Development of Emission and Removal Factors in Tonle Sap flooded forest, Cambodia

Diospyros bejaudii

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Development of Emission and Removal Factors in Tonle Sap flooded forest, Diospyros bejaudii, Cambodia

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EXECUTIVE SUMMARY

Context:

The Great lake ('Tonle Sap') is the largest lake in the Southeast Asia and is often seen as the heart of Cambodia as it provides countless social, economic, cultural and environmental values. The Tonle Sap is a natural basin that annually receives approximately 20% of the flood water from the Mekong River. At present, people living in 5 provinces surrounding the lake largely depend on the Tonle Sap and its surrounding floodplain in order to make a living.

A large area of the lake is composed of flooded forest ecosystem. The flooded forest of the Tonle Sap is rich in plant species, including trees, wood-shrubs, vines (climbing plants), grasses, and aquatic plants. However despites the importance of Tonle Sap lake and its flooded forest, both ecologically and economically, flooded forest have been little studied and the contribution to greenhouse gas emissions or uptake remains mostly unknown.

Objectives:

The objectives of this study is to develop biomass allometric equations to improve carbon stock estimates and emission/removal factors for the flooded forests.

Methodology:

The forest structure and composition were assessed in 2015 with tree measurement in 18 nested plots following the NFI plot design. The plots were established in areas representative of the flooded forests in two provinces: Battambang and Kampong Chhnang. The location of the plots didn't follow the NFI grid. During the current study 39 trees were felled of the species Diospyros bejaudii, following the recommendation of the previous findings to study *Diospyros bejaudii* the second most dominant tree in terms of abundance and diameter range. Tree aboveground biomass (AGB), diameter at breast height (DBH), total height (H), crown area (CA), hole dimensions, dominance and wood density (WD) were measured and allometric equations were developed to relate tree biomass to their diameter, height, crown area and wood density. Non-linear power models were tested with DBH, DBH and H, DBH, H and WD, and with or without crown area as an additional input variable. The influence of the province and the presence of holes inside the tree stem were tested as random effect on model parameters.

Results:

In total seven species of trees were recorded in the flooded forest structure and composition assessment, but more than 80 % of the trees belonged to one species, *Barringtonia acutangula*. For this species tree diameter ranged from 5 to 94 cm and the maximum tree height was 20m. Most *B. acutangula* trees with a diameter bigger than 60 cm were found to be hollow. For this species a monospecific model has been developed. The second most important species was *Diospyros bejaudii*. Lianas were very important in several plots and the understorey could grow very dense before the new seasonal flooding.

The biomass and wood density measurement of this follow up study focused on *Diospyros bejaudii*. The average wood density was found to be 0.536 $g.cm^{-3}$ with no influence of the tree DBH. All the models developed had a very similar goodness of fit with AIC[1] ranging from 466 to 481. Crown Area (CA) didn't improve the models, but many models including CA as input variable did not converge. The effect of the presence of holes improved the models.

Finally, two models were selected, the model with two input variables (DBH and H) being equally good:

- **220.227*D2H^0.98**

  with DBH in cm, D2H = (DBH/100)^2*H in m^3

Conclusion:

The allometric models, despite been based on small number of trees provide a first tool to estimate tree and forest biomass in this area. As they are monospecific and based on several areas around the lake, the models are expected to be robust enough to provide unbiased estimates of tree biomass.

Additional studies on large hollow trees of *B. acutangula* would improve these estimates, as well as studies on *Diospyros bejaudii*, the dense understorey, the shrub land that appears in this area, and the soil of this unique and particular ecosystem of the flooded forest.

[1] Akaike Information Criterion: a measure of the relative quality of statistical model for a given set of data

ACRONYMS AND ABBREVIATIONS

AGB	Aboveground Biomass
AIC	Akaike Information Criterion
BGB	Below Ground Biomass
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
FiA	Fishery Administration
GPS	Global Positioning System
H	Height
NFI	National Forest Inventory
RUA	Royal University of Agriculture
SSE	Sum of Squares Estimation
UNDP	United Nations Development Programme
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Country
WD	Wood Density

ACKNOWLEDGEMENTS

The authors would like to acknowledge the staff of the Fisheries Administration of the Royal Government of Cambodia for their support in coordination of the study and field measurements, the students and staff of the Royal University of Agriculture for collecting forest inventory data and conducting laboratory measurements. We also would like to acknowledge the General Department of Administration for Nature Conservation and Protection and the Forestry Administration of Cambodia, and institutions that contributed to the efforts in and around Tonle Sap flooded forests. It is crucial to better understand and manage flooded forest forests around the Tonle Sap.

We finally would like to thank the Food and Agriculture Organization of the United Nations, Forest Carbon Partnership Facility Project and the UN-REDD Programme for their continuous support on improving forest biomass estimates and emission factors for the forests in Cambodia.

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INTRODUCTION

The Great Lake ('Tonle Sap') is the largest lake in Southeast Asia and is often seen as the heart of Cambodia as it provides countless social, economic, cultural and environmental values. Since the Angkor period (9^{th} - 13th century) until the present, its natural resources were used to feed the Cambodian population. At present, people living in the 5 provinces surrounding the lake, including Kampong Chhnang, Pursat, Battambang, Siem Reap, and Kampong Thom still largely depend on the Tonle Sap and its surrounding floodplain in order to make a living.

The Tonle Sap is a natural basin that annually gets about 20% flood water from the Mekong River. Water flows in from the Mekong River in rainy season and water flows out to the Mekong River in the dry season. Owing to this hydrological phenomenon which rarely occurs in other places, the landscape of the Tonle Sap is variable during seasons. During the dry season, the water depth is 1 to 2 meter deep with a cover area of 250.000 to 300.000 ha (Tonle Sap Authority (TSA), 2011, estimates an area during the dry season of 250.000 ha), while the water depth is 8 to 11 meter in the rainy season, with a cover area of 1.000.000 to 1.6000.000 ha (TSA estimates 1.500.00 ha).

This phenomenon resulted in a wetland habitat with large biodiversity richness, such as fish, birds, reptiles, mammals, and a variety of plants species. The Tonle Sap's biodiversity includes over 200 fish species, 42 reptile species, 225 bird species, 46 mammal species, and 200 plants species. It provides for numeral ecological functions and particularly rich fishing grounds and places for fish breeding. The lake provides in about 60% to 75% of total fish captured in the Cambodia.

A large area surrounding the dry season lake but flooded during the wet season is flooded forest ecosystem. The flooded forest of the Tonle Sap is rich in plant species, including trees, wood-shrubs, vines (climbing plants), grasses, and aquatic plants. At present, the total land area of the temporally inundated forests covers 647.406 ha along 5 provinces surrounding Tonle Sap, including Kampong Chhang, Pursat, Battambang, Siem Reap, and Kampong Thom). It provides good conditions for ecosystem conservation but the extent and quality of the forest is not well known.

Allometric equations activities in Cambodia were part of the UN-REDD national programme under the activities to design of a National Forest Inventory and to develop emission and removal factors for REDD+ related activities. Several activities were also supported by a FAO Technical Cooperation Programme project to design Cambodia's first multipurpose National Forest Inventory (NFI) implemented by the Royal Government of Cambodia and FAO. The design that has been developed recommends three sampling strata with flooded forest around the Tonle Sap and the Mekong river covered by the Wetland strata with a 4 x 4 km sampling grid (Forest Administration, FAO, 2014).

Under support of these initiatives, existing allometric equations and forest inventory data were collected, and emission factors were developed for evergreen and deciduous forests. None of the available equations was found to be sufficiently reliable to estimate tree biomass but several pan-tropical equations could be used for these forest types. However no equation was found for flooded forest. Despite the fact that this forest type is very important and quite unique in Cambodia, it remained poorly studied.

Among the three main areas where flooded forest is located, Tonle Sap lake is the most important in terms of size and relevance. To better understand of the forest structure, species composition and biomass allometry of flooded forest of Tonle Sap area a study was undertaken in 2015 by the Fisheries Administration and Royal University of Agriculture (see report: Kim S., Sola G. and Van Rijn M. (2015) Technical Report: Development of Emission and Removal Factors in Tonle Sap flooded forest, UN-REDD Programme, Phnom Penh, Cambodia). The objectives of the 2015 study were: 1) To better understand the structure and floristic composition of Flooded forest in the Great Lake 'Tonle Sap', while testing the National Forest Inventory (NFI) design for tree measurement, 2) To develop biomass allometric equations to improve carbon stock estimates and emission/removal factors for the flooded forests.

The forest structure and composition were assessed with tree measurements in 18 nested plots following the NFI plot design. The plots were established in areas representative of the flooded forests in three provinces: Battambang, Kampong Chhnang and Kampong Thom. The location of the plots didn't follow the NFI grid.

As the assessment of the structure and floristic composition of flooded forest in the research sites showed dominance of three species, and in particular *Barringtonia acutangula,* the development of allometric equations focused in first instance on a developing single species allometric equation. 28 trees were felled for the species *Barringtonia acutangula*, which was very dominant in terms of abundance and diameter range. Tree aboveground biomass (AGB), diameter at breast height (DBH), total height (H), crown area (CA), hole dimensions, dominance and wood density (WD) were measured and allometric equations were developed to relate tree biomass to their diameter, height, crown area and wood density for this. Non-linear power models were tested with DBH, DBH and H, DBH, H and WD, and with or without crown area as an additional input variable. The influence of the province and the presence of holes inside the tree stem were tested as random effect on model parameters.

OBJECTIVES

The continued research on emission and removal factors in Tonle Sap flooded forest has one specific objective: To develop biomass allometric equations to improve carbon stock estimates and emission/removal factors for the flooded forests.

As the assessment of the structure and floristic composition of flooded forest in the research sites showed dominance of three tree species, and the most dominant species, and *Barringtonia acutangula,* had been developed the current study focused on a developing single species allometric equation[2] for the second most dominant specie, *Diospyros bejaudii*. A multi-species equation can be developed if additional inventories and samples are being carried out. In addition the wood density of this species has been studied.

[2]A single-species model is often established for commercial purposes (eg. Plantations)or for forest types with a dominant specie; multi-species models are established to establish the relation of a dendrometric parameter and the biomass (AGB, BGB) in a forest type or forest biome with multiple species

METHODOLOGY

To develop allometric equations for flooded forest in Tonle Sap two steps were followed which are described in more detail in the chapter below:

Step 1: measurement in 18 plots flooded forest around Tonle Sap following the National Forest Inventory (NFI) methodology to determine species composition and forest structure. The species composition and forest structure is based on the data collected in 2015

Step 2: felling and measurement of 39 trees for allometric equation development for flooded forest in Cambodia. This second step included also laboratory measurement to determine the wood densities and study the biomass.

3.1 Step 1: Forest inventory to determine species composition and forest structure

3.1.1. Plot setup & Organization

The size and shape of the sample plots is a trade-off between accuracy, precision, time, and cost of measurement. The most appropriate size and shape may also be dependent on the vegetation type found in the sampling area. To remain consistent with capacities and plan of implementing a National Forest Inventory in Cambodia, the study has adopted the plot design developed for the NFI. The study uses the sample plot of 30m x 50m which is recommended for the wetland strata[3] (figure 1).

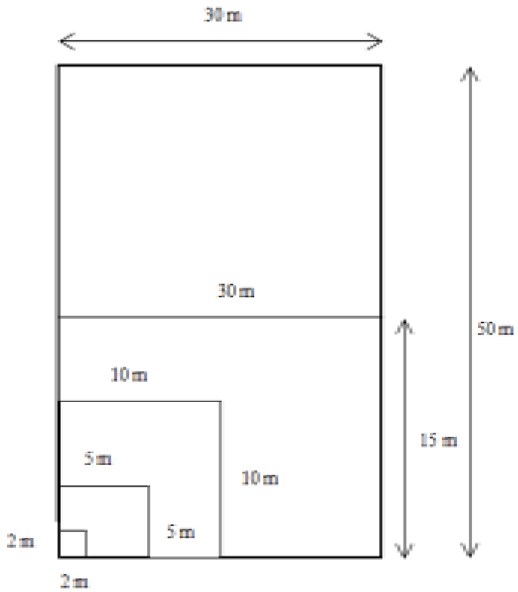


Figure 1: Rectangular plot layout

Setting up a sampling plot for measurement with the purpose of developing allometric equations should follow the following sampling criteria:

i) representativeness of the forest types being studied;
ii) representativeness for topographic conditions; and
iii) cover a number of different trees sizes.

The study did not follow NFI sampling grid to establish the plots for the study but the choose specific locations to match the above criteria.

The following steps are recommended for plot measurements:

1) The sampling strategy should be determined before the field work. Field constraints often lead to modifications of the initial sampling plan, and the following steps would need to be considered: Look for an area with less disturbed forests where large sized trees are present.
2) In the sampling area, set the “start point” with a stake;
3) The plot size is a 30m x 50m. This is called rectangular plot.

[3] Proposal for the Cambodian National Forest Inventory sampling design, Forest Administration, FAO, 2014.

4) One person[4] stands at "start point" and uses a GPS/compass to indicate the direction for the sides of the North plot following the Pythagorean Theorem;
5) Another person using the measuring tape measures the distance from "start point" following the direction of plot sides. The sides must be horizontal. Set a stake every 5m.
6) To make sure the plot is a rectangular; the corners between two sides of the "start point" must be 90 degrees.
7) After setting up the plot with stake markers at every 5m (or wider, depending on topographical conditions) on each side of the rectangular, use poly ropes to mark the plots through the stake makers.
8) Record general information (location, coordinates at plot centre) in the field data form for plot measurement of woody forests.
9) Use a camera to take pictures of the sample plots and plot measurement activities.

3.1.2 Research locations

For this research two provinces were selected (Kampong Chhang and Battambang) to capture possible diversity of the flooded forest around Tonle Sap. More sample trees were sampled in closed canopy forest compared to open woodland to better reflect the species diversity and diameters classes of this forest type (Figure2).

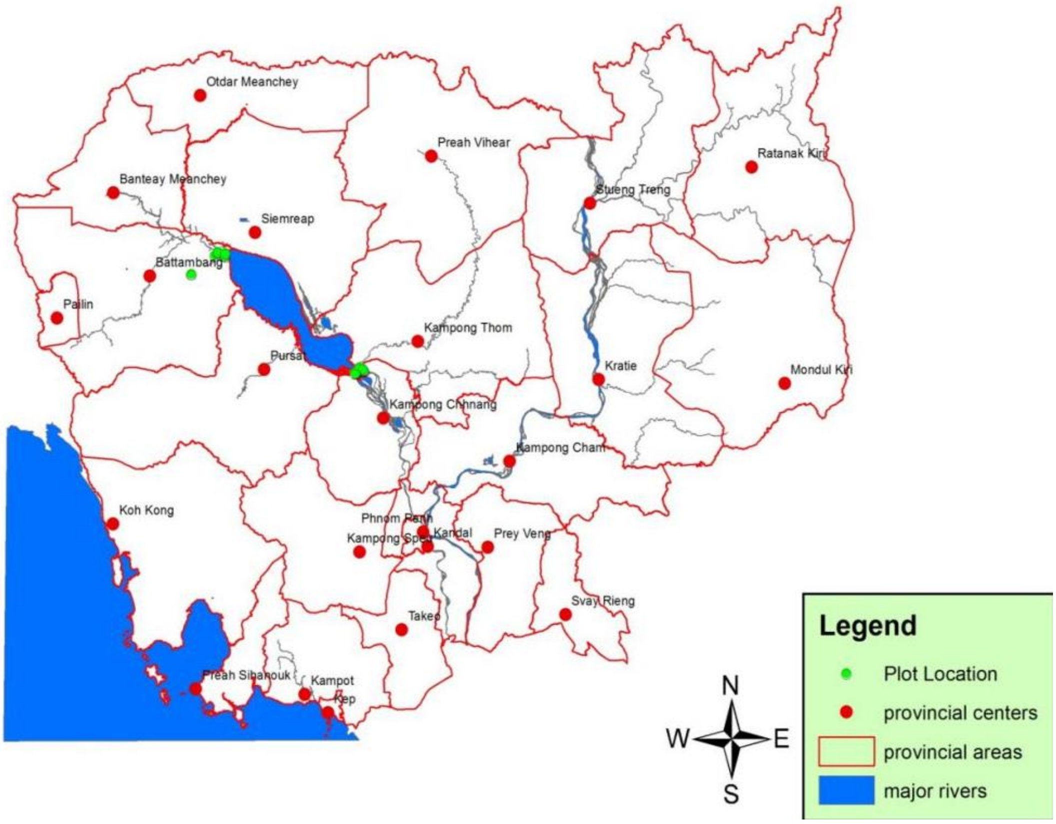


Figure 2: Map of research locations for allometric equation development

[4] Team Organization: for the sampling you should have at least a team of three technicians and two labourers.

3.1.3 Tree measurement to determine the forest structure

Once the plot has been established, the next step is to measure DBH and identify the species of all trees within the plot. This data will be used for: i) the analysing of tree species composition; ii) the distribution of tree numbers and species by DBH (N-D distribution) and basal area (N-G distribution) class; this information will be the basis for selecting the sampling trees for destructive measurements.

The following steps are recommended for DBH measurement:

1) For all live trees with DBH of 5cm and above in the sample plots identify tree species (Khmer and scientific names);
2) Using a 1.3 m pole, mark measuring position for DBH measurement with paint
3) Using a measuring tape, measure circumference of tree at marked position;
4) Record all collected information in the field data form for plot measurement of forests[5]

3.2 Step 2: Allometric equations development to improve forest biomass estimates in inundated areas

3.2.1 Destructive measurement of fresh aboveground biomass and stem volume of the trees

After the tree measurement to determine the forest structure, the sampling trees are selected for destructive measurements.

To select the trees to be felled, the following procedure can be used:

1) Enter the DBH data in excel spread sheet and group DBH data of trees by DBH class. The intervals of DBH classes are 10cm: 0-10cm; 10-20cm; 20-30cm; 30-40cm; 40-50cm; 50-60cm; 60-70cm; 70-80cm and >80cm.
2) Select randomly the sample trees in each DBH class in the sample plots. The total number of sample trees for cutting is 50 trees for each forest type. At least five sample trees should be cut and measured for each DBH class, with the same number of sample trees to be allocated for each DBH class.

Field measurement

Once the sampled trees have been selected, the measurement of stem volume and fresh aboveground biomass of sample trees is carried out as follows:

1) Use a chain saw to cut down the trees at its base;
2) Measure diameter at stump;
3) Measure DBH at 1.3m;
4) Measure total tree height (from the stump to the top of the crown);
5) Measure length of tree bole - from the stump to the first main branch;

[5] Team Organization: the measurement should be done by 3 technicians; one person to record the data and the others for identifying trees species, measuring DBH of trees and marking trees. Labourers may also assist in clearing ground vegetation for helping technicians to access the trees.

6) Measure length of tree bole - from the stump to the point where diameter becomes 10cm;
7) If tree with buttress, measure circumference 2 and height of the buttress;
8) Measure tree volume of sample trees. The measurement is done as follows:
   a. Determine and measure total length of fell tree. The length of fell tree is from cut point to the top of the main stem;
   b. Divide length of fell tree into 5 equal parts and mark these points as D00, D01, D02, D03 and D04 as shown below. The length of each part is equal to 1/5 of its length;

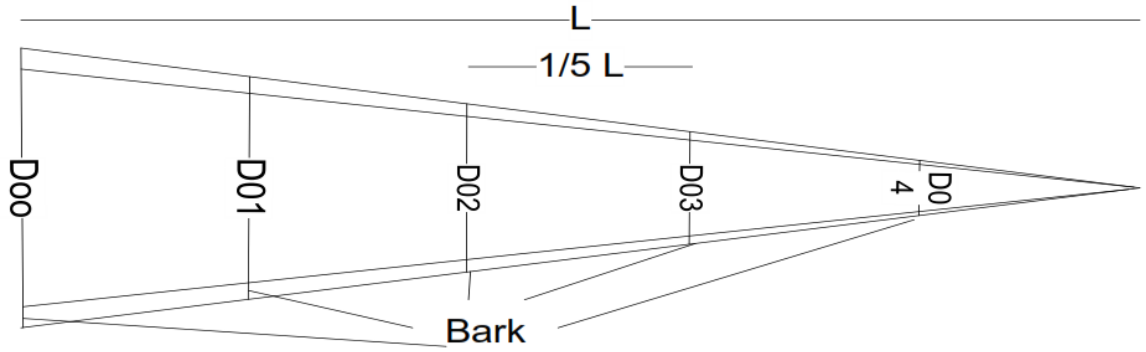


Figure 3: Wood density sample division

   c. Measure the diameter with bark at each marked point and record data;
   d. Remove bark and measure diameter without bark at every marked point and record the data.
9) Separate the cut trees into different parts (e.g. bole, branches and leaves);
10) Use a scale to immediately measure the weight of stems, branches, leaves and buttress if tree with buttress;
11) Carefully record all information on destructive measurement of sample trees in the Field data form for destructive measurement of tree biomass.

Taking samples for dry mass and wood density measurement

Sampling for dry mass analysis should be done immediately after measurement of fresh weight of each tree components. The following steps are recommended:

1) Sample for dry mass analysis: collect three or four samples per tree for each component (stems: 1, branches: 1, leaves: 1 and buttress: 1):
   a. Samples taken for each tree component should be a representative sample. Therefore, when taking the samples, always note that: the sample should be taken from different positions.
   b. To prepare a stem sample, take two to three disks (and if too large, radial sections of the disks).
   c. For branches, take four small disks from branches.
   d. The estimated weight of each sample is suggested to be 0.5-1.0kg for stems and branches; 0.3-0.5kg for leaves (ICRAF 2011).
2) Place samples of the tree components into poly bags and tightly tie to prevent evaporation.
3) Samples for wood density analysis will be four wood disk samples of the bole. The sampling procedures are as follows:

a. Mark the position for sampling. The sampling position is at stump level (0.0m), at 1/4 of bole length; 1/2 of bole length and 3/4 of bole length.
b. Take one disk (or radial section of the disk if big bole) for each sampling position with wood disk thickness of 5-10cm.
c. Label all samples for dry mass and wood density analysis for identification.

4) For samples, use a permanent pen to write information:
   a. for dry mass analysis: i) plot code; ii) tree code, iii) tree species; iv) DBH size; v) component name (stem, branch or leaves).
   b. for wood density analysis include: i) plot code; ii) sample tree code; iii) sample position (0.0m, 1/4 of bole length, 1/2 of bole length, 3/4 bole length).
5) The samples for dry mass analysis must be weighted immediately and carefully using a chemical scale (either on site, or off-site, but within the same day) to determine the exact fresh weight of each sample taken in the field;
6) All samples should be sent to a qualified laboratory in time for analysis;
7) All information on samples collection for dry mass and wood density analysis must be recorded fully in the Field data form in.

3.2.2 Laboratory Measurement

After on site measurement the samples are sent to a qualified laboratory for the drying and analysis of the samples to estimate the dry mass

Measurement for estimating dry mass of tree compartments

The following steps are taken to estimate dry mass of tree compartments:

1) Dry the samples using an oven at a temperature of 100°C until samples reach constant weight
2) Weight the dry samples;
3) All analytical data must be recorded carefully in a spread sheet format.

Measurement for wood density

The wood density of a tree compartment is followed by these steps:

1) Remove bark for those wood density sample
2) Take only a small part of the sample
3) Measure the volume of the wood density sample. The water displacement method can be used: the sample or a sub-sample is immersed in a graduated tube containing water. The volumes of displaced water correspond to the volume of the sample.
4) Measure the dry mass of the sample (or subsample).


Figure 5: Wood sample volume measurement with water displacement.

RESULTS

4.1 Flooded Forest and shrub lands at Tonle Sap

The shrub lands and forests of the Tonle Sap freshwater flooded forests ecoregion include two tree associations that were observed for the floodplain area of Tonle Sap, a short tree shrub covering the majority of the area and a more developed forest around the lake itself and at certain places further inland. The structure and composition of woody vegetation in the floodplain appears to be largely a function of soil moisture conditions and seasonal flood dynamics. Much of this ecoregion is flooded for at least a six-month period extending from August to January or February.

4.1.1 Structure of three shrub

In general, the dominant species of the short tree shrub form a nearly continuous canopy of deciduous species reaching no more than 4 meter (m) in height, with the tallest individuals occurring closer to the permanent lake basin and smaller individuals present at the periphery of the floodplain area. The flora of the short-tree shrub lands is dominated by species of Euphorbiaceae, Fabaceae, and Combretaceae, together with Barringtonia acutangula.

4.1.2 Structure of flooded forest

The flooded forest in Tonle Sap is of mixed growth with different tree species and different observable layers. We could observe four layers including a tree canopy layer, a second tree layer with of medium sized trees, a shrub layer, and a ground vegetation layer.

Tree and Shrub layers:

- The first tree layer: The tallest tree species have a height from 12m up, such as *Barringtonia acutangula, Mallotus anisopodus, Diospyros cambodiana, Xanthophyllum glaucum, Terminalia cambodiana Gagnep, Mitragyna speciosa, and Peltophorum dasyrrhachis*.
- The second tree layer: The second layer in which trees have a height from 5 to 10 meter, such as *Barringtonia acutangula, Garcinia loureiri, Crateva religiosa; Morinda tomentosa Roth, Hydnocarpus annamensis, Mimusops elengi, Cinnamomum polydelphum, and Homalium brevidens.*
- The third layer: The lowest layer in which shrubs and trees have a height of less than 5 meter such as: *Morinda, Ficus helerophylla, Vitex holpadenon, Barringtonia acutangula, Combretum trifoliatum, Cynodon dactylon, Croton caudatus, Ixora caueifolia, Diospyros,* and other mixed species of wood-shrub land.




Figure 6: The flooded forest structure in Tonle Sap lake

4.1.3 Species composition in NFI plots

For the purpose of our study we separated the flood forest into two layers, (i) the first layer is a tree layer and (ii) a vegetation layer. In the tree layer, 7 species were recorded in the 18 sample plots.

In the tree layer the major species found were *Barringtonia acutangula*, *Diospyros bejaudii* and *Coccoceras anisopodum.* One species was more dominant that other species, Barringtonia acutangula. Close to the Tonle Sap, Barringtonia acutangula was found with heights between 10 to 20 meters, with an average of DBH from 20 to 94 cm. At the vegetation layer, 24 species were found in the 18 established plots; such as *Morinda, Ficus helerophylla, Vitex holpadenon, Barringtonia acutangula* and *Combretum trifoliatum* (table1).

Table 1: The main species composition of tree layer and ground vegetation layer in gallery flooded Forest in Tonle Sap great lake, Cambodia 2015.

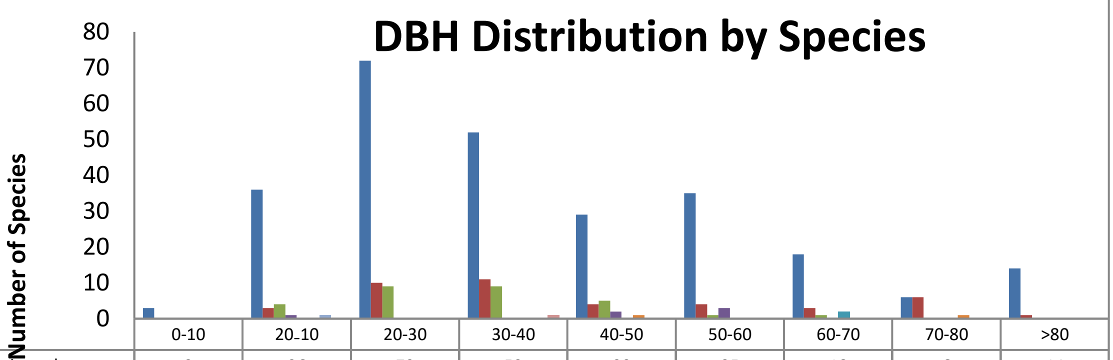
Tree Layer		**KP01**	**KP02**	**KP03**	**KP04**	**KP05**	**KP06**	**KP07**	**KP08**	**KP09**	**BB01**	**BB02**	**BB03**	**BB04**	**BB05**	**BB06**	**BB07**	**BB08**	**BB09**	**Constancy**	**Frecancy (%)**	**Class**
Khmer Name	**Species**																					
រាំង	*Barringtonia micrantha*	26	12	35	19	15	13	0	11	3	6	11	8	11	21	14	21	20	20	17	94.44	1
ផ្តៅល	*Diospyros bejaudii bejaudii bejaudii*	1	5	0	3	1	2	13	4	13	0	11	18	0	0	0	1	0	0	11	61.11	2
ច្រកែង	*Coccoceras anisopodum*	0	1	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	16.67	3
ត្អួរ	*Terminalia cambodiana*	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	11.11	4
កនៀង	*Xanthophyllum glancam*	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	2	11.11	4
ទន្លា	*Crataeva religiosa*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	5.56	6
ថ្វាន់	*Crateva andansonii or odorata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	5.56	6
Ground Vegetation Layer																						

ញរ	*Morinda*	25	45	40	49	25	25	15	200	135	2	1	0	85	70	1	7	0	0	15	83.33	1
ស្លូត	*Ficus helerophylla*	0	12	5	2	15	105	45	0	0	35	0	0	0	0	5	1	44	1	11	61.11	2
ទៀនព្រៃ	*Vitex holpadenon*	0	0	0	0	60	0	10	0	0	2	0	0	0	0	34	55	0	0	5	27.78	3
រាំង	*Barringtonia micrantha*	0	0	0	0	0	0	0	0	26	0	0	1	0	0	1	1	0	0	4	22.22	4
ត្រស់	*Combretum trifoliatum*	0	0	0	0	0	0	0	0	0	0	1	19	0	0	1	0	0	0	3	16.67	5
បបុស	*Cynodon dactylon*	0	0	3	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	2	11.11	6
ប្របួយមេ	*Croton caudatus*	0	0	0	0	0	0	0	0	0	0	1	25	0	0	0	0	0	0	2	11.11	6
ថ្លើមអណ្តើក	*Ixora caueifolia*	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	2	11.11	6
ផ្ទោល	*Diospyros*	0	0	0	0	0	0	0	0	10	0	0	8	0	0	0	0	0	0	2	11.11	6
ប្របាច	*Unknown*	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	11.11	6
សំរក	*Melanolepis vilifolia (Oktze)*	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5.56	11
ខ្នាយមាន់	*Dalbergia herrida*	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	5.56	11
បន្លាយួន	*Mimosa pigra*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	5.56	11
ភ្នែកព្រាប	*Breynia rhamnoides*	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	5.56	11
ថ្កាន់	*Crateva andansonii*	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	5.56	11
ត្រដក	*Unknown*	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1	5.56	11
ប្របួយឈ្មោល	*Croton joufra*	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	1	5.56	11
ភ្នំភ្លើង	*Hymenocardia wallichii*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	5.56	11
ផ្កាំ	*Unknown*	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	5.56	11

កនៀង	*Xanthophyllum glancam*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	5.56	11
ខ្ទាស់	*Diospyros sylvatica*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	1	5.56	11
កន្ទាំងហែ	*Polygonum tomentosum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	1	5.56	11
ស្លាបទា	*Cammelina slicifolia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	5.56	11
Unknown_1	*Unknown_1*	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	1	5.56	11

4.1.4 DBH Class distribution

There were considerable observable differences in the abundance of different sizes of trees based on the combined data from all 18 sample plots (Figure 7). The DBH of *Barringtonia acutangula* showed a normal distribution with the highest number of trees from 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm DBH range; whereas the majority of *Diospyros* DBH ranked between 20-30 cm and 30-40 cm, and DBH between 0-10cm could not be found.



	0-10	20-10	20-30	30-40	40-50	50-60	60-70	70-80	>80
Barringtonia micrantha	3	36	72	52	29	35	18	6	14
Diospyros		3	10	11	4	4	3	6	1
ផ្កាំ(Unknown)		4	9	9	5	1	1		
Coccoceras		1			2	3			
Xanthophyllum glancam							2		
Terminalia cambodiana					1			1	
Crateva andansonii or odorata		1							
Crataeva religiosa				1					

Figure 8: DBH distribution by species

4.2 Allometric Equations for flooded forest in the Tonle Sap

4.2.1 Sample tree selection for allometric equation development of *Diospyros bejaudii*

The selection of the sample trees to be felled is based on DBH classification from the inventory data. Table 2 displays the DBH ranges classified into 9 categories. 39 individual trees were felled, of which 31 in Kampong Chhnang and Kampong Thom areas and 9 trees in Battambang to complement the Kampong Chhnang/Kampong Thom measurements, ranking from > 0cm to > 80cm.

Table 2: Felling sample tree for allometric equation development (*Diospyros bejaudii*)

Kampong Chhnang/Thom Province		Battambang Province	
DBH	Number of Trees	DBH	Number of Trees
0-10	2	0-10	2
10-20	2	10-20	2
20-30	4	20-30	0
30-40	4	30-40	0
40-50	4	40-50	0
50-60	4	50-60	0
60-70	4	60-70	0
70-80	2	70-80	2
>80	5	>80	2
Total			**39**

4.2.2. Relationship between tree height and diameter

After studying the result is seems that the tree height (h) - diameter (dbh) relationship and the relation between aboveground biomass (AGB) and dbh, dbh + h or dbh + h + wd (wood density) seem not to be influenced by the growth location of the trees or the presence of holes in the stem (Figure 9). Holes were mostly visible in trees with a dbh bigger than 60 cm. The graphs show that its follow the same trend in terms of agb - dbh relationship regardless origin location or holes in the stem, the influence of the crown area and the volume of the tree holes are not very visible on the graphs but should be tested in the model to see whether they improve the models or not.

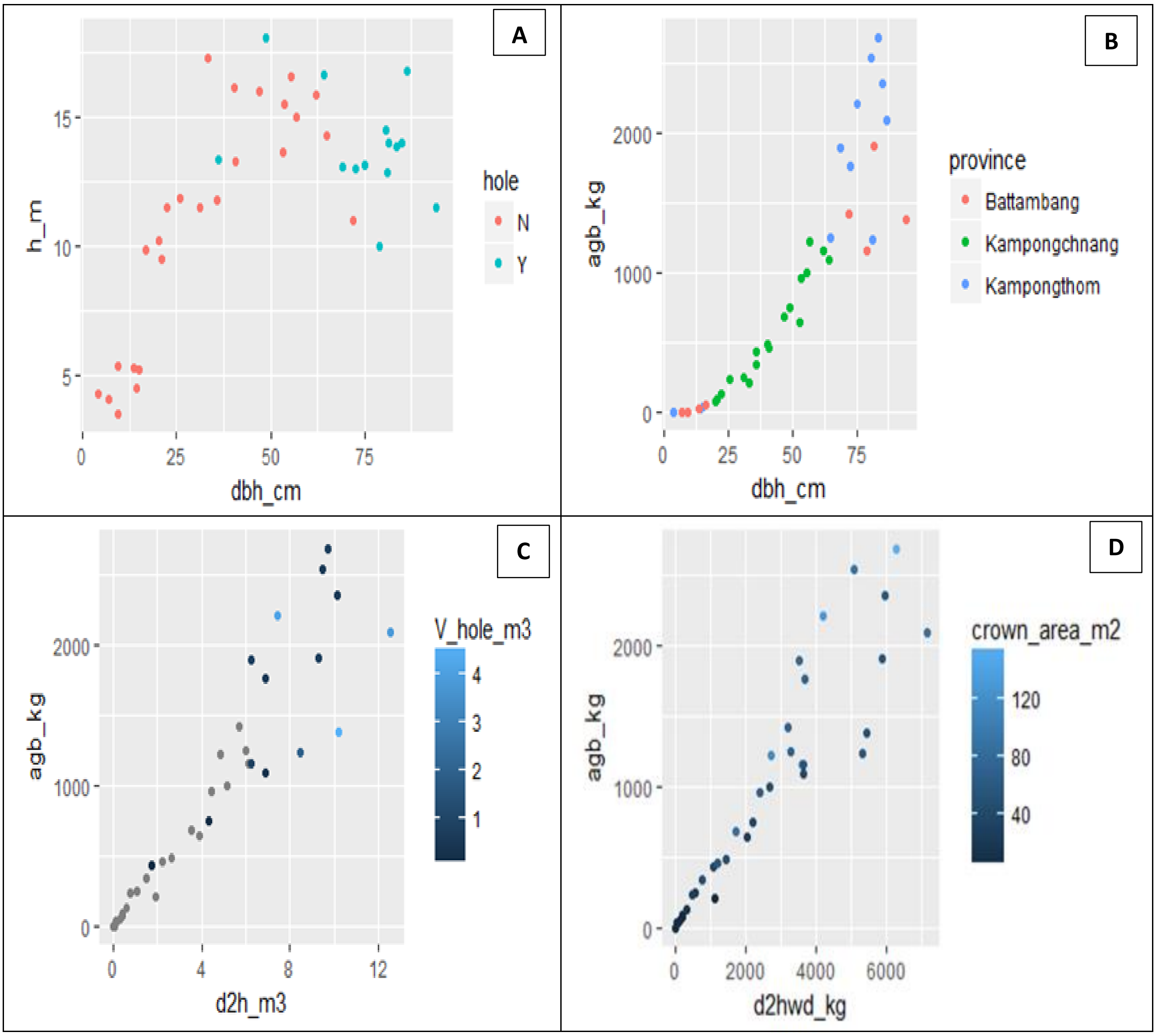


Figure 9 Relationship between tree height and diameter (A), tree aboveground biomass and dbh (B), dbh+h (C) and dbh+h+wd (D).

4.2.3 Model development

Power model forms were tested for the biomass models. H-D relationships were not developed as part of this study. H-D relationship can be better developed with national forest inventory data, as a much larger number of measurements will be available.

Table 3: Model development indicators for the aboveground biomass equations.

Id	Model equation	Start	Model variance	Rand . effect	Rane f Par.	parameters	AIC
m1	agb_kg~1.3+a*dbh_cm^b	starter <- c(1,1)	varPower (form=~dbh_cm)	no	no	fixef(m1) a b 0.051 2.424	481.32

Id	Model equation	Start	Model variance	Rand. effect	Ranef Par.	parameters	AIC
m2	agb_kg~a*dbh_cm^b	starter <- c(1,1)	varPower (form=~dbh_cm)	no	no	fixef(m2) a b 0.050 2.436	473.28
m3	**agb_kg~a*d2h_m3^b**	**starter <- c(213.3,0.98)**	**varPower (form=~d2h_m3)**	**no**	**no**	**fixef(m3) a b 220.227 0.980**	**466.52**
m4	agb_kg~a*d2hwd_kg^b	starter <- c(0.62,0.93)	varPower (form=~d2hwd_kg)	no	no	fixef(m4) a b 0.645 0.933	466.39
m5	agb_kg~a*dbh_cm^b*h_m^c	starter <- c(1,1,1)	varPower (form=~dbh_cm)	no	no	fixef(m5) a b c 0.032 2.185 0.552	467.78
m6	agb_kg~a*dbh_cm^b*wd^c	starter <- c(1,1,1)	varPower (form=~dbh_cm)	no	no	fixef(m6) a b c 0.186 2.300 1.30 1	472.26

Based on the AIC values the best models is m3 (Table3). The models without random effect are therefore recommended:

- **AGB = 220.227*D2H^0.98**

The model quality increases (i.e. AIC is smaller) with the number of input variables, therefore the measurement of tree height should be included in tree measurements carried out as part of forest inventories.

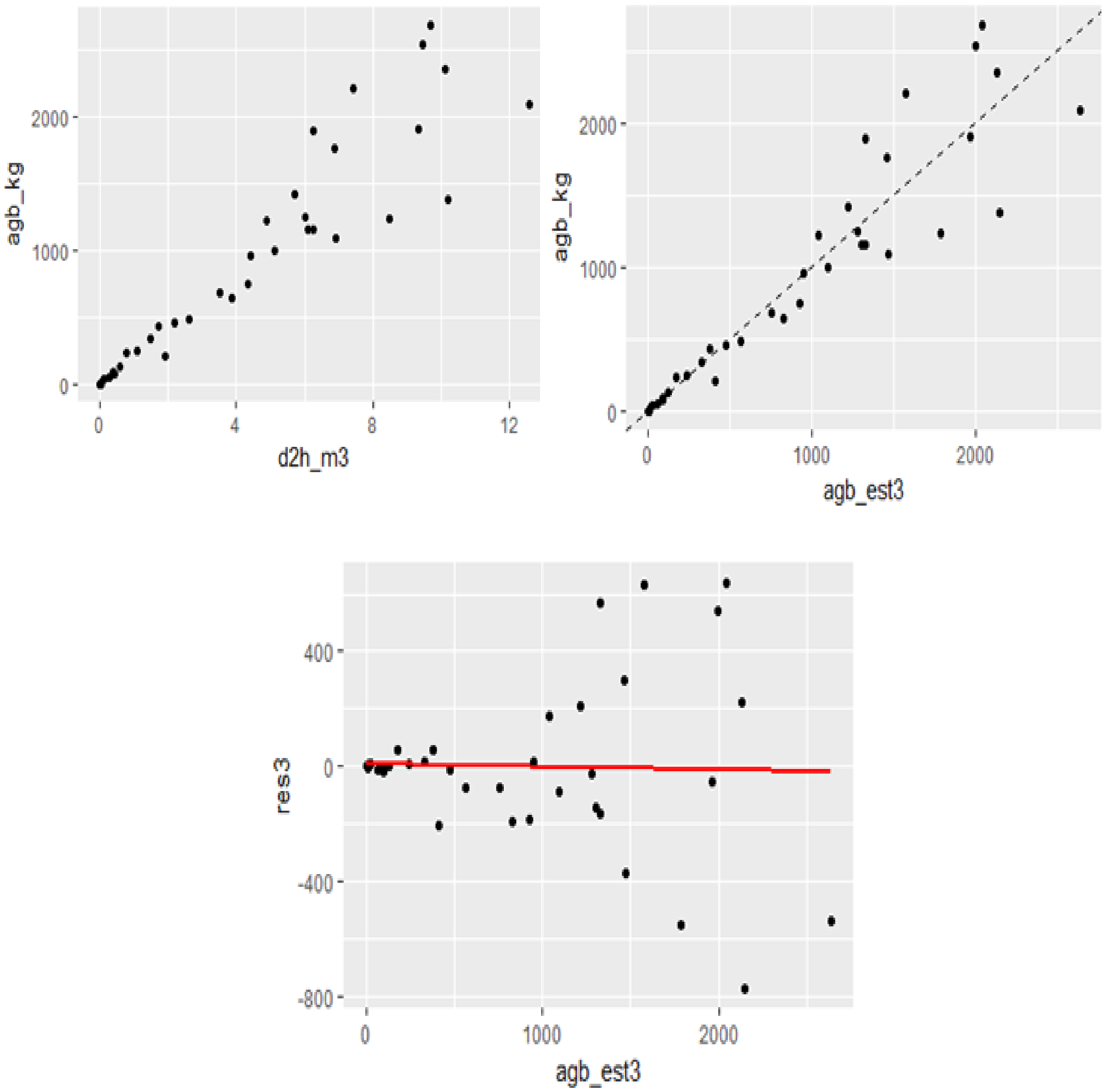


Figure 4: Graph 1: model + observations, Graph 2: Observed against Predictions, Graph 3: Res against the predictions of model m3

4.3 Wood Density

The main species composition in the flooded forest are Barringtonia micrantha, Diospyros bejaudii and Coccoceras anisopodum. In 2015, FiA and RUA also conducted a study on wood density for single species of Barrintonia, its density was found to be 0.512 g/cm3. In this study the research focused the flooded forest species Diospyros bejaudii, for the development of an allometric equation. Also wood density was determined in a laboratory using the water replacement method, the would density of Diospyros bejaudii was found to be 0.536 g/cm3 (see **Appendix 2).**

CONCLUSION AND DISCUSSION

The shrub lands and forests of the Tonle Sap freshwater flooded forests ecoregion include two tree associations that were observed for the floodplain area of Tonle Sap, a short tree shrub covering the majority of the area and a more developed forest around the lake itself and at certain places further inland. One tree species, *Barringtonia acutangula* was found most dominant in the more developed forest around to the Tonle Sap. *Diospyros bejaudii* was found the second most present species. Since the Barringtonia had been studied in 2015 the current study focused on *Diospyros bejaudii* 39 individual trees were felled and measured model development.

In total, with DBH ranging from > 0cm to > 80cm, with the number trees felled distributed over the various DBH classes. The study results showed that the tree height (h) - diameter (dbh) relationship and the relation between aboveground biomass (AGB) and dbh, dbh + h or dbh + h + wd (wood density) doesn't seem to be influenced by the region, although for the development most individual trees were felled in the Kampong Chhnang/Kampong Thom site. Finally, two models were selected, the model with three input variables (DBH, H and WD) and two input variables (DBH and H) being equally good:

- **AGB = 220.227*D2H^0.98**

Furthermore, a wood density measurement based on 40 sample trees was undertaken with results showing a **wood density (WD) of 0.*536* g/cm^3 for *Diospyros bejaudii*.** Standard Deviation of Wood Density for ***Diospyros bejaudii*** is 0.067.

As the above models are monospecific and based on several areas around the lake, the models are expected to be robust enough to provide unbiased estimates of tree biomass, however they are based only on a single tree species. Development of multi-species allometric equation for flooded forests would improve these estimates. A much larger number of measurements will be available with a National Forest Inventory (NFI), which should allow to develop a D-H model and again support the development of more accurate emission factors. Further studies are also necessary to ascertain the importance of tree holes and their role on the biomass estimates.

Other studies that are recommended are, the determination of the wood density of each of species in flooded forest in Cambodia, biomass contained in Lianas, dense understorey, and the shrub land that appears in this area, as well as development of belowground allometric equations and studies on soil organic carbon for this unique and particular ecosystem of the flooded forest in Cambodia.

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Sub-decree No.197, 2011 on boundary establishment of flooded forest site surrounding Tonle Sap lake in 6 provinces, including Kampong Chhnang province, Pursat province, Battambang province, Banteay Meanchey province, Siem Reap province and Kampong Thom Provinc

Appendixes

Appendix 1: List of Sample Tree Cutting

ID_plot	tree_no	X	Y	scientific_name	local_name	dbh_cm	h_m	h_first_branch_m	fresh_mass_branches_kg	fresh_mass_leaves_kg	fresh_agb_kg
KP03	in1	451034	1385954	Diospyros Cambodiana	ផ្ដោល	48.9	18.1	3.2	622.7	47.63	1405.83
KP03	out1	451072	1385947	Diospyros Cambodiana	ផ្ដោល	33.2	17.3	7.9	60.5	9.5	385.5
KP03	out2	451062	1385937	Diospyros Cambodiana	ផ្ដោល	40.2	16.2	6	309.2	21.6	886
KP03	out3	451068	1385900	Diospyros Cambodiana	ផ្ដោល	20.8	9.5	2.95	47.8	5.5	174.3
KP03	out4	451067	1385950	Diospyros Cambodiana	ផ្ដោល	64.4	16.7	3	1183.5	53.3	1946.6
KP03	out5	451091	1386002	Diospyros Cambodiana	ផ្ដោល	53.2	13.7	2.64	499.4	37.1	1196.7
KP03	out6	451085	1385995	Diospyros Cambodiana	ផ្ដោល	20.4	10.2	3	38	5.7	148.2
KP03	out7	451096	1385998	Diospyros Cambodiana	ផ្ដោល	55.6	16.6	4.2	913.7	52	1724.6
KP03	out8	451111	1386010	Diospyros Cambodiana	ផ្ដោល	31	11.5	4.5	178.5	6.8	460.1
KP02	out9	450997	1386167	Diospyros Cambodiana	ផ្ដោល	53.5	15.5	3.5	972.3	37	1722.5
KP02	out10	451008	1386166	Diospyros Cambodiana	ផ្ដោល	46.9	16	5.5	548.4	34	1253.4
KP02	out11	451008	1386193	Diospyros Cambodiana	ផ្ដោល	35.8	11.8	3.5	285.5	24.6	642.1
KP02	out12	451006	1386217	Diospyros Cambodiana	ផ្ដោល	22.5	11.5	8.5	52.6	3.9	248.5
KP02	out13	451010	1386215	Diospyros Cambodiana	ផ្ដោល	36	13.4	4.9	242.5	19.5	685.5
KP02	out14	450972	1386181	Diospyros Cambodiana	ផ្ដោល	62	15.9	3.5	961.7	65.6	2060.8
KP02	in2	450957	1386209	Diospyros Cambodiana	ផ្ដោល	57	15	4	1149	64.2	2096.8
KP02	out15	450977	1386201	Diospyros Cambodiana	ផ្ដោល	25.9	11.9	3	91	10	304
KP02	out16	450986	1386194	Diospyros Cambodiana	ផ្ដោល	40.7	13.3	4.8	288	18	752
KP08	out17	445621	1384279	Diospyros Cambodiana	ផ្ដោល	81	12.9	5.5	1159.6	33.4	1983
KP08	out18	445603	1384274	Diospyros Cambodiana	ផ្ដោល	69	13.1	5	1827.9	50.6	2959
KP08	out19	445615	1384293	Diospyros Cambodiana	ផ្ដោល	86.5	16.8	4.5	1831.8	93.8	3153.7
KP08	out20	445710	1384221	Diospyros Cambodiana	ផ្ដោល	85	14	2.3	2108.9	46.7	3862.2
KP08	out21	445686	1384218	Diospyros Cambodiana	ផ្ដោល	75	13.2	2.15	1976.8	77.2	3460.5
KP09	out22	444781	1384196	Diospyros Cambodiana	ផ្ដោល	9.5	3.5	1.75	6.25	1	15.55
KP09	out23	444778	1384200	Diospyros Cambodiana	ផ្ដោល	3.9	4.3	0.65	0.74	0.26	3.5
KP09	out24	444769	1384212	Diospyros Cambodiana	ផ្ដោល	15.1	5.2	1.2	26.5	1.77	69.27
KP09	out25	444779	1384211	Diospyros Cambodiana	ផ្ដោល	14.1	4.5	1.2	25	4.05	55.55
KP08	out26	445860	1384220	Diospyros Cambodiana	ផ្ដោល	83.5	13.9	2.5	2214.5	113.6	4068.4
KP08	out27	445788	1384204	Diospyros Cambodiana	ផ្ដោល	64.9	14.3	2.25	1311.9	72.5	2355.8
KP08	out28	445871	1384269	Diospyros Cambodiana	ផ្ដោល	80.8	14.5	2.9	2095.4	108	4224.5
KP08	out29	445875	1384203	Diospyros Cambodiana	ផ្ដោល	72.8	13	3.8	1504.3	53.5	2623.8
BB08	out30	356150	1461491	Diospyros Cambodiana	ផ្ដោល	94.2	11.5	3.5	1045.4	74.5	2345.6
BB08	out31	354831	1462678	Diospyros Cambodiana	ផ្ដោល	81.6	14	3.2	1712.8	90	3226.1
BB08	out33	354822	1462688	Diospyros Cambodiana	ផ្ដោល	72.1	11	1.7	1373.4	76	2444.4
BB08	out34	354980	1462667	Diospyros Cambodiana	ផ្ដោល	79	10	5	560.5	50	2070.5
BB09	out35	354853	1464039	Diospyros Cambodiana	ផ្ដោល	16.7	9.9	5.7	31	6.7	99.2
BB09	out36	354821	1464215	Diospyros Cambodiana	ផ្ដោល	9.5	5.4	3.5	0.6	0.14	13.54
BB09	out37	354825	1464210	Diospyros Cambodiana	ផ្ដោល	7	4.1	2.97	1.5	0.25	10.75
BB09	out38	354841	1464219	Diospyros Cambodiana	ផ្ដោល	13.5	5.3	2.2	21.5	5.5	58.5

Appendix 2: The table of wood density analysis in the laboratory

Sample Information		Stem Sample							
		Whole Sample							
Plot Code	Tree Code	Fresh mass with bag(Kg)	Fresh mass without bag(Kg)	Fresh mass with bag(Kg)	Fresh mass without bag(Kg)	Fresh mass with bag(Kg)	Fresh mass without bag(Kg)	Fresh mass with bag(Kg)	Fresh mass without bag(Kg)
KP03	1(in1)	1.94	1.9292	0.74	0.7292	0.72	0.7092	0.42	0.4092
KP03	2(out 1)	1.01	0.9992	1.29	1.2792	0.89	0.8792	0.24	0.2292
KP03	3(out2)	1.12	1.1092	1.35	1.3392	0.86	0.8492	0.27	0.2592
KP03	4(out3)	0.415	0.4042	0.75	0.7392	0.465	0.4542	0.27	0.2592
KP03	5(out4)	0.815	0.8042	0.96	0.9492	1.05	1.0392	0.39	0.3792
KP03	6(out5)	0.645	0.6342	2.075	2.0642	1.48	1.4692	0.455	0.4442
KP03	7(out6)	0.485	0.4742	0.5	0.4892	0.235	0.2242	0.115	0.1042
KP03	8(out7)	1.07	1.0592	2.38	2.3692	1.225	1.2142	0.395	0.3842
KP03	9(out8)	1.06	1.0492	0.95	0.9392	0.38	0.3692	0.24	0.2292
KP02	10(out9)	1.5	1.4892	1.43	1.4192	0.945	0.9342	0.355	0.3442
KP02	11(out10)	0.34	0.3292	1.36	1.3492	1	0.9892	0.385	0.3742
KP02	12(out11)	1.06	1.0492	1.9	1.8892	0.965	0.9542	0.4	0.3892
KP02	13(out12)	0.36	0.3492	1.01	0.9992	0.62	0.6092	0.19	0.1792
KP02	14(out13)	1.09	1.0792	2.38	2.3692	0.99	0.9792	0.36	0.3492
KP02	15(out14)	0.85	0.8392	0.96	0.9492	0.91	0.8992	0.39	0.3792
KP02	16(in2)	0.92	0.9092	1.54	1.5292	0.51	0.4992	0.18	0.1692
KP02	17(out15)	0.73	0.7192	1.24	1.2292	0.42	0.4092	0.22	0.2092
KP02	18(out16)	1.33	1.3192	1.395	1.3842	1.16	1.1492	0.38	0.3692
KP08	19(out17)	0.88	0.8692	1.595	1.5842	0.78	0.7692	0.255	0.2442
KP08	20(out18)	1.94	1.9292	1.57	1.5592	1.26	1.2492	0.48	0.4692
KP08	21(out19)	1.345	1.3342	0.9	0.8892	0.425	0.4142	0.31	0.2992
KP08	22(out20)	1.38	1.3692	1.99	1.9792	1.57	1.5592	0.17	0.1592
KP08	23(out21)	1.48	1.4692	1.87	1.8592	0.63	0.6192	0.41	0.3992
KP09	24(out22)	0.4	0.3892	0.26	0.2492	0.1	0.0892	0.05	0.0392
KP09	25(0ut23)	0.15	0.1392	0.075	0.0642	0.065	0.0542	0.04	0.0292
KP09	26(out24)	0.53	0.5192	0.68	0.6692	0.35	0.3392	0.095	0.0842
KP09	27(out25)	0.53	0.5192	0.61	0.5992	0.15	0.1392	0.06	0.0492
KP08	28(out26)	2.28	2.2692	2.48	2.4692	1.48	1.4692	1.32	1.3092
KP08	29(out27)	1.64	1.6292	1.98	1.9692	0.15	0.1392	0.22	0.2092
KP08	30(out28	1.315	1.3042	2.5	2.4892	1.27	1.2592	0.69	0.6792
KP08	31(out29)	1.51	1.4992	1.43	1.4192	1.13	1.1192	0.31	0.2992
BB08	32(out30)	0.455	0.4442	0.698	0.6872	0.203	0.1922	0.175	0.1642
BB08	33(out31)	0.692	0.6812	0.15	0.1392	0.79	0.7792	0.255	0.2442
BB08	35(out33)	0.705	0.6942	0.875	0.8642	1.15	1.1392	0.52	0.5092
BB08	36(out34)	0.81	0.7992	0.968	0.9572	0.602	0.5912	0.23	0.2192
BB09	37(out35)	0.408	0.3972	0.45	0.4392	0.29	0.2792	0.11	0.0992
BB09	38(out36)	0.2	0.1892	0.32	0.3092	0.06	0.0492	0.035	0.0242
BB09	39(out37)	0.192	0.1812	0.128	0.1172	0.095	0.0842	0.075	0.0642
BB09	40(out38)	0.47	0.4592	0.283	0.2722	0.32	0.3092	0.088	0.0772

Sample Information		Separate wood from bark											
		Sample at stump			Sample at 1/4			Sample at 1/2			Sample at 3/4		
Plot Code	Tree Code	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio
KP03	1(in1)	0.0352	0.0189	0.537	0.025	0.0145	0.580	0.0378	0.0155	0.410	0.0283	0.011	0.389
KP03	2(out 1)	0.0229	0.0079	0.345	0.0622	0.0282	0.453	0.0598	0.027	0.452	0.0339	0.0122	0.360
KP03	3(out2)	N/A	N/A	N/A	0.0758	0.0333	0.439	0.0666	0.029	0.435	0.0351	0.0131	0.373
KP03	4(out3)	N/A	N/A	N/A	0.0605	0.0254	0.420	0.0545	0.0235	0.431	0.0433	0.0179	0.413
KP03	5(out4)	N/A	N/A	N/A	0.0359	0.0147	0.409	0.075	0.035	0.467	0.0431	0.0179	0.415
KP03	6(out5)	0.0482	0.0201	0.417	0.0994	0.043	0.433	0.1152	0.053	0.460	0.0502	0.0211	0.420
KP03	7(out6)	N/A	N/A	N/A	0.0456	0.0178	0.390	0.0307	0.0114	0.371	0.0233	0.0072	0.309
KP03	8(out7)	N/A	N/A	N/A	0.0967	0.045	0.465	0.084	0.0395	0.470	0.0503	0.0213	0.423
KP03	9(out8)	0.0426	0.0214	0.502	0.0631	0.028	0.444	0.0443	0.017	0.384	0.0388	0.0159	0.410
KP02	10(out9)	0.0305	0.0151	0.495	0.0687	0.0314	0.457	0.0797	0.0364	0.457	0.0475	0.0198	0.417
KP02	11(out10)	0.0155	0.003	0.194	0.0768	0.0358	0.466	0.069	0.0328	0.475	0.0465	0.0193	0.415
KP02	12(out11)	N/A	N/A	N/A	0.0853	0.0385	0.451	0.0892	0.04	0.448	0.0565	0.022	0.389
KP02	13(out12)	0.0163	0.0034	0.209	0.0737	0.0339	0.460	0.0608	0.0279	0.459	0.0362	0.014	0.387
KP02	14(out13)	N/A	N/A	N/A	0.1162	0.056	0.482	0.0632	0.0322	0.509	0.0437	0.019	0.435
KP02	15(out14)	N/A	N/A	N/A	0.0711	0.0321	0.451	0.0446	0.0186	0.417	0.0583	0.0238	0.408
KP02	16(in2)	0.0276	0.01	0.362	0.0821	0.0415	0.505	0.057	0.0246	0.432	0.0345	0.0122	0.354
KP02	17(out15)	N/A	N/A	N/A	0.0679	0.0324	0.477	0.0467	0.0189	0.405	0.0297	0.0091	0.306
KP02	18(out16)	0.0584	0.026	0.445	0.0658	0.028	0.426	0.0807	0.0387	0.480	0.0549	0.0226	0.412
KP08	19(out17)	0.0175	0.0053	0.303	0.0899	0.0454	0.505	0.0793	0.039	0.492	0.0397	0.0171	0.431
KP08	20(out18)	0.0899	0.049	0.545	0.0715	0.04	0.559	0.0924	0.0525	0.568	0.0561	0.028	0.499
KP08	21(out19)	N/A	N/A	N/A	0.0457	0.022	0.481	0.0549	0.0277	0.505	0.0533	0.0267	0.501
KP08	22(out20)	0.1046	0.054	0.516	0.0355	0.0153	0.431	0.1218	0.07	0.575	0.0399	0.0167	0.419
KP08	23(out21)	0.0857	0.0456	0.532	N/A	N/A	N/A	0.0663	0.0363	0.548	0.049	0.0232	0.473
KP09	24(out22)	0.0302	0.011	0.364	0.0295	0.0096	0.325	0.0192	0.0043	0.224	0.0134	0.0016	0.119
KP09	25(0ut23)	0.021	0.0064	0.305	0.0167	0.0031	0.186	0.0158	0.0028	0.177	0.013	0.0014	0.108
KP09	26(out24)	0.0284	0.0083	0.292	0.0538	0.0207	0.385	0.0404	0.0139	0.344	0.0184	0.0042	0.228
KP09	27(out25)	0.0427	0.014	0.328	0.0557	0.0208	0.373	0.0232	0.0061	0.263	0.0147	0.0022	0.150
KP08	28(out26)	0.0729	0.0344	0.472	0.0893	0.0473	0.530	0.0647	0.031	0.479	0.0828	0.0468	0.565
KP08	29(out27)	0.0461	0.023	0.499	0.0641	0.031	0.484	0.059	0.0266	0.451	0.033	0.0121	0.367
KP08	30(out28	0.0659	0.0305	0.463	0.0594	0.0322	0.542	0.0672	0.0359	0.534	0.0792	0.04	0.505
KP08	31(out29)	N/A	N/A	N/A	N/A	N/A	N/A	0.1021	0.053	0.519	0.0565	0.0269	0.476
BB08	32(out30)	0.04	0.016	0.400	0.039	0.016	0.410	0.024	0.008	0.333	0.031	0.012	0.387
BB08	33(out31)	0.046	0.019	0.413	0.089	0.041	0.461	0.074	0.039	0.527	0.046	0.02	0.435
BB08	35(out33)	0.055	0.023	0.418	0.05	0.023	0.460	0.061	0.029	0.475	0.066	0.035	0.530
BB08	36(out34)	0.067	0.028	0.418	0.062	0.027	0.435	0.028	0.01	0.357	0.035	0.014	0.400
BB09	37(out35)	0.042	0.016	0.381	0.039	0.014	0.359	0.037	0.015	0.405	0.027	0.009	0.333
BB09	38(out36)	0.024	0.006	0.250	0.038	0.012	0.316	0.017	0.003	0.176	0.014	0.001	0.071
BB09	39(out37)	0.024	0.006	0.250	0.02	0.004	0.200	0.019	0.004	0.211	0.017	0.003	0.176
BB09	40(out38)	0.038	0.012	0.316	0.033	0.01	0.303	0.042	0.017	0.405	0.022	0.006	0.273

Samlpe Information		Measurement for wood density																							
		Sample at stump						Sample at 1/4						Sample at 1/2						Sample at 3/4					
Plot Code	Tree Code	Fresh mass(Kg)	Fresh volume(ml)	Dry mass without bag (kg)	Dry mass(g)	Dry_Fresh_Ratio	WOOD DENSITY (g/ml)	Fresh mass(Kg)	Fresh volume(ml)	Dry mass without bag (Kg)	Dry mass(g)	Dry_Fresh_Ratio	WOOD DENSITY (g/ml)	Fresh mass(Kg)	Fresh volume(ml)	Dry mass without bag (Kg)	Dry mass(g)	Dry_Fresh_Ratio	WOOD DENSITY (g/ml)	Fresh mass(Kg)	Fresh volume(ml)	Dry mass without bag (Kg)	Dry mass(g)	Dry_Fresh_Ratio	WOOD DENSITY (g/ml)
KP03	1(in1)	0.088	82	0.044	44.000	0.500	0.537	0.0512	46	0.0174	17.400	0.340	0.378	0.0568	48	0.024	24.000	0.423	0.500	0.0621	52	0.0307	30.700	0.494	0.590
KP03	2(out 1)	0.0664	60	0.032	32.000	0.482	0.533	0.0612	44	0.029	29.000	0.474	0.659	0.0691	56	0.034	34.000	0.492	0.607	0.0551	44	0.0279	27.900	0.506	0.634
KP03	3(out2)	0.0668	82	0.0344	34.400	0.515	0.420	0.0899	62	0.045	45.000	0.501	0.726	0.0783	68	0.039	39.000	0.498	0.574	0.0558	47	0.025	25.000	0.448	0.532
KP03	4(out3)	0.0549	60	0.0247	24.700	0.450	0.412	0.0681	64	0.032	32.000	0.470	0.500	0.0669	58	0.032	32.000	0.478	0.552	0.0589	50	0.0276	27.600	0.469	0.552
KP03	5(out4)	0.0798	82	0.04	40.000	0.501	0.488	0.057	50	0.029	29.000	0.509	0.580	0.0711	80	0.0387	38.700	0.544	0.484	0.066	60	0.0348	34.800	0.527	0.580
KP03	6(out5)	0.051	60	0.023	23.000	0.451	0.383	0.0696	64	0.032	32.000	0.460	0.500	0.0724	64	0.0419	41.900	0.579	0.655	0.0736	62	0.036	36.000	0.489	0.581
KP03	7(out6)	0.0527	60	0.022	22.000	0.417	0.367	0.0528	44	0.025	25.000	0.473	0.568	0.0479	30	0.0246	24.600	0.514	0.820	0.0492	42	0.0259	25.900	0.526	0.617
KP03	8(out7)	0.0588	62	0.027	27.000	0.459	0.435	0.0641	70	0.0336	33.600	0.524	0.480	0.0531	44	0.023	23.000	0.433	0.523	0.077	65.5	0.042	42.000	0.545	0.641
KP03	9(out8)	0.0612	66	0.0309	30.900	0.505	0.468	0.066	64	0.0319	31.900	0.483	0.498	0.0713	66	0.034	34.000	0.477	0.515	0.0798	66	0.041	41.000	0.514	0.621
KP02	10(out9)	0.0525	46	0.023	23.000	0.438	0.500	0.0603	50	0.029	29.000	0.481	0.580	0.0561	44	0.027	27.000	0.481	0.614	0.0706	68	0.034	34.000	0.482	0.500
KP02	11(out10)	0.0367	44	0.0151	15.100	0.411	0.343	0.0638	60	0.0313	31.300	0.491	0.522	0.045	37	0.0193	19.300	0.429	0.522	0.0614	50	0.029	29.000	0.472	0.580
KP02	12(out11)	0.0565	62	0.0265	26.500	0.469	0.427	0.0715	66	0.033	33.000	0.462	0.500	0.0723	62	0.034	34.000	0.470	0.548	0.0695	60	0.033	33.000	0.475	0.550
KP02	13(out12)	0.0434	42	0.0195	19.500	0.449	0.464	0.0599	55	0.028	28.000	0.467	0.509	0.0776	66	0.038	38.000	0.490	0.576	0.0669	52	0.033	33.000	0.493	0.635
KP02	14(out13)	0.0687	60	0.033	33.000	0.480	0.550	0.0556	48	0.0305	30.500	0.549	0.635	0.0436	30	0.0229	22.900	0.525	0.763	0.051	40	0.0252	25.200	0.494	0.630
KP02	15(out14)	0.043	38	0.0186	18.600	0.433	0.489	0.0472	40	0.0208	20.800	0.441	0.520	0.0485	38	0.0219	21.900	0.452	0.576	0.0623	40	0.031	31.000	0.498	0.775
KP02	16(in2)	0.0824	79	0.041	41.000	0.498	0.519	0.0779	76	0.039	39.000	0.501	0.513	0.0479	38	0.0225	22.500	0.470	0.592	0.0406	20	0.017	17.000	0.419	0.850
KP02	17(out15)	0.0505	40	0.0234	23.400	0.463	0.585	0.0578	50	0.029	29.000	0.502	0.580	0.0551	36	0.025	25.000	0.454	0.694	0.0664	57	0.032	32.000	0.482	0.561
KP02	18(out16)	0.0659	68	0.031	31.000	0.470	0.456	0.0767	72	0.038	38.000	0.495	0.528	0.0576	45	0.029	29.000	0.503	0.644	0.0788	64	0.04	40.000	0.508	0.625
KP08	19(out17)	0.0437	38	0.019	19.000	0.435	0.500	0.0485	42	0.0246	24.600	0.507	0.586	0.0689	59	0.038	38.000	0.552	0.644	0.077	62	0.045	45.000	0.584	0.726
KP08	20(out18)	0.0927	96	0.05	50.000	0.539	0.521	0.0595	50	0.0308	30.800	0.518	0.616	0.0875	78	0.049	49.000	0.560	0.628	0.0558	46	0.0234	23.400	0.419	0.509
KP08	21(out19)	0.0525	52	0.0246	24.600	0.469	0.473	0.057	48	0.027	27.000	0.474	0.563	0.0592	52	0.03	30.000	0.507	0.577	0.0558	44	0.03	30.000	0.538	0.682
KP08	22(out20)	0.0612	54	0.031	31.000	0.507	0.574	0.0656	70	0.0386	38.600	0.588	0.551	0.0984	88	0.051	51.000	0.518	0.580	0.0749	66	0.043	43.000	0.574	0.652
KP08	23(out21)	0.0658	59	0.032	32.000	0.486	0.542	0.0511	46	0.0251	25.100	0.491	0.546	0.0663	58	0.036	36.000	0.543	0.621	0.0655	58	0.032	32.000	0.489	0.552
KP09	24(out22)	0.0417	42	0.0168	16.800	0.403	0.400	0.0471	48	0.0209	20.900	0.444	0.435	0.0506	53	0.0231	23.100	0.457	0.436	0.0298	25	0.0107	10.700	0.359	0.428
KP09	25(Out23)	0.0483	53	0.0196	19.600	0.406	0.370	0.0163	9	0.0032	3.200	0.196	0.356	0.0277	22	0.0097	9.700	0.350	0.441	0.0237	18	0.007	7.000	0.295	0.389
KP09	26(out24)	0.0495	50	0.021	21.000	0.424	0.420	0.0571	62	0.027	27.000	0.473	0.435	0.0491	46	0.0235	23.500	0.479	0.511	0.0558	50	0.024	24.000	0.430	0.480
KP09	27(out25)	0.0401	42	0.0161	16.100	0.401	0.383	0.0405	39	0.013	13.000	0.321	0.333	0.0472	44	0.02	20.000	0.424	0.455	0.0345	28	0.013	13.000	0.377	0.464
KP08	28(out26)	0.0576	56	0.029	29.000	0.503	0.518	0.0608	42	0.03	30.000	0.493	0.714	0.0587	50	0.0367	36.700	0.625	0.734	0.058	48	0.031	31.000	0.534	0.646
KP08	29(out27)	0.0525	50	0.024	24.000	0.457	0.480	0.0591	54	0.03	30.000	0.508	0.556	0.545	46	0.028	28.000	0.051	0.609	0.432	36	0.019	19.000	0.044	0.528
KP08	30(out28	0.0498	50	0.0259	25.900	0.520	0.518	0.1123	104	0.056	56.000	0.499	0.538	0.0647	58	0.0277	27.700	0.428	0.478	0.0601	50	0.031	31.000	0.516	0.620
KP08	31(out29)	0.0576	64	0.027	27.000	0.469	0.422	0.0619	66	0.031	31.000	0.501	0.470	0.0496	40	0.025	25.000	0.504	0.625	0.0806	70	0.045	45.000	0.558	0.643
BB08	32(out30)	0.044	42	0.02	20.000	0.455	0.476	0.043	38	0.019	19.000	0.442	0.500	0.047	40	0.023	23.000	0.489	0.575	0.037	28	0.017	17.000	0.459	0.607
BB08	33(out31)	0.052	54	0.024	24.000	0.462	0.444	0.054	43	0.026	26.000	0.481	0.605	0.049	38	0.028	28.000	0.571	0.737	0.052	30	0.026	26.000	0.500	0.867
BB08	35(out33)	0.059	62	0.03	30.000	0.508	0.484	0.052	46	0.024	24.000	0.462	0.522	0.062	44	0.032	32.000	0.516	0.727	0.062	57	0.031	31.000	0.500	0.544
BB08	36(out34)	0.044	38	0.02	20.000	0.455	0.526	0.074	68	0.036	36.000	0.486	0.529	0.073	64	0.038	38.000	0.521	0.594	0.074	62	0.042	42.000	0.568	0.677
BB09	37(out35)	0.052	44	0.024	24.000	0.462	0.545	0.061	64	0.028	28.000	0.459	0.438	0.05	40	0.025	25.000	0.500	0.625	0.067	62	0.039	39.000	0.582	0.629
BB09	38(out36)	0.038	38	0.014	14.000	0.368	0.368	0.051	54	0.02	20.000	0.392	0.370	0.052	52	0.023	23.000	0.442	0.442	0.031	27	0.011	11.000	0.355	0.407
BB09	39(out37)	0.053	58	0.021	21.000	0.396	0.362	0.056	62	0.022	22.000	0.393	0.355	0.047	48	0.018	18.000	0.383	0.375	0.04	42	0.015	15.000	0.375	0.357
BB09	40(out38)	0.051	55	0.022	22.000	0.431	0.400	0.046	36	0.02	20.000	0.435	0.556	0.083	80	0.046	46.000	0.554	0.575	0.074	64	0.043	43.000	0.581	0.672

Sample Information		Remaining wood											
		Sample at stump			Sample at 1/4			Sample at 1/2			Sample at 3/4		
Plot Code	Tree Code	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio	Fresh mass(Kg)	Dry mass without bag (Kg)	Dry_Fresh _Ratio
KP03	1(in1)	1.645	0.986	0.599	0.72	0.392	0.544	0.63	0.335	0.532	0.345	0.187	0.542
KP03	2(out 1)	0.935	0.523	0.559	1.17	0.659	0.563	0.76	0.427	0.562	0.16	0.084	0.525
KP03	3(out2)	1.05	0.588	0.560	1.205	0.695	0.577	0.69	0.394	0.571	0.175	0.098	0.560
KP03	4(out3)	0.355	0.188	0.530	0.625	0.338	0.541	0.34	0.192	0.565	0.165	0.088	0.533
KP03	5(out4)	1.72	0.973	0.566	0.85	0.502	0.591	0.905	0.524	0.579	0.275	0.156	0.567
KP03	6(out5)	0.56	0.292	0.521	1.88	1.024	0.545	1.31	0.733	0.560	0.33	0.188	0.000
KP03	7(out6)	0.45	0.234	0.520	0.425	0.233	0.548	0.18	0.093	0.517	0.0452	0.023	0.509
KP03	8(out7)	1.055	0.562	0.533	2.215	1.282	0.579	1.075	0.628	0.584	0.265	0.154	0.581
KP03	9(out8)	0.98	0.551	0.562	0.855	0.463	0.542	0.295	0.163	0.553	0.125	0.081	0.648
KP02	10(out9)	1.405	0.843	0.600	1.3	0.747	0.575	0.79	0.461	0.584	0.235	0.133	0.566
KP02	11(out10)	0.295	0.178	0.603	1.205	0.681	0.565	0.865	0.497	0.575	0.28	0.155	0.554
KP02	12(out11)	0.98	0.54	0.551	1.73	0.947	0.547	0.805	0.449	0.558	0.27	0.141	0.522
KP02	13(out12)	0.295	0.136	0.461	0.89	0.493	0.554	0.49	0.282	0.576	0.09	0.051	0.567
KP02	14(out13)	1.02	0.881	0.864	2.2	1.311	0.596	0.87	0.55	0.632	0.2602	0.157	0.603
KP02	15(out14)	0.805	0.663	0.824	0.84	0.467	0.556	0.818	0.453	0.554	0.292	0.161	0.551
KP02	16(in2)	0.82	0.701	0.855	1.38	0.791	0.573	0.53	0.29	0.547	0.117	0.06	0.513
KP02	17(out15)	0.685	0.576	0.841	1.1	0.64	0.582	0.3169	0.185	0.584	0.1162	0.72	0.000
KP02	18(out16)	1.32	1.153	0.873	1.25	0.75	0.600	1.05	0.639	0.609	0.2511	0.138	0.550
KP08	19(out17)	0.822	0.691	0.841	1.47	0.86	0.585	0.645	0.404	0.626	0.1459	0.089	0.610
KP08	20(out18)	1.75	1.543	0.882	1.45	0.89	0.614	1.075	0.674	0.627	0.3722	0.219	0.588
KP08	21(out19)	1.3	1.123	0.864	0.81	0.474	0.585	0.3467	0.213	0.614	0.2095	0.131	0.625
KP08	22(out20)	1.82	1.593	0.875	1.25	0.712	0.570	1.32	0.761	0.577	0.0513	0.027	0.526
KP08	23(out21)	1.71	1.523	0.891	1.425	0.827	0.580	0.495	0.319	0.644	0.3093	0.185	0.598
KP09	24(out22)	0.356	0.2783	0.782	0.1944	0.101	0.520	0.0395	0.015	0.380	N/A	N/A	N/A
KP09	25(0ut23)	0.0865	0.0518	0.599	0.0436	0.017	0.390	0.0267	0.008	0.300	N/A	N/A	N/A
KP09	26(out24)	0.46	0.3609	0.785	0.559	0.285	0.510	0.2622	0.131	0.500	0.0262	0.009	0.000
KP09	27(out25)	0.469	0.3695	0.788	0.523	0.256	0.489	0.0846	0.039	0.461	N/A	N/A	N/A
KP08	28(out26)	2.133	1.932	0.906	2.3	1.395	0.607	1.352	0.809	0.598	1.152	0.734	0.637
KP08	29(out27)	1.512	1.323	0.875	1.8	1.053	0.585	0.73	0.425	0.582	0.1536	0.085	0.553
KP08	30(out28	1.2	1.023	0.853	2.255	1.319	0.585	1.125	0.685	0.609	0.55	0.323	0.587
KP08	31(out29)	1.5	1.323	0.882	1.4	0.764	0.546	0.959	0.591	0.616	0.245	0.153	0.624
BB08	32(out30)	0.391	0.218	0.558	0.627	0.351	0.560	0.146	0.083	0.568	0.123	0.076	0.618
BB08	33(out31)	0.612	0.368	0.601	1.019	0.607	0.596	0.682	0.45	0.660	0.174	0.112	0.644
BB08	35(out33)	0.613	0.358	0.584	0.792	0.456	0.576	1.051	0.647	0.616	0.393	0.246	0.626
BB08	36(out34)	0.715	0.407	0.569	0.847	0.478	0.564	0.512	0.3	0.586	0.137	0.085	0.620
BB09	37(out35)	0.327	0.17	0.520	0.364	0.208	0.571	0.219	0.133	0.607	0.035	0.017	0.486
BB09	38(out36)	0.155	0.074	0.477	0.25	0.113	0.452	N/A	N/A	N/A	N/A	N/A	N/A
BB09	39(out37)	0.132	0.064	0.485	0.069	0.018	0.261	0.047	0.029	0.617	0.037	0.014	0.378
BB09	40(out38)	0.393	0.2	0.509	0.221	0.111	0.502	0.211	0.142	0.673	N/A	N/A	N/A

Sample Information		Branches and leaves samples								Wood Density Per Tree D=M/V
		Branches sample				Leaves sample				
Plot Code	Tree Code	Fresh mass with bag(Kg)	Fresh mass without bag(Kg)	Dry mass without bag(Kg)	Dry_Fresh _Ratio without bag	Fresh mass with bag(Kg)	Fresh mass without bag(Kg)	Dry mass without bag(Kg)	Dry_Fresh _Ratio without bag	
KP03	1(in1)	0.345	0.3342	0.169	0.506	0.54	0.529	0.222	0.420	0.509
KP03	2(out 1)	0.4	0.3892	0.22	0.565	0.55	0.539	0.223	0.414	0.602
KP03	3(out2)	0.7	0.6892	0.384	0.557	0.53	0.519	0.198	0.381	0.554
KP03	4(out3)	0.4	0.3892	0.218	0.560	0.56	0.549	0.236	0.430	0.501
KP03	5(out4)	1.195	1.1842	0.672	0.567	0.73	0.719	0.313	0.435	0.524
KP03	6(out5)	0.98	0.9692	0.528	0.545	0.51	0.499	0.203	0.407	0.532
KP03	7(out6)	0.215	0.2042	0.115	0.563	0.445	0.434	0.173	0.398	0.554
KP03	8(out7)	0.5	0.4892	0.298	0.609	0.66	0.649	0.29	0.447	0.520
KP03	9(out8)	0.16	0.1492	0.081	0.543	0.465	0.454	0.187	0.412	0.526
KP02	10(out9)	1.085	1.0742	0.597	0.556	0.64	0.629	0.25	0.397	0.543
KP02	11(out10)	0.63	0.6192	0.336	0.543	0.59	0.579	0.254	0.439	0.496
KP02	12(out11)	0.31	0.2992	0.165	0.551	0.655	0.644	0.285	0.442	0.506
KP02	13(out12)	0.3	0.2892	0.15	0.519	0.61	0.599	0.258	0.431	0.551
KP02	14(out13)	0.62	0.6092	0.379	0.622	0.52	0.509	0.223	0.438	0.627
KP02	15(out14)	1.02	1.0092	0.523	0.518	0.55	0.539	0.213	0.395	0.592
KP02	16(in2)	0.76	0.7492	0.418	0.558	0.64	0.629	0.281	0.447	0.561
KP02	17(out15)	0.32	0.3092	0.171	0.553	0.49	0.479	0.19	0.396	0.598
KP02	18(out16)	0.79	0.7792	0.445	0.571	0.46	0.449	0.192	0.427	0.554
KP08	19(out17)	1.335	1.3242	0.814	0.615	0.47	0.459	0.199	0.433	0.630
KP08	20(out18)	0.945	0.9342	0.572	0.612	0.665	0.654	0.312	0.477	0.567
KP08	21(out19)	0.75	0.7392	0.482	0.652	0.46	0.449	0.208	0.463	0.569
KP08	22(out20)	1.13	1.1192	0.625	0.558	0.48	0.469	0.201	0.428	0.588
KP08	23(out21)	0.88	0.8692	0.52	0.598	0.46	0.449	0.203	0.452	0.566
KP09	24(out22)	0.095	0.0842	0.04	0.475	0.55	0.539	0.231	0.428	0.426
KP09	25(0ut23)	0.096	0.0852	0.036	0.423	0.26	0.249	0.112	0.449	0.387
KP09	26(out24)	0.16	0.1492	0.072	0.483	0.51	0.499	0.257	0.515	0.459
KP09	27(out25)	0.165	0.1542	0.061	0.396	0.51	0.499	0.226	0.453	0.406
KP08	28(out26)	1.38	1.3692	0.884	0.646	0.6	0.589	0.269	0.457	0.646
KP08	29(out27)	0.61	0.5992	0.311	0.519	0.53	0.519	0.228	0.439	0.543
KP08	30(out28	1.355	1.3442	0.768	0.571	0.445	0.434	0.201	0.463	0.537
KP08	31(out29)	0.77	0.7592	0.513	0.676	0.445	0.434	0.225	0.518	0.533
BB08	32(out30)	0.695	0.6842	0.445	0.650	0.378	0.367	0.173	0.471	0.534
BB08	33(out31)	0.475	0.4642	0.28	0.603	0.36	0.349	0.147	0.421	0.630
BB08	35(out33)	0.59	0.5792	0.349	0.603	0.362	0.351	0.091	0.259	0.560
BB08	36(out34)	0.625	0.6142	0.359	0.585	0.4	0.389	0.191	0.491	0.586
BB09	37(out35)	0.155	0.1442	0.078	0.541	0.352	0.341	0.154	0.451	0.552
BB09	38(out36)	0.04	0.0292	0.016	0.548	0.36	0.349	0.151	0.432	0.398
BB09	39(out37)	0.045	0.0342	0.018	0.526	0.322	0.311	0.12	0.386	0.362
BB09	40(out38)	0.22	0.2092	0.114	0.545	0.42	0.409	0.211	0.516	0.557
										0.536

Appendix 3: Field activities