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Estimating forest carbon biomass in stem for a forestland area managed by local community

Study site: protection forest of Lung San village, Lung Sui commune, Simacai district, Lao Cai province, furthest Northern region of Vietnam

Thanks to Hmong villagers, local technicians, SPERI colleagues,

and Prof. Cris Brack and Dr. Matthew Brookhouse.

Photo 1: Local technician instructed Hmong villager.

Photo 2: Villagers marked sampled plot.

Photo 3: Local technician instructed villagers to measure DBH.

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Abstract: This paper provides quality estimate of forest carbon biomass in stem for a forestland area of approximately 124.4 hectares in Lung San village, Lung Sui commune, Simacai district, Lao Cai province. Forest carbon biomass in stem is estimated in a range of 22.3 tonnes/ha to 33.3 tonnes/ha ($\alpha = 0.05$, $N = 1804$). This is low compared to Protocol; nevertheless, does contribute useful insights reflecting the efforts of local villagers in collectively managing common forestland area.

INTRODUCTION

Understanding biomass in standing stock is very important in the far Northern region of Vietnam. The region plays an important water catchment role and in conserving biodiversity for downstream communities. Estimating forest carbon biomass in stem currently sequestered in forestland area that has long been managed by local villagers in this upper catchment is crucial to help us realizing the role small-scale local communities play in managing and conserving forest resources.

It is often thought biomass estimation required tree dimensions to be collected and measured by technicians. This paper provides estimation of forest carbon biomass in stem from diameter at breast height over bark (DBH) and height (H) data mainly collected by villagers with some supervision from local technicians. Despite data quality issues, this raises the significance of participatory inventory approach, which enables villagers to take part in the process of learning and estimating what is available in their own forest. Engaging local villagers in collecting data on the ground crucially provides them the tools to understand more of their direct resource use and management. This will further promote a greater sense of autonomy and ownership in the local community of their local landscapes. In the growing interest of the implementation of Payment for Environmental Services (PES) and Reduced Emissions from Deforestation and Forest Degradation (REDD+), programs currently happening in Vietnam, empowering local villagers with forest measurement skills is even more beneficial for the villagers themselves. They can be in a better position to ensure benefits generated through the on-ground works are benefiting the local communities.

There are allometric equations and approaches to quantifying biomass, and they often vary depending on context, site specifics and environmental variables associated with site. Allometric equations provide a means of estimating tree biomass from the relationship between component biomass and tree dimensions. This paper uses a simple volume equation (Vietnam) to derive volume estimation and assumes the average wood density of 0.69 g/cm^3 (Wood Density Database, FSIV) as the average density for all trees sampled, given the inability to conduct destructive sampling to work out the final forest carbon biomass in stem.

The study site is particularly unique in its remote location. The Hmong minority community has long managed the forest area through their customary practices. There is yet any literature or scientific paper studying the place. Findings from this paper can provide some insights into the importance of participatory inventory approach and the search for best integrative approach towards biomass estimation (i.e. integrative between ground measurements and mathematical modelling to derive quality estimate of forest carbon biomass). Findings will contribute evidence for the REDD+ program indicating forest managed by local community enhances forest carbon biomass in the landscape.

SITE DESCRIPTION

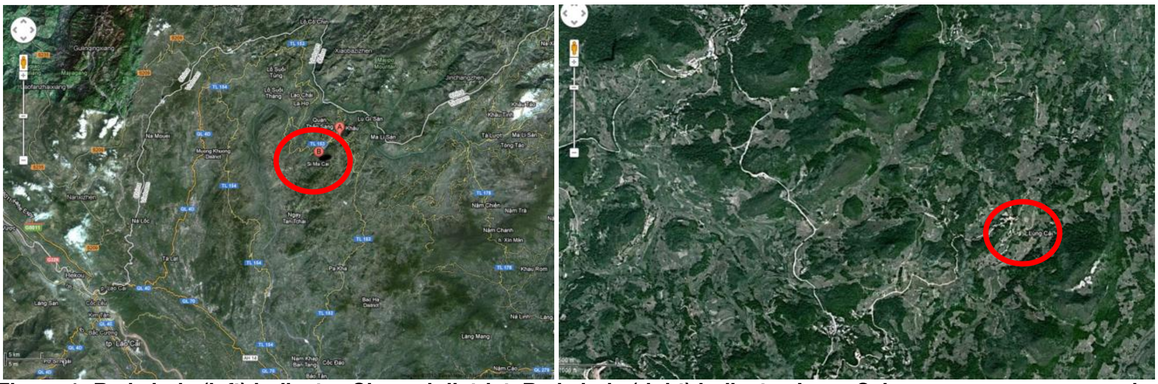


Figure 1: Red circle (left) indicates Simacai district. Red circle (right) indicates Lung Cai commune, a commune border to the study site. Google Map did not produce a result for Lung Sui commune.

Lung Sui commune (red circle: *left*) locates to the East of Simacai district. It has a total area of 2,056 hectares, more than 1,200 meters above sea level (ASL) in elevation. The commune borders to the north with Xin Man district of Ha Giang province. It nexts to Lung Cai commune of Bac Ha district to the east, with Lu Than commune to the south and Can Cau and San Chai communes to the west. Lung San village (red circle: *right*) belongs to Lung Sui commune. It is located in the centre of Lung Sui commune with a total land area of about 314 hectares. The village is located on a very hilly area (slope >25%), with elevation ranging between 800 m to almost 1,500 m ASL (the highest point is Hang Cha at 1,431 m ASL and the lowest point is Coc Pha at 804 m ASL). There are mountains with extensive fragmentation and integrated with deep valleys. A few areas are cliff-like with very low forest cover. In the rainy season, these areas easily erode and are prone to landslides.

Lung San village has 63 households, with 327 people. Males account for 166 people and there are 161 females. About 141 people are currently of working age. The village is 100% ethnic Hmong. Forest use and management is largely practiced by the Hmong according to customary regulations and community norms. Villagers strongly identify their need to conserve the forests due to the hardness in their everyday lives and the need to maintain clean water resources.

Current land uses practiced by the villagers is shown in Table 1. Data of DBH and H comes from forest inventory in the protection forest area (highlight in red).

Table 1: Current land uses in Lung San village, data up to July 2012.

	Unit: hectares
Total land area	314
Agricultural land	58.5
Forestland	139.6
• **Protection forest (natural regeneration)**	**124.4**
• **Production forest (natural generation)**	13.8
• **Plantation**	1.4
Residential land	10.5
Unused land and others	105.5

METHOD

Nature of the data: Villagers with some guidance from local technicians directly measured DBH and H. Vietnamese standard of measuring DBH is also at 1.3 m. Using the collected data, local technicians worked out volume estimates per tree in every plot. Hand-written data was handed to the postgraduate student. Undergraduate students conducted data entry, with data analysis conducted by postgraduate students. Analysis involved working thoroughly through error checking, missing data and any other data problems; second examination of volume estimation and final estimation of forest carbon biomass in stem was derived. Senior forestry expert/professor provided supervision.

Access to data was made available through the current advocacy work on community forestland rights recognition initiated by the Social Policy Ecology Research Institute (SPERI) in collaboration with Simacai District Peoples Committee, Lung Sui Communal Peoples Committee and Lung San community with funding support from Norwegian People's Aid (NPA). The proposal planned to lobby for allocation and recognition of community forestland rights of about 124.4 hectares for Lung San village of the protection forest area. The forestland allocation program conducted in July 2012 could only achieve surveying 84 hectares out of the 124.4 hectares (Figure 14).

Sampling method: Villagers and local technicians discussed and identified sampling plots and location of plots. Plot approach followed the Vietnamese standard of forest inventory. Standard plot size for measuring forest volume is 25 m x 20 m (equivalent to 500 m^2). In a forestland area that is smaller than 1000 m^2, villagers were asked to count for all the trees in it. All trees in a plot that have DBH smaller than 5 cm were not counted.. In the forestland area from 1000 m^2 – 5000 m^2, villagers only conducted one plot. The plot is selected on the most representative area i.e. containing almost all tree species. In the forestland area that is greater than 5000 m^2 villagers conducted two to three plots and still select the most representative areas to study. Overall, plots are selected to ensure the representativeness of the area. There was no indication of whether sampled plots were entirely random.

Analysis of data collected by villagers: Careful and thorough analysis of data collected by the villagers was conducted (see Discussion). Quality checking of data used a variety of tools including Pivot Table look, Scatter Plot, Analyse Distribution and Bivariate Fit from JMP version 9. The reason for using different approaches altogether is to allow a thorough check of all the errors.

DATA QUALITY AND DISCUSSION

Overview of data: Table 2 provides a summary of the entire data records between the initial phase (i.e. without errors checked) and later phase (i.e. errors checked).

Table 2: Summary of data attributes for forest surveyed area of Lung San village (2012).

	without errors checked	errors checked
Total number of data records	1856	**1804**
Total plots measured	88	**88**
Total forest types	8	**4**
Total forest species	41	**21**
DBH at 1.3 (cm)	5-50 Data in ranges (-) (blanks)	**5 - 50**
Tree H (m)	1-35 Data in ranges (-) (blanks)	**4 - 35**

My initial overview of original data (without errors checked) showed that there were 1856 records of 88 plots. They were a mix between natural and plantation forest types; however, more records found for natural forest than plantation forest. There were numerous transcription errors with naming tree species. There were more than 20 forest species found. Seven trees species were unidentified names or names contained with typographical errors. DBH ranged from 5 cm to 50 cm. There were also records of DBH in a range instead of the specific value. About 74 records found DBH in the form of (-) or (blanks). Total tree height ranged from 1 to 35 m. The same pattern happened with height data in terms of finding records in a range instead of the specific value. About the same number of height records i.e. 74 records found in the form of (-) or (blanks).

Data from the 88 surveyed plots further helped identifying proportions of forest types in Lung San village. Figure 2 indicates the natural forest accounts for the largest area. There is a proportion of forest type with "no-name" and this due to a lack of experience of villagers in recording the data.

About 1.21% of the area is natural (closure) forest, which implies there is a tiny area where villagers experiment growing natural species under controlled environment. Area of plantation only accounts for 1.3% which suggests villagers may have less preference in growing them or climatic and terrain conditions are not favourable for plantations.

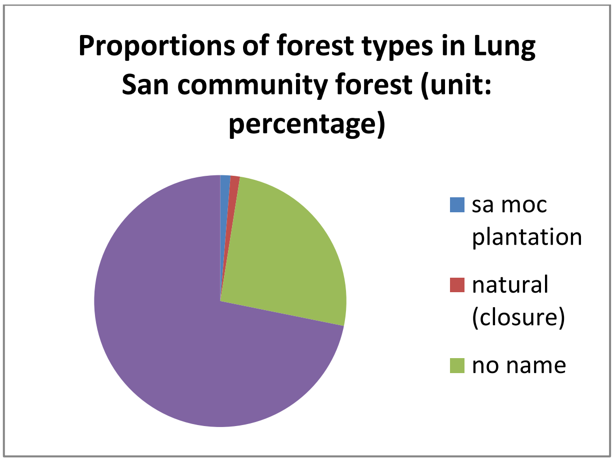


Figure 2: Proportion of forest types in Lung San village.

Data quality check was firstly conducted using **Pivot Table**. I examined DBH data, followed by H data, forest types and trees species. Table 7 (Annex) identified data problems found at plots 38, 47, 50, 60, 72 and 78 with errors in DBH. There were more DBH identified for natural forests than plantation forest. Only one record was found for plantation forest, which required further data examination. Table 8 (Annex) found similar data problems in height in the same plots (38, 47, 50, 60, 72 and 78). Quality check for data on forest types also conducted. Table 9 (Annex) showed that initially, there were eight forest types including (1) -; (2) two types of 'Rừng trồng' forests; (3) sa mộc; (4) two types of 'Tự nhiên' forests; (5) one type of 'Tự nhiên' (khoanh nuôi) and (6) blanks. There were data (-) and data (blanks) for forest types that required examination. Accounting for errors contained in naming tree species also conducted. Tables 13 and 14 (Annex) indicated all data problems found in the naming of trees species and the intervention undertaken to fix them.

Phase-two of quality check was conducted using **Scatter Plot**. I plotted DBH data and H data separately then plotted DBH data against the H data. Figure 3 shows six plots have data problems, indicated by red circle. Plot 14 has average DBH of 45 cm, which needs second check (indicated by green cirle). Overall, most of the plots have trees of average DBH ranging from about slightly below 10 cm to about 25 cm.

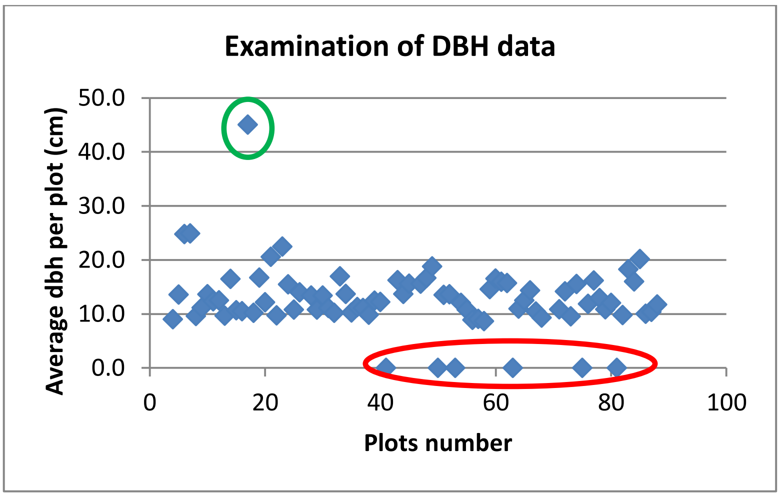


Figure 3: Examination of original DBH data in 88 plots at Lung San village (2012).

Figure 4 indicates the same data problems in height data in the same six plots, indicated by red circle. A few trees that is quite high. Most of the plots contained trees of a height range from slightly below 6 m to below 18 m. Scatter Plot appears to reconfirm of data problems identified in Pivot Table.

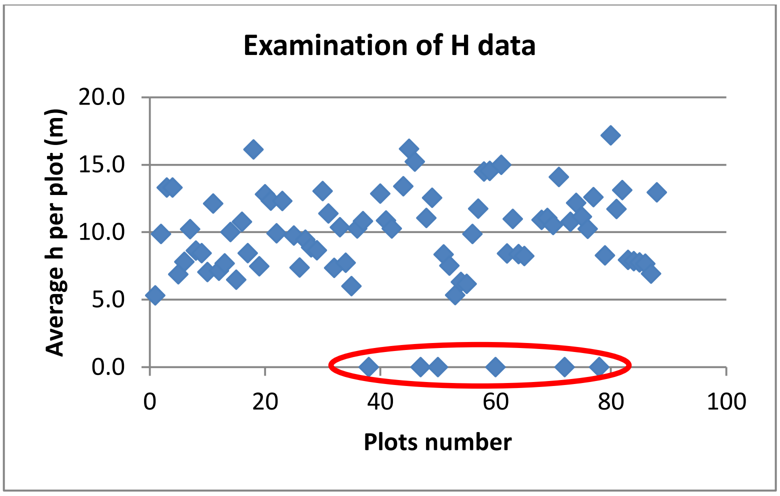


Figure 4: Examination of original H data of 88 plots at Lung Sui village (2012).

Scatter plot of DBH and H further conducted. The first relation between DBH and H, indicated by R-square = 0.7291, was not useful given there were many missing data. At this stage, no account was yet taken for errors. Scatter plot of DBH and H data after the first stage of accounting errors (DBH and H) shown in Figure 5. Figure 5 indicates there is a relation between DBH and H, indicated by R-square = 0.5407 (1856 records, 88 plots). After accounting errors, it is now 54.07% of variation in H explained by DBH, which critically implied there were numerous errors contained in the original datasets.

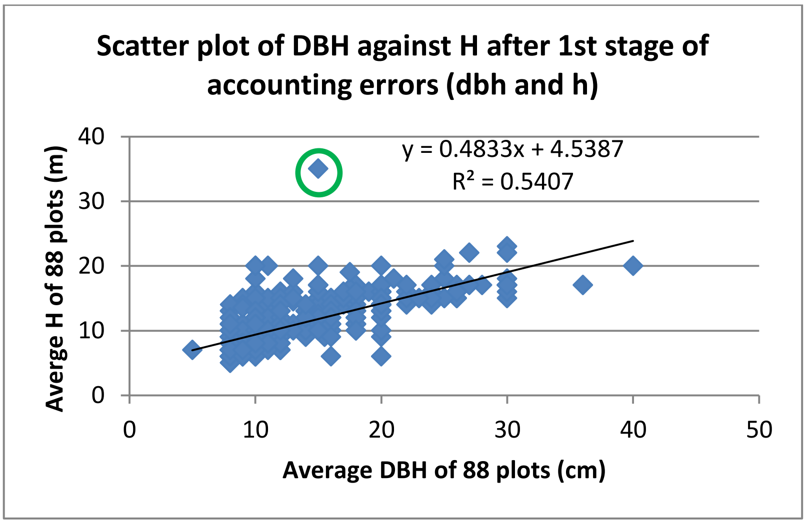


Figure 5: The first stage of accounting errors in DBH and H.

Scatter plot of DBH and H data after the second stage of accounting errors (DBH and H and forest types) and all the missing data shown in Figure 6. Figure 6 indicates an improvement in the R-square = 0.6117 (1805 records, 88 plots); i.e. about 61.2 percent of H explained by DBH. The improvement implies errors and missing data values tackled. Figure 6 also suggests that much of data clumped close together (indicated by red circle). There are a few unusual data points such as trees (15 cm, 35 m); (45 cm, 10 m), indicated by the two green circles. Double checked with hand-written data appear that the data entry were correct. Tree A appears to be less likely being in real life and tree B would also be very unusual. Further examination is required.

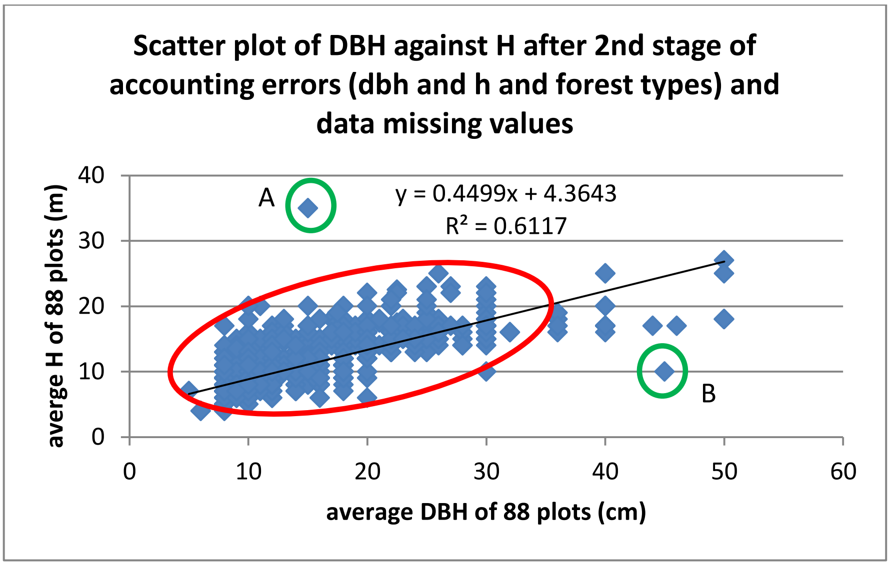


Figure 6: The second stage of accounting errors and data missing in DBH and H and forest types.

Scatter plot of DBH and H data after the third stage of accounting any final errors (DBH and H and forest types and tree names) shown in Figure 7. Figure 7 indicates another level of improvement in R-square from the second-stage of quality assurance (R-square = 0.6117) to this stage (R-square = 0.613). This implies that errors still contained in the datasets; and accounting for errors improved the data quality by 0.613-0.6117 = 0.0013 that is about 0.13%. Green circles indicate some unusual data that require further examination.

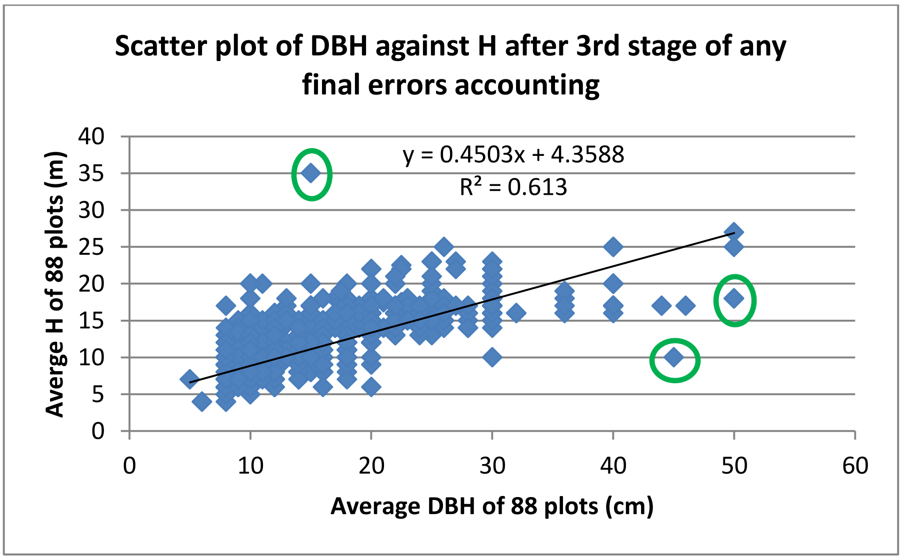


Figure 7: The third stage of accounting for any final errors in all data attributes.

Dealing with errors: I thoroughly go through every hand-written record and check with data entry in the electronic file. Specific fixes of data applied depending on the nature of data attributes. Table 10 (Annex) included data errors accounted for DBH and H and my first-stage of fixing errors. Table 11 (Annex) showed data problems found in forest types and remained data problems in DBH and H and my accounts for errors/missing data. Table 12 (Annex) provides a few continuous data errors found in DBH and H. Table 14 (Annex) showed my account for data problems in tree species. A decision to account all the unidentified or odd-names of tree species and group them as B was made with a total record of 35.

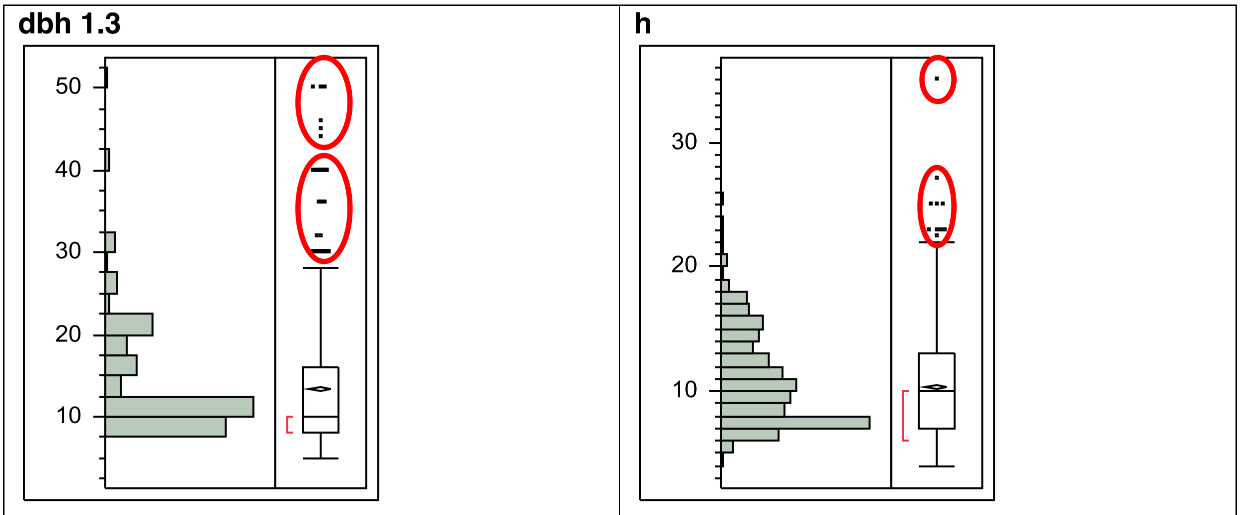
Table 3 below summarises my stages of accounting errors with associated R-square improvement with indication of specific Tables in Annex showing details of my intervention in fixing errors.

Table 3: Summary of errors and sensitivity to errors accounting.

	R-square	Improvements/Not improvements	Comments
DBH and H after accounting errors	**0.5407**	- 18.84%	Significant drop suggest that data contained lots of errors
DBH and H after accounting errors and missing data and fix forest types	**0.6117**	+ 7.1%	Quite an improvement, errors and missing data tackled
DBH and H after accounting errors missing data and accounted for data problems in forest types, tree species	**0.613**	+ 0.13%	Slight improvement

Overall, a conclusion is that there are data quality issues with data collected by villagers. **Scatter Plot** approach indicates the linear relation between DBH and H by R-square but also implies there is sensitivity in DBH and H data after accounting for every stage of dealing with errors. This implies villagers may need further training in forest measurement techniques, specifically to DBH and H. Other factors such as given areas of forest surveyed were on steep slips that can cause issues e.g. down slope leads to overestimate and vice versa up slope may underestimate height.

Advanced quality check of data further examined using **Analyse Distribution and Bivariate Fit** in JMP. 9 to identify outliers (Table 4, indicated by red circles). Figure 8 shows that average DBH is estimated about 13.4 cm ± 0.15 (se) (α = 0.05, N = 1804). This implies most of the trees in the area are relatively young and growing. Average H is estimated about 10.4 m ± 0.08 (se) (α = 0.05, N = 1804). This also indicates trees are reasonable tall and growing.



Moments (dbh 1.3)

Mean	13.377217
Std Dev	6.4927133
Std Err Mean	0.152865
Upper 95% Mean	13.677028
Lower 95% Mean	13.077406
N	1804

Moments (h)

Mean	10.383038
Std Dev	3.7344479
Std Err Mean	0.0879241
Upper 95% Mean	10.555482
Lower 95% Mean	10.210594
N	1804

Figure 8: Analyse distribution of quality data of DBH and H to ensure quality assurance.

Eight records found DBH above 40 cm i.e. rather big. They scatter in plots 3, 4, 14, 46 and 59; and are mainly natural forest species. Fifty-nine records found DBH from 30-40 cm, which are still quite large trees. In general, the site found very few big trees; mainly small and growing trees of less than

20 cm DBH were found. This could indicate the forest structure may be good i.e. at the smaller diameters; many more trees are needed to make up the basal area and that only a few large trees are needed.

Distribution of height data shows that there is less outlier picked for height data compared to DBH data. One record of tree measured at 35 m height indicated as a potential outlier. Double-checked with the hand-written data of this record conducted but the data entry appeared correct. Further examination of residuals required. There are also several other outliers picked in the height distribution required further examination.

Further examination of the quality data was conducted. **Bivariate Fit** used to plot DBH against H to look at specifically residuals. Table 4 provides detailed analysis of a series of fits undertaken. The Fit Polynomial by quadratic indicates the highest R-square, small RMSE and standard error mean of residuals.

Table 4: A series of Fits examined to look for the best one.

			R-square	RMSE	Comments on residuals	Mean errors	Standard Error Mean
1	Fit Mean			3.734448	Skew; Pick up outliers;	5.975e-15	0.0879
2	Fit Linear	h = 4.358781 + 0.4503371*dbh	0.613021	2.323758	Pick up many outliers; Not quite normally distributed;	5.965e-15	0.0546
3	Fit Polynomial Degree = 2	h = 3.1819582 + 0.5682846*dbh - 0.0095174*(dbh-13.3772)^2	0.651163	2.206881	Many more outliers pick up; Not quite normally distributed yet; but slightly better than Fit Linear	8.424e-16	0.0519
4	Fit Polynomial Degree = 3	h = 3.1804016 + 0.5704604*dbh - 0.0105762*(dbh-13.3772)^2 + 3.2671e-5*(dbh-13.3772)^3	0.651219	2.207316	Pick up many outliers; Not as good as Fit Polynomial Degree = 2.	-4.66e-15	0.0519
5	Fit to Log (DBH)	h = -8.159538 + 7.4095406*Log(dbh)	0.646732	2.220235	Pick up many outliers; Quite normal-ish distributed	-3.39e-14	0.0522
6	Fit to Log (H) and Log (DBH)	Log(h) = 0.5928959 + 0.6741282*Log(dbh)	0.630881	0.20906	Pick up many outliers; quite normal-ish distribution;	0.207	0.0532

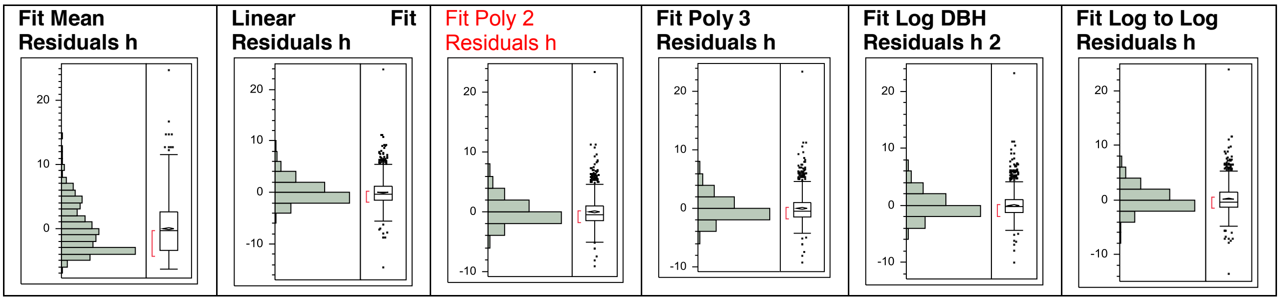


Figure 9: Distribution of residuals through varied examination of Fits.

Figure 9 provides representation of distribution of residuals. Residuals of Fit Mean were skew right and picked up far less outliers compared to other fits. Most of other Fits had their residuals not quite normal-ish distributed, but performed better than Fit Mean. They picked up outliers very visibly. Indicated by distribution of residuals and standard error mean of residuals, Fit Polynomial by quadratic appears with the least value. Decision made to approach Fit Polynomial by quadratic and attempted to deal with outliers by reviewing the datasets the 4th time. At this stage, critical outliers identified in Table 16.

Table 5: My working through every stage of identifying outliers and exclusion by stages.

	Fit Polynomial Degree = 2	R-square	RMSE	Comments on residuals	Mean errors	Standard Error Mean
Without excluding outliers **N = 1804**	**h = 3.1819582 + 0.5682846*dbh - 0.0095174*(dbh-13.3772)^2**	**0.651163**	**2.206881**	**Many more outliers pick up; Not quite normally distributed yet; but slightly better than Fit Linear**	**8.424e-16**	**0.0519**
1st stage: Exclude 9 outliers N = 1795	h = 3.1034083 + 0.5703937*dbh - 0.0089789*(dbh-13.3557)^2	0.690662	2.041256	Less outliers picked; Better distribution;	-4.96e-15	0.0481
2nd stage: Exclude further 56 outliers N = 1739	h = 3.0187871 + 0.5667596*dbh - 0.0101979*(dbh-13.2237)^2	0.73576	1.744595	Much better distribution; not quite normal-ish yet; Very few outliers left	3.943e-15	0.0418
3rd stage: Exclude further 14 outliers N = 1725	*h = 2.9390004 + 0.5716608*dbh - 0.0105139*(dbh-13.2206)^2*	*0.746966*	*1.697426*			*0.0408*

After the stages of examination, 79 outliers have identified. Table 5 indicates stages of going through to exclude them and R-square(excluded) improved by 0.746966-0.651163 = 0.095803 i.e. equivalent to 9.6%, which does imply error and unusual data is still contained in the datasets.

A critical decision needs to be made. If outliers are retained (which may very much likely inherently contain errors), the distribution of residuals is not so normal. R-square = 0.651163 with RMSE = 2.206881 associated with standard error mean = 0.0519. Final estimate would be affected by errors contained in the data. In this case, if we excluded all the outliers, the results may not fully appreciate the realistic nature of data and at the same time, not fully contain all the trees for the full estimation of final forest carbon biomass in stem. If about 79 data points are not included, given these data were measured incorrectly (either typo errors or measurement error), these trees would still store certain amount of forest carbon biomass.

My decision is that I continued checking between hand-written notes and excel files the fourth time. I still found errors remained, some were typo errors and some were mistaken between columns of data. I also treated the critical individual unusual data points by taking an average of all the data points within that plot to assign the value for such a point. Result is followed given I have reviewed all the 79 data points and no exclusion required (Table 6).

Table 6: Fit Polynomial Degree with excluding 79 outliers (top) and without excluding outliers (below).

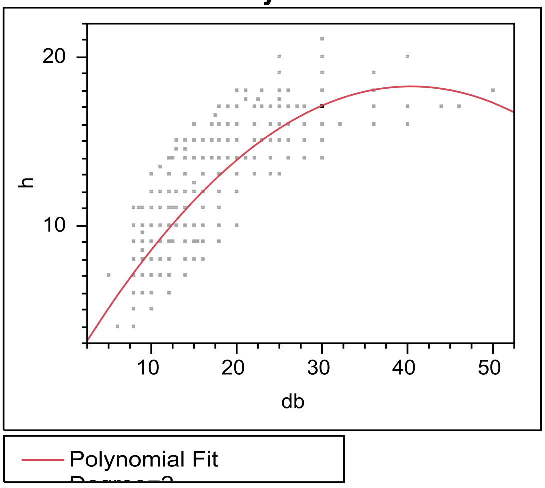
	Fit Polynomial Degree = 2	R-square	RMSE	Comments on residuals	Mean errors	Standard Error Mean
3rd stage: Exclude further 14 outliers N = 1725	h = 2.9390004 + 0.5716608*dbh - 0.0105139*(dbh-13.2206)^2	0.746966	1.697426			0.0408
Full review of 79 outliers N = 1804	h = 3.0034246 + 0.5692212*dbh - 0.0105093*(dbh -13.3699)^2	0.735251	1.756994	Fairly normal-ish distribution		0.0416

Table 6 indicates that given the review of the 79 outliers (indicated in red) and that, the revised Fit Polynomial by quadratic indicates result of R-square = 0.735251, which is close to the one that attempted with exclude them all. This means that 73% of variation of H explained by DBH, which is reasonably high. Besides the errors such as measurement errors, transcription mistakes; the deviation away from expectation remained, reflecting the nature of the site, stand conditions, tree ages and species variety.

Representation of my workings towards dealing with 79 outliers without excluding them shown in Figure 10. Left side indicates model predicted when we simply excluded all the unusual data. Right side indicates my working on fixing all 79 outliers and Bivariate Fit almost indicates similar R-square and RMSE.

EXCLUDING 79 OUTLIERS

Bivariate Fit of h By dbh



Polynomial Fit Degree=2

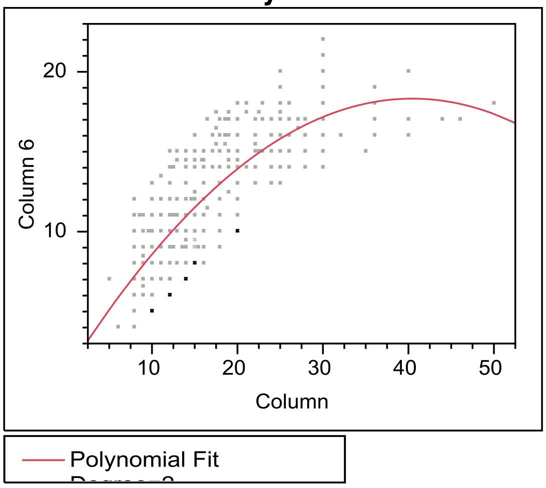
h = 2.9390004 + 0.5716608*dbh - 0.0105139*(dbh-13.2206)^2

Summary of Fit

RSquare	0.746966
RSquare Adj	0.746672
Root Mean Square Error	1.697426
Mean of Response	10.08551
Observations (or Sum Wgts)	1725

WORKING ON OUTLIERS

Bivariate Fit of h By dbh



Polynomial Fit Degree=2

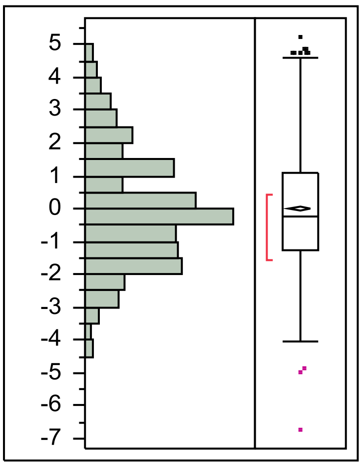
h = 3.0034246 + 0.5692212*dbh - 0.0105093*(dbh - 13.3699)^2

Summary of Fit

RSquare	0.735251
RSquare Adj	0.734957
Root Mean Square Error	1.756994
Mean of Response	10.20322
Observations (or Sum Wgts)	1804

Figure 10: Comparison of Fit between exclusion and non-exclusion of 79 outliers.

Distributions
Residuals Column 6



Moments

Mean	6.845e-15
Std Dev	1.7682087
Std Err Mean	0.0416308
Upper 95% Mean	0.0816498
Lower 95% Mean	-0.08165
N	1804

Figure 11: Distribution of residuals of revised Fit.

Distribution of residuals of the revised Fit shown in Figure 11. I still retained some outliers in the datasets because it may partly reflect the realistic nature of the site. I did not pursue a model (Fit) that contained zero errors. There would very much likely be some unusual trees with odd shapes or growth forms presented at the landscape. In other cases, there may be large trees with the tops broken by storms, which often are trees with large DBH for the relative low height recorded. This may act as an input for future measurements in terms of recording tree-form on record sheets. Important is that distribution of residuals are quite normal-ish and standard error mean is 0.0416 which is tiny enough of the entire datasets of N = 1804. Representation of residuals by predicted plot between exclusion and non-exclusion shown in Figure 12. Residuals distributed fanning out, almost homogeneous.

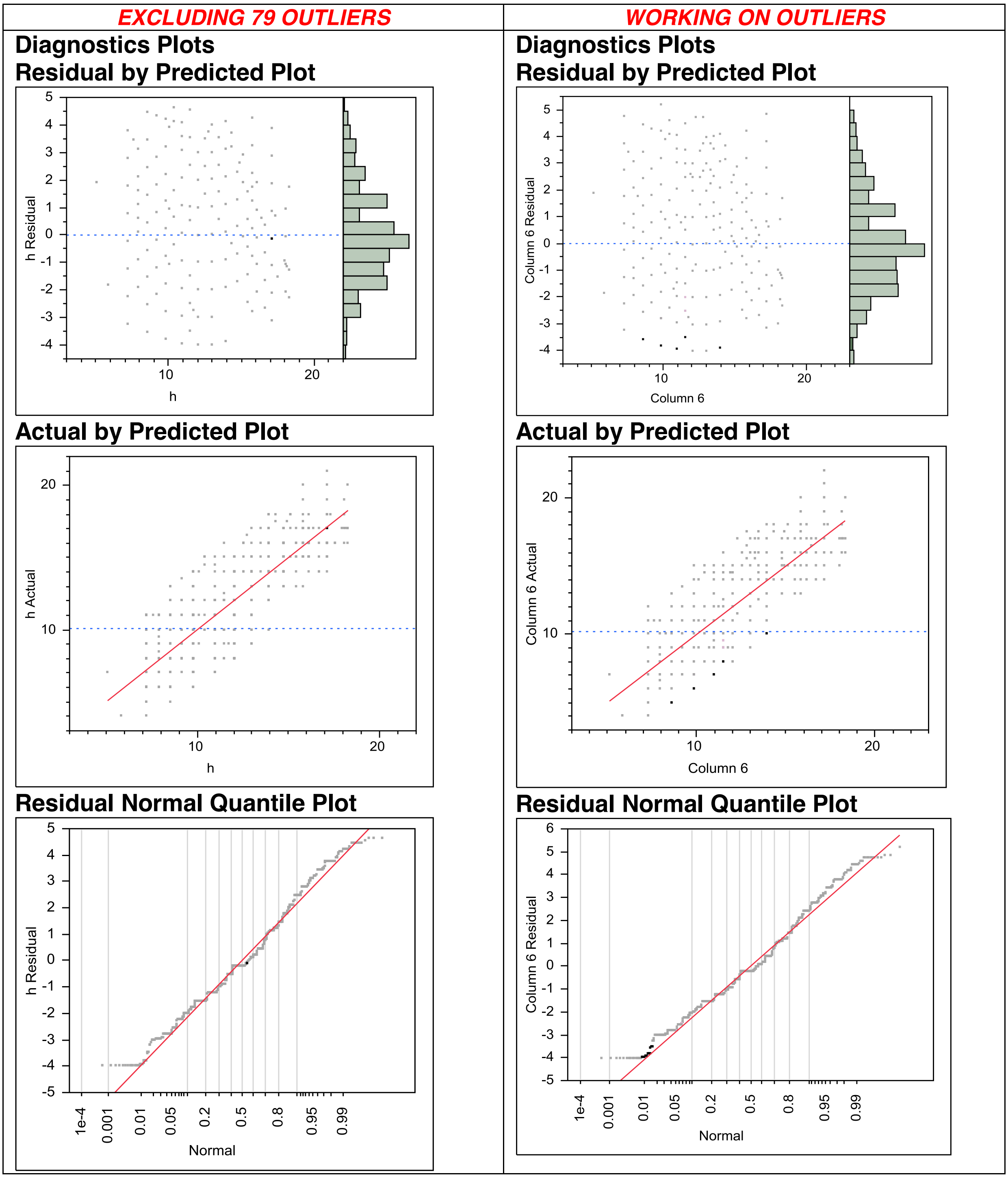


Figure 12: Representation of residuals by predicted plot between exclusion and non-exclusion.

My conclusion is that given N = 1804 the Fit Polynomial Fit by quadratic of the reviewed outliers indicates best result of DBH and H data. These will be the quality data assured for the subsequent volume estimate and forest carbon biomass in stem. Latest DBH and H data shown in Table 17.

RESULTS

Volume estimates used volume function below.

Volume (m^3)	$Volume = \frac{DBH^2}{40000} \times H \times 0.44 \times (\pi)$ Form factor = 0.44

Results of sum of volume by plot shown in Figure 13. In general, most of the plots have sum of volumes below five cubic meters. Plot 3 really stands out and has a sum of volume of almost 10 cubic meters. Double check with field data indicated that this plot contains trees that are high and large in diameters.

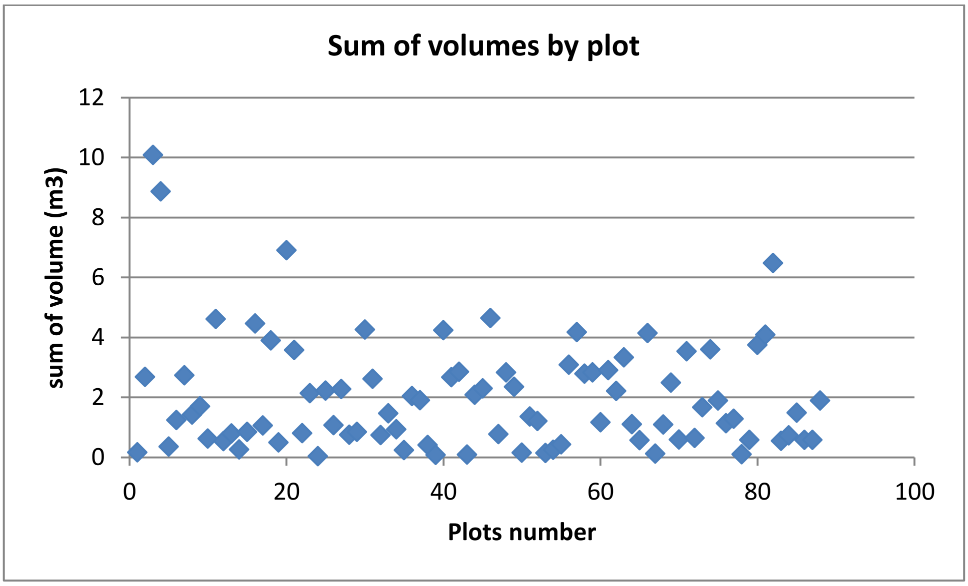


Figure 13: Sum of volumes by plot.

Total sum volumes for 88 plots is estimated = 177.41 m^3 and that an assumption made that most of the plots have been measured from standard plot size (500 m^2 plot i.e. plot = 1/20 hectare). Average sum of volume per plot is estimated about 2.016 m^3/plot ± 0.201 (s.error) (α = 0.05, N = 1804). Conversion of units undertaken and our estimate of forest carbon biomass in stem are:

$$Forest\ carbon\ biomass\ (stem) = Volume\frac{m3}{plot} \times \frac{plot}{ha} \times average\ wood\ density\ 0.69\ \frac{tonne}{m3}$$

On average, forest carbon biomass in stem is estimated at 27.82 tonnes/ha, or in the range from 22.3 tonnes/ha to 33.3 tonnes/ha. Given the area surveyed was 84 hectares and an assumption also made that most of the sampled plots conducted randomly and still ensured representativeness, extrapolation for the total forest carbon biomass (in stem) for the protection forest area of 124.4 hectare is estimated in a range from **2773.976 tonnes to 4148.018 tonnes**.

Average estimate of forest carbon biomass in stem in the area ranges from 22.3 tonnes/ha to 33.3 tonnes/ha ± 2.78 (s.error) (α = 0.05, N = 1804) is relatively reliable estimate given the inputs data had errors that were minimized and reviewed thoroughly. Compared this range with figures with Table 1: Order of magnitude and relative size of biomass pools in forests (Details Protocol for *in situ* Tree and

Stand Biomass estimation/measurement) indicates that the range of forest carbon biomass stored in the area is still in the lower end. Ranges of above ground biomass were indicated from 50 tonnes/ha (mangrove forest) to 650 tonnes/ha (peat and health forest) in which about from 40% to 80% of the total would be stem. Despite the estimate of range is lower than the Protocol numbers, nevertheless, factors taken into account such as site condition, growth forms and almost trees in the area are very diverse of species (more than 20 species). Most of the forests are third and second natural regeneration forest, indicated by DBH and H data. We would expect the final estimate of forest carbon biomass in stem in such a range.

CONCLUSION

Quality of the data is highly assured, indicated by the Bivariate Fit of H by DBH shown in R-square = 0.735251, which is very high, almost 74% of total variation in H explained by DBH. RMSE = 1.75, which is small. Distribution of residuals (Figure 11) has standard error mean = 0.0416308 which is small; although there are still very few outliers that I did not resolve. The reason is because firstly my inability to actually field-check of such trees in real so I found it challenge to make a change to datasets without visually observing them. Secondly, it would make sense to me in terms of there must be some level of errors (not large though) in the model because there may be unusual tree forms in real life (not all trees are homogeneously similar). There was also a fact needed to account is that this is a second and third rotation natural regeneration forest of a tropical moist climate condition. Bias in the data will always be inherent; however, I have attempted at best to ensure ground measurements and modelling has met at a point where they show relatively closed to each other.

Forest carbon biomass in stem is estimated in the range from 22.3 tonnes/ha to 33.3 tonnes/ha ± 2.78 (s.error) ($\alpha = 0.05$, $N = 1804$) for the site which is low compared to Protocol. However, site-specific conditions are deterministic of the carbon amount sequestered in trees; and as the Lung San village itself is located in a very harsh and poor site-condition (water limited), we can expect an estimation of such a range. Extrapolation of forest carbon biomass in stem for the 124.4 hectares (although derived on an assumption that all plots sampled random and ensured representativeness) appears to be a reliable estimate (of the 88 plots surveyed, 1804 trees measured, quality of data checked and assured).

Given that villagers directly measuring the data for their first time, it appears the quality of datasets is not very low at-all after checking all data errors and problems. The estimate of protection forest area of 124.4 hectare in Lung San village is currently sequestering from **2773.976 tonnes to 4148.018 tonnes** of forest carbon biomass in stem indicated as a high-quality estimate. This is the first account to estimate forest carbon biomass in stem for a forestland area managed by a local community in such a remote area up in Simacai district. The study and result contributes to the REDD+ program some insights of the amount of forest carbon biomass the villagers in remote areas of Vietnam are currently managing and conserving their forests.

REFERENCES

Current status of knowledge on forest volume and biomass assessment in Vietnam. Nguyen Dinh Hung, Forest Inventory and Planning Institute.

Details Protocol for *in situ* Tree and Stand Biomass estimation/measurement.

Email communications with Le Van Ka (date: Fri, Sep 7, 2012 at 1:17 PM on Subject: tai lieu goc do tru luong rung) and (date: Mon, 8 Oct 2012 23:50:57 +0700 on Subject: Chia sẻ thong tin ve tinh toan tru luong rung).

Nhat ky Giao dat giao rung Lung Sui thang 6, nam 2012. Nguoi ghi chep: Le Van Ka.

Phuong an quan ly, su dung dat lam nghiep. Thon Lung San, xa Lung Sui, huyen Simacai, tinh Lao Cai. UBND huyen Simacai, tinh Lao Cai. UBND xa Lung Sui, Cong dong dan cu thon Lung San. Simacai thang 7 nam 2012.

ANNEXES:

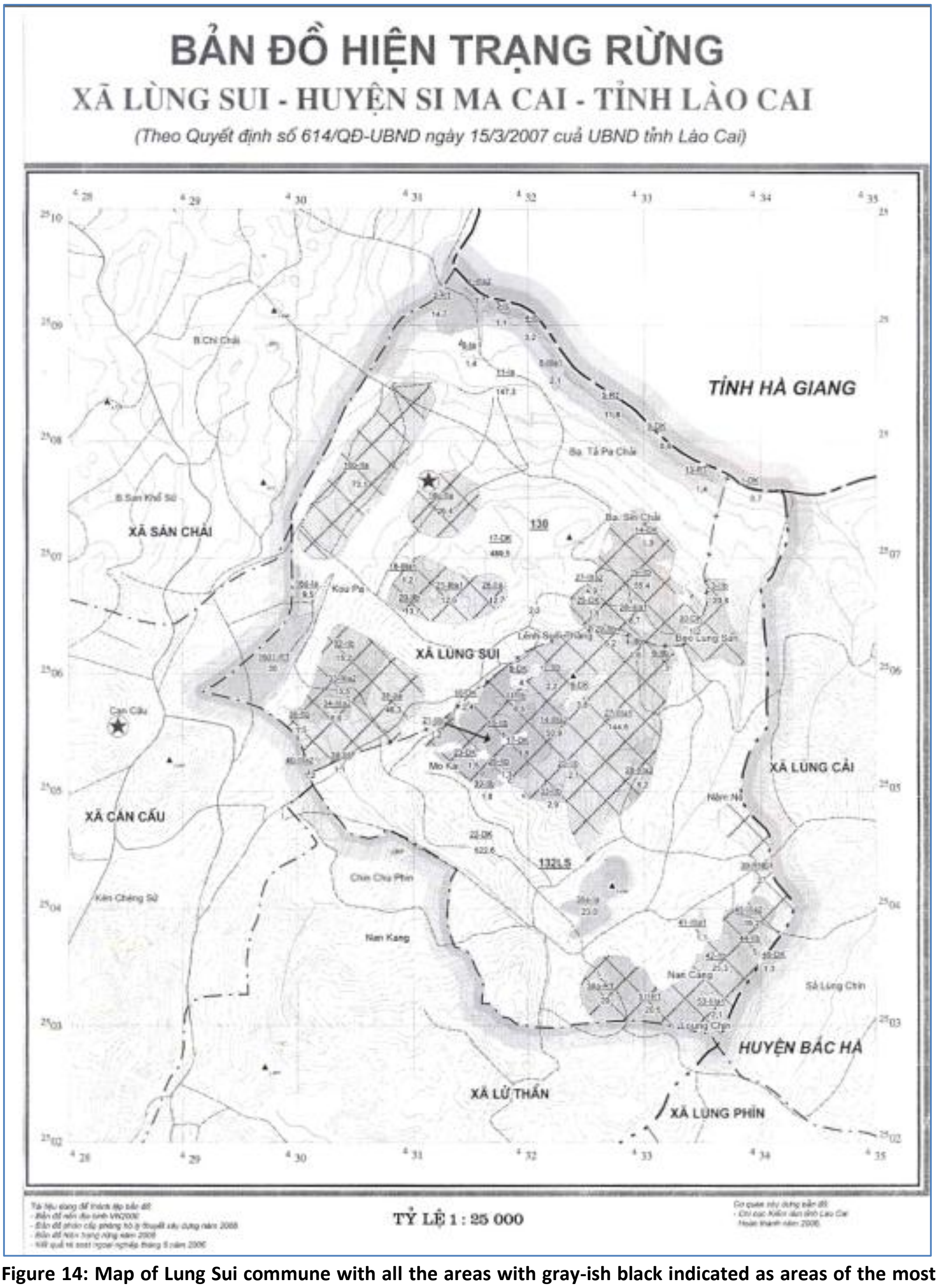


Figure 14: Map of Lung Sui commune with all the areas with gray-ish black indicated as areas of the most recent forest inventory.

Table 7: Average DBH at plot level of entire 88 plots without errors fixed (2012).

Average of D1.3 (cm)	Column Labels								
Row Labels	**-**	**Tự nhiên**	**Rừng trồng**	**Rừng trồng**	**sa mộc**	**Tự nhiên**	**Tự nhiên (khoanh nuôi)**	**(blank)**	**Grand Total**
1								9.00	9.00
2								13.54	13.54

3	24.78				24.78
4	24.86				24.86
5	9.60				9.60
6	11.10				11.10
7	13.61				13.61
8	12.33				12.33
9	12.52				12.52
10				9.65	9.65
11	16.43				16.43
12				10.63	10.63
13				10.45	10.45
14				45.00	45.00
15	10.20				10.20
16	16.72				16.72
17	12.13				12.13
18	20.53				20.53
19	9.68				9.68
20				22.47	22.47
21	15.48				15.48
22				10.79	10.79
23				13.95	13.95
24					
25	13.38				13.38
26	10.80				10.80
27	13.36				13.36
28		11.05			11.05
29				10.15	10.15
30	16.96				16.96
31	13.67				13.67
32				10.26	10.26
33				11.27	11.27
34	11.05				11.05
35	9.82				9.82
36	12.44				12.44
37	12.20				12.20
38	#DIV/0!				#DIV/0!
39					
40			16.22		16.22
41			13.66		13.66
42			15.57		15.57
43					
44				15.60	15.60
45			16.61		16.61
46			18.79		18.79
47			#DIV/0!		#DIV/0!
48			13.48		13.48

49						13.64			13.64
50						#DIV/0!			#DIV/0!
51						12.00			12.00
52						10.80			10.80
53						8.89			8.89
54						9.08			9.08
55						8.62			8.62
56						14.57			14.57
57						16.54			16.54
58						15.95			15.95
59						15.70			15.70
60						#DIV/0!			#DIV/0!
61								10.97	10.97
62						12.47			12.47
63						14.34			14.34
64						10.43			10.43
65							9.27		9.27
66									
67									
68						10.82			10.82
69						14.17			14.17
70								9.53	9.53
71						15.54			15.54
72						#DIV/0!			#DIV/0!
73						11.84			11.84
74						16.15			16.15
75								12.92	12.92
76						10.84			10.84
77						12.00			12.00
78	#DIV/0!								#DIV/0!
79								9.79	9.79
80								18.22	18.22
81						16.00			16.00
82								20.15	20.15
83								10.00	10.00
84								10.38	10.38
85						11.71			11.71
86						9.20			9.20
87								9.35	9.35
88						13.78			13.78
(blank)									
Grand Total	**#DIV/0!**	**14.07**			**11.05**	**13.42**	**9.27**	**12.41**	**13.29**

Table 8: Average H at plot level of entire 88 plots without errors fixed (2012).

Average of Hvn (m)	**Column Labels**								
Row Labels	**-**	**Tự nhiên**	**Rừng trồng**	**Rừng trồng**	**sa mộc**	**Tự nhiên**	**Tự nhiên (khoanh nuôi)**	**(blank)**	**Grand Total**

1				5.30	5.30
2				9.85	9.85
3	13.30				13.30
4	13.29				13.29
5	6.87				6.87
6	7.79				7.79
7	10.21				10.21
8	8.63				8.63
9	8.44				8.44
10				7.04	7.04
11	12.10				12.10
12				7.13	7.13
13				7.68	7.68
14				10.00	10.00
15	6.47				6.47
16	10.76				10.76
17	8.44				8.44
18	16.12				16.12
19	7.47				7.47
20				12.79	12.79
21	12.33				12.33
22				9.89	9.89
23				12.30	12.30
24					
25	9.73				9.73
26	7.37				7.37
27	9.43				9.43
28		8.85			8.85
29				8.65	8.65
30	13.04				13.04
31	11.37				11.37
32				7.35	7.35
33				10.35	10.35
34	7.71				7.71
35	6.00				6.00
36	10.26				10.26
37	10.80				10.80
38	#DIV/0!				#DIV/0!
39					
40			12.85		12.85
41			10.86		10.86
42			10.26		10.26
43					
44				13.40	13.40
45			16.17		16.17
46			15.21		15.21

47				#DIV/0!			#DIV/0!
48				11.04			11.04
49				12.55			12.55
50				#DIV/0!			#DIV/0!
51				8.33			8.33
52				7.50			7.50
53				5.33			5.33
54				6.31			6.31
55				6.15			6.15
56				9.87			9.87
57				11.73			11.73
58				14.47			14.47
59				14.52			14.52
60				#DIV/0!			#DIV/0!
61						14.97	14.97
62				8.40			8.40
63				10.97			10.97
64				8.37			8.37
65					8.23		8.23
66							
67							
68				10.91			10.91
69				11.04			11.04
70						10.53	10.53
71				14.08			14.08
72				#DIV/0!			#DIV/0!
73				10.76			10.76
74				12.15			12.15
75						11.13	11.13
76				10.24			10.24
77				12.59			12.59
78	#DIV/0!						#DIV/0!
79						8.26	8.26
80						17.17	17.17
81				11.70			11.70
82						13.12	13.12
83						7.94	7.94
84						7.83	7.83
85				7.75			7.75
86				7.64			7.64
87						6.92	6.92
88				12.94			12.94
(blank)							
Grand Total	**#DIV/0!**	**9.96**	**8.85**	**10.74**	**8.23**	**10.07**	**10.27**

Table 9: Original and re-classify forest type's data.

	Original datasets			Revised datasets	
Forest types	Number of records	Percentage (%)	New classification	Number of records	Percentage (%)
-	1				
Rừng trồng	53				
sa mộc	20		Sa mộc (plantations)	23	1.3
Tự nhiên	1297		Tự nhiên (natural)	1296	71.84
Tự nhiên (khoanh nuôi)	22		Tự nhiên (khoanh nuôi) (natural closure)	22	1.21
Blanks	463		No name	463	25.66
	Total = 1856 records			Total = 1804 records	

Table 10: Data errors accounted for DBH and H and the 1st-stage of accounting for errors in DBH and H (2012).

		Problems found and fix for DBH	Problems found and fix for H	Notice
14		One record found data missing	One record found data missing	Doubled check with raw hand-written data, fixed
38	######	Average DBH	Average H	Doubled check with raw hand-written data, fixed
47	######	Average DBH	Average H	Doubled check with raw hand-written data, fixed
50	######	Average DBH	Average H	Doubled check with raw hand-written data, fixed
60	######	Average DBH One record found no data on DBH (1258, 60)	Average H Same record found no data on H (1258, 60)	Doubled check with raw hand-written data, fixed The record with no data, highlighted (DELETE)
72	######	Average DBH	Average H	Doubled check with raw hand-written data, fixed
78	######	One record found no data on DBH (1624, 78)	Same record found no data on DBH (1624, 78)	Doubled check with raw hand-written data, fixed

Table 11: Data problems identified with forest types and the 2nd-stage of accounting for errors in DBH and H (2012).

Forest types	Records Total = 1856 records	Data problems	Intervention	Records after fix	Percentage of total	Naming in English and new classification	
Rừng trồng	53	52 records found missing data on DBH and H for these at plot 24 and one record on plot 67.	Doubled check with raw hand-written data; Average data on DBH, H; Group between 'Rừng trồng' and 'Xa mộc'	3	3/1805 records = 0.166%	Plantations	1.27%
Xa mộc	20			20	=20/1805 records = 1.108%		
Tự nhiên	1298	Typo error (font) so fixed it One record missing data for DBH and H (1258, 60) Filtering data on H (1-27) m Two records found data on H = 1 m trees (strange!), given DBH are quite big (682, 30) and (689, 30)	Doubled check with raw hand-written data; Fixed (typo error) H = 14 m. Found (1258, 60) without data on hand-written, decided DELETE	DBH (5-50) cm H (4-27) m Total data points = 1856	= 1297/1805 records = 71.86%	Natural	71.86%
Tự nhiên (khoanh nuoi)	22				22/1805 records = 1.22%	Natural (closure)	1.22%
Blanks	514	Records from 490-540 found no data (no plot identified) Record (938, 43) no data found	Deleted Doubled check with raw hand-written data; fixed		463/1805 records = 25.65	No name	25.65%

	14 records found data missing for DBH and H	

Table 12: Few final data errors in DBH and H that were not previously addressed.

Plot	(DBH, H) concerns over typo errors	Solutions
11	(20, 14)	(20, 14)
18	(12, 17)	(22, 17)
26	(18, 7)	(18, 7)
39 (1)	Average DBH (10,15) Average H (12,16)	(12.5, 14)
39 (2)	No data so deleted	Total records = 1804

Table 13: Problems found in the names of trees species and decision made to group into B.

	Plot	Forest types	Tree species	DHB	H
19	2	no name	lenió	10	9
406	20	no name	B	12	15
408	20	no name	B	10	8
414	20	no name	B	30	15
416	20	no name	B	10	10
418	20	no name	B	30	10
419	20	no name	B	15	12
549	27	Tự nhiên	d	8	7
577	28	sa mộc	B	12	10
579	28	sa mộc	B	10	12
581	28	sa mộc	B	12	7
582	28	sa mộc	B	12	8
586	28	sa mộc	B	12	10
587	28	sa mộc	B	12	11
588	28	sa mộc	B	11	10
593	28	sa mộc	B	10	10
642	30	Tự nhiên	//	12	11
947	47	Tự nhiên	B	12.5	9
1217	61	no name	B	10	15
1218	61	no name	B	11	14
1219	61	no name	B	8	12
1226	61	no name	-	8	13
1227	61	no name	-	10	15
1228	61	no name	-	9	15
1229	61	no name	-	10	16
1230	61	no name	-	8	13
1231	61	no name	-	9	14
1232	61	no name	-	10	18
1233	61	no name	-	11	20
1234	61	no name	-	10	20
1354	66	no name	BTB	40	20
1355	66	no name	B	10	10
1452	72	Tự nhiên	B	17.5	16.5
1454	72	Tự nhiên	B	9	13.5
1572	78	Tự nhiên	-	15	12.5

Table 14: All the errors accounted for Trees Species and fixed transcription.

Trees species	Number of records
B	35
Chẹo	249
Đào rừng	213
Kháo	157
Mận rừng	55
Sa mộc	9
SP	489
Tông dù	33
Vối thuốc	514
Xiến đất	14
Xoan đào	23

Table 15: Third stage of data quality checked for all data attributes (DBH, H, forest types, plots, and total records)

Column Labels	Tự nhiên		no name		sa mộc		Tự nhiên (khoanh nuôi)		(blank)		Total Average of D1.3 (cm)	Total Average of Hvn (m)
Row Labels	**Average of D1.3 (cm)**	**Average of Hvn (m)**	**Average of D1.3 (cm)**	**Average of Hvn (m)**	**Average of D1.3 (cm)**	**Average of Hvn (m)**	**Average of D1.3 (cm)**	**Average of Hvn (m)**	**Average of D1.3 (cm)**	**Average of Hvn (m)**		
1			9.0	5.3							9.0	5.3
2			13.5	9.8							13.5	9.8
3	24.8	13.3									24.8	13.3
4	24.9	13.3									24.9	13.3
5	9.6	6.9									9.6	6.9
6	11.1	7.8									11.1	7.8
7	13.6	10.2									13.6	10.2
8	12.3	8.6									12.3	8.6
9	12.5	8.4									12.5	8.4
10			9.7	7.0							9.7	7.0
11	16.4	12.1									16.4	12.1
12			10.6	7.1							10.6	7.1
13			10.5	7.7							10.5	7.7
14			27.0	9.8							27.0	9.8
15	10.2	6.5									10.2	6.5
16	16.7	10.8									16.7	10.8
17	12.1	8.4									12.1	8.4
18	21.1	16.1									21.1	16.1
19	9.7	7.5									9.7	7.5
20			22.5	12.8							22.5	12.8
21	15.5	12.3									15.5	12.3
22			10.8	9.9							10.8	9.9
23			14.0	12.3							14.0	12.3
24					11.0	9.0					11.0	9.0
25	13.4	9.7									13.4	9.7
26	10.8	7.4									10.8	7.4

27	13.4	9.4									13.4	9.4
28					11.1	8.9					11.1	8.9
29			10.2	8.7							10.2	8.7
30	17.0	14.1									17.0	14.1
31	13.7	11.4									13.7	11.4
32			10.3	7.3							10.3	7.3
33			11.3	10.3							11.3	10.3
34	11.0	7.7									11.0	7.7
35	9.8	6.0									9.8	6.0
36	12.4	10.3									12.4	10.3
37	12.2	10.8									12.2	10.8
38	18.3	16.0									18.3	16.0
39	12.5	14.0									12.5	14.0
40	16.2	12.9									16.2	12.9
41	13.7	10.9									13.7	10.9
42	15.6	10.3									15.6	10.3
43			14.0	12.0							14.0	12.0
44			15.6	13.4							15.6	13.4
45	16.6	16.2									16.6	16.2
46	18.8	15.2									18.8	15.2
47	17.5	16.6									17.5	16.6
48	13.5	11.0									13.5	11.0
49	13.6	12.5									13.6	12.5
50	9.4	12.1									9.4	12.1
51	12.0	8.3									12.0	8.3
52	10.8	7.5									10.8	7.5
53	8.9	5.3									8.9	5.3
54	9.1	6.3									9.1	6.3
55	8.6	6.2									8.6	6.2
56	14.6	9.9									14.6	9.9
57	16.5	11.7									16.5	11.7
58	15.9	14.5									15.9	14.5
59	15.7	14.5									15.7	14.5
60	25.0	18.0									25.0	18.0
61			11.0	15.0							11.0	15.0
62	12.5	8.4									12.5	8.4
63	14.3	11.0									14.3	11.0
64	10.4	8.4									10.4	8.4
65							9.3	8.2			9.3	8.2
66			21.1	15.1							21.1	15.1
67					13.3	9.0					13.3	9.0
68	10.8	10.9									10.8	10.9
69	14.2	11.0									14.2	11.0
70			9.5	10.5							9.5	10.5
71	15.5	14.1									15.5	14.1
72	12.5	13.3									12.5	13.3

73	11.8	10.8									11.8	10.8
74	16.2	12.2									16.2	12.2
75			12.9	11.1							12.9	11.1
76	10.8	10.2									10.8	10.2
77	12.0	12.6									12.0	12.6
78	15.0	12.5									15.0	12.5
79			9.8	8.3							9.8	8.3
80			18.2	17.2							18.2	17.2
81	16.0	11.7									16.0	11.7
82			20.2	13.1							20.2	13.1
83			10.0	7.9							10.0	7.9
84			10.4	7.8							10.4	7.8
85	11.7	7.8									11.7	7.8
86	9.2	7.6									9.2	7.6
87			9.3	6.9							9.3	6.9
88	13.8	12.9									13.8	12.9
(blank)												
Grand Total	**13.7**	**10.5**	**12.7**	**10.2**	**11.2**	**8.9**	**9.3**	**8.2**			**13.4**	**10.4**

Table 16: Identify of outliers.

	Outliers	DBH, H	Marked as
First stage	1	15, 35	x
	2	10, 20	+
	3	10, 18	+
	4	11, 20	+
	5	10, 20	+
	6	8, 17	+
	7	20, 6	^
	8	30, 10	^
	9	45, 10	^
Second stage	10, 11	16, 6 18, 7	Blue dots
		54 more outliers identified	Colour by entire row (green)
Third stage		2 more outliers picked 18, 8 (183) 20, 9 (1346)	Round circle
		12 more outliers identified	Square

Table 17: Latest DBH and H data and Sum of Volumes

Row Labels	Average of D1.3 (cm)	Average of Hvn (m)	Sum of Volume (m3)2
1	9	5.3	0.157858748
2	13.53846154	9.846153846	2.672816764
3	24.7826087	13.30434783	10.08512817
4	24.85714286	13.28571429	8.868012344
5	9.6	6.866666667	0.349307404
6	11.10344828	7.793103448	1.235362196
7	13.60714286	10.21428571	2.733914458
8	12.33333333	8.625	1.418793508
9	12.51851852	8.444444444	1.694009591
10	9.652173913	7.043478261	0.616506142
11	16.56666667	11.95	4.608262463

12	10.625	7.125	0.530388805
13	10.45454545	7.681818182	0.787082057
14	17.75	9.5	0.257138181
15	10.2	6.466666667	0.841130017
16	16.72	10.76	4.461375727
17	12.125	8.4375	1.055248406
18	19.82352941	15.23529412	3.88896498
19	9.684210526	7.473684211	0.490302082
20	22.76315789	13	6.90437635
21	15.48148148	12.33333333	3.578223767
22	10.78947368	9.894736842	0.797933118
23	13.95	12.3	2.130851191
24	11	9	0.037633138
25	13.38461538	9.730769231	2.21555167
26	10.66666667	7.45	1.07107575
27	13.35714286	9.428571429	2.275681754
28	11.05	8.85	0.750589317
29	10.15384615	8.653846154	0.846140857
30	16.95833333	14	4.259594373
31	13.66666667	11.37037037	2.608643451
32	10.26086957	7.347826087	0.73842507
33	11.26923077	10.34615385	1.465722619
34	11.04761905	7.714285714	0.932361868
35	9.818181818	6	0.23388529
36	12.44444444	10.25925926	2.035990801
37	12.2	10.8	1.894028512
38	18.25	16	0.404370491
39	12.5	14	0.075594573
40	16.22222222	12.85185185	4.239792914
41	13.65517241	10.86206897	2.670052163
42	15.56521739	10.26086957	2.846986661
43	14	12	0.081279285
44	15.26666667	13	2.082366991
45	15.36111111	14.44444444	2.289681869
46	17.375	14.33333333	4.643208754
47	15.375	13.5	0.763787049
48	14.2962963	11.03703704	2.825284539
49	13.63636364	12.54545455	2.346040863
50	9.5	11.375	0.145893207
51	12	8.333333333	1.351613691
52	10.8	7.5	1.204951579
53	8.888888889	5.333333333	0.138921227
54	9.076923077	6.307692308	0.242455555
55	8.615384615	6.153846154	0.430724919
56	14.56666667	9.866666667	3.082496154
57	16.53846154	11.73076923	4.174963008

58	15.42105263	13.73684211	2.785958082
59	13.93478261	13.36956522	2.825500523
60	25	18	1.166316273
61	15.27586207	10.65517241	2.904628603
62	12.46666667	8.4	2.207949016
63	14.34482759	10.96551724	3.332588921
64	10.43333333	8.366666667	1.100276853
65	9.272727273	8.227272727	0.569784376
66	21.57142857	14.17857143	4.139472436
67	13.25	9	0.112355134
68	10.81818182	10.90909091	1.093399907
69	14.17391304	11.04347826	2.488417842
70	9.529411765	10.52941176	0.588860127
71	16.16666667	13.45833333	3.534646735
72	13.35714286	12.42857143	0.645486942
73	11.84	10.76	1.669024504
74	16.15384615	12.15384615	3.590940934
75	12.91666667	11.125	1.893337361
76	10.84	10.24	1.133590302
77	12.17647059	12.41176471	1.284710333
78	15	12.5	0.097193023
79	9.789473684	8.263157895	0.581050128
80	18.25	15.52777778	3.745084748
81	16	11.7	4.086772219
82	20.15384615	13.11538462	6.474558565
83	10	7.944444444	0.541170751
84	10.04166667	7.958333333	0.727712239
85	11.64285714	7.892857143	1.478508901
86	9.2	7.64	0.576073845
87	9.346153846	6.923076923	0.579667827
88	13.77777778	12.94444444	1.888775769
(blank)			
Grand Total	**13.38234479**	**10.20537694**	**177.4125896**