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Impact of training on different observers in forest inventory

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Observers with different experience levels are involved in the measurement of large number of sample plots during forest inventories, particularly in national forest inventories. However, limited information exist on the quality of data produced by different observers in forest inventory after certain levels of training. This study tries to evaluate the measurement error in forest inventory associated with observers' experience after initial and field-based training for measuring the most fundamental variables- DBH (cm), total tree height (m), and horizontal distance (m) together with bearing (azimuth) to tree from the plot-centre. On completing the second level of training, the mean of the differences in DBH measurement decreased for both the 'experienced' and 'inexperienced' groups. The mean of the differences in height measurement in the case of the experienced observers was very low as compared to the inexperienced ones. However, the mean of the differences in azimuth measurement showed that the experienced groups were overestimating by at least 1 degree. There was no trend in deviation of measurement for all four variables regardless of tree size. The decrease in the mean and error of differences in measurements after second training showed that field-based training with supervision and training on the use of instruments at laboratories were required for inexperienced surveyors whereas update in working and measurement procedure would be sufficient for the experienced ones.

Key words: Forest inventory, Measurement Error, observers' experience, training

Forest inventory is a complex and time consuming, multiple steps project with involvement of many personnel from planning to field execution (Butt *et al*., 2013), making the process costly as well as error-prone. Kleinn (2013) concluded that errors generally occurred in selection of field crews, location and establishment of plots, identification of trees for measurement, measurement and classifying the variables of interest, recording the measurements and transporting and transferring data to central database. Nature and extent of errors vary with sampling techniques, instruments selected for measurement, and people involved in planning and implementing the forest inventory (Kangas, 1998). Among various sources of errors contributing to overall uncertainty of estimates in forest inventory, Measurement Error (ME) is one of the most important and often neglected in large-scale forest sampling (Berger *et al*., 2012).

A ME is a difference between an observed or estimated and the actual or population value for the attribute, and can occur in both fixed and stochastic predictor and the response variable (Canavan & Hann, 2004). Measurement Errors of different variables measured in forest inventory commonly occur due to composition of crews, lack of adequate training, inappropriate use of instrument, carelessness, etc. (Muller-Landau *et al*., 2013). Since Forest Inventory is time consuming and difficult in nature, field measurement teams are likely to change over time (Ghosh *et al*., 1995). In such cases, it is not always possible that field teams are composed of

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highly experienced and extensively trained observers in conducting forest inventory, and inclusion of inexperienced crew members is unavoidable (Westfall & Woodall, 2007) resulting in variation in measurement. Eid (2000) and Islam *et al*. (2009) studied the effects of systematic and random errors in inventory data at holding-level, and concluded that errors in site index estimations had most significant effects on contents of plans, particularly for treatments of young stands. Canavan (2001) summarized that biased and imprecise estimates of stand and tree attributes might result from the presence of ME which as a result affect forest models and management decisions. The consequences of having ME in variables are varied, and include producing biased and inefficient parameter estimates as well as leading to incorrect interpretations such as invalid statistical tests of model coefficients (Köhl *et al*., 2006). The accuracy of inventory data is required for proper forest management decisions such as timing of thinning, final harvesting time, international reporting, etc. (Chen *et al*., 2011). Measurement of erroneous data clearly affects the extent of thinning at holding-level (time to conduct thinning activities) during the planning period. Similarly, ME lead to modest losses in timber production, at a maximum of 3.7 %, the loss being higher when more errors are made in the measurements (Islam *et al.*, 2009).

It is difficult to determine the size of ME from a single measurement, but it can be done by repeated measurements of same objects and evaluation of the variability of those results (Kleinn, 2013). In forest inventory project, ME is evaluated through blind re-measurement of a portion of inventory plots that helps in problem identification during field surveys and improvement of measurement methods (Kitahara *et al*., 2009). Measurement Errors do not result from sampling procedure, and increasing sample size is not a viable method for reducing their effects; instead of cancelling out the ME, effects may be cumulative (Canavan, 2001). In such cases, proper training to field crews can contribute to minimize the MEs, but they cannot be eliminated completely (Elzinga *et al*., 2005). Training of field surveyors is important to reduce ME to meet quality assurance needed for any long-term and large-scale environmental monitoring program (Ferretti *et al*., 1999), especially when new inexperienced surveyors and sophisticated instruments are involved (Kitahara *et al*., 2010). Training ensures observer's basic skills which meet the measurement quality objectives for data collections. However, the level of precision that can be achieved by different surveyors and the optimum level of training needed to achieve adequate data quality of measured variables are unknown (Kitahara *et al.*, 2010).

Theoretical developments outside forestry have shown that ME can be a significant source of error in many types of field surveys, among which forest inventory is most liable (Gertner, 1989). Although MEs have been known to contribute significantly to the total error of the forest inventory (Omule, 1980), only a few empirical studies have been done to determine the extent of these errors by crews of different working experience, e.g., McRoberts *et al*. (1994), Nester (1981), Gerner & Kohl (1992), and Kitahara *et al*. (2010). None of the studies conducted, so far, compared the data quality from inexperienced surveyors or analyzed the effects of training on the performance of observers. There is a need for wider assessment of data quality and clarification of the independent effects of professional training, task training, experience with the task, observer's age, training duration, and mode of training on large ecological monitoring program to evaluate the ME (Dickinson *et al*., 2010). Furthermore, information about impacts of training on observers and data quality produced in forest inventory are rarely available. Therefore, this study aims to evaluate the impact of training on observers of different knowledge and compares the role of previous experience of observers on data quality in forest inventory.

Methodology

Study area

The study area lies within a state forest (situated on the north of Göttingen City) owned by the federal state of Lower Saxony, Germany. The forest is used for training forestry students (Figure 1). It is located between 5^{0}31'24" - 5^{0}33'53" N latitudes and 9055'30"- 9^{0}57'39" E longitudes. The forest is mainly composed of the secondary growth of Beech (*Fagus sylvatica*), but also consists of the plantations of European Ash (*Fraxinus excelsior*), Field Maple (*Acer campestre*), Norway Spruce (*Picea abies*), etc.

The study was completed in collaboration with the Master's degree-level students participating in "Exercises in Forest Mensuration and Inventory" at the Department of Forest Inventory and Remote

Sensing, Georg-August-University of Göttingen in 2015.

Group formation and training:

Two groups of individuals with different levels of experience in forest inventory were formed with modification on categories of observers as defined by Trenda & Burkman (2012) in forest inventory project. The "inexperienced group" consisted of the students who did not participate in any forest inventory work previously and those with experience were under "experienced group". Altogether, five teams, each with two individuals were formed, wherein three teams were under "inexperienced group" and the remaining two were under "experienced group".

Two levels of training were designed. The first-level of training was focused on the methods of field measurement, variables to be recorded, use of instruments through a power point presentation together with practical measurement and recording information for two days while the second-level of training was practice-based rather than instructing at laboratory or practicing in forest. After finishing the first measurement (part of second training), a four-hour interaction meeting was conducted with the teams. This meeting focused mainly on the discussion concerned with: i) tension applied to tape, ii) making transponder-fixed monopod perpendicular, iii) transponder being exactly at 1.3m during height measurement, and iv) ample distance between tree and point of measurement. Besides, there was also a discussion on any unexpected obstacles encountered.

Data collection

Altogether, 47 sample plots, each with the size of 75m × 75m, were laid out in the field for the purpose of this study and also for conducting training to the students. Out of the total sample plots, 11 plots (Plot Nos. 1, 2, 5, 6, 7, 11, 12, 13, 14, 18 and 19) with Beech (*Fagus sylvatica*) as dominant species were selected for analyzing the ME. The diameter at breast height (DBH, cm), total height (m), and the horizontal distance together with the bearing (azimuth) from the plot-centre to each of the trees falling within each sample plot were measured; the DBH was measured using the Diameter Tape, total tree height and horizontal distance using the Ultrasonic Vertex IV, and bearing were measured using the Suunto Clinometer. Altogether, 250 trees within the sample plots with the desired 12.61 m radius were selected and marked; the marked trees were the observation units for this study.

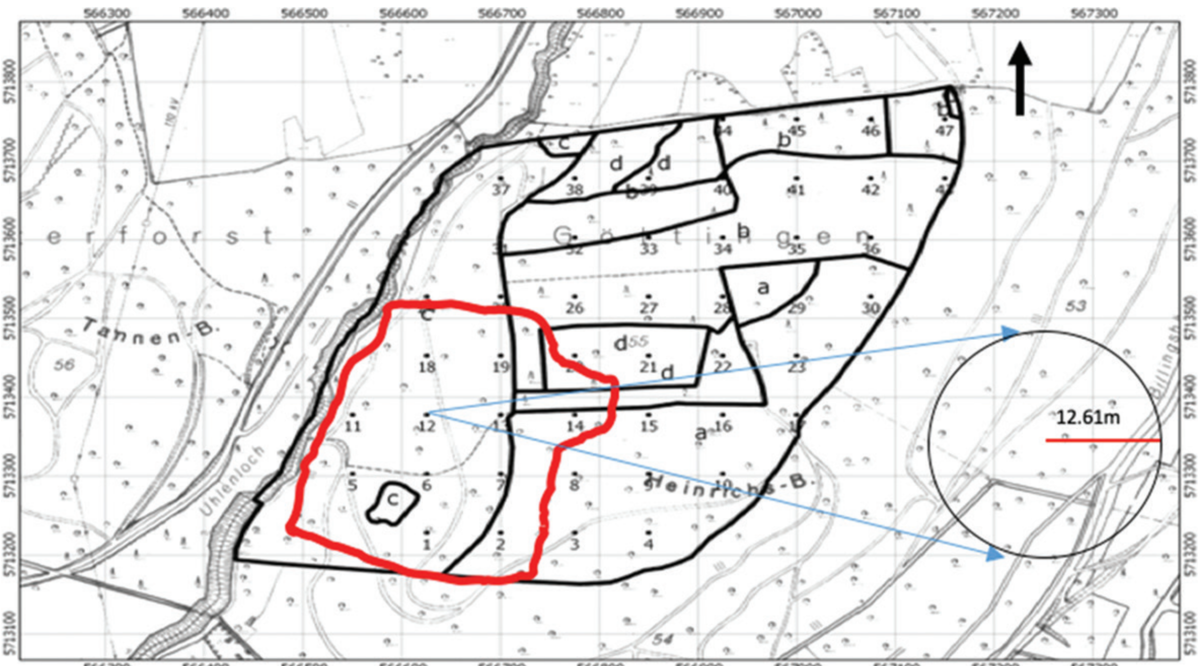

Figure 1: Map showing the location of study area (area with red boundary used for analysis) and layout of sample plots for measuring tree

In all the selected 11 sample plots, the plot-centers were marked and fixed with wooden stick so that the horizontal distance was always measured from the same point. All the trees ≥ 7cm in diameter at breast height (DBH) within the defined area of 500 m^2 were marked with yellow tape (not necessarily at breast height). The marked trees were given specific identification (ID) to make sure that the tree ID would be same for every measurement. For the purpose of comparing the MEs, the "inexperienced group" measured 750 trees while the "experienced group" measured 500 trees in both the measurements. At the same time, control data was produced to analyze the effect of training and previous experience on the ME by measuring the same tree for five times by an experienced researcher using the same instruments; the average of these five measurements was considered as the "true value".

Data analysis

In order to evaluate the accuracy and bias in measuring different variables, both groups and individual trees were treated independently, and all the sample trees were compared to control data. The deviations from true value of the teams' measurements were calculated for each tree to evaluate the bias which is mathematically expressed as:

$D_{ijk}=X_{ijk}-X_i$ .... (1)

Where,

D_{ik} = measurement bias on the i^{th} tree in the j^{th} measurement by the k^{th} group (difference)

X_i = True measurement of the i^{th} tree

X_{ijk} = measurement of the i^{th} tree in j^{th} measurement by the k^{th} group

The mean and variance of measurements were calculated for each group, and each group was instructed to evaluate the overall bias of every single tree considered as sample. Matched paired *t*-test was used to test the center of differences of two measurements done by the same team to analyze the effects of training and previous experience using R Software. The *t.test()* functions with the argument *paired=TRUE* with 95% of confidence interval (CI) was used to perform the paired tests whereas with the argument *paired=FALSE* was used for performing the normal *t*-test. On the other hand, F-test was applied to test the equality of variances between the measurements and between the groups; the *var.test()* function with the argument *ratio=1* and *alternative=two-sided* was used to conduct F-test with 95% of confidence interval.

Results

DBH measurement

The measurements done by both the groups after two levels of training showed that there was no any visible difference in distribution of outliers. However, after second measurement, the experienced group measured more accurately (Figure 2). Except for some outliers, the differences in DBH measurement were within ±2.5 cm for both the groups in both the measurements.

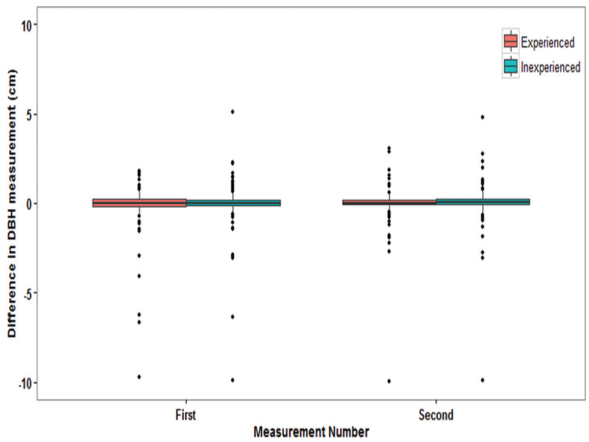

Figure 2: Difference in DBH measurement for two groups corresponding to two levels of training

The mean of the differences in DBH measurement was found to be decreased (from) after second training. It was found to be smaller for "inexperienced group" in both the measurements (–0.08 cm and almost 0 in the first and second measurements, respectively, Table 1). The *t*-test revealed that the variance of differences in DBH measurement was almost the same in the first measurement for both the groups with no significant difference (around 1.40).

Table 1: Mean and variance of differences in DBH measurement for each group

Measurement No.	Mean of differences (cm)		Variance of differences	
	Inexperienced	Experienced	Inexperienced	Experienced
First	–0.080	–0.107 (*p*=0.7764)	1.402	1.39 (*p*=0.937)
Second	0.0002	–0.02 (*p*=0.8164)	1.14	1.51* (*p*=0.016)

* Significant difference between the two groups (p<0.05) with 95% CI using F- and *t*-tests

Height measurement

The difference in height measurements for both the groups indicated that there was a reduction of deviation in the difference in measurements after second training. The difference was up to 20m for the "inexperienced group" in the first measurement whereas those extreme outliers decreased in the second measurement (Figure 3). For experienced group, there was more deviation in the first measurement as compared to the second measurement.

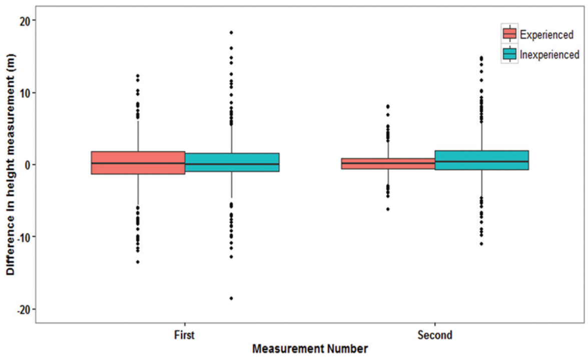

Figure 3: Difference in height measurement for the two groups corresponding to two levels of training

The mean of the differences in height measurement showed that the "inexperienced group" had overestimated in both the measurements (48 cm in the first measurement and 77 cm in the second one) whereas the experienced group had underestimated (6 cm) in the first measurement and overestimating (21 cm) in the second one. The variance was found to be almost equal (around 16) for both the groups in the first measurement; however in the second measurement, it was found to be quite low (3.53) in the case of "experienced group".

The *t*-test showed that there was no significant difference in the mean of the differences between the two groups in the first measurement but in second measurement there was significant difference (Table 2). However, the variance of the differences in height measurement between the two groups was not significantly different (around 16) in the first measurement, but was significantly different (11.32 and 3.53 for the inexperienced and experienced groups, respectively) in the second measurement (Table 2).

Table 2: Mean and variance of differences in height measurement for each group

Measurement No.	Mean of differences (m)		Variance of differences	
	Inexperienced	Experienced	Inexperienced	Experienced
First	0.48	–0.06 (*p*=0.1037)	16.529	16.14251 (*p*=0.4226)
Second	0.77	0.21* (*p*=0.008351)	11.323	3.529* (*p*=0.2e–16)

* Significant difference between the two groups (p<0.05) with 95% CI using F-test and *t*-test.

Measuremnet of horizontal distance

The differences in the measurement of horrizontal distances (HDs) from the plot-centre to the trees showed that both the groups had measured the HD with variation showing a number of outliers

(Figure 4). The differences in the horizantal distance measurement were found to be higher for the expereinced group as comapred to the inexpereinced one in both the measurements with the presence of more outliers (Figure 4).

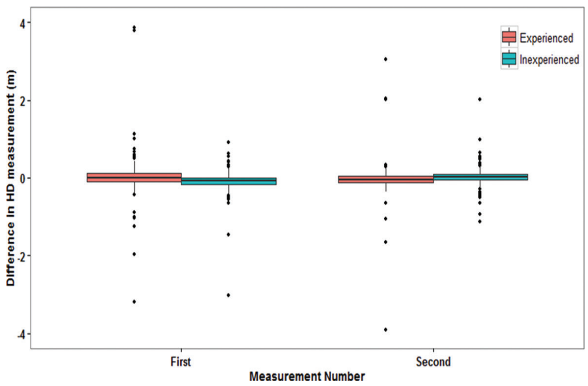

Figure 4: Difference in HD measurement for two groups corresponding to two levels of training (denoted by first and second measurements)

The mean of the differences in HD measurement was found to be the same (–0.015 m) for the "experienced group" in both the measurements whereas the "inexperienced group" had slightly overestimated the HD (with 0.02 m) in the second measurement (Table 3). However, the variance of the differences in HD was almost the same (0.35 and 0.48 for the inexperienced and inexperienced groups, respectively) in the first measurement whereas it was low (0.16) for the "experienced group" as compared to the inexperienced one (0.51) in the second measurement. The *t*-test showed that the mean of the differences in HD measurement was not significantly different between the two groups (with –0.065 for the "inexperienced group" and –0.015 for the "experienced" one) in both the measurements, but the *F*-test showed that there was a significant difference in variance of the differences in the second measurement ($p<0.05$).

Table 3: Mean and variance of differences in HD measurement for each group

Measurement No.	Mean of differences (m)		Variance of differences	
	Inexpereinced	Expereinced	Inexpereinced	Expereinced
First	–0.065	–0.015 (p=0.3582)	0.353	0.482 (p=0.996)
Second	0.023	–0.015 (p=0.1709)	0.505	0.163* (p=2.2e-16)

* Significant difference between the two groups ($p<0.05$) with 95 % CI using *F*- and *t*-tests.

Measurement of bearing (azimuth)

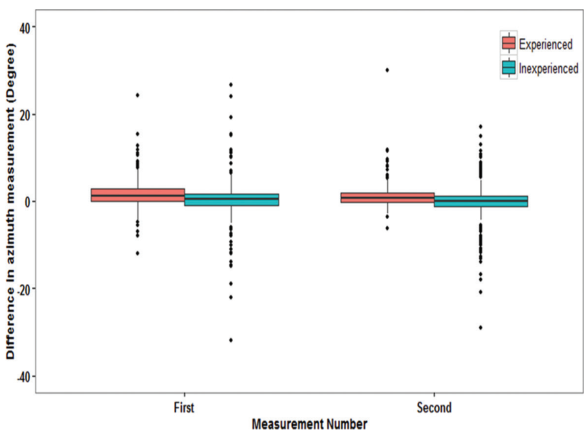

Figure 5: Difference in azimuth measurement for two groups correspondingto two levels of training, denoted by first and second measurements

In both the measurements, the "inexperienced group" had measured the bearings to the trees from the plot-center with high deviation as compared to the "experienced" one. There was a decrease in the outliers in the second measurement for the "experienced group" as compared to the ones in the first measurement whereas the extreme positive outliers decreased in the second measurement for the "inexperienced group" (Figure 5).

The mean of the differences in azimuth measurement was smaller for the "inexperienced group" in both the measurements in comparison with the "experienced group". In the second measurement done by the "inexperienced group", there was an underestimation of bearings whereas the "experienced group" had measured the same with overestimation in both the measurements. The variance of the differences in azimuth measurement was nearly the same in the first measurement in the case of both the groups; however, after the second training, it was found to have decreased in the case of the "experienced group" (Table 4). The *t*-test showed that the means of the differences in azimuth measurement was significantly different (p<0.05) between the experienced and inexperienced groups in both the measurements. However, the *F*-test showed that there was a significant difference in the variance of the differences in azimuth measurement ($p<0.05$) (with 22.02 for the "inexperienced group" and 8.97 for the "experienced" one) between the two groups only in the second measurement.

Table 4: Mean and variance of differences in azimuth measurement for each group

Measurement No.	Mean of differences (Degree)		Variance of differences	
	Inexperienced	Experienced	Inexperienced	Experienced
First	–0.008	1.206* (p=0.04618)	55.02	53.65 (p=0.4172)
Second	–0.259	1.279* (p=1.291e-06)	22.02	8.97* (p=1.049e-13)

* Significant difference ($p<0.05$) between the two groups with 95% CI using *F*-test and *t*-test.

Relation between training, observer's experience and error distribution in DBH measurement

The relation between the different levels of training and the observers' experience on the ME was assessed by plotting the differences in measurement against the tree size. There were no trends in deviation in the measurement of DBH (of big and small trees), height, horizontal distance and bearing (Figure 6) for both the groups in both the first and second measurements. In the second measurement, more precise measurement was accomplished, and the differences in measurement were found to be closer to horizontal line with zero mean and with only a few extreme outliers for the "experienced group".

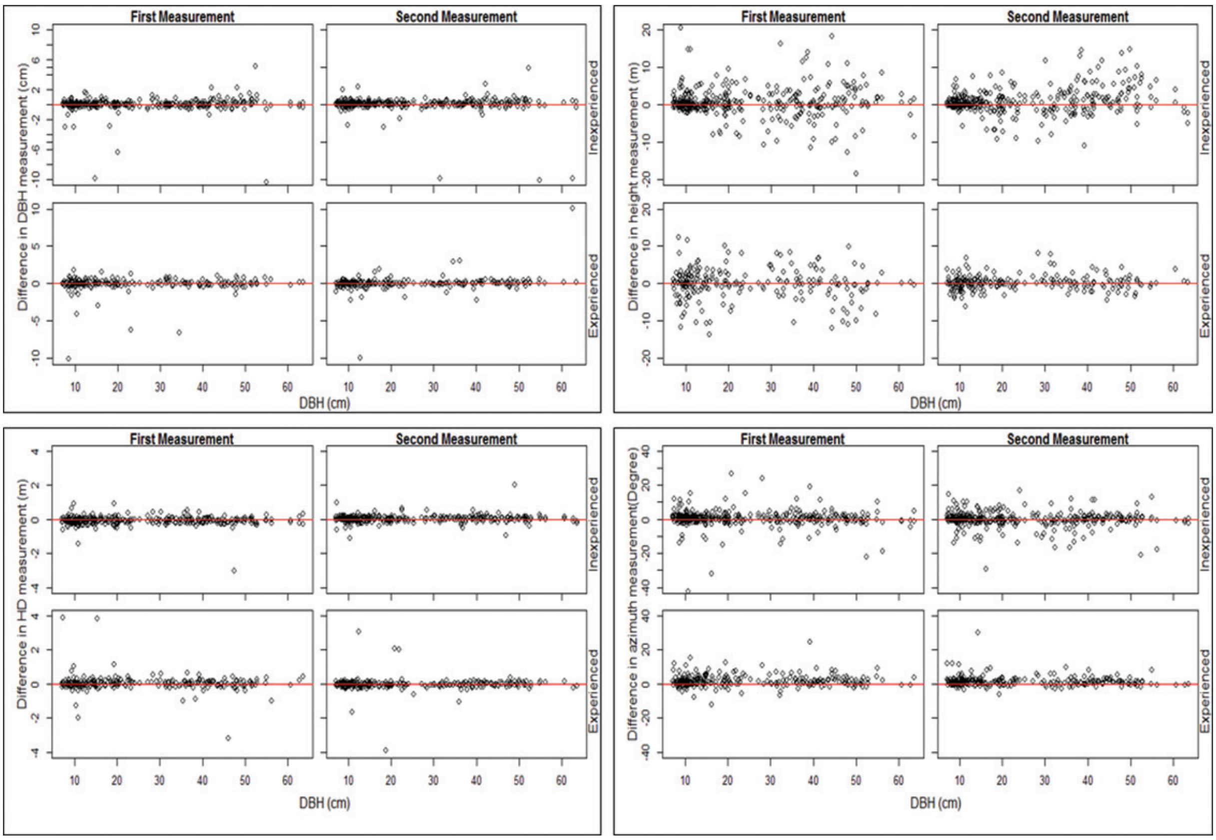

Figure 6: Differences in DBH, height, HD, and azimuth measurements against DBH for two groups corresponding to two levels of training

Discussion

The difference in DBH measurement was found to be within the range of ±2.5 cm for both the groups, which was smaller in magnitude as compared to the other studies. Theilade *et al*. (2015) found that 95% of the measurements were within the range of ±6 cm against the actual DBH size for any kind of observer whereas Elzinga *et al*. (2005) concluded that the difference in DBH measurement was within the range of −3.5 cm to 2.8 cm with the mean of zero. Likewise, the difference in DBH measurement was low as compared to the values obtained by McRoberts *et al*. (1994) who found the distribution of the differences between the individual measurements to be around the mean of 0.13 cm for the experienced observers. The main reason for very small difference in DBH measurement in this study was mainly because the forest stand within the study area chosen for the purpose of study was dominated by beech trees where measurement is rather easy. Similarly, the trees were of almost regular shape, and the undergrowth was not hindering the DBH measurement. Theilade *et al*. (2015) concluded that large errors in DBH measurement occurred mostly in the odd-shaped trees, especially the buttressed, presence of dense undergrowth vegetation or mosses in tree-trunk.

The mean difference in height measurement, in this study, was found to be within −0.06m to 0.77m for both the groups in both the measurements; however, some outliers were up to 20m in the first measurement and up to 14m in the second one. These mean differences in tree-height measurement were similar to those of Kitahara *et al*. (2010) who found those as −0.21 m, 0.11 m and −0.10 m after the first, second and third levels of training, respectively for the inexperienced observers. The presence of some large outliers, in this study, could be due to the shorter distance between the observers and the trees while measuring the tree-height or not correctly locating the tree top, and/or measuring the outer branch instead of the tree-top. According to Larjavaara & Muller-Landau (2013), accurate measurement of tree-height depends on the distance between tree and observer, types of instruments used, and experience in handling instruments. After initial training, there was overestimation for both the groups and in second measurement mean difference was found to have decreased. The measurement of height performed by the experienced group was better than the one done by the "inexperienced group", where the inexperienced group measured 6 cm less in the first measurement while 21 cm more in the second measurement as compared to the controlled measurement data. These results indicated that the height measurement accomplished by the "inexperienced group" could have bigger impacts on plot-level estimation where height is used as independent variable. Caciano & Paudel (2016) estimated that the error due to measurement of height and DBH contributed to 1−41% in above ground biomass per tree resulting in significant variation in plot-level estimation of the same.

All the trees to be measured in this study were already marked, which could lead the observers to pay less attention on measuring the HD and azimuth. Omule (1980) claimed that there could be up to ±6 tree counter error in the case of the relatively inexperienced crews if they were asked to identify the unmarked trees to be measured. It showed that if the trees to be measured were not marked and tagged, the teams were likely to record a greater number of trees than the actual number to be measured. The higher difference in azimuth measurement might be due to misreading the data or recording those incorrectly. Improper orientation of compass or due to improper reading of compass (from the opposite direction), leading to cause a difference of at least 10 degrees (Klienn, 2013). Decrease in number of outliers after second training could be due to improper handling of the instrument. Kitahara *et al.* (2000) concluded that the measurement of forest attributes increased with the decrease in bias after second level of training.

A relatively higher error in tree-height measurement was recorded as compared to DBH measurement which might be related to the inherent difficulties in measuring the height rather than DBH of the trees. However, other variables were measured relatively easily due to marking of the trees to be measured and having less under growth and clear bole. Among the measured variables, the major problem was, therefore, in tree height measurement of the broad-leaved trees, as no consistent improvements were found with successive levels of training. Kitahara *et al*. (2010) concluded that single training session for inexperienced surveyors could not achieve the measurement quality objectives (MQO) of a forest inventory program but follow-up training improved the data quality significantly. In terms of overall data quality, the "experienced group" in this study was found to be better than the inexperienced one in measurement, which is similar to the findings of Theilade *et al.* (2015). The quality of data measured after second training showed the importance of training to any kind of observer. Therefore, another training session with feedback instructions on the results from the second measurement can be more effective in order to make precise measurements and the reasons for measuring extreme values might become apparent. In addition, these results showed that the "inexperienced group" could collect data with high precision, if the proper training on handling instruments and eliminating personal error along with discussion on sources of error in field measurements is provided. It can be assumed that inexperienced surveyors will achieve higher accuracy for the 'measured' variables rather than the 'identified' and 'visually estimated' ones and, therefore, it would be logical to assign them to field measurements of the 'measured' variables as has been suggested by Kitahara *et al.* (2010). Therefore, these results highlight the importance of quantifying the ME in large-scale forest inventories.

Conclusion

The errors in all measurements originate from various sources which depended on observers' personal attitude, motivation and time spent in measurement. The extent of decrease in measurement deviation after second training, clearly indicated the need of training or cautions against using untrained crews in forest inventory. Even the experienced observers' results showed that there is an obvious need for rigorous monitoring and training program and establishment and implementation of check-cruising guidelines during measurement process. For the inexperienced observers, the initial training on instrument use was not sufficient for the measurement of tree-height but was just enough for the measurement of DBH. Further, six to seven hours of field training on handling instruments along with detail explanation of field protocol at laboratory followed by feedback instruction after field training will be sufficient for any kind of observer to achieve the measurement quality objective.

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