6). In plants populations with 'random' spatial pattern the RRMSE and RBIAS values show no differences among the new PCQM orders. And the new PCQM estimators and square plot are nearly same when the spatial patterns of population are random.

'Aggregated' spatial pattern in plant population when R value is lower the RRMSE values are higher than zero in new PCQM estimators (Fig.5). In the square plot, RRMSE and RBIAS values are positive (Fig.5, Fig.6). It refers that for aggregation pattern there is error in square plot. In new PCQM estimators for aggregated pattern the RBIAS values are negative (Fig.6). The RBIAS in new PCQM suggests underestimation of true density. So the performance of new PCQM estimators is comparable to the square plot for the aggregated spatial pattern.

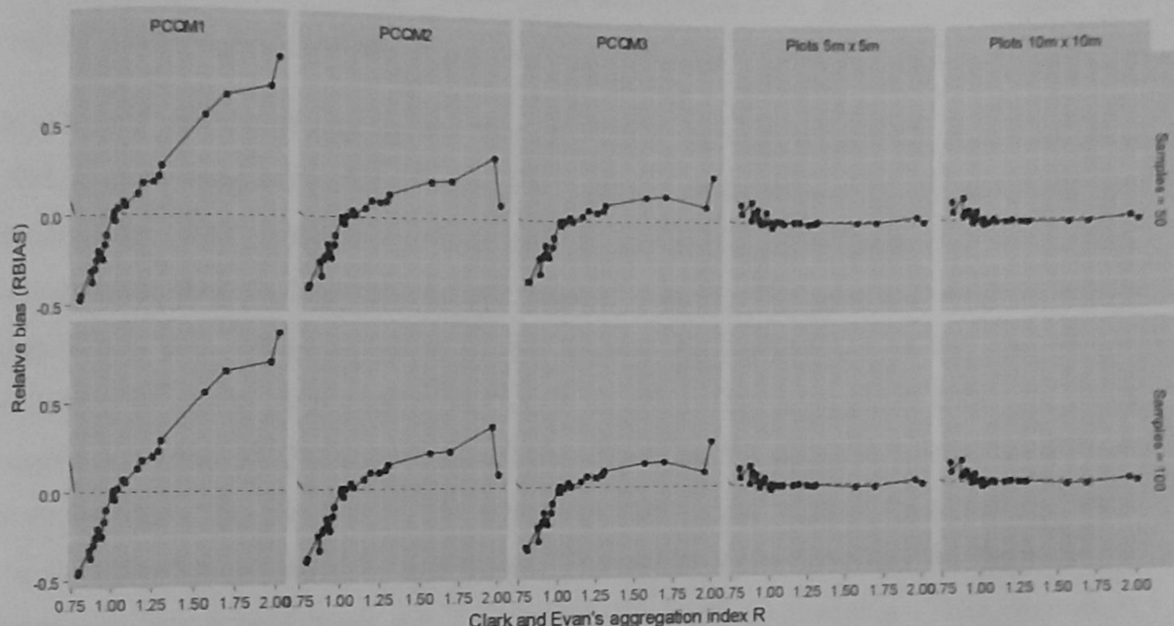

Figure 6: Relative bias (RBIAS) of PCQM and square plots in plant density estimation in different populations having a wide range of spatial patterns.

In 'regular' spatial pattern (the R value is higher) in plant populations by new PCQM estimators, the RRMSE and RBIAS values are positive (Fig.5, Fig.6). It seems that error is higher. So the RRMSE and RBIAS values show differences among the PCQM orders when the repulsion distance is >75cm. But the value shows no differences when the repulsion distance is < 75cm.

When the plants show strong regularity the performance of new PCQM is not better. The RBIAS values with PCQM1 become more positive, but the tendency is less strong to PCQM3. In PCQM2, the RBIAS values become negative (Fig6). When repulsion distance is small the new PCQM perform better. In square plot, the RRMSE and RBIAS values are very close to zero (Fig.5, Fig.6). It means there is less error in square plot.

In both RRMSE and RBIAS it is evident that in case of random distribution PCQM3 is very close to square plots.

4.3 Discussion:

After simulation using 'NetLogo virtual plant assemblages have 'random', 'aggregated' and 'regular' patterns were created.

In randomly distributed populations the new PCQM approach is generally accurate(Cottam 1953, Cottam and Curtis 1956, Pollard 1971). In this study, the new PCQM shows the best performance with 'random' pattern and a reasonable performance for other plant assemblages, such as 'aggregated' and 'regular' patterns. The estimated result in natural populations with semi-aggregated pattern suggest the applicability of the new PCQM estimators in natural plant population(Khan et al. 2016). Only when plants show very strong regularity the new PCQM doesn't show better result. But the square plot shows better result in strong regularity. The new PCQM estimators show similar result as the square plot when the plant population pattern is 'aggregated' .The repulsion distance refers that the minimum distance of closest neighbours, e.g. a plantation with seedlings planted at >75cm intervals in all direction (Khan et al. 2016). So the performance of square plot is better than the new PCQM orders except aggregated spatial pattern.

Root mean square error (RRMSE) and relative bias (RBIAS) are sensitive to outliers in the predicted value. The median values in the box plot (Fig.4), which are not sensitive to outliners, suggests no remarkable differences among new PCQM1, new PCQM2 and new PCQM3. And the new PCQM estimators and square plot are very close when the population pattern is random. The first order PCQM offers accurate density estimations if more than 50 sample points are used, and if the spatial pattern is completely random. Across all the patterns except aggregated spatial pattern, we found that square plot estimators are more robust and the estimated densities closer to true density and therefore more accurate than new PCQM (Engeman et al. 1994, White et al. 2008).

The estimated densities of natural populations were very close to true density obtained in the field (revealed by the RBIAS values closeness to zero). NetLogo model mimics real population in the field. Higher order PCQM (PCQM2, PCQM3) shows better result of density estimation but in most cases such as in random and aggregated spatial patterns and in regular plant assemblages with a repulsion distance of < 75cm, the differences are not significant if the sample size is greater than 50. The higher order PCQM shows differences among the new PCQM versions when repulsion distance >75cm (Khan et al. 2016).

In square plots, the estimated densities are very close to true density (revealed by the RBIAS values closeness to zero). This method shows better prediction of density for all type of vegetation pattern and plant assemblages except aggregation plant assemblages. In both RRMSE and RBIAS it is found that in case of random distribution PCQM3 is very close to square plots.

So higher order PCQM offers high accuracy in density prediction for plant assemblages with random and aggregated pattern (R value is less). It shows difference for having strong repulsion (R value is higher). On the other hand, the square plot always shows higher accuracy in density prediction for all type of plant assemblages other than the aggregated pattern. But for random distribution new PCQM and square plot are same. The square plot is more efficient than the new PCQM estimators when R value is more than 1.

Chapter 5: Conclusion

When the plant assemblages are random (R value is 1) and aggregated (R value is less than 1) new PCQM and the square plot are very near. The higher order PCQM (PCQM2, PCQM3) offers better density prediction for regular (R value is greater than 1) and aggregation pattern. The square plot shows higher accuracy in density estimation for all types of plant assemblages except aggregation distribution (R< 1). The results of the study suggest that sampling efficiency not only depends on sampling methods (plotless or plot-based) but also varies among plant assemblages or vegetation pattern.

References

Baddeley, A., and R. Turner. 2005. Spatstat: an R package for analyzing spatial point patterns. Journal of Statistical Software 12:1–42.

Beasom, S. L., and H. H. Haucke. 1975. A Comparison of Four Distance Sampling Techniques in South Texas Live Oak Mottes. Journal of Range Management 28:142–144.

Clark, P. J., and F. C. Evans. 1954. Distance to Nearest Neighbor as a Measure of Spatial Relationships in Populations. Ecology 35:445–453.

Cottam, G. 1953. Some Sampling Characteristics of a Population of Randomly Dispersed Individuals. Ecology 34:741–757.

Cottam, G., and J. Curtis. 1956. The Use of Distance Measures in Phytosociological Sampling. Ecology:451–460.

Dahdouh-Guebas, F., and N. Koedam. 2006. Empirical estimate of the reliability of the use of the Point-Centred Quarter Method (PCQM): Solutions to ambiguous field situations and description of the PCQM+ protocol. Forest Ecology and Management 228:1–18.

Engeman, R. M., R. M. Nielson, and R. T. Sugihara. 2005. Evaluation of optimized variable area transect sampling using totally enumerated field data sets. Environmetrics 16:767–772.

Engeman, R. M., D. Wildlife, U. Aphis, P. O. Box, R. T. Sugihara, H. F. Station, L. F. Pank, and W. E. Dusenberry. 1994. A comparison of plotless density estimators using Monte Carlo simulation. Ecology 75:1769–1779.

Grimm, V., U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske, and S. F. Railsback. 2010. The ODD protocol: A review and first update. Ecological Modelling 221:2760–2768.

Grimm, V., and S. Railsback. 2005. Individual-based Modelling and Ecology.

Hijbeek, R., N. Koedam, M. N. I. Khan, J. G. Kairo, J. Schoukens, and F. Dahdouh-Guebas. 2013. An Evaluation of Plotless Sampling Using Vegetation Simulations and Field Data from a Mangrove Forest. PLoS ONE 8:e67201.

Khan, M. N. I., R. Hijbeek, U. Berger, N. Koedam, U. Grueters, S. M. Z. Islam, M. A. Hasan, and F. Dahdouh-Guebas. 2016. An Evaluation of the Plant Density Estimator the Point-Centred Quarter Method (PCQM) Using Monte Carlo Simulation. PLoS ONE 11:e0157985.

Kumarathunge, D. P., R. O. Thattil, and S. P. Nissanka. 2011. Evaluation of the plotless sampling method to estimate aboveground biomass and other stand parameters in tropical rain forests. Applied Ecology and Environmental Research 9:425–431.

Pollard, J. H. 1971. On distance estimators of density in randomly distributed forests. Biometrics 27:991–1002.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

White, N., R. M. Engeman, R. T. Sugihara, and H. W. Krupa. 2008. A comparison of plotless density estimators using Monte Carlo simulation on totally enumerated field data sets. BMC ecology 8:6.

Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/.

Zurell, D., U. Berger, J. S. Cabral, F. Jeltsch, C. N. Meynard, T. Münkemüller, N. Nehrbass, J. Pagel, B. Reineking, B. Schröder, and V. Grimm. 2010. The virtual ecologist approach: simulating data and observers. Oikos 119:622–635.