Khulna University
Life Science School
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Author(s): S. M. Zahirul Islam

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

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COMPARISON OF PLOT-BASED VERSUS PLOT-LESS METHODS IN STUDYING FOREST VEGETATION STRUCTURE

S. M. ZAHIRUL ISLAM
STUDENT ID: 100522

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA – 9208
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S.M. Zahirul Islam

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Comparison of plot-based versus plot-less methods in studying forest vegetation structure

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SUBMITTED TO

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Dr. Md. Nabiul Islam Khan
Professor
Forestry and Wood Technology Discipline
Khulna University
Khulna.

SUBMITTED BY

16.02.15

S.M. Zahirul Islam
Student ID: 100522
Forestry and Wood
Technology Discipline
Khulna University
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Zahirul
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S.M. Zahirul Islam
Student ID: 100522
Forestry and Wood
Technology Discipline
Khulna University
Khulna.

DEDICATED

TO

MY BELOVED

FAMILY

DECLARATION

I, here, by declare that the project thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Khulna University or other institutions.

Zahirul 16.12.15

S.M. Zahirul Islam
Student ID: 100522
Forestry and Wood technology Discipline
Khulna.

APPROVAL

This is to certify that, S.M. Zahirul Islam, Student ID. 100522 has prepared this thesis entitled **'Comparison of plot-based versus plot-less methods in studying forest vegetation structure' under my direct supervision and guidance.** I do hereby approve the style and content of the thesis. This thesis has been prepared in partial fulfillment of the requirement for the four years B. Sc. (Hon's) Degree in Forestry.

16.02.2015

Dr. Md. Nabiul Islam Khan
Professor
Forestry and Wood Technology Discipline
Khulna University
Khulna.

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ABSTRACT

Tree importance value (IV) is often used as a variable to determine vegetation structure in vegetation science and forest management. To determine the IV, tree density, frequency, and basal area are used. There are two sampling methods plot-based and plot-less widely used to determine those variables. When vegetation is sparse or not easily accessible, the use of sample plots is not feasible in the field. Therefore, plot-less methods are often used as an alternative. Plot-less method have been shown useful in plant density estimation. However, the applicability of these methods in studying vegetation structure is yet to be tested. In this study we conducted an extensive simulation study based on empirical datasets of tree positions to compare the performance of plot-based and plot-less sampling estimators to obtain clarification of their performance. In this study we observed that in all cases the error of the estimate (measured as relative root mean square error) reduced with increasing sample size. All PCQM (Point Centered Quarter Method) estimator of plot-less sampling methods showed better performance in all species with high and low importance values compared to other methods. In all cases the error (RRMSE) of the methods increased with the reduction of density of the individual species. The RRMSE and RBIAS values obtained through some of the plot-less methods, such as PCQM and the (VAT) variable area transect are very close to the plot-based methods. This was found true for the most dominant species Chapalish (*Artocarpus Chaplasha* Roxb.) (IV = 74.86%) as well as for the moderately dominant Pisti (*Micromelum minutum* G. Forester.) (IV = 14%). Our results suggest that as likely with the plot-less methods there is considerably high sampling uncertainty in plot-based methods too. We recommended that PCQM or VAT can be considered as a suitable alternative of plot-based method for studying vegetation structure in terms of IV.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background and justification of the study

A wide variety of methods have been used to study forest vegetation structure. These methods fall into two broad categories: plot-based and plot-less. Plot-based methods begin with one or more plots (quadrates, belts) of known area in which the characteristics of interest are measured for each plant. In contrast, plot-less methods involve measuring distance from a random sample point to a desired tree and recording the characteristics of interest for this sample (Dahdouh-Guebas and Koedam, 2006; Mitchell, 2007).

The plot-less method serve as suitable methods in vegetation study when there is an accessibility issue· as commonly observed in mangroves (Cintron and Schaeffer-Novelli, 1984; Dahdouh-Guebas et al., 2004; Neukermans et al., 2007; Satyannarayana et al., 2010) and hill forests. The plot-less methods can be very efficient in sampling for indices of forest structure (Kint et al., 2004; Pretzsch, 1997) and for forest inventories (Kleinn and Vilcko, 2006; Nothdurft et al., 2010). The plots-less method are preferred as faster methods, require less equipment, require fewer workers and when plot-based sampling would be difficult or to costly (Picard et al., 2005; Sheil et al., 2003; Mitchell, 2007).

The comparison of various plot-based and plot-less methods (Engeman et al., 1994; Magnussen and Boyle, 1995: white et al., 2008) reveal that plot-less methods has more statistical uncertainty than the plot-based methods and there is no uniformity best plot-less method for all types of vegetation assemblages. In vegetation study, these comparisons help to select suitable methods and overcome many of weaknesses making them more or less suitable for achieving a given objective. Since many research is characterized by hard field conditions making it difficult to access sites and trees, using this comparison study provide them excellent option to select sampling measure with desired statistical accuracy in evaluating vegetation structure.

The performance of various plot-less methods have been investigated to estimate plant density (e.g., Engeman et al., 1994; Magnussen and Boyle, 1995: white et al., 2008). However, their performance in studying vegetation structure is yet to be examined. In this study, we determine the importance value of tree species in Lawachara National Park (further details are provided in the section of Materials and Methods). For this purpose, we used simulation of empirical dataset of plant populations (real tree x-y positions) collected from Lawachara National Park. The term importance value can mean many things depending on context. Measuring importance can aid understating the successional stage of forest habitat at different stage and different species of trees will dominate (Mitchell, 2007). Three factors that we will use to determine the importance value of a species are the density, the size, and the frequency.

The results can be useful to choose a suitable method for a specifying sampling objective with desired statistical accuracy. Whereas these results are applicable to a wide range of disciplines in plant ecology in which vegetation structure plays a role.

1.2 Objectives of the study

- Comparison between plot-based and plot-less methods in studying vegetation structure.
- To compare the statistical accuracy among the methods.

CHAPTER 2

2.0 MATERIALS AND METHODS

2.1 Description of the study site

Lawachara National Park is located in Kamalganj Upzila of Maulvibazar District nearly 160 km northeast of Dhaka and approximately 60 km south of Sylhet city. It lies between $24°30' - 24°32'$ N and $91°37' - 91°39'$ E (Feeroz et al., 1994) and is nearly eight km east of Srimongal, on way to Kamalganj. The National Park and proposed extension comprise forests of southern and eastern parts of West Bhanugach Reserve Forest (RF). The NP was notified (a copy annexed) in 1996 as per the Wildlife (Preservation) (Amendment) Act, 1974, with a total forest area of 1250 ha (GOB, 1992).

The Lawachara park is very rich in bio-diversity and the park is located on the high rainfall biogeographic region and Bio-ecological zone (9b-Sylhet Hills) (Nishat et al, 2002) having evergreen and semi-evergreen forests (Champion et. al., 1965; Feeroz and Islam., 2000; Ahsan, 2000). The National Park represents several features of the bio-diversity of north-eastern subcontinent, which is one of the mega bio-diversity regions with many endemic floral species. At present, there are few patches of natural forests. Large deciduous trees are mixed with evergreen smaller trees and bamboos. About 107 species were recorded in Lawachara Park (Leech and Ali, 1997). About 40 species were recorded depend on the food and feeding habit of monkeys, langurs and hoolock gibbon in Lawachara Forest (Feeroz et al.,1994).The top canopy includes *Artocarpus chaplasha*, *Dipterocarpus turbinatus*, *Elaeocarpus floribundaas*, Dillenia pentagyna, *Castanopsis tribuloides*, etc. The second canopy comprises *Quercus sp.*, *Syzygium sp.*, *Gmelina sp.*, *Dillenia sp.*, *Grewia sp.*, *Ficus sp.* etc. The underneath includes *Bambusa sp.*, *Alsophila sp. Geodorum sp.*, *Eupatorium odoratumetc*, and several ferns and epiphytes (Islam and Feeroz, 1992; Feeroz and Islam, 2000).

2.2 Sample plot layout and mapping of tree location in the field

A sampling plot was established at a natural patches of the study site, and had an area of one ha (100 m × 100 m) which was divided into 100 subplots (10 m × 10 m) to measure the tree position accurately. The x- and y- coordinates (tree position), DBH (diameter at breast height, i.e. 1.3 m from the ground) and height of single trees were recorded in study site with proper identification of species. This x- and y- coordinates was measured by making field grids of 10 m by 10 m and by measuring the distances from the trees to the grid borders and adding radius (DBH / 2) of each tree to record the xy-coordinates approximately at the stem center.

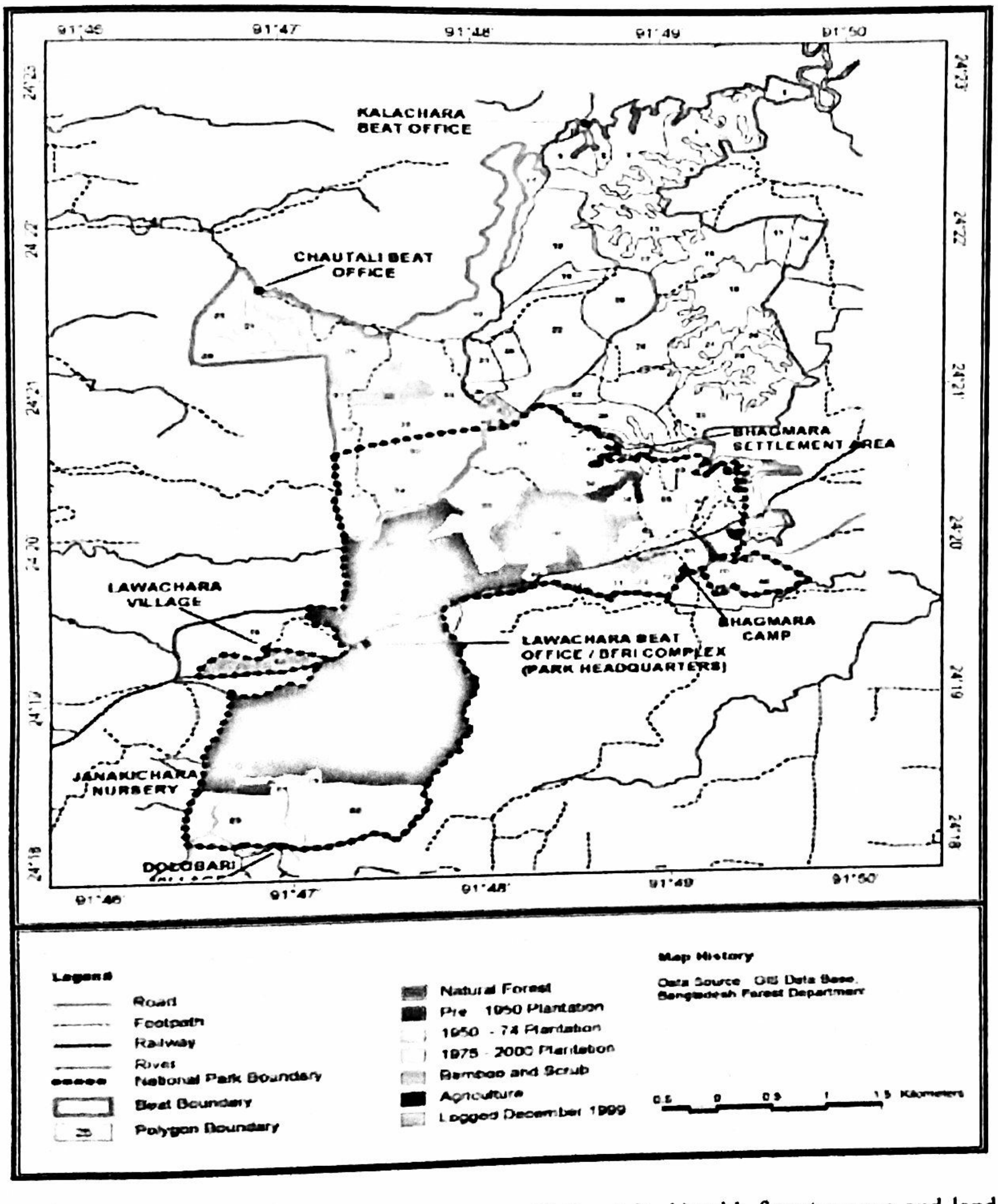


Figure (2.1). Map of the study site (Lawachara National Park) with forest covers and land use patterns (Source: Bangladesh Forest Department).

2.3 Experimental design

In order to investigate the comparison of plot-based and plot-less method on vegetation structure, simulation experiments were performed using the individual-based modelling platform NetLogo (Wilensky, 1999). Appropriate codes had been developed to perform experiments using the plot-based and plot less method based on an imported datasets on plant populations collected from Lawachara National Park. We also developed a user interface for this purpose (NetLogo model may be provided as supplementary material (Wilensky,1999). The other Statistical analysis were performed using the Microsoft Excel 2013 and the 'spatstat' package (Baddeley and Turner, 2005) of R- Software version 2.15.1.

Empirical datasets on x-y positions of all the individual trees in one ha field plot, Diameter at Breast Height (DBH) and tree height were imported into the NetLogo environment where plants are located identically to the real plot keeping the original x-y positions. About 60 species were recorded in study site and among them top 10 species were considered in the simulation study in order to compare the importance values and relevant parameters and to simplify the analysis in Netlogo environment (Wilensky,1999).

Following the 'virtual ecologist approach' (Berger *et al.*, 1999; Zurell *et al.*, 2010), we applied virtual sampling to empirical datasets in order to estimate the comparison of the plot-based and plot-less estimators. For this, random sample points (30, 50,75 and 100 points per simulation) were generated inside the surveyed area excluding a boundary strip of 10% of the length and width of the area to remove the bias associated with sampling close to the edge of the study area. Each random sample point we were generated plot (5 m× 5 m), (10 m × 10 m), nearest individual (distance of closest tree from the sample point), nearest neighbour (distance of neighbour from the nearest individual), PCQM (Point central quarter method) and VAT (variable area transect method). In PCQM, four quadrants were created at each sample point and the distance from the sample points to the desired nearest individuals in each of four quadrants (depending on the PCQM order) were measured Fig (2.3). In VAT, we were considered 5 m, 10 m vat-width and 5^{th} vat-nth-tree. The data of distances, DBH, and frequency were converted to Importance value by using specific formulae (see below) of plot-based and plot-less estimators. A total of 100 simulations were performed for each sample size and each method.

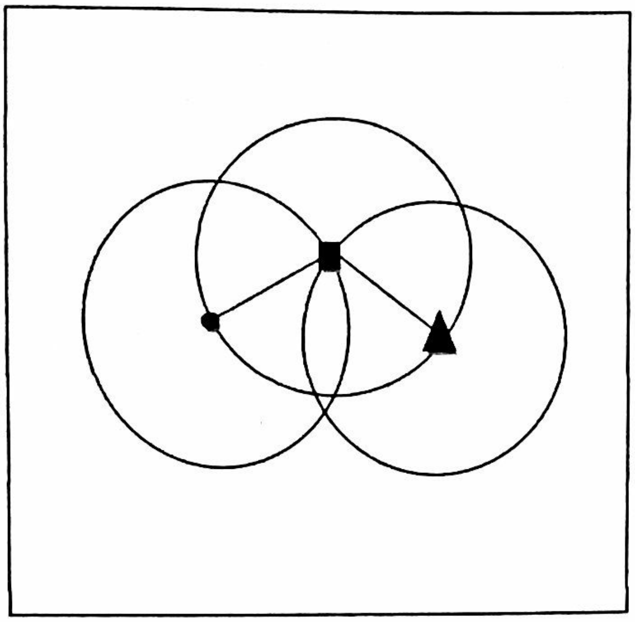


Figure (2.2); Schematic representation of NI (Nearest Individual) and NN (Nearest Neighbor) (■, represent NI desistence form ● the simple point, and ▲ represent NN desistence form the NI).

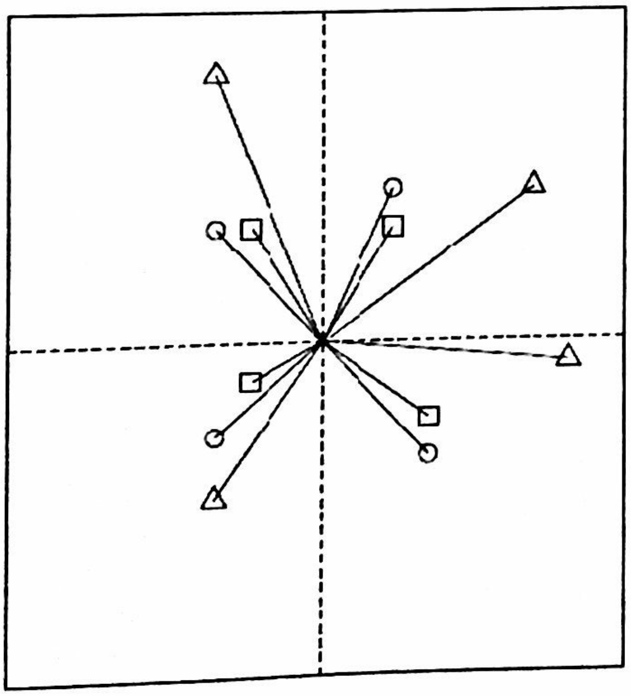


Figure (2.3); Schematic representation of PCQM1 (Λ, 1st closest individual in each quarter), PCQM2 (o, 2nd closest individual in each quarter) and PCQM3 (Δ, 3rd closest individual in each quarter).

2.4 Plot-based methods

For each plot-based method, the following parameters were calculated, derived by of Odumand Barret, (2005)

$$\text{Density [ha}^{-1}] = \frac{\textit{Number of individuals}}{\textit{Area of plot}}$$

$$\text{Relative density [\%]} = \frac{\textit{Density for a species}}{\textit{Total density for all species}} \times 100$$

$$\text{Frequency [\%]} = \frac{\textit{Number of plots in which a species occurs}}{\textit{Total number of plots sampled}} \times 100$$

$$\text{Relative frequency [\%]} = \frac{\textit{Frequency of a species}}{\textit{Total frequency for all species}} \times 100$$

$$\text{Basal Area (BA) [m}^2\text{ ha}^{-1}] = \frac{\pi}{10000}\left(\frac{DBH}{2}\right)^2$$

$$\text{Coverage [m}^2\text{ha}^{-1}] = \frac{\textit{Total basal area for a species}}{\textit{Area of plot}}$$

$$\text{Relative coverage [\%]} = \frac{\textit{Dominance for a species}}{\textit{Total dominance for all species}} \times 100$$

$$\text{Importance value} = \textit{Relative density} + \textit{Relative frequency} + \textit{Relative coverage}$$

2.5 Plot-less methods

For each plot less method, the following parameters were calculated based on different literature sources.

Density

Method	Description of distance(s) measured	Equation	Literature source
Nearest individual	The distance between a point and the nearest tree is measured.	$D = \frac{1}{4 * (\sum R_{(1)}/n)^2}$	(Cottam and Curtis., 1956); (Renske et al., 2013).
Nearest neighbor	The distance between a tree and the nearest tree is measured	$D = \frac{1}{2.778 * (\sum R_{(1)}/n)^2}$	(Cottam and Curtis., 1956); (Engeman et al., 1994); (White et al., 2008); (Renske et al., 2013).
PCQM 1	The distances between a point and the nearest tree in each quadrant around the point are measured.	$D = \frac{4(4n-1)}{\pi \sum_{i=1}^{n} \sum_{j=1}^{4} R_{ij}^{2}}$	(Renske et al., 2013).
PCQM 2	The distances between a point and the second nearest tree in each quadrant around the point are measured.	$D = \frac{4(8n-1)}{\pi \sum_{i=1}^{n} \sum_{j=1}^{4} R_{ij(2)}^{2}}$	(Renske et al., 2013).
PCQM 3	The distances between a point and the third nearest tree in each quadrant around the point are measured.	$D = \frac{4(12n-1)}{\pi \sum_{i=1}^{n} \sum_{j=1}^{4} R_{ij(3)}^{2}}$	(Renske et al., 2013).
VAT	The distance from a point to the gth individual in a given direction with a certain width (a transect) is measured.	$D = \frac{gn-1}{w \sum_i L_{(g)i}}$	(Parker, 1979); (Renske et al., 2013).

PCQM= Point-Centered Quarter Method; VAT= Variable Area Transect; D = estimated density, R = distance measured in the field, i = number of sampling point, j = number of quadrant, n = number of sampling points.

Relative density [%] $= \frac{Absolute\ density\ of\ a\ species}{Total\ absolute\ density\ of\ all\ species} \times 100$ [(Mitchell, 2007)]

Absolute frequency [%] $= \frac{Number\ of\ sample\ points\ with\ a\ species}{Total\ number\ of\ sample\ points} \times 100$ [(Mitchell, 2007)]

Relative frequency [%] $= \frac{Absolute\ frequency\ of\ a\ species}{Total\ frequency\ of\ a\ all\ species} \times 100$ [(Cottam and Curtis., 1956); (Mitchell, 2007)]

Relative coverage [%] $= \frac{Total\ basal\ area\ of\ a\ species}{Total\ basal\ of\ all\ species} \times 100$ [(Cottam and Curtis, 1956); (Mitchell, 2007)]

Importance value $= Relative\ density + Relative\ frequency + Relative\ coverage$

2.6 Statistical analysis of the results

The relative root square error (RRMSE) was used as the basis of comparisons between plot-based and plot-less estimators, where *I* is the number of simulations (100), $\hat{v}$ is the estimated value and *v* is the true value in the population, such that:

$$RRMSE = \sqrt{\frac{\sum(\hat{v} - v)^2}{I.v^2}}$$

Along with the RRMSE, in order to detect the bias of the estimated value to the true value, the relative bias (RBIAS) was used, where *I*, $\hat{v}$ and *v* represent the same as equation of RRMSE, Such that:

$$RBIAS = \frac{(\sum \hat{v} / I) - v}{v}$$

CHAPTER 3

3.1 Results

Observation of the performance of methods based on relative root mean square error (RRMSE) and relative bias (RBIAS) (Table 3) was undertaken for estimators and simulated data sets are described in Table 2. An ideal method is one that shows low RRMSE and RBIAS, and where the amount of required fieldwork can be minimized or at least be undertaken efficiently.

In this study, the RRMSE and RBIAS values obtained through PCQM and VAT are very close to the plot-based methods. This was found true for the most dominant species Chapalish (*Artocarpus Chaplasha* Roxb.) as well as for the moderately dominant Pisti (*Micromelum minutum* G. Forester.) (IV = 14.53%) (Table 2). PCQM and VAT (variable area transect) showed well performance in term of relative density and relative coverage for all species than other silvimetric methods. Higher PCQM (second closest individual- PCQM2 and third closest individual- PCQM3) showed better performance than the lower PCQM (first closest individual- PCQM1) in term of relative density. However, the entire plot-less methods showed poor performance in estimating the relative frequency which gradually increases from the true value with decreasing individual species frequency (Figure 3.11-3.16).

In all cases the error of the estimate (measured as relative root mean square error) reduced with increasing sample size. All PCQM (first closest individual- PCQM1, second closest individual- PCQM2 and third closest individual- PCQM3) silvimetric method of plot-less sampling methods showed better performance in all high and low density of individual species comparison to other methods. In all cases the error (RRMSE) of the methods increased with the reduction of density of the individual species.

Nearest individual (closest individual from the random simple point) and nearest neighbor showed little poor performance in term of comparison than plot-based method. In all cases those methods showed poor performance in term of importance value, relative density, relative frequency and relative coverage. But the performance observed little better with increasing sample point (Table 3).

Plot with sample size (10 m×10 m) always showed better performance in all sample number but plot with sample size (5 m×5 m) observed poor performance in low number of sample.

Only the plot-based methods showed well performance in term of relative frequency for all species.

3.2 Discussion

Among the plot-less methods, the best performance of density estimation was observed by higher order PCQM and VAT, which is supported by other studies (Engeman et al., 1994; Magnussen and Boyle, 1995: white et al., 2008) to compare the performance of plot-less methods to plot based ones for density estimation.

In case of relative coverage, all the plot-less methods observed very close results in comparison with the plot-based method. The best performance of relative dominance was observed by PCQM and VAT, which is supported by other studies (Cottam and Curtis, 1956; Dahdouh-Guebas and Koedam, 2006).

The plot-less methods were found less efficient in estimating the relative frequency. The performance was found better in the dominant species and gradually decreasing with less frequent species. As presented in Table 2 and Table 3, the overall performance of the plot-less methods in estimating the importance values are comparable with the plot-based methods. The RRMSE and RBIAS values obtained through some of the plot-less methods, such as PCQM and VAT which are very close to the plot-based methods. This is true for the most dominant species Chapalish (*Artocarpus Chaplasha* Roxb.) (IV = 74.86%) as well as for the moderately dominant Pisti (*Micromelum minutum* G. Forester.) (IV = 14.53%). This indicates that like the plot-less methods there is considerably high sampling uncertainty in plot-based methods too.

3.3 Conclusion

This study has given well results, but there are several possibilities for further research. Preferably, we would like to find a sampling method that is easy and fast to use while giving reliable results. Our observed results suggest that for vegetation structure study in natural forests the plot-less methods PCQM or VAT can be considered as a suitable alternative of plot-based method.

Table 1: Relative Density, Relative Dominance (RDo %), Relative Frequency (RF %) and Importance Value (IV %) of top 10 dominated species recorded in one ha plot.

Species Name	**Relative Density (RD %)**	**Relative Frequency (RF %)**	**Relative Dominance (RDo %)**	**Importance Value (IV %)**
Chapalish (*Artocarpus Chaplasha* Roxb.)	11.26	10.84	52.76	74.86
Deua (*Artocarpus lakucha* Roxb.)	18.69	15.96	9.28	43.94
Badam (*Terminalia catappa*)	14.86	14.76	4.47	34.09
Kakra (*Glochidion lanceolaris*)	12.84	12.95	2.20	27.99
Khudijam (*Syzygium fruticosum* (Roxb.) DC.)	11.71	11.14	4.01	26.87
Banaritha (*Accacia Concinna* Willd.)	4.05	5.12	12.63	21.81
Dumur (*Ficus hispida* L.)	6.76	7.83	7.09	21.68
Jolpai (*Eleaocarpus robustus* Roxb.)	7.43	6.93	2.98	17.34
Pitafol	7.21	8.13	1.56	16.90
Pisti (*Micromelum minutum* G. Forester.)	5.18	6.33	3.02	14.53

Table 2: Importance Values (IV %) of 10 most dominant species estimated based on 30, 50,75 and 100 random samples in the simulation using different plot-based and plot-less silvimetric methods.

Species name	True IV (%)	Sample point	Importance Value (IV %)								
			Estimator								
			PB1	PB2	NI	NN	PCQM 1	PCQM2	PCQM 3	VAT1	VAT2
Chapalish	74.86	30	66.65	75.69	58.33	70.57	64.76	76.67	73.13	78.49	78.35
		50	67.66	74.65	63.98	74.61	67.75	76.35	77.04	78.79	79.17
		75	71.75	75.70	65.96	77.63	68.27	75.59	74.96	79.01	79.75
		100	75.31	75.26	66.03	77.10	68.22	77.36	73.90	78.96	79.78
Deua	43.94	30	52.37	47.29	46.02	43.58	42.84	40.30	40.62	44.39	42.25
		50	51.30	46.10	44.59	42.57	41.75	40.97	39.48	40.22	41.03
		75	49.91	45.53	46.48	43.15	41.76	41.44	38.96	40.31	40.82
		100	49.35	46.25	44.26	42.72	41.51	41.38	39.00	41.03	41.14
Badam	34.09	30	35.74	32.89	36.32	36.35	33.13	33.37	33.41	36.12	35.39
		50	33.44	33.36	33.92	35.61	33.44	31.99	33.25	36.31	35.09
		75	34.13	33.37	33.50	34.96	33.29	31.49	32.61	35.78	34.66
		100	33.42	32.61	32.55	34.50	32.50	31.38	32.89	34.63	33.80
Kakra	27.99	30	24.94	25.15	22.53	23.45	22.68	24.88	23.93	24.24	23.41
		50	25.56	25.50	22.34	23.88	22.64	24.75	23.93	23.74	23.36
		75	25.78	25.73	22.27	23.41	22.13	24.55	23.79	23.72	22.80
		100	24.81	25.81	21.93	23.49	22.20	24.35	23.72	23.22	22.65
Khudijam	26.87	30	30.42	30.01	26.32	24.89	25.56	23.82	26.07	27.97	26.07
		50	28.87	30.75	24.83	24.34	24.65	23.82	25.94	26.17	25.66
		75	28.38	29.89	23.07	23.41	24.49	24.12	25.29	26.00	25.45
		100	28.48	29.15	23.84	23.82	24.54	24.01	25.26	26.43	25.15
Banaritha	21.81	30	19.77	19.17	21.82	22.30	28.52	24.29	19.51	17.41	20.41
		50	20.42	20.16	21.01	21.34	27.78	23.22	19.38	18.01	21.03
		75	20.32	20.28	24.42	22.55	28.50	24.10	20.60	18.82	21.35
		100	19.55	21.15	24.01	22.35	28.21	25.44	20.51	18.65	21.30
Dumur	21.68	30	20.01	21.65	28.97	23.80	27.08	21.20	27.17	20.31	23.20
		50	21.50	20.93	31.06	24.89	28.43	21.22	26.12	20.04	22.81
		75	19.25	21.32	30.59	24.42	27.67	21.22	25.67	20.86	23.55
		100	19.46	21.20	31.97	25.35	27.59	20.44	26.67	20.84	23.55
Jolpai	17.34	30	19.53	18.36	21.18	22.75	20.57	21.23	21.00	17.55	16.71
		50	20.36	17.50	20.66	22.33	19.74	21.00	19.95	17.31	16.32
		75	18.02	17.73	20.22	22.05	20.09	20.62	20.51	17.30	16.56
		100	19.34	17.61	20.29	22.29	20.24	21.10	19.87	17.36	16.60
Pitafol	16.90	30	18.38	17.75	18.94	21.62	18.76	19.12	18.52	18.80	18.56
		50	19.87	18.15	20.16	21.32	19.04	19.61	18.64	18.30	18.46
		75	18.96	17.90	19.08	21.07	18.99	19.43	18.56	18.33	18.26
		100	17.74	17.76	18.59	21.04	18.97	19.04	19.16	18.44	18.43
Pisti	14.53	30	8.76	9.07	13.93	15.84	14.90	15.14	16.84	15.98	12.68
		50	10.48	9.93	14.54	16.40	15.05	15.67	17.77	16.82	14.09
		75	9.12	9.57	15.64	17.15	15.68	15.66	16.94	17.04	13.83
		100	10.58	10.22	16.23	16.94	16.23	15.89	17.84	17.49	14.63

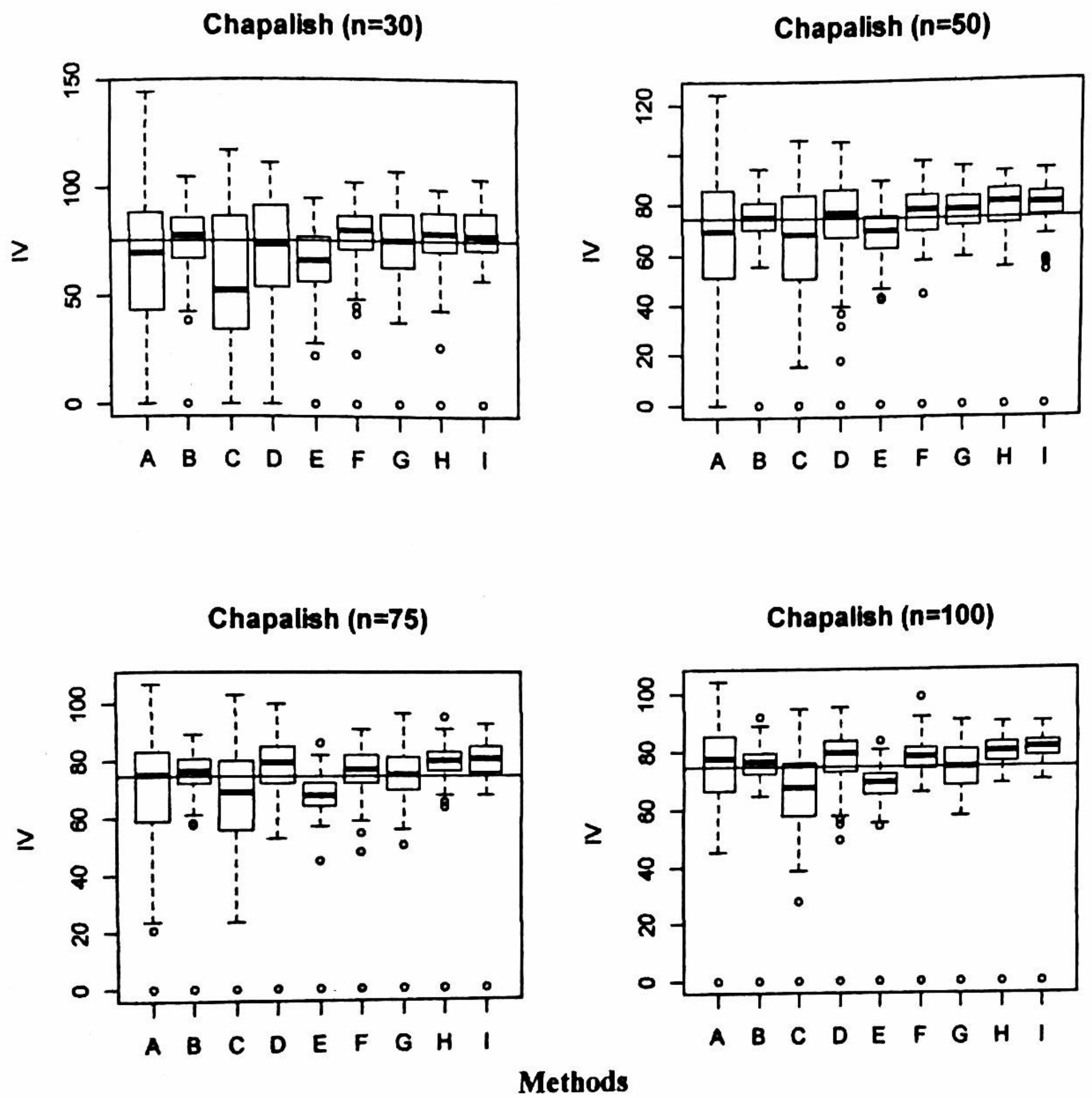
PB1= Plot-based method with sample size (5m×5m), PB2= Plot-based method with sample size (10m×10m), NI=nearest individual, NN= nearest neighbor, PCQM= point centered quarter method, VAT1= variable area method with 5th tree and 5m width and VAT2= variable area method with 5th tree and 10m width.

Table 3. Relative Root Mean Square Error (RRMSE) and Relative Bias (RBIAS) of 10 most dominant species estimated based on 30, 50,75and 100 random samples in the simulation using different plot-based and plot-less silvimetric methods.

	RRMSE				RBIAS			
	Sample point				Sample point			
Estimator	30	50	75	100	30	50	75	100
				Chapalish				
PB1	0.442	0.349	0.247	0.203	-0.101	-0.087	-0.032	0.016
PB2	0.203	0.154	0.132	0.123	0.021	0.007	0.021	0.015
NI	0.463	0.368	0.281	0.235	-0.213	-0.137	-0.110	-0.109
NN	0.322	0.231	0.167	0.160	-0.048	0.007	0.047	0.040
PCQM1	0.261	0.185	0.155	0.147	-0.126	-0.086	-0.079	-0.080
PCQM2	0.216	0.169	0.144	0.136	0.034	0.03	0.020	0.044
PCQM3	0.232	0.151	0.150	0.143	-0.013	0.039	0.011	-0.003
VAT1	0.203	0.167	0.146	0.137	0.059	0.063	0.066	0.065
VAT2	0.185	0.159	0.146	0.137	0.057	0.068	0.076	0.076
				Deua				
PB1	0.566	0.393	0.300	0.250	0.204	0.179	0.147	0.134
PB2	0.226	0.163	0.136	0.133	0.087	0.06	0.047	0.063
NI	0.360	0.263	0.226	0.178	0.058	0.025	0.068	0.017
NN	0.235	0.185	0.155	0.133	0.002	-0.021	-0.008	-0.018
PCQM1	0.196	0.145	0.128	0.120	-0.015	-0.04	-0.04	-0.046
PCQM2	0.196	0.165	0.138	0.130	-0.074	-0.058	-0.048	-0.049
PCQM3	0.201	0.176	0.164	0.160	-0.066	-0.092	-0.104	-0.103
VAT1	0.184	0.221	0.155	0.132	0.02	-0.076	-0.073	-0.057
VAT2	0.179	0.150	0.137	0.124	-0.029	-0.057	-0.062	-0.054
				Badam				
PB1	0.468	0.327	0.238	0.205	0.059	-0.009	0.011	-0.01
PB2	0.217	0.149	0.127	0.122	-0.026	-0.012	-0.011	-0.034
NI	0.348	0.234	0.176	0.170	0.076	0.005	-0.008	-0.036
NN	0.250	0.183	0.137	0.126	0.077	0.055	0.036	0.022
PCQM1	0.169	0.134	0.118	0.117	-0.018	-0.009	-0.014	-0.037
PCQM2	0.167	0.156	0.148	0.140	-0.010	-0.052	0.036	-0.07
PCQM3	0.170	0.149	0.135	0.123	0.070	-0.015	-0.014	-0.026
VAT1	0.308	0.182	0.142	0.163	0.049	0.076	-0.067	0.026
VAT2	0.175	0.133	0.119	0.111	0.059	0.04	-0.034	0.001
				Kakra				
PB1	0.433	0.339	0.241	0.239	-0.100	-0.078	-0.07	-0.105
PB2	0.230	0.180	0.144	0.135	-0.093	-0.08	-0.072	-0.069
NI	0.354	0.287	0.264	0.251	-0.187	-0.194	-0.197	-0.209
NN	0.249	0.207	0.206	0.192	-0.154	-0.138	-0.155	-0.153
PCQM1	0.234	0.220	0.233	0.226	-0.182	-0.183	-0.201	-0.199
PCQM2	0.186	0.169	0.166	0.165	-0.102	-0.107	-0.114	-0.122
PCQM3	0.209	0.195	0.188	0.184	-0.136	-0.136	-0.142	-0.144
VAT1	0.249	0.199	0.189	0.197	-0.125	-0.144	-0.144	-0.162
VAT2	0.211	0.200	0.210	0.213	-0.155	-0.157	-0.177	-0.183
				Khudijam				
PB1	0.643	0.435	0.317	0.257	0.143	0.085	0.067	0.071
PB2	0.281	0.238	0.188	0.153	0.128	0.156	0.124	0.096
NI	0.360	0.247	0.235	0.197	-0.011	-0.066	-0.133	-0.104
NN	0.219	0.190	0.182	0.158	-0.064	-0.085	-0.12	-0.104
PCQM1	0.184	0.155	0.145	0.137	-0.039	-0.073	-0.079	-0.077
PCQM2	0.213	0.184	0.161	0.158	-0.105	-0.105	-0.093	-0.098
PCQM3	0.181	0.153	0.145	0.137	-0.02	-0.025	-0.049	-0.05
VAT1	0.206	0.159	0.170	0.124	0.051	-0.016	-0.023	-0.007

VAT2	0.182	0.143	0.130	0.123	-0.02	-0.036	-0.043	-0.055
Banaritha								
PB1	0.959	0.734	0.539	0.445	-0.084	0.002	-0.103	-0.093
PB2	0.431	0.295	0.217	0.174	-0.112	-0.025	-0.007	-0.012
NI	0.938	0.622	0.548	0.427	0.011	0.447	0.425	0.49
NN	0.547	0.361	0.310	0.251	0.033	0.16	0.138	0.181
PCQM1	0.620	0.427	0.399	0.371	0.321	0.325	0.289	0.286
PCQM2	0.532	0.357	0.305	0.285	0.125	-0.011	-0.011	-0.048
PCQM3	0.478	0.327	0.246	0.218	-0.096	0.217	0.196	0.243
VAT1	0.380	0.330	0.224	0.223	-0.194	-0.066	-0.028	-0.029
VAT2	0.361	0.260	0.201	0.154	-0.055	0.063	0.097	0.097
Dumur								
PB1	0.718	0.598	0.430	0.362	-0.068	0.002	-0.103	-0.093
PB2	0.366	0.239	0.185	0.149	0.009	-0.025	-0.007	-0.012
NI	0.767	0.745	0.579	0.622	0.35	0.447	0.425	0.49
NN	0.413	0.363	0.265	0.274	0.109	0.16	0.138	0.181
PCQM1	0.405	0.405	0.335	0.323	0.262	0.325	0.289	0.286
PCQM2	0.297	0.263	0.195	0.164	-0.012	-0.011	-0.011	-0.048
PCQM3	0.453	0.364	0.297	0.309	0.266	0.217	0.196	0.243
VAT1	0.252	0.287	0.209	0.152	-0.054	-0.066	-0.028	-0.029
VAT2	0.300	0.225	0.177	0.166	0.081	0.063	0.097	0.097
Jolpai								
PB1	0.745	0.576	0.377	0.354	0.137	0.186	0.049	0.127
PB2	0.339	0.232	0.172	0.143	0.069	0.02	0.033	0.026
NI	0.648	0.401	0.291	0.261	0.234	0.203	0.178	0.182
NN	0.489	0.390	0.330	0.333	0.325	0.3	0.284	0.298
PCQM1	0.313	0.214	0.330	0.219	0.198	0.15	0.17	0.179
PCQM2	0.343	0.294	0.251	0.267	0.236	0.223	0.201	0.229
PCQM3	0.343	0.294	0.250	0.213	0.223	0.162	0.195	0.158
VAT1	0.220	0.141	0.128	0.116	0.23	0.008	0.008	0.011
VAT2	0.175	0.145	0.120	0.116	-0.026	-0.05	-0.035	-0.033
Pitafol								
PB1	0.652	0.507	0.398	0.302	0.098	0.188	0.133	0.06
PB2	0.262	0.231	0.175	0.152	0.061	0.085	0.07	0.061
NI	0.570	0.359	0.251	0.220	0.132	0.205	0.14	0.111
NN	0.424	0.344	0.307	0.290	0.293	0.274	0.26	0.258
PCQM1	0.279	0.207	0.187	0.183	0.121	0.138	0.135	0.134
PCQM2	0.256	0.242	0.217	0.189	0.143	0.172	0.162	0.138
PCQM3	0.250	0.200	0.190	0.199	0.107	0.114	0.11	0.145
VAT1	0.212	0.218	0.157	0.199	0.124	0.094	0.096	0.102
VAT2	0.214	0.181	0.152	0.152	0.109	0.104	0.092	0.102
Pisti								
PB1	0.730	0.580	0.500	0.399	-0.391	-0.272	-0.3661	-0.265
PB2	0.464	0.381	0.374	0.322	-0.37	-0.31	-0.3345	-0.289
NI	0.683	0.493	0.323	0.242	-0.032	0.011	0.0875	0.128
NN	0.454	0.323	0.263	0.238	0.101	0.14	0.1921	0.178
PCQM1	0.266	0.195	0.171	0.184	0.036	0.046	0.0899	0.128
PCQM2	0.335	0.224	0.184	0.17	0.053	0.089	0.0886	0.105
PCQM3	0.350	0.323	0.256	0.289	0.171	0.235	0.1776	0.24
VAT1	0.321	0.324	0.251	0.267	0.111	0.169	0.1844	0.216
VAT2	0.282	0.195	0.162	0.128	-0.118	-0.02	-0.0386	0.017

PB1= Plot-based method with sample size (5m×5m), PB2= Plot-based method with sample size (10m×10m), NI=nearest individual, NN= nearest neighbor, PCQM= point centered quarter method, VAT1= variable area method with 5th tree and 5m width and VAT2= variable area method with 5th tree and 10m width.



Figure(3.1). Box plot of the importance value distribution of Chapalish *(Artocarpus chaplasha)* of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

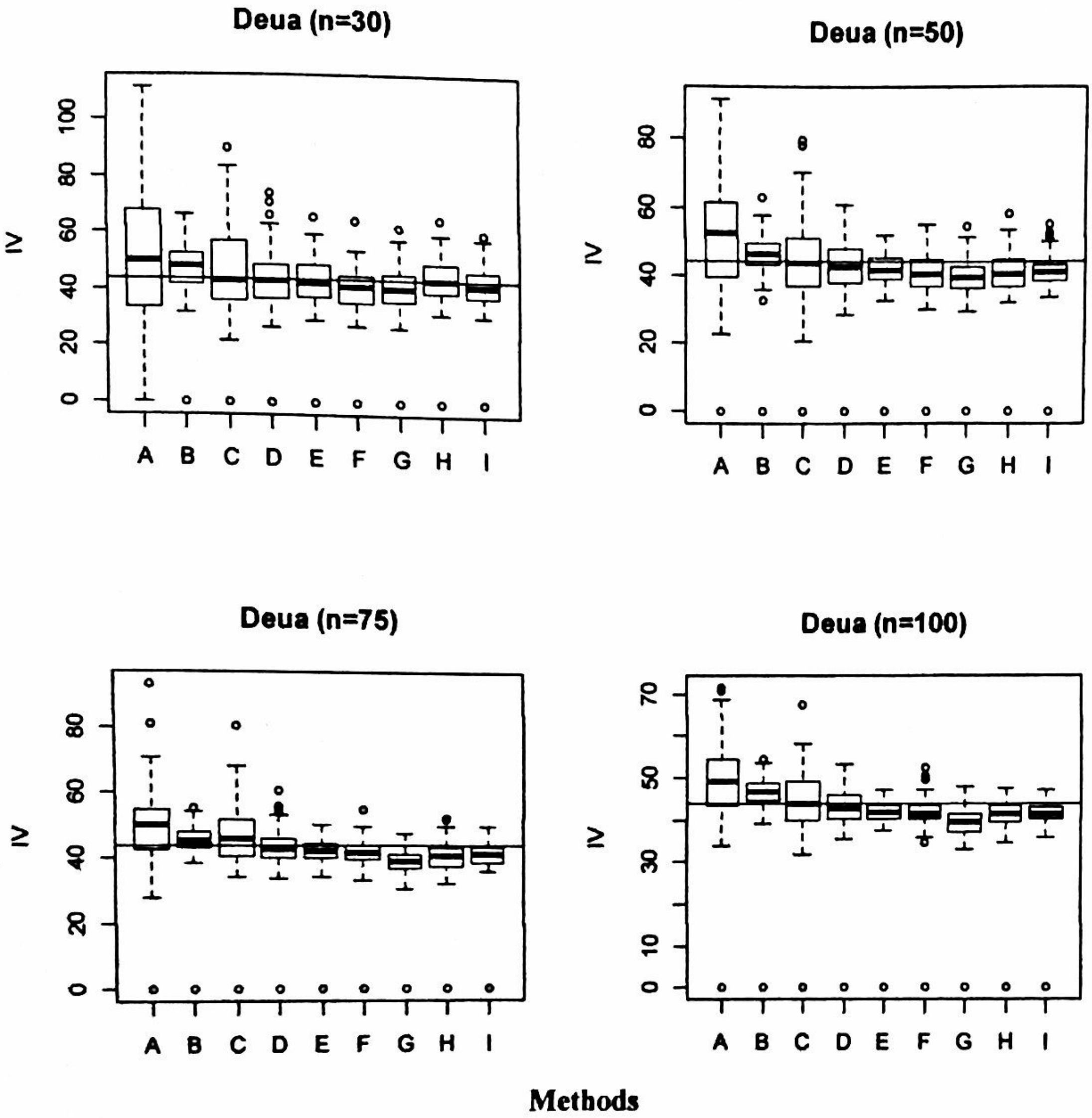


Figure (3.2). Box plot of the importance value distribution of Deua (*Artocarpus lakucha* Roxb.) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

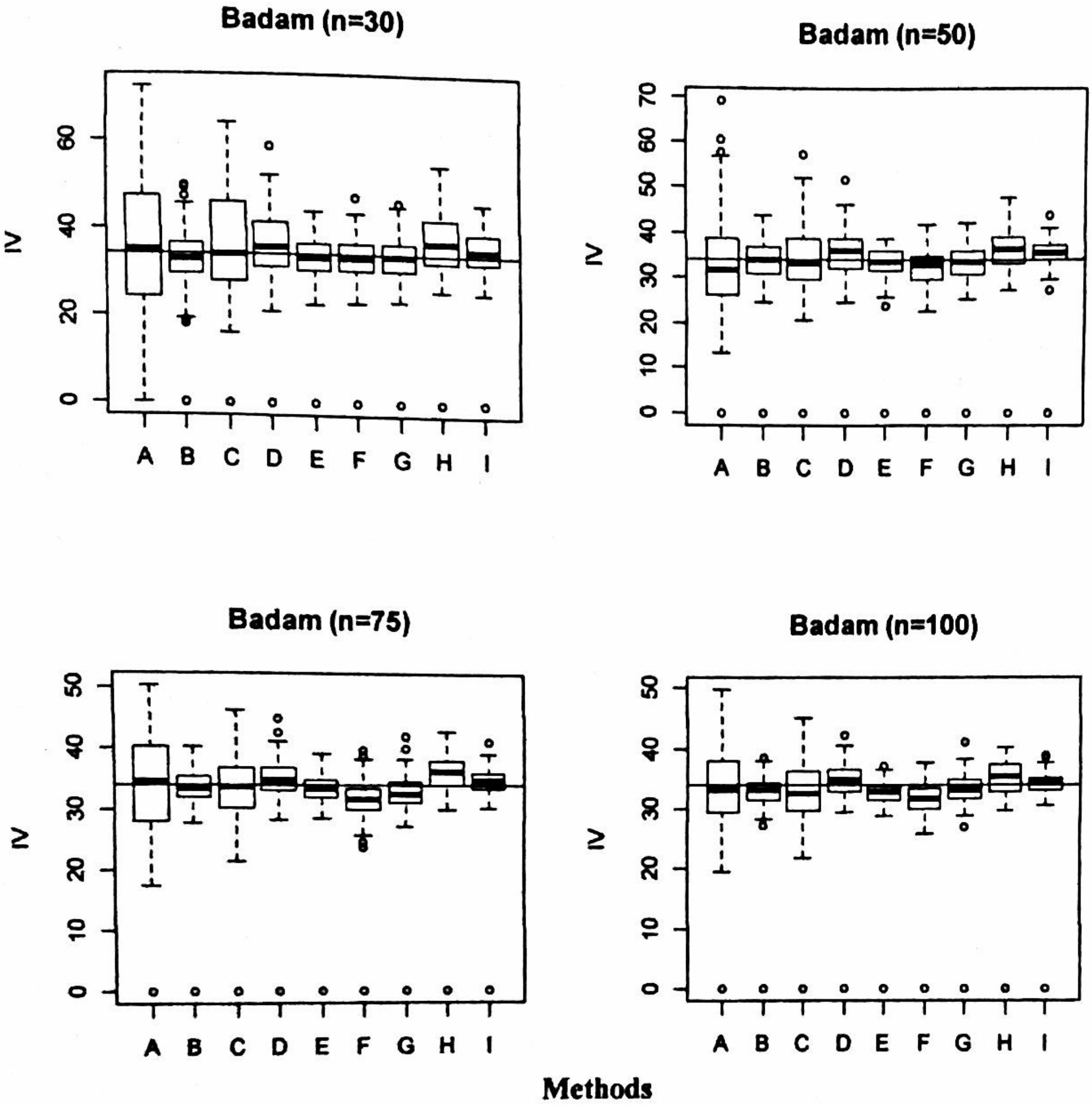


Figure (3.3). Box plot of the importance value distribution of Badam (*Terminalia catappa*) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

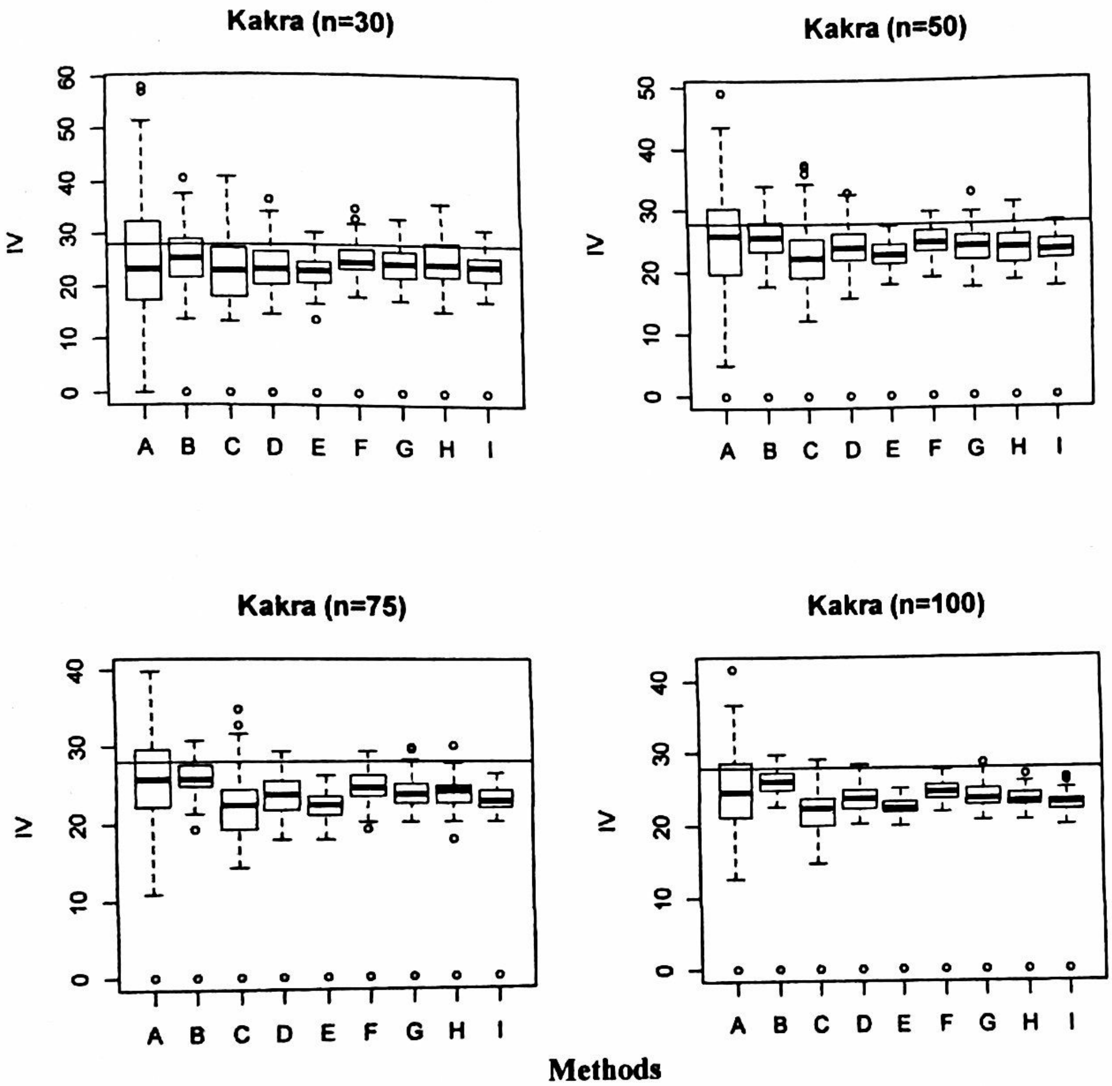


Figure (3.4). Box plot of the importance value distribution of Kakra (*Glochidion lanceolaris*) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

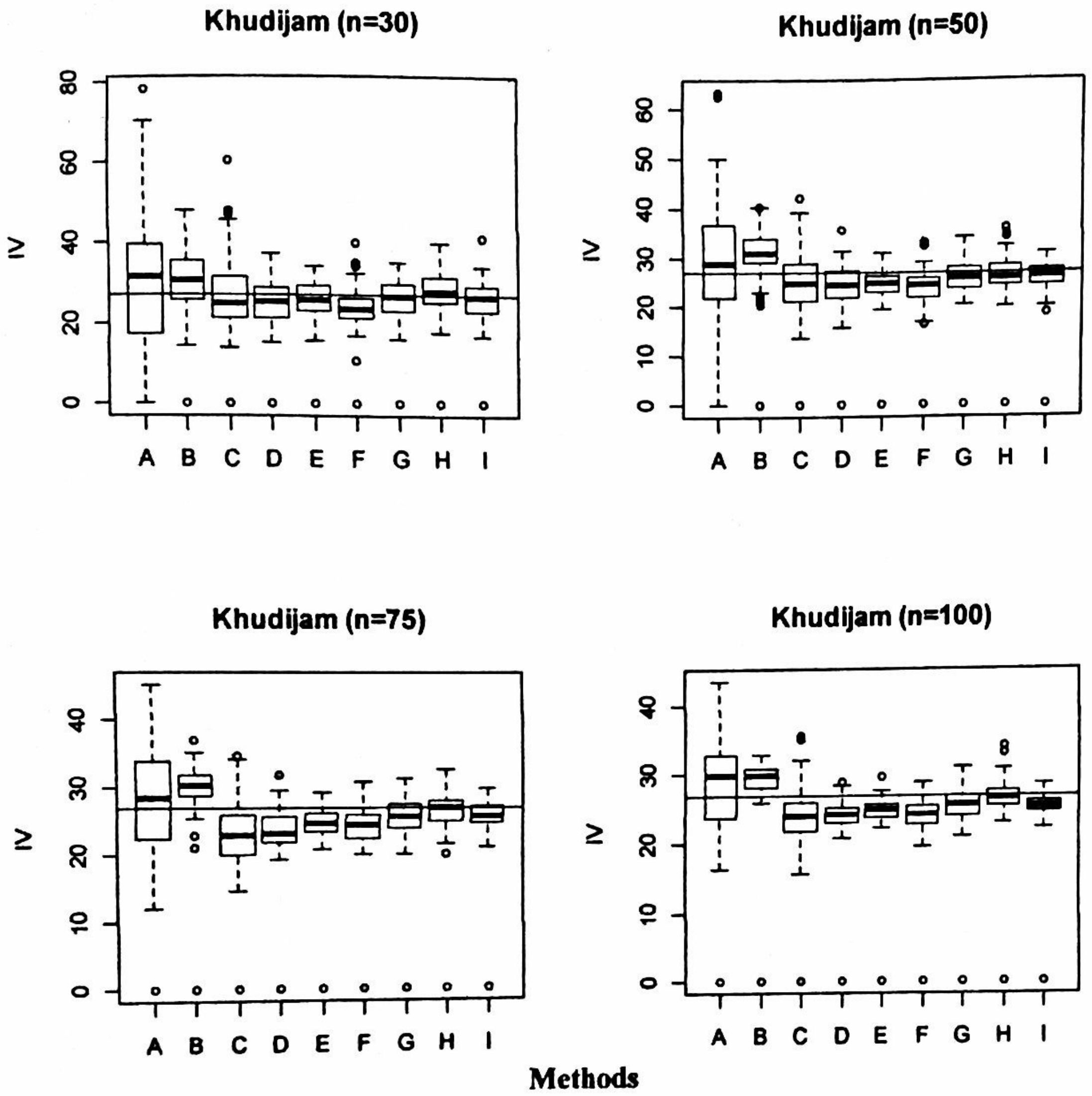


Figure (3.5). Box plot of the importance value distribution of Khudijam (*Syzygium fruticosum* (Roxb.) DC.)of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

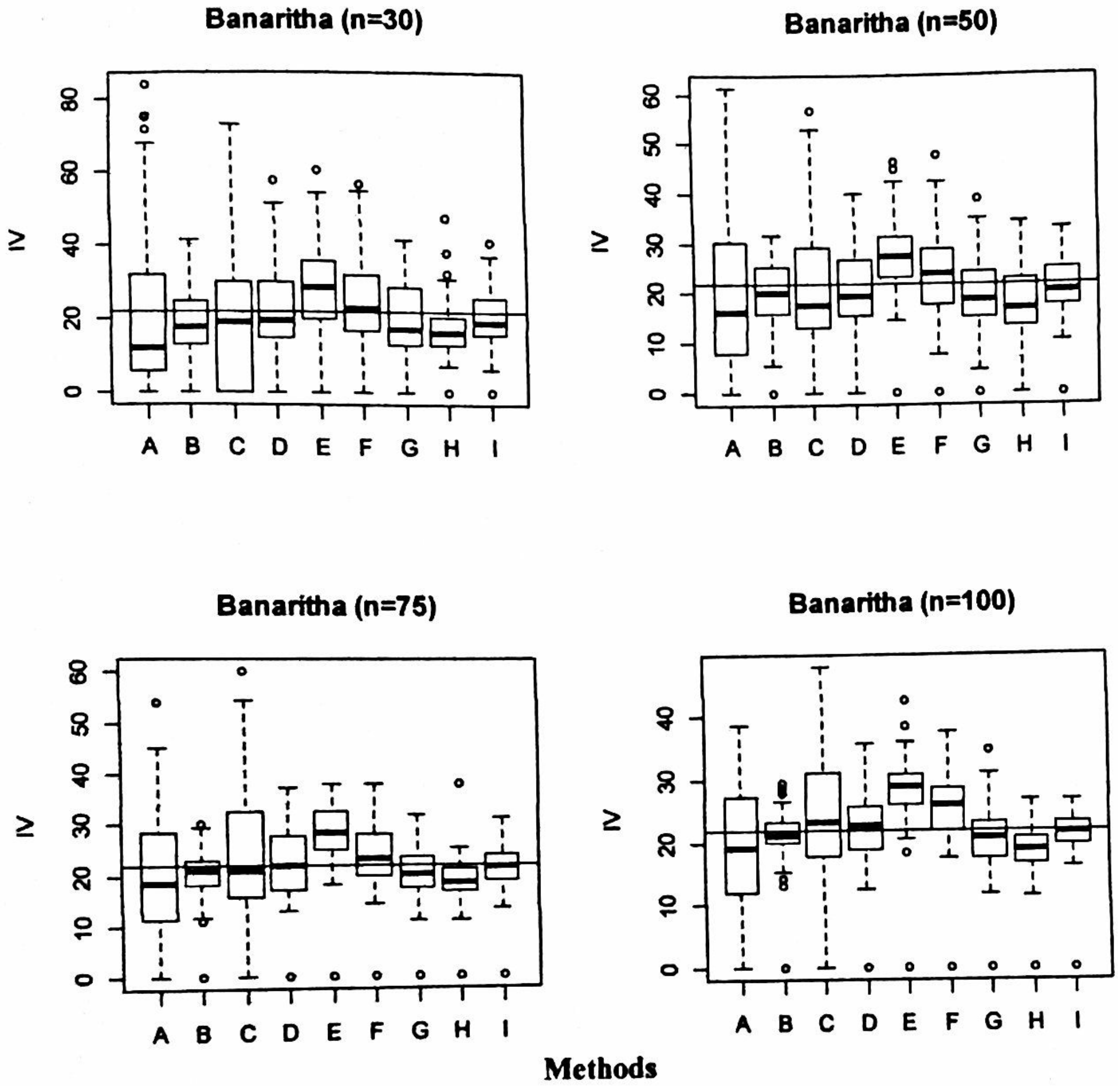


Figure (3.6). Box plot of the importance value distribution of Banaritha (*Accacia Concinna* Willd.) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

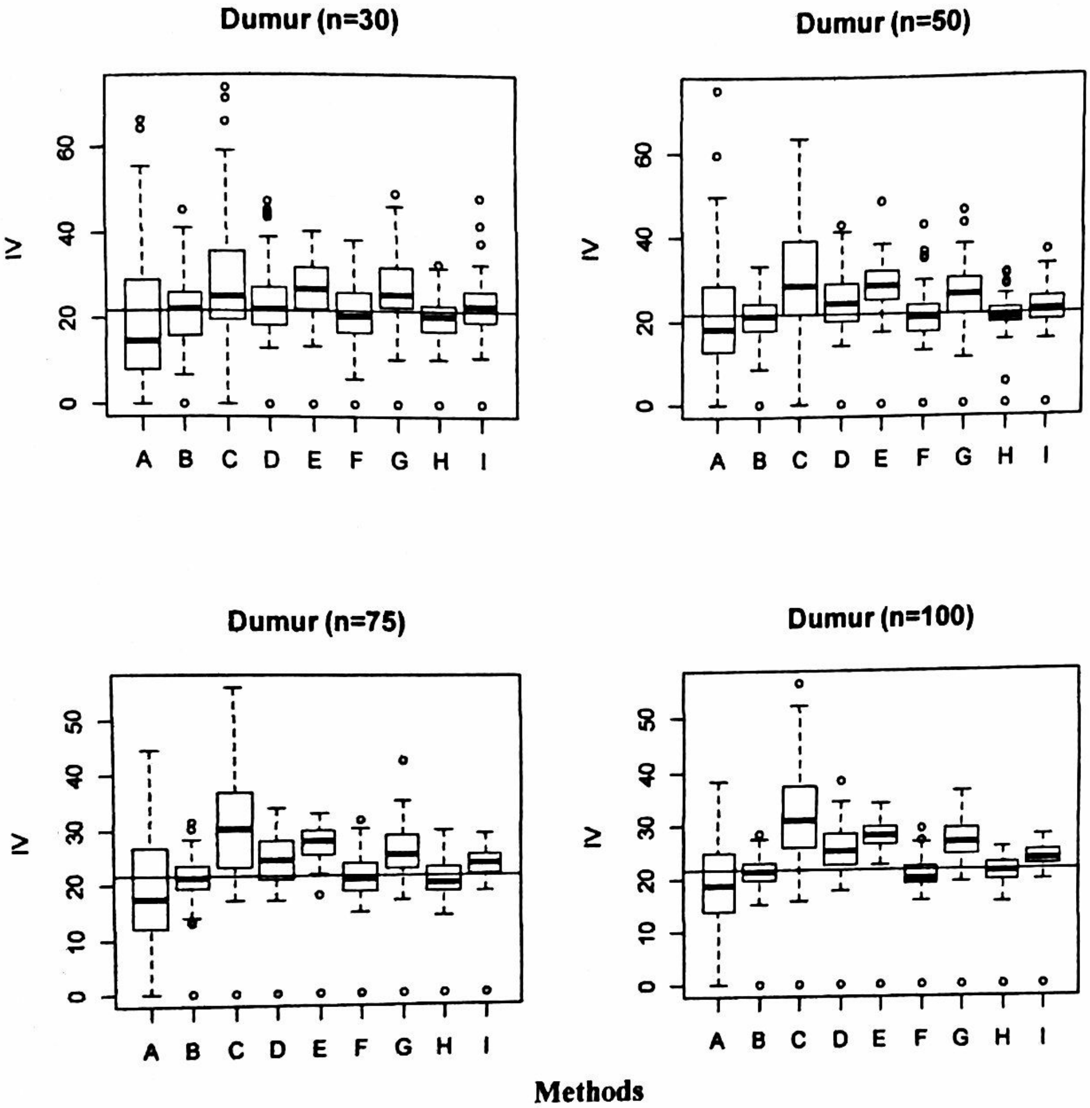


Figure (3.7). Box plot of the importance value distribution of Dumur (*Ficus hispida* L.) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

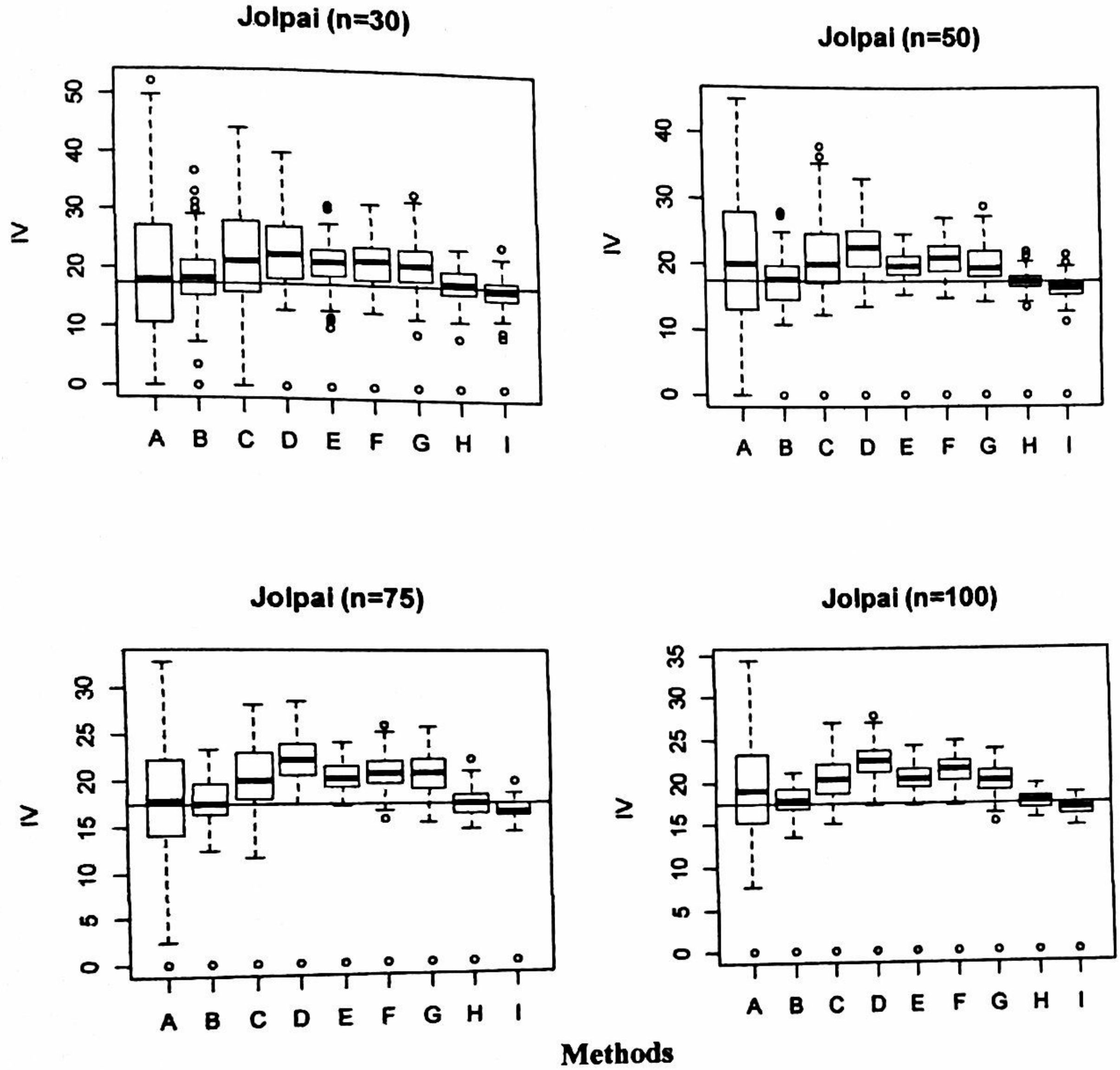


Figure (3.8). Box plot of the importance value distribution of Jolpai (*Eleaocarpus robustus* Roxb.) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

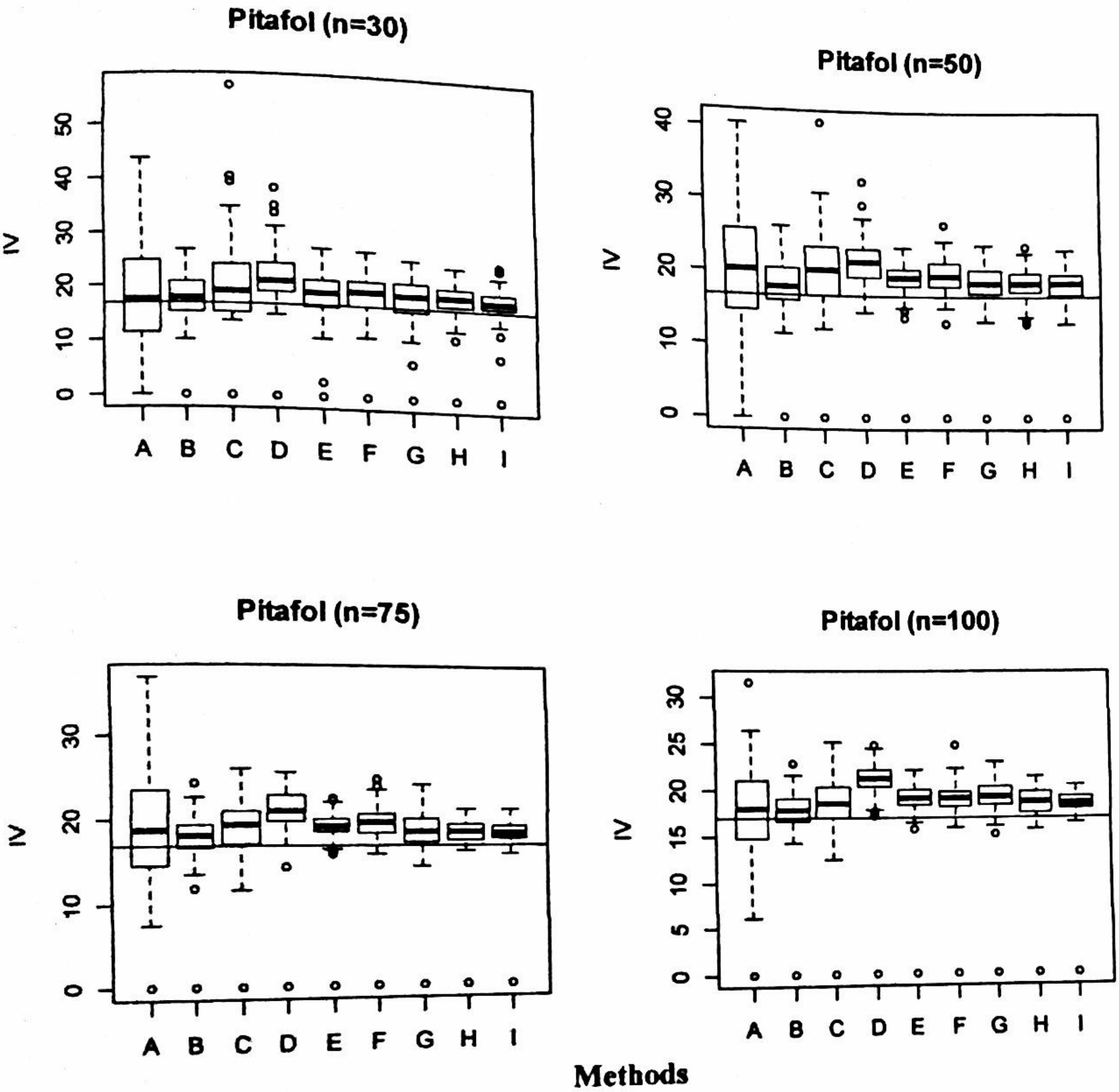


Figure (3.9). Box plot of the importance value distribution of Pitafol of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

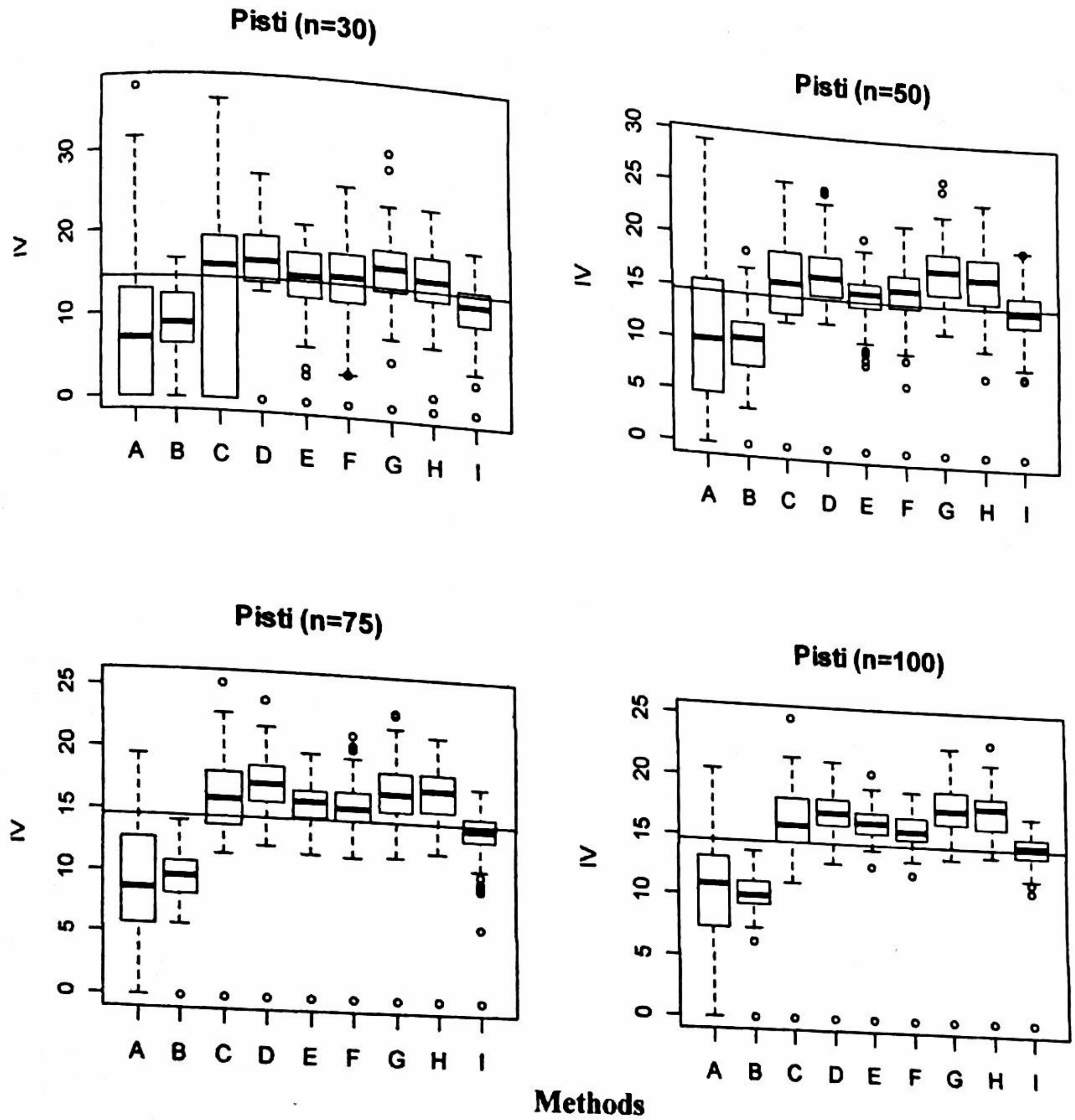


Figure (3.10). Box plot of the importance value distribution of Pisti (*Micromelum minutum* G. Forester.) of 100 simulations estimated with different methods in random simple point and method A=plot-based (5 m×5 m), method B=plot-based (10 m×10 m), method C= nearest individual, method D= nearest neighbor, method E=PCQM1, method F=PCQM2, method G=PCQM3, method H=variable transact method with 5 number of tree and 5 m width and method I=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

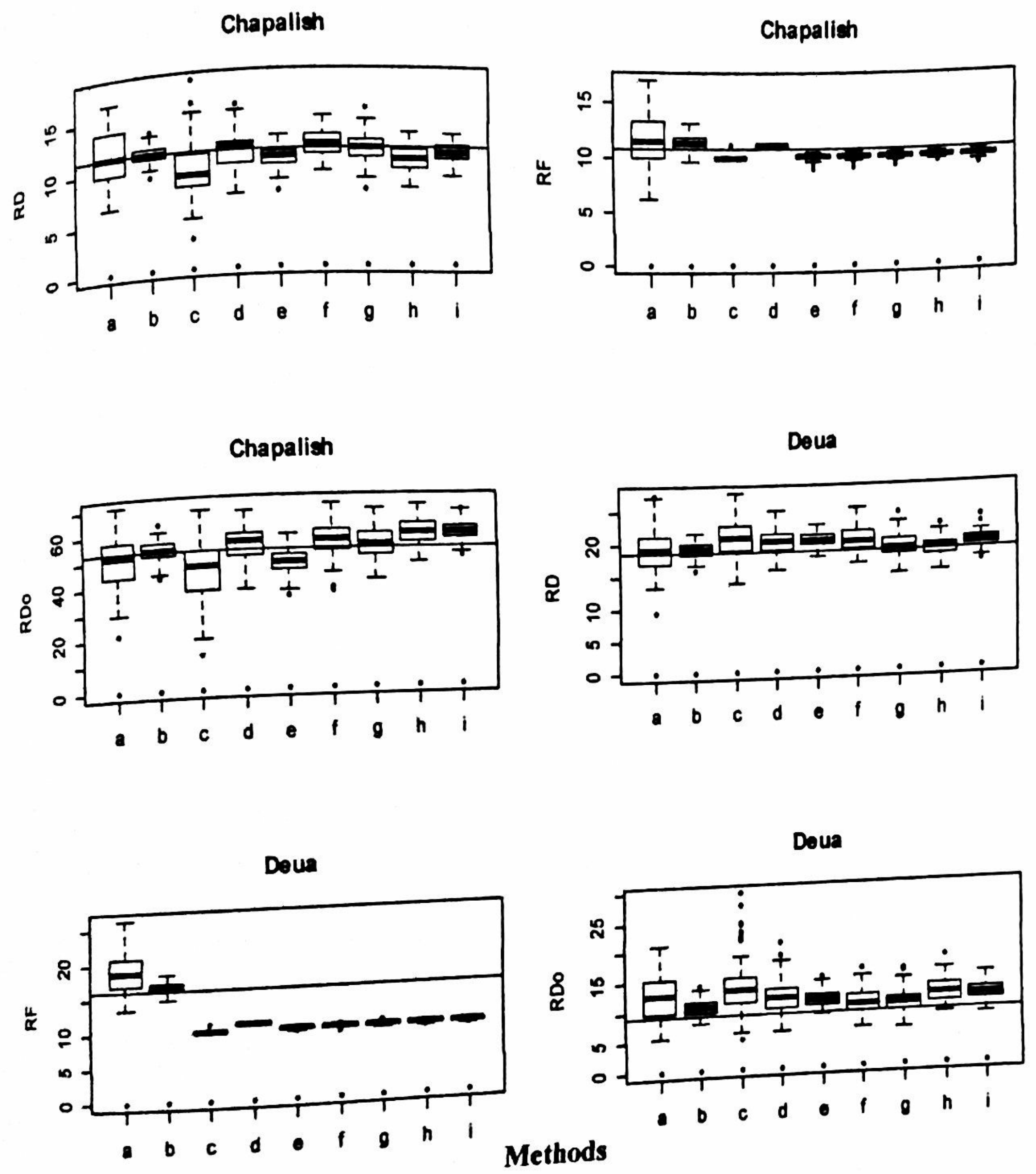


Figure (3.11). Box plot of the Relative density(RD), Relative frequency(RF) and Relative dominance (RD) distribution of Chapalish and Deua of 100 simulations estimated with different methods in 100 random simple point and method a=plot-based (5 m×5 m), method b=plot-based (10 m×10 m), method c= nearest individual, method d= nearest neighbor, method e=PCQM1, method f=PCQM2, method g=PCQM3, method h=variable transact method with 5 number of tree and 5 m width and method i=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

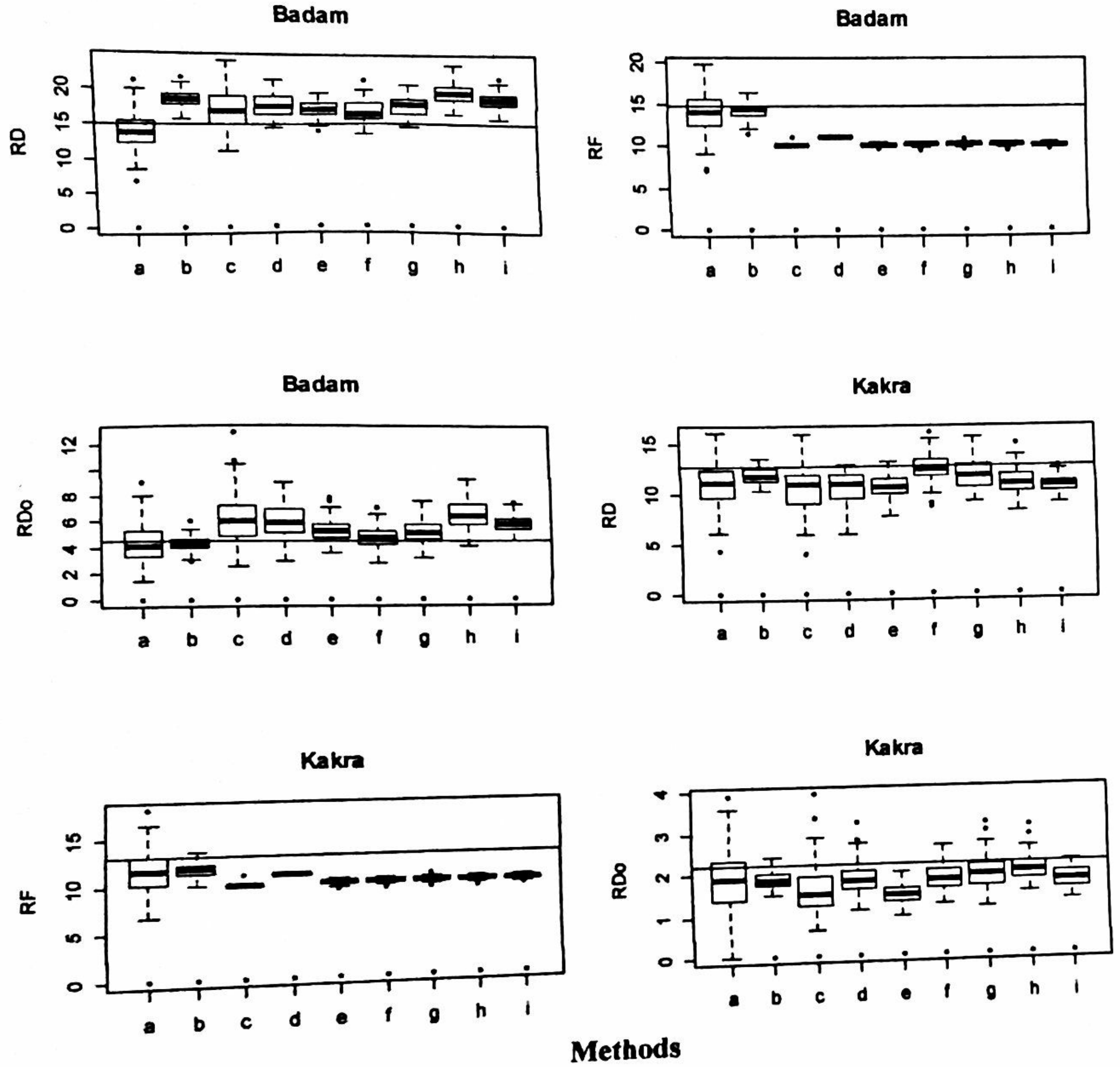


Figure (3.12). Box plot of the Relative density(RD), Relative frequency(RF) and Relative dominance (RD) distribution of Badam and Kakra of 100 simulations estimated with different methods in 100 random simple point and method a=plot-based (5 m×5 m), method b=plot-based (10 m×10 m), method c= nearest individual, method d= nearest neighbor, method e=PCQM1, method f=PCQM2, method g=PCQM3, method h=variable transact method with 5 number of tree and 5 m width and method i=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

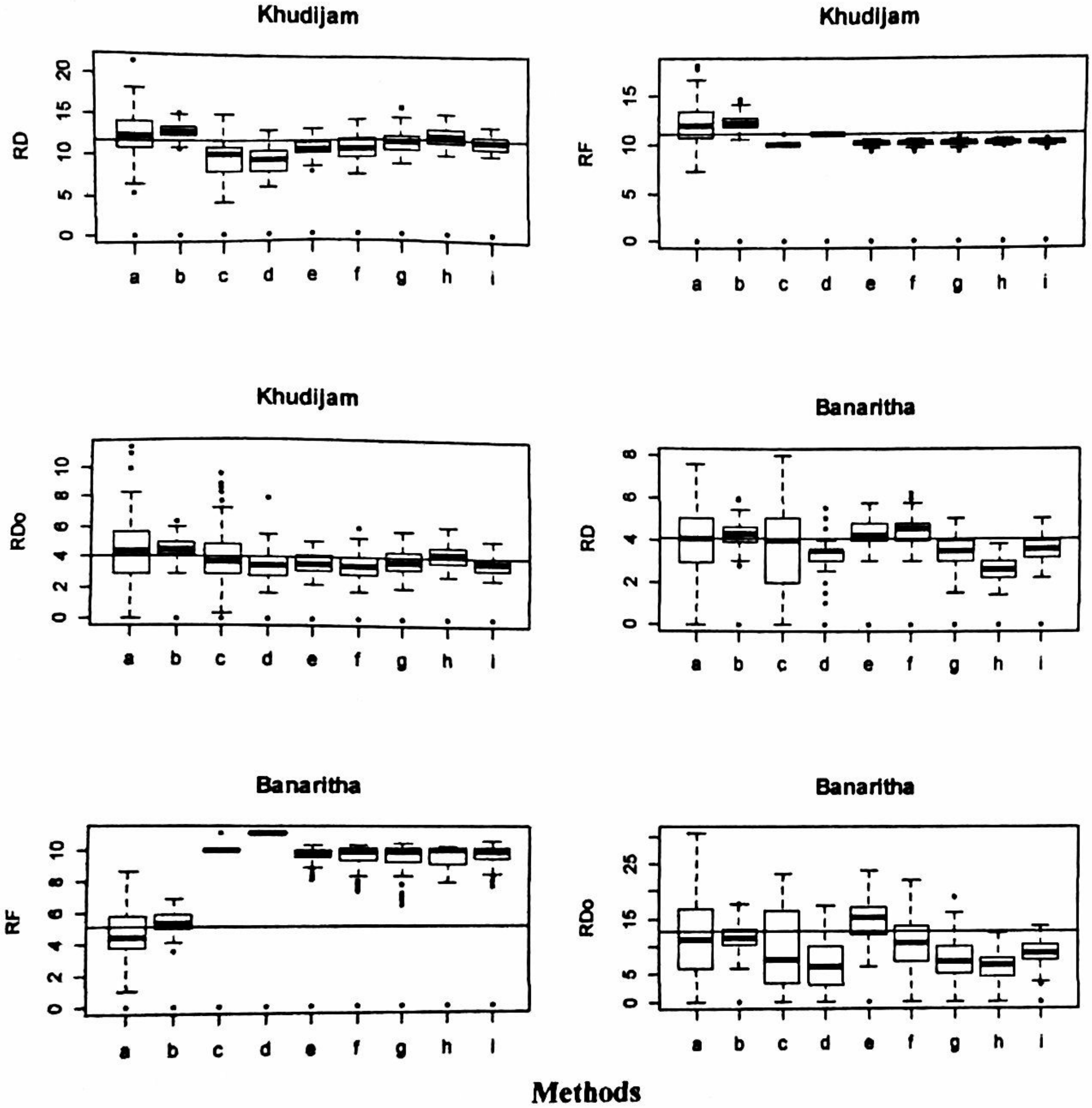


Figure (3.13). Box plot of the Relative density(RD), Relative frequency(RF) and Relative dominance (RD) distribution of Khudijam and Banaritha of 100 simulations estimated with different methods in 100 random simple point and method a=plot-based (5 m×5 m), method b=plot-based (10 m×10 m), method c= nearest individual, method d= nearest neighbor, method e=PCQM1, method f=PCQM2, method g=PCQM3, method h=variable transact method with 5 number of tree and 5 m width and method i=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

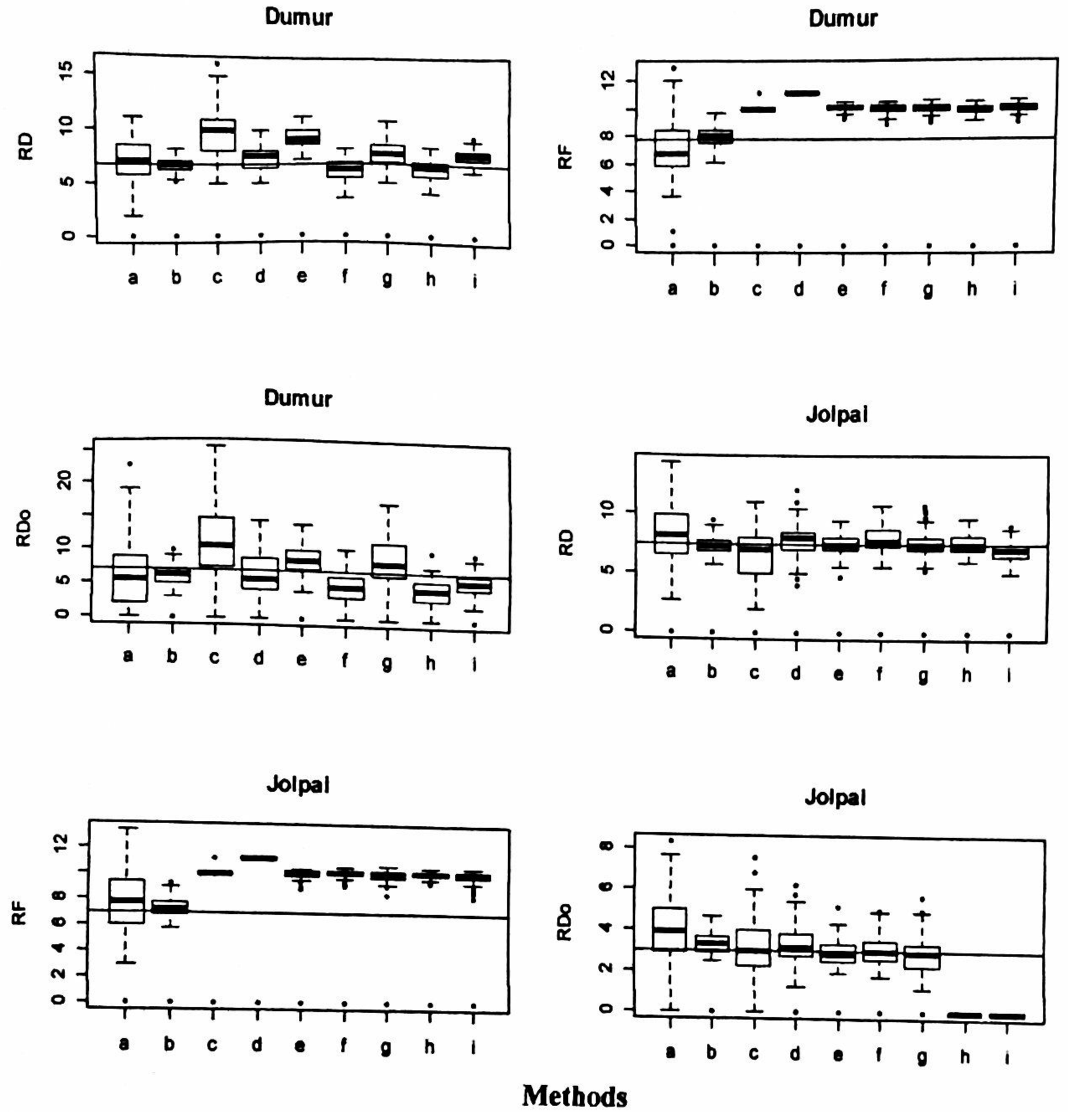


Figure (3.14). Box plot of the Relative density (RD), Relative frequency (RF) and Relative dominance (RD) distribution of Dumur and Jolpai of 100 simulations estimated with different methods in 100 random simple point and method a=plot-based (5 m×5 m), method b=plot-based (10 m×10 m), method c= nearest individual, method d= nearest neighbor, method e=PCQM1, method f=PCQM2, method g=PCQM3, method h=variable transact method with 5 number of tree and 5 m width and method i=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

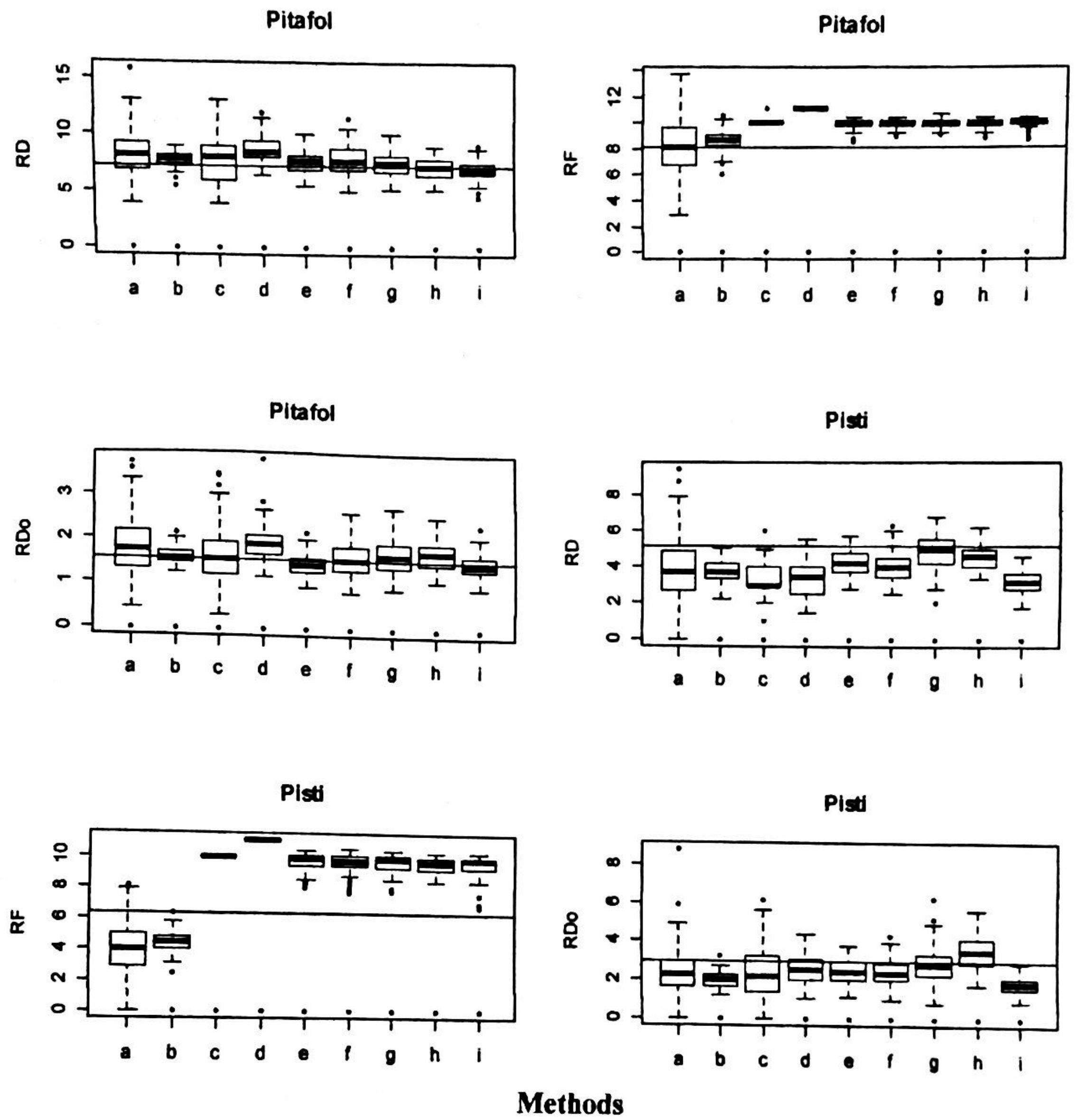


Figure (3.15). Box plot of the Relative density (RD), Relative frequency (RF) and Relative dominance (RD) distribution of Pitafol and Pisti of 100 simulations estimated with different methods in 100 random simple point and method a=plot-based (5 m×5 m), method b=plot-based (10 m×10 m), method c= nearest individual, method d= nearest neighbor, method e=PCQM1, method f=PCQM2, method g=PCQM3, method h=variable transact method with 5 number of tree and 5 m width and method i=variable transact method with 5 number of tree and 10 m width. The horizontal line indicates the true value based on 100 m×100 m plot.

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