



Proceeding of the fourth training on R for forest statistics and modelling



Bangladesh Forest Department
09 – 10 October 2016



The Forest Department of Bangladesh leads actions to improve forest management and conservation, adopting forward thinking, innovative approaches in its management of approximately 1.55 million hectares of land across the country.

In 2015, the Forest Department began a process to establish a National Forest Inventory and Satellite Land Monitoring System for improved forest and natural resource management. The process supports national objectives related to climate change mitigation and provides information in support of the UN-REDD programme aimed at Reducing Emissions from Deforestation and Forest Degradation (REDD+). The process also addresses domestic information needs and supports national policy processes related to forests and the multitude of interconnected human and environmental systems that forests support.

The activities implemented under the Bangladesh Forest Inventory process are collaboration between several national and international institutions and stakeholders. National partners from multiple government departments and agencies assist in providing a nationally coordinated approach to land management. International partners, including the United States Agency for International Development (USAID) and the Food and Agriculture Organization of the United Nations (FAO) are supporting the development of technical and financial resources that will assist in institutionalizing the process.

The results will allow the Forest Department to provide regular, updated information about the status of trees and forests for a multitude of purposes including for assessment of role of trees for firewood, medicines, timber, and climate change mitigation.

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Disclaimer

This report is designed to reflect the activities and progress related to the project GCP/GD/058/USAID “Strengthening National Forest Inventory and Satellite Forest Monitoring System in support of REDD+ in Bangladesh”. This report is not authoritative information sources – it does not reflect the official position of the supporting international agencies including USAID or FAO and should not be used for official purposes. Should readers find any errors in the document or would like to provide comments for improving its quality they are encouraged to contact one of above contacts.

EXECUTIVE SUMMARY

The fourth R training was held at the Bureau of Statistics in Dhaka, October 2-4. The objective of the training was to follow up on the R training dedicated to forest modelling and allometric equations by practicing non-linear modelling to develop tree height-diameter relationship using historical Bangladesh inventories. Six participants (all male) attended to the training. All the participants attended the second R training on forest data analysis but half of them could not participate to the third training on forest modelling.

The training was divided in four half day sessions. One half day was dedicated to practice basic R command lines to check the data and remove outliers. The theory on non-linear was presented during one hour, then the rest of the time was spend on practice. The last part of the training was used to show how to validate a model using an external dataset to calculate model bias. At the end of the training four non-linear models with mixed effects were developed. The best model selected followed Gompertz formula and specific parameters were calculated for each forest type.

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1 INTRODUCTION

The fourth R training was held at the Bureau of Statistics in Dhaka, October 2-4. This training followed an introduction to R training, a second training focusing on using R for forestry data analysis and a third training dedicated for allometric equations and modelling. The objective of this fourth training was:

To follow up on the R training dedicated to forest modelling and allometric equations by practicing non-linear modelling to develop tree height-diameter relationship using historical Bangladesh inventories.

The training was divided into one half day session on theory, one half day session on practicing R for data cleansing and preparation, one day session on model development and one half day session on calculating bias to estimate the model performance with an independent dataset.

2 SUMMARY OF THE THEORY SESSION

2.1 Introduction to the training

The theory session was divided in two parts. The first part recalled the different steps presented to calculate forest biomass estimates based on national forest inventory (NFI) usual data (Figure 1). The training focused on the steps 4 and 5 where tree height measurement can be used to develop a relationship or allometric equation between tree height (H) and diameter at breast height (DBH).

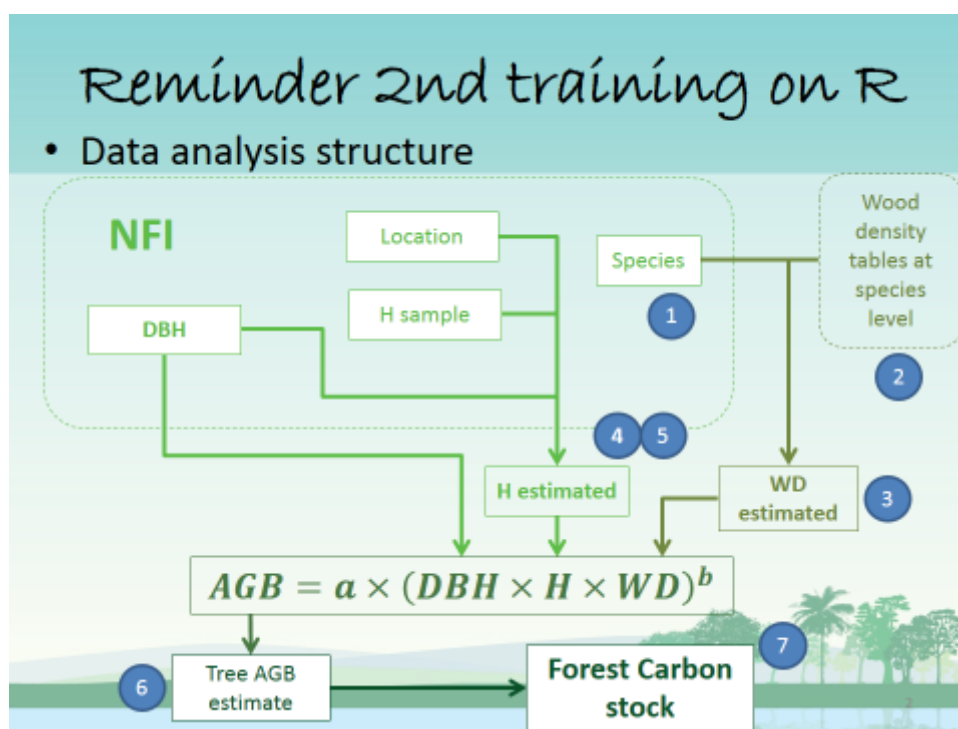


Figure 1: Step by step approach to estimate forest biomass.

Overall developing allometric equations require seven steps, from the design of the data to be collected to the field work and the model fitting and validation (Figure 2). The training specifically focus on the four final steps, preparing the data, observe it with graphs and summary tables, fitting the models and validating the best model selected.

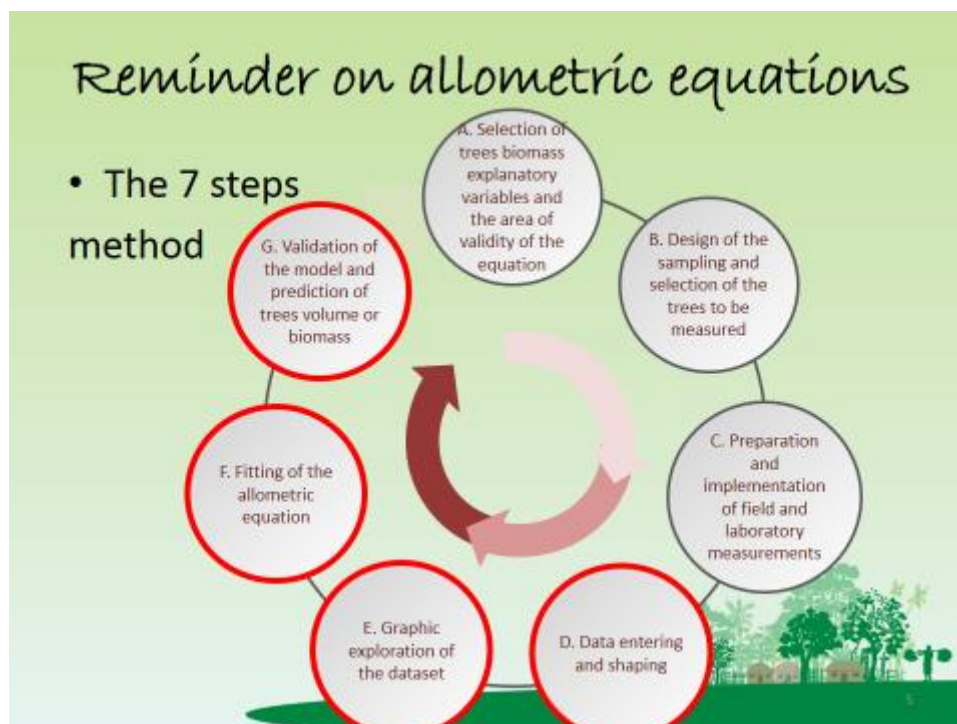


Figure 2: The seven step methodology for developing allometric equations.

2.2 Reminder on theoretical aspects of fitting allometric equations

The training module on model fitting was presented a second time (same module as in the training on allometric equations) with an emphasis on non-linear models.

The most important concepts to take home from this module are:

- Definitions of output variable, input variables and parameters; and observation, prediction and error.
- Developing a model corresponds to finding the optimal parameters that minimize the model error. Each time users run a model fitting command in R, the software's response is the best possible model given the formula of the equation desired and the data used to develop the model.
- Non-linear models using the maximum likelihood procedure are based on an iterative process, relying on user defined starting values for the parameters.
- Key information given by model summary should be checked to ensure that the model fits to the data and compare it with other models developed (Figure 3).
- The model quality is based on:
 - The parameters are significantly different from 0 ($p\text{-value} < 0.01$),
 - Graphical representation of the fitted values against the observation don't show strong bias (large deviation from the line $y = x$),
 - The model heteroscedasticity is controlled.
- Among all the model meeting the quality requirement the model with the lowest AIC can be selected as the best model to estimate the output variable based on the input variables. If several model have similar AIC (difference smaller than 5), the most simple model should be selected.

```

> summary(nlm)
Nonlinear mixed-effects model fit by maximum likelihood
Model: AGB ~ DBH^b
Data: cbind(df, g = "a")
      AIC      BIC    logLik
30.72627 28.27145 -11.36314

Random effects:
Formula: b ~ 1 | g
          b Residual
stddev: 2.245066e-10 26.93095

Variance function:
Structure: Power of variance covariate
Formula: ~DBH
Parameter estimates:
  power
-1.5636
Fixed effects: b ~ 1
  value Std.Error DF t-value p-value
b 1.395057 0.01463998 3 95.2909 0

Standardized within-Group Residuals:
      a      a      a      a
0.148528 1.467475 -1.331872 0.224889
attr(,"label")
[1] "Standardized residuals"

Number of Observations: 4
Number of Groups: 1

```



Figure 3: Key information in non-linear model summary.

3 DEVELOPPING H-D RELATIONSHIPS FOR BANGLADESH

3.1 Data preparation

The first script used for the training was divided into two sections. The first section was mainly for practicing the functions and command lines from the second R training on forestry data analysis. The following example show the use of the functions `summary()`, `length()` and `unique()`.

```

# Display the summary of broad_f_type
summary(tree$broad_f_type)

## Bamboo or mixed bamboo/forest          Coastal forest
##                               934          38909
## Hill forest                             mangrove
##                               98262        3892
## mangrove plantations                    Non forest
##                               7           49694
## plantations                             Sal forest
##                               139         23809
## Sundarbans forest
##                               149066

# How many broad_f_type do we have?
length(unique(tree$broad_f_type))

## [1] 9

```

The second part was dedicated to prepare the dataset for modelling, by selecting only trees having both DBH and H measured and removing errors or outliers. In the data used for modelling, errors were negative tree height values and stumps with tree height smaller than 2 m.

```

# Create the table t_hd containing only trees with both dbh and h measured
# (Use the subsetting technic with the function which() and is.na() )
t_hd <- tree[which(!is.na(tree$h_m)),]

```

```
# Display the summary of t_hd
summary(t_hd$h_m)

##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## -20.70   8.20   11.70   11.91  15.00   60.00

# Remove the trees smaller than 2 m height
t_hd <- t_hd[which(t_hd$h_m > 2),]
```

The Figure 4 show the result of the following command lines, applied before and then after removing the tree with a DBH smaller than 2 m.

```
# Plot h against dbh
p <- ggplot(t_hd)
p <- p + geom_point(aes(x=dbh_cm, y=h_m))
p
```

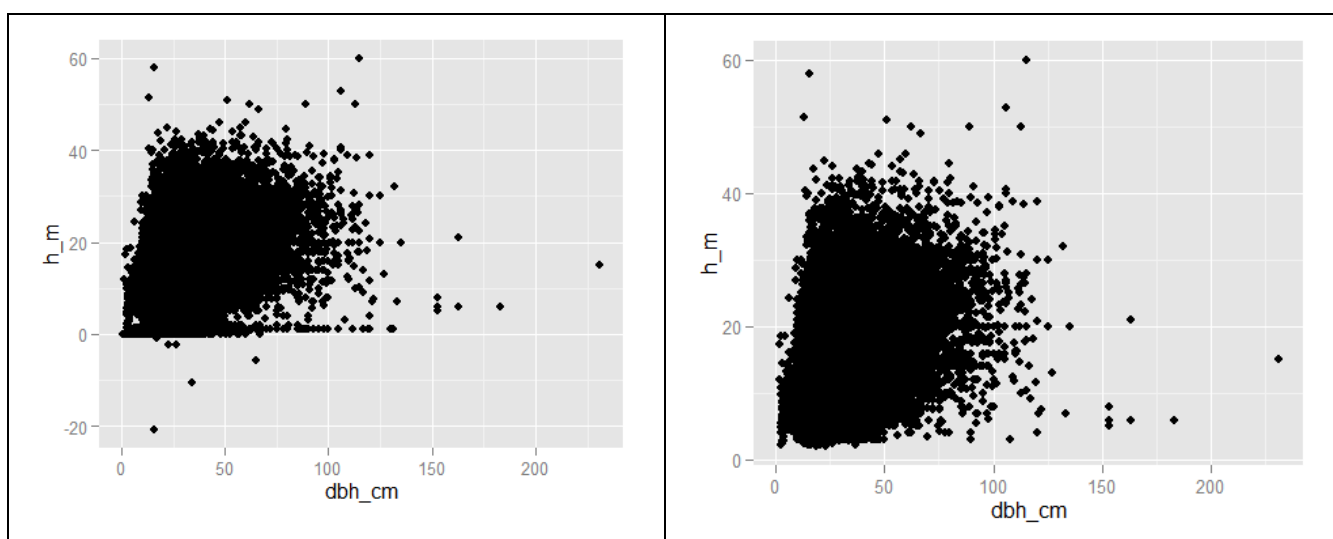


Figure 4: tree height against diameter before (left) and after (right) removing outliers and potential errors.

3.2 Method for model fitting

The second script shared during the training contained all the basic functions for fitting non-linear model, in particular the function `nlme()`, using the maximum likelihood procedure to fit non-linear models with mixed effects. The code used to fit a model and display the necessary information to check the model quality is divided in several parts.

The first part sets the starting value of the parameters. In the following example the model has three parameters and the starting values were set to 25, -2 and -0.05.

```
mystart <- c(25, -2, -0.05)
names(mystart) <- c("a", "b", "c")
```

The second part run the `nlme()` formula with the model characteristics: formula, dataset¹, parameters name, starting values, mixed effect tested (category variable), and residual function.

¹ The `nlme()` function is designed to test the effect of a variable on parameters and define specific parameters for each value of the tested variable. In case users don't want to test a random effect, a column `g` is created in the dataset containing only the value 'a', forcing the function to consider all the data as part of only one group. This is the role of the function `cbind(tree, g="a")`.


```
# Run the model
m1 <- nlme(h_m~1.3+a*exp(b*exp(c*dbh_cm)),
           data=cbind(tree,g="a"),
           fixed=a+b+c~1,
           start=mystart,
           groups=~broad_f_type,
           weights=varPower(form=~dbh_cm))
```

Then last part display the model summary, the fixed values for each parameter (fixef()) and specific values for each parameter and each value of the grouping variable(ranedf()), incorporate the model fitted values, residuals and weighted residuals into the dataset and display the graphs:

- observation and fitted values against an input variable (dbh here),
- fitted values against observations,
- residuals against fitted values,
- weighted residuals against fitted values.

In the summary the key information is that the p-value of each parameter is smaller than 0.01, check that formula corresponds to the needs of the user and note the AIC.

```
# Display the basic information on the model
summary(m1)

## Nonlinear mixed-effects model fit by maximum likelihood
## Model: h_m ~ 1.3 + a * exp(b * exp(c * dbh_cm))
## Data: cbind(tree, g = "a")
##      AIC      BIC logLik
## 772342.1 772450.3 -386160
##
## Random effects:
## Formula: list(a ~ 1, b ~ 1, c ~ 1)
## Level: broad_f_type
## Structure: General positive-definite, Log-Cholesky parametrization
##      StdDev   Corr
## a      3.94789122 a      b
## b      1.17575461 0.860
## c      0.04895612 0.995 0.905
## Residual 1.01935760
##
## Variance function:
## Structure: Power of variance covariate
## Formula: ~dbh_cm
## Parameter estimates:
##      power
## 0.4463008
## Fixed effects: a + b + c ~ 1
##      Value Std.Error   DF  t-value p-value
## a 18.554938 1.6158821 138760 11.482854      0
## b -2.396482 0.4819025 138760 -4.972961      0
## c -0.085879 0.0200336 138760 -4.286733      0
## Correlation:
##      a      b
## b 0.855
## c 0.994 0.903
##
```

```
## Standardized Within-Group Residuals:
##      Min      Q1      Med      Q3      Max
## -3.21768462 -0.66053476 -0.09656928  0.55043649 10.62231078
##
## Number of Observations: 138768
## Number of Groups: 6
```

The command lines `fixef()` and `ranef()` provide the values of the model's parameters.

```
fixef(m1)
```

```
##      a      b      c
## 18.5549376 -2.3964821 -0.0858785
```

```
ranef(m1)
```

```
##      a      b      c
## Bamboo or mixed bamboo/forest -3.4374308 -0.8023843 -0.041811428
## Coastal forest                -0.7825549  0.3263286 -0.005516092
## Hill forest                    1.9197672  0.9246212  0.027100645
## Non forest                     6.8512568  0.9963419  0.078594078
## Sal forest                     0.8590608  0.7961460  0.015135553
## Sundarbans forest             -5.4100990 -2.2410534 -0.073502756
```

The function `AIC()` gives directly the model's AIC.

```
AIC(m1)
```

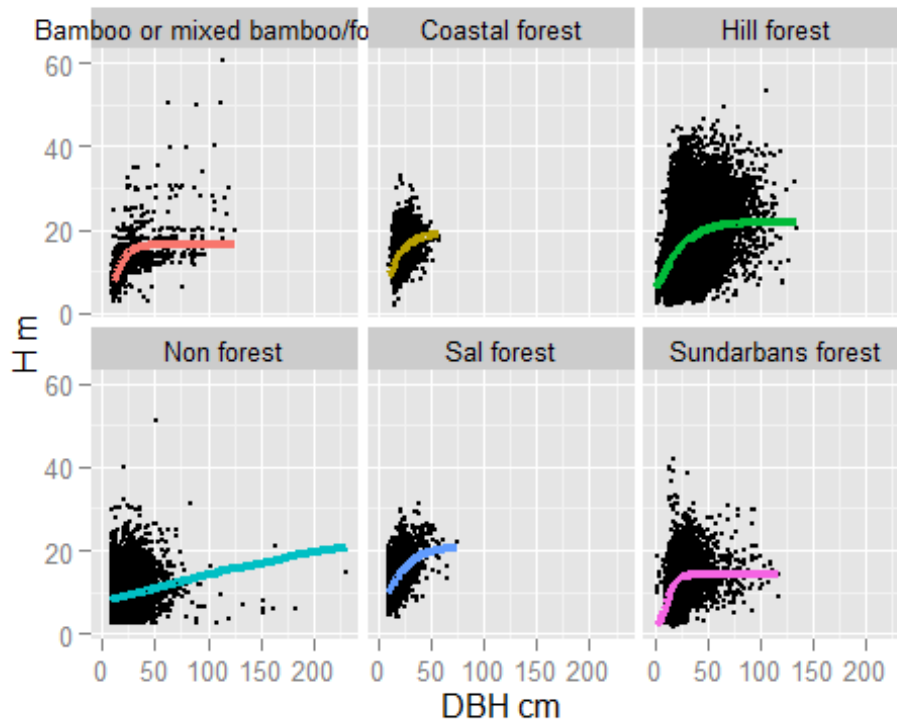
```
##
## 772342.1
```

The next piece of code incorporates the model fitted values, residuals and weighted residuals for each observation as new columns in the dataset.

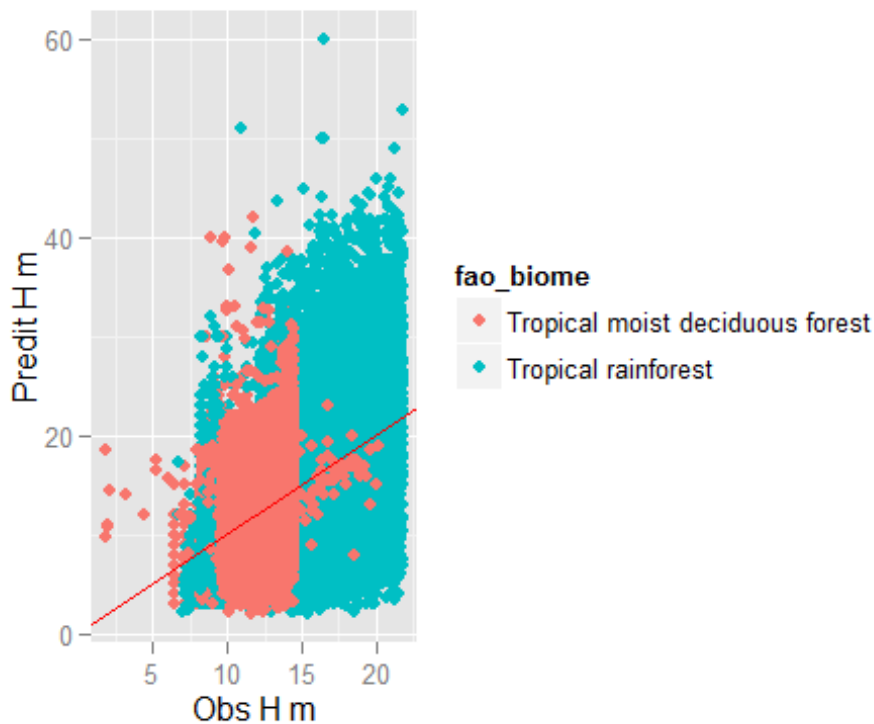
```
# Add the fitted values and the error to the table tree
tree$fit_m1 <- fitted.values(m1)
tree$res_m1 <- residuals(m1) # h_m - fit_m1
k <- summary(m1)$modelStruct$varStruct[1]
tree$resw_m1 <- residuals(m1)/tree$dbh_cm^k
```

Finally the rest of the code display the necessary graphs to check the model quality.

```
# Verify visually the model quality
p <- ggplot(tree)
p <- p + geom_point(aes(x=dbh_cm, y=h_m), position="jitter", cex=0.5)
p <- p + geom_line(aes(x=dbh_cm, y=fit_m1, colour=broad_f_type), cex=1.5)
p <- p + xlab("DBH cm") + ylab("H m")
p <- p + facet_wrap(~broad_f_type)
p
```

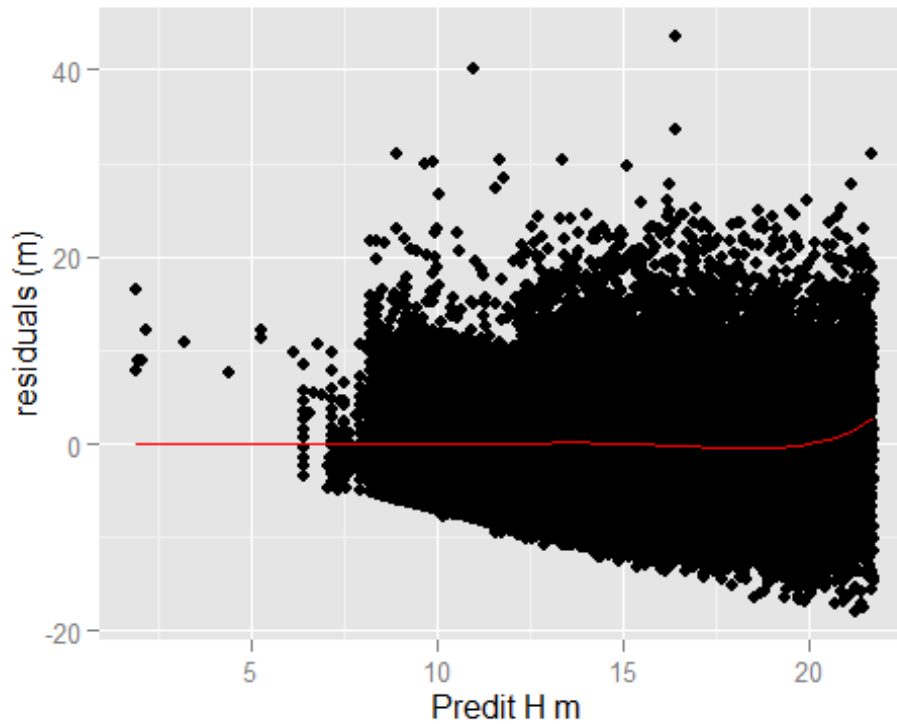


```
p <- ggplot(tree, aes(x=fit_m1, y=h_m, colour=fao_biome))
p <- p + geom_point()
p <- p + geom_abline(intercept = 0, slope = 1, col="red")
p <- p + xlab("Obs H m") + ylab("Predit H m")
p
```

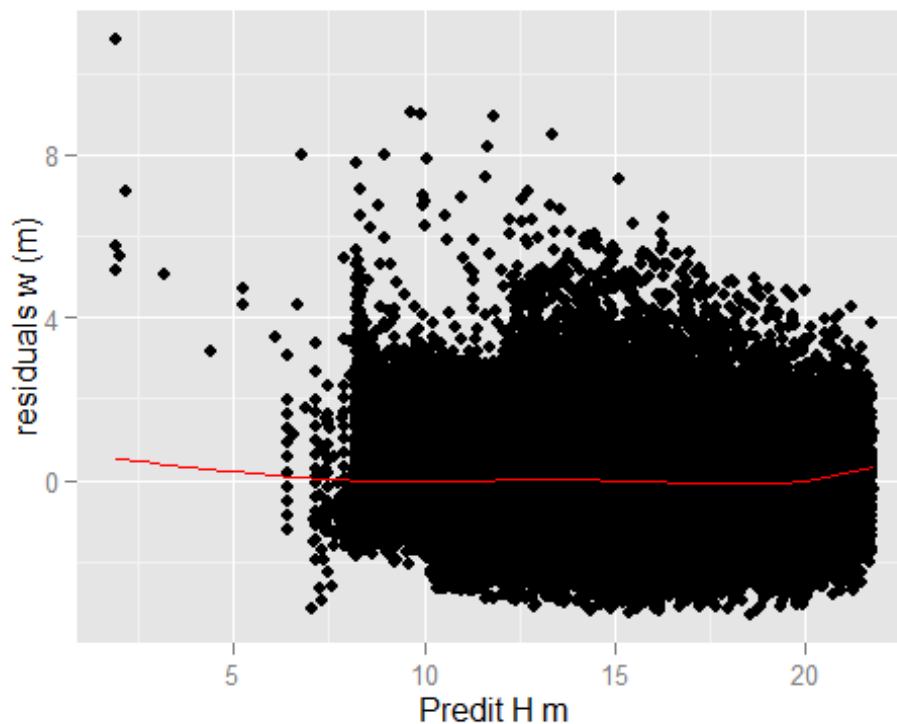


```
p <- ggplot(tree, aes(x=fit_m1, y=res_m1))
p <- p + geom_point()
p <- p + stat_smooth(method = "auto", se = FALSE, colour="red")
p <- p + xlab("Predit H m") + ylab("residuals (m)")
#p <- p + facet_wrap(~broad_f_type)
p
```

```
## geom_smooth: method="auto" and size of largest group is >=1000, so using gam with f  
ormula: y ~ s(x, bs = "cs"). Use 'method = x' to change the smoothing method.
```



```
p <- ggplot(tree, aes(x=fit_m1, y=resw_m1))  
p <- p + geom_point()  
p <- p + stat_smooth(method = "auto", se = FALSE, colour="red")  
p <- p + xlab("Predit H m") + ylab("residuals w (m)")  
p
```



3.3 H-D model developed

Four models were developed during the training and one model selected as the best model developed (Table 1). None of these models is final as more data need to be incorporated to the final dataset. The final model can be found in the report: “Forest Biomass in Bangladesh: An historical review of forest inventories to assist national estimates” (publication on-going). A full description of each model developed is detailed in annex.

Model formula	Random effect	AIC
$h_m \sim 1.3 + a * dbh_{cm}^b$	no	805589
$h_m \sim 1.3 + a * dbh_{cm}^b$	fao_biome	799068
$h_m \sim 1.3 + a * dbh_{cm}^b$	broad_f_type	773494
$h_m \sim 1.3 + a * \exp(b * \exp(c * dbh_{cm}))$	broad_f_type	772342

Table 1: Models developed during the training. The model in bold was selected as the best model.

4 BIAS CALCULATION

Calculating the model bias require using an external dataset, independent from the data used to fit the model. For this section, few plots were extracted from the data, the model form and random effect selected as the best model in the previous section were re-used with the data subset and the resulting new model was tested against the data from the few plots isolated.

The few plots were selected manually in the coastal forest area.

```
# table for valdiation
tree_valid <- tree[which(tree$main_plot_id == "P_5335" |
                        tree$main_plot_id == "P_5426" |
                        tree$main_plot_id == "P_5458" |
                        tree$main_plot_id == "P_4863" |
                        tree$main_plot_id == "P_4909"),]
```

Then the model was developed with the rest of the data. The resulting fixed effect parameters were and the random effect value for coastal forest were added to create the specific parameters of the model for coastal forest.

```
### Add the model to validation table
a_co <- 18.56448339 + (-0.6998076)
b_co <- -2.39976035 + 0.3380848
c_co <- -0.08581488 + (-0.004762724)
```

Finally the tree height was estimated using the model (new column h_es), the error was calculated as the difference between the observed and estimated values, and the bias was calculated as the sum of the errors divided by the sum of the observations, in percentage. The result was -14.7 %, meaning that the model tends to overestimate the tree height by 14%.7 % on average.

```
tree_valid$h_es <- 1.3 + a_co*exp(b_co*exp(c_co*tree_valid$dbh_cm))
tree_valid$h_error <- tree_valid$h_m - tree_valid$h_es

bias <- sum(tree_valid$h_error)/sum(tree_valid$h_m)*100
bias
## [1] -14.74698
```

5 EVALUATION OF THE TRAINING AND CONCLUSION

Six Participants attended to the training. All the participants attended the second R training on forest data analysis but half of them could not participate to the third training on forest modelling.

At the end of the training three participants had a good understanding of the code and demonstrated that they were able to develop models by themselves. The other participants need more practice on R basics to be more confident with the code and focus more on the new code provided specifically for developing models.

Only three participants answered the evaluation, they overall felt that the training was useful and that they would be able to use it for their work. It was particularly appreciated that Bangladesh data was used for the training.

ANNEX 1: AGENDA

Dates and venue: January 31st – February 4th 2016 at BBS in Dhaka

Date	Topic	Speaker / facilitator
Day 1	Opening session	
8:30	Registration	
9:00	Welcoming remarks Training objectives	UN-REDD Focal point / Gael Sola
9:30	Overview of the first R training	Liam Costello
9:45	Overview of the current data analysis process	RIMS
10:15	Break	
	Session 1: General introduction	
10:45-11:45	General introduction to forest modelling and statistics in the context of REDD	Gael Sola
11:45-12:15	<ul style="list-style-type: none"> • Verification of software and packages installation • Overview of the data 	
	Session 2: hands on R – Objects and simple calculations	
14:00-17:00	<ul style="list-style-type: none"> • Simple exercises on R • Basic calculations. 	
Day 2	Session 3: hands on R – operations on data frames	
8:30-12:00	<ul style="list-style-type: none"> • Creating a file ready for R • Reading the file with R • Adding new columns • Select columns • Aggregate data 	
	Session 4: hands on R – graphs and visual interpretation	
14:00-17:00	<ul style="list-style-type: none"> • Basic graphs • Introduction to ggplot2 • Practice 	
Day 3	Session 5: NFI to forest biomass	
8:30-12:00	<ul style="list-style-type: none"> • Correction of species names • Linking wood densities 	
	Session 6: NFI to Forest biomass	
14:00-17:00	<ul style="list-style-type: none"> • Practice 	
Day 4	Session 7: NFI to forest biomass	
8:30-12:00	<ul style="list-style-type: none"> • Applying a H-D model using FAO biomes and plot Hmax • Applying a pantropical biomass equation 	
	Session 8: NFI to forest biomass	
14:00-17:00	<ul style="list-style-type: none"> • Aggregating tree biomass to plot and forest types 	
Day 5	Session 8: Conclusion	
8:30-10:30	<ul style="list-style-type: none"> • Extraction of results into a report 	
10:30	Break	
11:00-12:00	Conclusion	

ANNEX 2: PARTICIPANTS LIST

Name	Organisation	Sex	Designation	Phone no.	e-mail
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ANNEX 3: EVALUATION RESULTS

Total Response=3			
	Male	3	100%
	Female	0	0%
1	How often do you participate in training related to forest monitoring?		
	First time	0	0%
	1-3 every year	3	100%
	More than 3 per year	0	0%
	Regularly (approximately one per month)	0	0%
2	I would describe my self as?		
	A professor/academic	1	33%
	A student	0	0%
	Forest Department staff	2	67%
	Government staff (outside Forest Department)	0	0%
	NGO staff	0	0%
	Private consultant	0	0%
	Other	0	0%
			0%
3	My professional background relates most closely to:		
	Forester	3	100%
	GIS/RS	0	0%
	Statistics	0	0%
	Social survey/assessment	0	0%
	Economics	0	0%
	Natural Resource Management	0	0%
	Ecology	0	0%
	other	0	0%
4	My years of relevant experience is:		
	1-2 years	0	0%
	3-5 years	0	0%
	5-7 years	0	0%
	8-10 years	1	33%
	More than 10 years	2	67%
5	The training was relevant to my daily work		
	Strongly agree	2	67%
	Agree	1	33%
	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
6	I had enough previous knowledge to understand the content of the event		
	Strongly agree	2	67%
	Agree	1	33%

	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
7	The training met my expectations in terms of the content and learning outcomes		
	Strongly agree	1	33%
	Agree	2	67%
	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
8	The learning resources provided were adequate and useful		
	Strongly agree	1	33%
	Agree	2	67%
	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
9	The resource person presented information in a way that i could understand and was easy to follow		
	Strongly agree	1	33%
	Agree	2	67%
	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
10	I feel confident to be able to carry out the tasks described in the training without supervision.		
	Strongly agree	0	0%
	Agree	3	100%
	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
11	I was pleased with the venue/meeting room/snacks etc.		
	Strongly agree	2	67%
	Agree	1	33%
	Neutral	0	0%
	Disagree	0	0%
	Strongly disagree	0	0%
12	Are there other people/agencies/organizations that you think should have been included in the training?		
	More people from FD especially ACF and research officers.		
	More ACF and Research Officers of BFD should have this training.		
13	Any other comments?		

	It is good that data set taken for practice is from Bangladesh. Schedule is very tight. It needs more practice.		
	It's good that the resource person have dealt with data set of Bangladesh Context for practice.		

6 ANNEX: DETAILS ON THE MODELS DEVELOPED

Formula $h_m \sim 1.3 + a * dbh_{cm}^b$

N_parameters 2

N_observations 138768

ranef_variable NA

residual_function varPower

residual_coeff 0.5050294

AIC

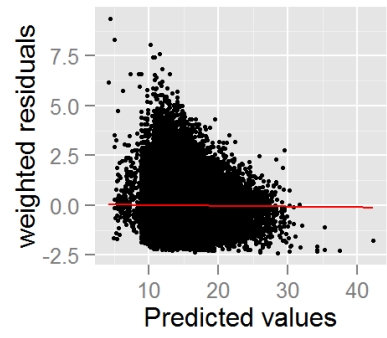
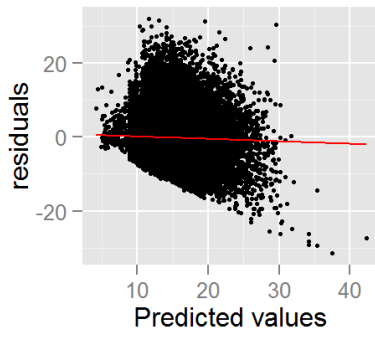
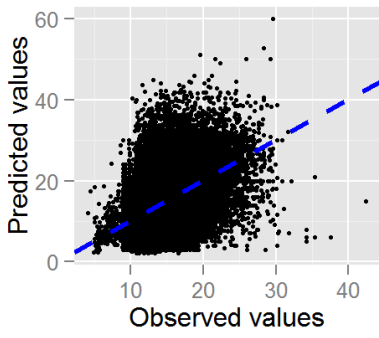
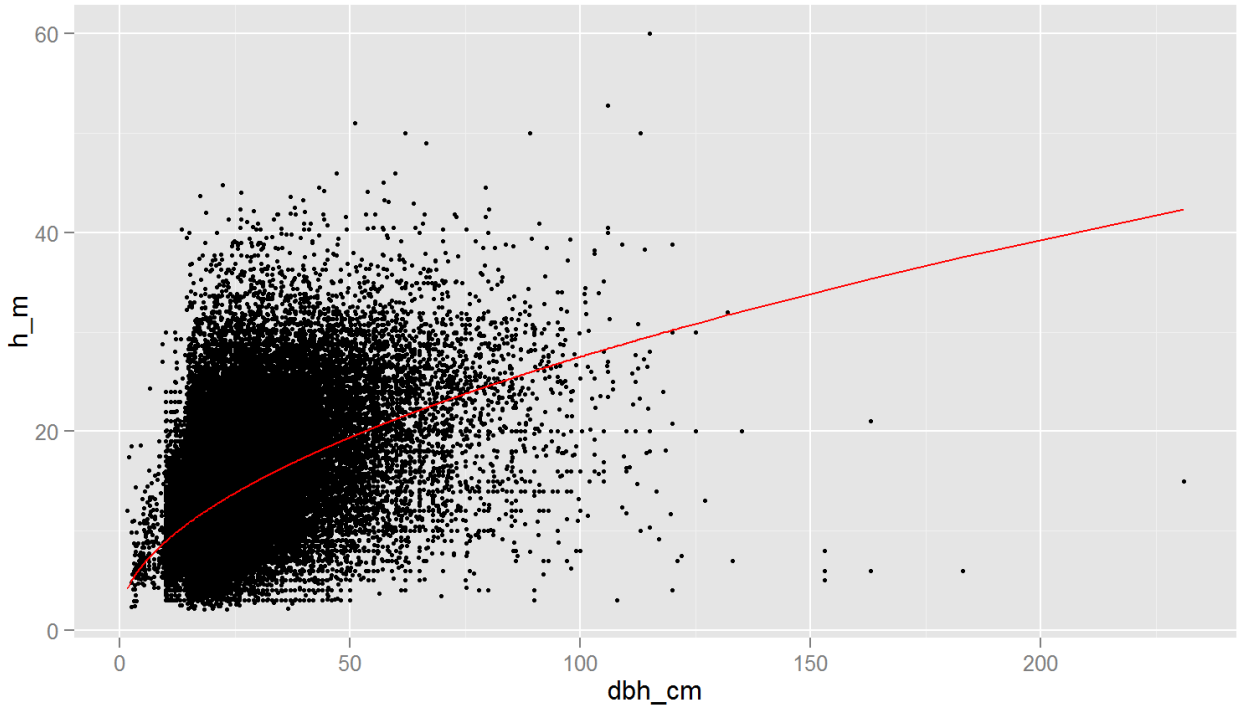
805589

Fixed parameters

	a	b
starting values	2.000000	0.500000
MODEL PARAMETERS	2.225103	0.5354296
p_values	0.000000	0.000000
se	0.018160	0.0026800

Random effect parameters

Graphes



Formula $h_m \sim 1.3 + a * dbh_{cm}^b$

N_parameters 2

N_observations 138768

ranef_variable fao_biome

residual_function varPower

residual_coeff 0.4615575

AIC

799068.2

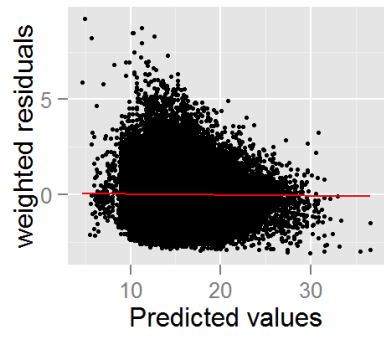
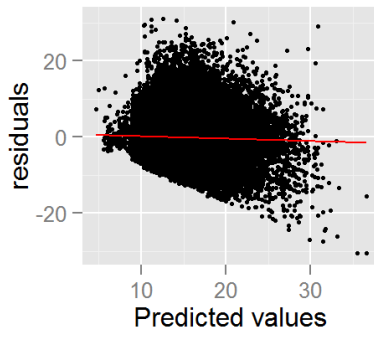
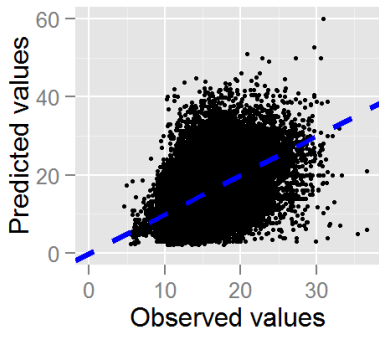
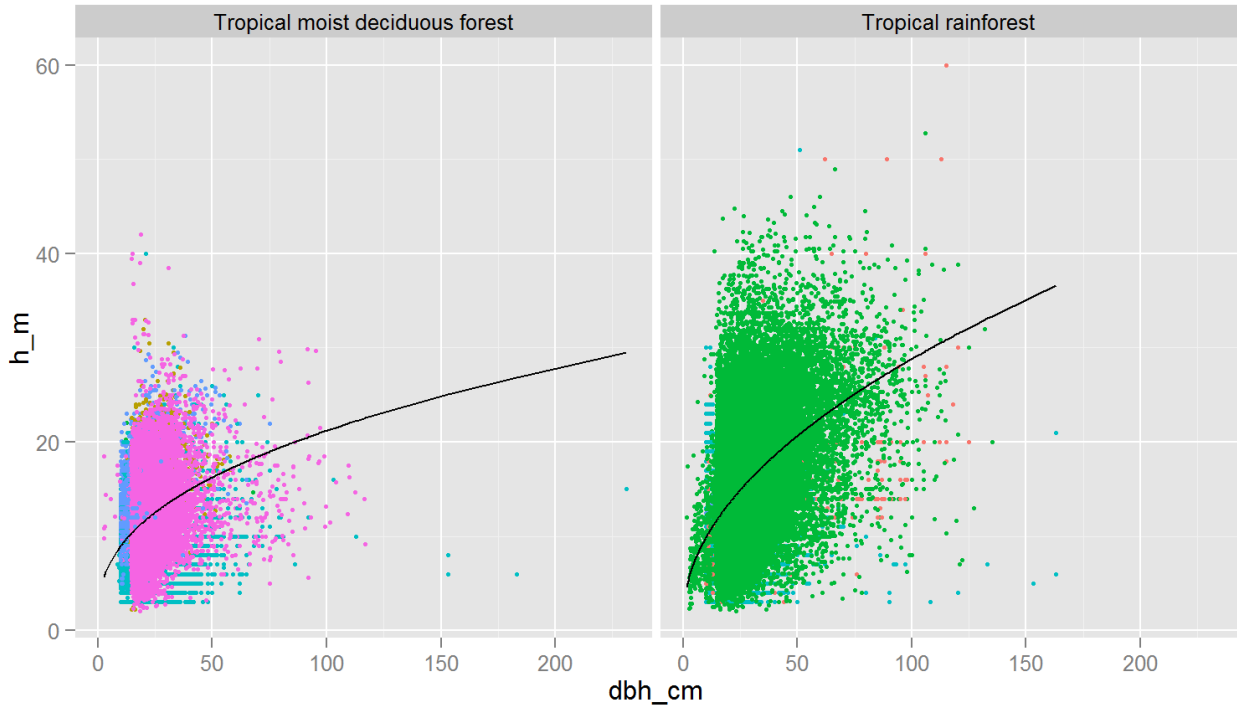
Fixed parameters

	a	b
starting values	2.000000	0.500000
MODEL PARAMETERS	2.794236	0.4618278
p_values	0.000000	0.000000
se	0.110180	0.0333700

Random effect parameters

	a	b
Tropical moist deciduous forest	0.1525109	-0.0470426
Tropical rainforest	-0.1525109	0.0470426

Graphes



Formula $h_m \sim 1.3 + a * dbh_{cm}^b$

N_parameters 2

N_observations 138768

ranef_variable broad_f_type

residual_function varPower

residual_coeff 0.4460745

AIC

773493.8

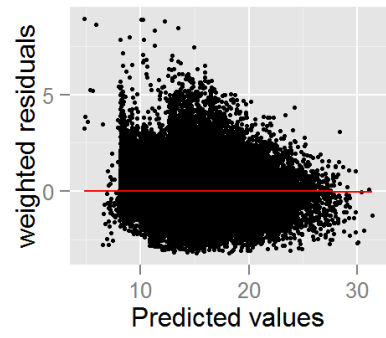
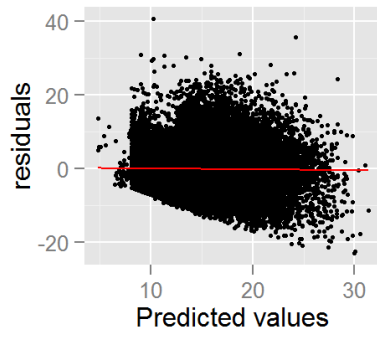
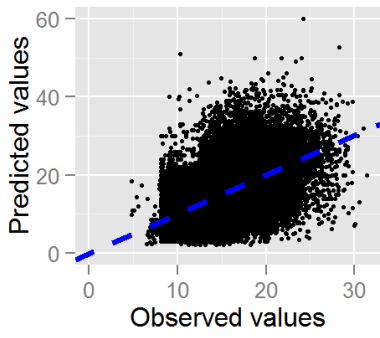
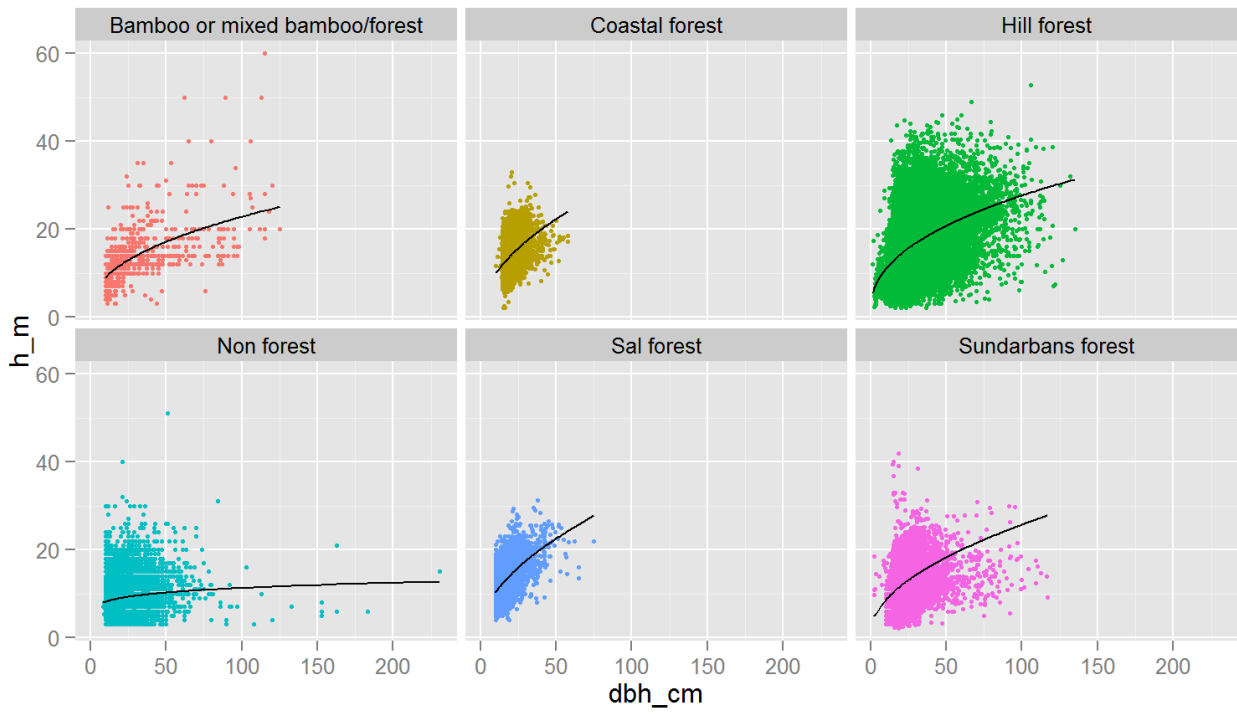
Fixed parameters

	a	b
starting values	2.000000	0.500000
MODEL PARAMETERS	3.001644	0.446082
p_values	0.000000	0.000000
se	0.354390	0.055050

Random effect parameters

	a	b
Bamboo or mixed bamboo/forest	-0.2026067	-0.0029129
Coastal forest	-0.6337751	0.1123704
Hill forest	0.4665119	-0.0058454
Non forest	1.6720330	-0.2811247
Sal forest	-0.4280278	0.0936599
Sundarbans forest	-0.8741354	0.0838527

Graphes



Formula $h_m \sim 1.3 + a * \exp(b * \exp(c * dbh_{cm}))$
 N_parameters 3
 N_observations 138768
ranef_variable broad_f_type
 residual_function varPower
 residual_coeff 0.4463008

AIC

772342.1

Fixed parameters

	a	b	c
starting values	25.00000	-2.000000	-0.0500000
MODEL PARAMETERS	18.55494	-2.396482	-0.0858785
p_values	0.00000	0.000000	0.0000200
se	1.61588	0.481900	0.0200300

Random effect parameters

	a	b	c
Bamboo or mixed bamboo/forest	-3.4374308	-0.8023843	-0.0418114
Coastal forest	-0.7825549	0.3263286	-0.0055161
Hill forest	1.9197672	0.9246212	0.0271006
Non forest	6.8512568	0.9963419	0.0785941
Sal forest	0.8590608	0.7961460	0.0151356
Sundarbans forest	-5.4100990	-2.2410534	-0.0735028

Graphes

