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FINAL REPORT

IMPROVEMENT OF ACTIVITY DATA AND EMISSION FACTORS FOR FORESTRY SECTOR IN CAMBODIA

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ABBREVIATIONS

AGB	Aboveground Biomass
ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
AMI	Annual Biomass Increment
BBC	Biomass Before Conversion
BEF	Biomass Expansion Factor
BV	Biomass-inventoried Volume
C	Carbon
CF	Conversion Factor
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
D	Diameter
DBH	Diameter at Breast Height
DoFW	Department of Forestry and Wildlife
Eqv.	Equivalent
Exp	Exponential
FAO	Food and Agriculture Organization
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Positioning System
GRB	Growth Rate of tree Biomass
ICSEA	Impact Center for Southeast Asia
IPCC	Intergovernmental Panel on Climate Change
kt	Kilotonne
LEAP	Long-Range Energy Alternative Planning
LTB	Live Tree Biomass
LULUCF	Land Use, Land Use Change and Forestry
MAFF	Ministry of Agriculture, Forestry, and Fisheries
MAI	Mean Annual Increment
MIME	Ministry of Industry, Mines and Energy
MoE	Ministry of Environment
MoF	Ministry of Forestry
N_2O	Nitrous Oxide
NatCom	National Communication
NIS	National Institute of Statistic
NOx	Nitrogen Oxides
QSD	Quadratic Mean Diameter
R^2	Regression
RWEDP	Regional Wood Energy Development Programme
SQRT	Squares Root
Stdev	Standard Deviation
SY	Stand Yield
tdm	Tonne of Dry Matter

UNDP	United Nations Development Program
UTM	Universal Transfer Mercator
VAC	Volume Available for Cutting
VOB	Volume Over Bark
WB	World Bank
WD	Wood Density
WV	Wood Volume

EXECUTIVE SUMMARY

In the Initial National Communication (NatCom) of Cambodia, the Land Use, Land Use Change and Forestry (LULUCF) sector contributed to about 97% of total national CO_2 emissions. However, the estimates have high uncertainties due to the complexity of biological factors and lack of reliable data. Most of emission factors used were IPCC default values and some activity data have been estimated from other available sources.

This study aims at improving some of activity data and emission factors in the LULUCF sector in Cambodia. The improvement was made for three areas: (i) forest area and rate of forest conversion estimates, (ii) annual growth rate of tree biomass, and (iii) the level of analysis. The satellite data of 1992 and 1996 were used to estimate forest areas and rate of forest conversion, while data of other studies (in the country or from the neighboring countries) and field measurement was used as a basis to improve the mean annual biomass increments of each forest type. The level of analysis was made on provincial basis not on national basis.

The result of analysis showed that the rate of GHG emissions in 1994 from the LULUCF sector varied considerably by provinces. Koh Kong is the province with the highest CO_2 emissions, while Mondul Kiri was the province with the highest CO_2 sequestration. In term of CO_2-equavalent, more than half of provinces in Cambodia were already net emitter provinces in 1994. These include Battambang, Banteay Meanchey, Kandal, Kampong Cham, Kompong Chhnang, Kompong Speu, Kampot, Krong Kep, Koh Kong, Prey Veng, Svay Rieng, Takeo, and Otdar Meanchey. The total net CO_2-eqv. emissions of these provinces were about 9,047 kt. The other provinces were a net sinker with total net carbon removal of about 16,266 kt CO_2-eqv. Thus in 1994, forestry sector of Cambodia was still a net sinker. The error of the CO_2 removal estimates ranged from 16% to 38% with mean of about 26%, while error of the CO_2 and non-CO_2 emissions estimates ranged from 1% to 22% with mean of about 6%.

In comparison with GHG inventory reported in the NatCom, it was found that the improved GHG inventory gave lower estimates than those of the NatCom. The discrepancy between the improved and the NatCom was 39% for CO_2 removal, 30% for CO_2 emission and about 60% for non-CO_2 emissions. In term of CO_2-eqv, the net emission estimates were -7,219 kt and -17,908 kt for the improved inventory and the NatCom respectively. Thus the discrepancy was about 60%.

For further improvement, allometric equations for estimating forest biomass for each forest types should be developed locally based on destructive sampling. The growth rate of tree biomass of the over-logged evergreen, mixed & coniferous, and deciduous forests (in term of diameter growth) and some important tree species should also be measured in more locations at different level of degradation and in more number of sample plots. This work should be prioritized since it is not only important for the further improvement of national GHG inventory but also for estimation of carbon stock potential of forest carbon projects.

INTRODUCTION

1.1. Background

The Cambodian Climate Change Enabling Activity Project Team has prepared the inventory of greenhouse gas emissions by sources and removals by sinks following the Revised 1996 IPCC Guidelines and using the base year of 1994. The results showed that Cambodian Land Use, Land Use Change and Forestry (LULUCF) sector contributed to about 97% of total national CO_2 emissions. However, the estimates have high uncertainties due to the complexity of biological factors and lack of reliable data. In the study, most of emission factors used were IPCC default values and some of activity data have to be estimated from other available sources. Therefore, improvement of the GHG inventory for this sector should be done through developing local emission factors and increasing accuracy of estimates of activity data.

The important data for developing GHG inventory in LULUCF sector are converted area per forest type, mean annual increment of trees, above ground biomass of natural forests, biomass expansion factors, biomass density, fraction biomass burnt on site/off site and decay. Among these parameters, the most important data include converted forest area, mean annual increment, wood harvest, and biomass density of each forest type. Less accurate estimates to these data will lead to underestimation or overestimation of the GHG uptake/emission. A survey to five sites was conducted to improve these data. The five sites were (1) Kirirom national park; (2) Ream national park; (3) Forest community in Siem Reap province; (4) Landscape protected area in Tonle Sap Lake; and (5) Forest plantation in Kompong Cham province. These forest areas represent: “mixed (semi-evergreen), coniferous, secondary, inundated, mangrove, and forest plantation”.

1.2 Objectives

The objectives of this study are:

- To develop a database on emission factors;
- To improve activity data and develop local emission factors; and
- To conduct uncertainty analysis for the GHG inventory.

II. REVIEW ON LULUCF EMISSION FACTORS

ICSEA (1999) has evaluated the relative importance of activity data and emission factors for LULUCF (Table 1). The most important data for developing GHG inventory in LULUCF sector are converted area per forest type, mean annual increment of trees, forest typology, and followed by wood harvest data and biomass. Whereas, data on abandoned land and soil-carbon as well as in-situ burning are less important.

Table 1. Priority data domains for the LULUCF sector

Priority data domains	Importance [a]
Converted forest area per forest type	*3*
Growth rate of forest and vegetation types (including plantations)	*3*
Forest typology (biomass-based, floristic, ecology, climatic, administrative)	*3*
Wood harvest (legal + illegal, half-life time by use)	*2.5*
Biomass of each forest and vegetation type	*2.5*
Root biomass per vegetation / land use land cover type	2.2
Wood to biomass expansion factor, allometrics	2.2
Abandoned land: area + growth rate (increment)	1.7
Soil C stock (including organic soils + land use impacts)	1.1
On-site (in situ) burning	0.5

[a] 3 = very high, 2 = high, 1 = medium, 0 = low or not important. Source: ICSEA (2000).

A review of studies on emission factors revealed that there is a great variability in emission factors used by countries. IPCC default values were not relevant for some countries. Therefore, GHG inventory reported by countries, which used IPCC default values may be overestimated or underestimated. The following section discusses the variation of emission factors used by some tropical countries and their comparison with IPCC default values.

2.1. Mean Annual Biomass Increment

Annual Biomass Increment plays an important role in estimating carbon-sequestration by forests. The accuracy of the C-sequestration estimation will depend on the accuracy of the selection of this value (Macandog, 2000). Studies in many countries indicated that the growth rate of a single tree species varied considerably between locations, due to the difference in a biotic environmental condition, such as soil, rainfall, temperature, topography, as well as management system. In addition, age of tree is also important in considering the selection of mean annual increment. The growth of tree decreases as the growth stage close to the climax stage. Table 2 shows how the mean annual increment of tree varies with species, location and age.

Table 2. Mean annual increment (MAI) of tree species by countries and age

Species	Age (year)	MAI (tdm/ha)	Location (site, country)	Sources
Tectona Grandis	Not mentioned	8	IPCC Default Value for tropical forestsJava,	IPCC (1997)
	Not mentioned	3.3-10.2[1]	Indonesia	Askari (2000)
	Not mentioned	6.7	Indonesia[2]	MoF (1996)
	Not mentioned	3.9	Indonesia[3]	MoE (1999)
	Not mentioned	<10	ALGAS countries[4]	Macandog (2000)
Pinus mercusii	Not mentioned	11.5	IPCC Default Value for tropical forests	IPCC (1996)
	Not mentioned	6.93	Indonesia	MoE (1999)
Acacia spp.	Not mentioned	15.0	IPCC Default Value for tropical forests	IPCC (1997)
	Not mentioned	>14	Indonesia	ALGAS (1998)
	Not mentioned	25	Indonesia	SME (1999)
Eucalyptus	Not mentioned	14.5	IPCC Default Value for tropical forests	IPCC (1997)
	Not mentioned	>14	Indonesia	ALGAS (1998)
	Not mentioned	>14	Indonesia	Initial Nat. Communication (1999)
Mixed Hardwoods	Not mentioned	6.8	IPCC Default Value for tropical forests	IPCC (1997)
	Not mentioned	5.6	Indonesia	US-EPA country study (1996)
Mixed Fast-Growing Hardwoods	Not mentioned	12.5	IPCC Default Value for tropical forests	IPCC (1997)
	Not mentioned	10.4	Indonesia	US-EPA country study (1996)
Mixed Softwoods	Not mentioned	14.5	IPCC Default Value for tropical forests	IPCC (1997)
	Not mentioned	12.0	Indonesia	US-EPA country study (1996)
Douglas fir	Not mentioned	6.0	IPCC Default Value for temperate forests	IPCC (1997)
Loblolly pine	Not mentioned	4.0	IPCC Default Value for temperate forests	IPCC (1997)
Paraserianthes falcaltaria (Albizzia)	Not mentioned	16.5-25.7[1]	Java, Indonesia	Askari (2000)
	Not mentioned	6.0	Philippines	Kawahara et al. 1981
	Not mentioned	9.8	Philippines	Kawahara et al. 1981
	3	20.2	Philippines	Kawahara et al. 1981
	3	11.2	Philippines	Kawahara et al. 1981
	5	8.4	Philippines	Kawahara et al. 1981
	7	5.3	Philippines	Kawahara et al. 1981
Gmelina arborea	Not mentioned	10.8	Mindanao, Philippines	Kawahara et al. 1981
	Not mentioned	18.8	Visavas, Philippines	Lasco et al. 1998
	6	11.3	Philippines	Kawahara et al. 1981
	8	10.5	Philippines	Kawahara et al. 1981
	8	9.6	Philippines	Kawahara et al. 1981
Leucaena leucocephala	1	4.4	Philippines	Kung'u (1993), Lasco and Suson (1999)
	2	11.8	Philippines	

Species	Age (year)	MAI (tdm/ha)	Location (site, country)	Sources
fallow	3 4 5 6	1.4 18.8 17.4 9.8	Philippines Philippines Philippines Philippines	
Secondary forest	Not mentioned Not mentioned Not mentioned Not mentioned	7.81 2.1 5.2 2.0	Luzon, Philippines Visavas, Philippines Mindanao, Philippines Indonesia[4]	Lasco et al. 1999 Lasco 1999 Kawahara et al. 1981 MoF (1999)

[1]Ranges of MAI from the worst and the best site indices
[2]MAI used in US-Country Study
[3]MAI used in National GHG Inventory
[4]ALGAS countries include Indonesia, Philippines, Vietnam, etc.

2.2. Aboveground Biomass

Aboveground biomass is required for the estimation of carbon loss from forest due to its conversion to other land uses (e.g. plantation), logging or burnt. Biomass is defined as the total amount of aboveground living organic matter in tree expressed as oven-dry tons per unit area. It is referred to as biomass density when expressed as mass per unit area. Aboveground biomass of different forest types in several countries is presented in Table 3. Table 3 shows that the aboveground biomass of tropical countries varied considerable within or between countries. In general, the aboveground biomass of natural forest in tropical countries is more than 300 ton per ha. About 15-30 years after logging (using selective logging system), the biomass of the logged-over forest could regenerate close to its original stage. Biomass of some agroforest systems is also quite high. Some systems have biomass density are not very different from that of natural forest.

Estimation of CO_2 emissions from wood harvesting required biomass expansion factor[1]. In most cases, data available in many countries are only round wood production data (in m^3). The biomass expansion factor (BEF_T) is therefore required to estimate the total biomass of trees from the volume of round wood (V). For undisturbed forest, the BEF is about 1.5 (Ruhiyat, 1995). For plantation forest, the BEF_T range from 1.2 and 2.0 depending on species, and age (Askari, 2000; Hendri *et al.*, 2001). Young trees have higher BEF_T. For teak with age of between 1-10 years, the biomass expansion factor is between 1.20 and 1.74 with average of about 1.4, while for teaks with age of more than 10 years, the BEF_T is between 1.17 and 1.36 with average of about 1.25. IPCC (2000) used BEF of 1.75 for undisturbed forest, 1.9 for logged-forest and 2.0 for unproductive forest.

[1]Biomass expansion factor (BEF_T) is ratio between total weight of biomass (total weight of above and below ground biomass) and weight of harvested wood (calculated as the product of VOB/ha in m^3/ha and wood density in t/m^3). Brown and Lugo (1992) defined BEF_A as the ration between total above ground oven-dry biomass density of trees with a minimum dbh of 10 cm or more and the oven-dry biomass density of the inventoried volume.

Table 3. Aboveground biomass of different forest types

Forest	Age of the system (year)	AGB (tdm/ha)	Location (site, country)	Sources
Primary forest (Virgin forest)	Not applicable	460 425 655 490	Kalimantan, Indonesia Pasoh, Malaysia Malaysia	Ruhiyat, 1995 Kira, 1978 Kato *et al.*, 1978 Edwards & Grubb, 1977
Secondary forest	15[1] Not mentioned Not mentioned	441 279; 499 262	Jambi, Indonesia Luzon, Philippines Mindanao	Tomich *et al.*, 1998 Lasco et al., 1999 Kawahara et al., 1981
Agroforestry	3 Not mentioned Not mentioned Not mentioned	30(17) 236 68 32	Lampung, Indonesia Multistorey system in Luzon, Philippines Alley cropping in Luzon, Phillipines Fallow system in Visayas, Philippines	Tomich *et al.*, 1998 Lasco and Pulhin, 2000b Lasco and Pulhin, 2000b Lasco and Pulhin, 2000b
Junggle-rubber	35	304(26)	Jambi, Indonesia	Tomich *et al.*, 1998
Tectona grandis (teak)	87	355	Cepu, Indonesia	Hendri *et al.*, 2001
Acacia mangium	9 Not mentioned	146-189 245; 57; 196	South Sumatra, Indonesia Visayas, Philippines	Hardiyanto *et al.*, 2000; Lasco and Pulhi, 2000b
Paraserienthes falcataria	4 Not mentioned	29 35; 82; 108	Malang, Indonesia Mindanao, Philippines	Tomich *et al.*, 1998 Lasco and Pulhi, 2000b
Cordia alliadora	20	67[2]	Latin America	Powel et al. (1998)
G. arborea	Not mentioned	133	Mindanao, Philippines	Lasco and Pulhi, 2000b
S. macrophylla	Not mentioned	261	Mindanao, Philippines	Lasco and Pulhi, 2000b
Brushlands	Not mentioned	65	Visayas, Philippines	Lasco et al., 1999
Grasslands	Not mentioned	29	Visayas, Philippines	Lasco et al., 1999

[1] Year after logging; [2]Number of tree per ha is 50.

If data on biomass expansion factor (BEF_A) is not available, Brown and Lugo (1992) proposed to use the following equation:

$$BEF = Exp\{3.213-0.506*Ln(BV)\} \text{ for } BV < 190 \text{ t/ha}$$
$$BEF = 1.74 \text{ for } BV \geq 190 \text{ t/ha}$$

BV is biomass-inventoried volume in t/ha, product of VOB in m^3/ha and wood density (t/m^3).

2.3. Off-Site and On-Site Biomass Burning

Conversion of forest or grassland to other uses will result in GHG emissions. Tropical forest clearing is usually accomplished by cutting undergrowth and felling trees followed by burning biomass on-site or as fuel wood. By this process some of the biomass is burned while some remains on the ground where it decays slowly (usually over a period of ten years in the tropics). Of the burned material, a small fraction (5-10 percent) is converted to charcoal which resists decay for 100 years or more, and the remainder is released instantaneously into the atmosphere as CO_2. Similarly, when grassland is converted into other uses, it is normally done by cutting and then burning the grassland. This process will also release GHGs. Carbon is also lost from the soils after conversion, particularly when the land is cultivated. Therefore, in estimating GHG emissions from the conversion process, data on biomass before and after conversion should be known. In addition, fraction of biomass left to decay, burnt on-site and off-site should be also available (IPCC, 1997). This data is also hardly available in Cambodia. A study in Indonesia found that fraction of biomass burned in site during the conversion was about 66% (Prayogo *et al.* in Hairiah and Sitompul, 1999) and about 10% off site and the remaining left to decay (Boer *et al.*, 2000).

III. KEY ACTIVITY DATA AND EMISSION FACTORS IN CAMBODIA

3.1. Activity Data

3.1.1. Land Use, Land Use Change and Forestry (LULUCF) in Cambodia

World Bank/UNDP/FAO (1996) divided land-use in Cambodia into urban, rice fields, other crops, forests, shrublands, abandoned lands and water. In 1993, the Land-use Mapping Office of the Ministry of Agriculture, Forestry and Fisheries and the Remote Sensing Mapping Unit of the Mekong Secretariat estimated the land-use and land cover in Cambodia (Table 4). The most significant changes in land cover during the last 20 years are 11.2% reduction in total forest cover, 113.9% increase in shrublands and 26% increase in agriculture land (World Bank *et al*. 1996).

Table 4: Land Use and Land Use Change and Forestry of Cambodia

Land-Use Category	**Area (ha)**		**Change**	**Annual Change (%)**
	1973	**1993**		
Rice fields	2,521,000	2,639,000	118,000	0.2
Other crops	582,000	1,275,400	693,400	6.0
Dry land forests	11,678,600	10,568,600	-1,110,000	-0.5
Edaphic forests	1,032,500	715,600	-316,900	-1.5
Shrublands	1,056,900	2,260,600	1,203,700	5.7
Abandoned lands	786,300	278,700	-507,600	-3.2
Water surface	481,500	411,100	-70,400	-0.7
Total	18,153,500	18,153,500	0	0.0

Source: World Bank *et al.* (1996).

Two major forest types in Cambodia are dryland and edaphic forests. Dryland forests consist of evergreen, coniferous, deciduous, mixed, and secondary forests, whereas edaphic forests include flooded forest, flooded secondary and mangrove (for detail, see Appendix 1). In 1998, total area of Cambodia covered by forests was only about 10.5 million hectare, or about 58 percent of the total country's land area. About 10 million hectare (96%) were dry-land forests and 0.5 million hectare (4%) were edaphic forests. All edaphic forests and some of 2.8 million hectares of dry-land forests were put under National Protected Area System, which presently consists of 23 protected areas. The total protected area is 3,568,100 hectares or 19.7 % of the country's total area. These areas are classified as National Parks, Wildlife Sanctuaries, Protected Landscapes and Multiple-Use Area.

Based on historical data of 1973 up to 1998, it was indicated that area of dry-land forests decreased significantly by about 1.6 million ha and edaphic forests by about 0.6 million ha (Figure 1). In the period between 1973 and 1984, annual reduction rate of dry-land forests and edaphic forests were about 33,500 ha and 31,000 ha, respectively. In the period between 1984-1994, the annual reduction rate of dry-land forests futher increased to about 88,200 ha, while that of edaphic forest decreased to about 21,600 ha. The data suggested that some of these forest areas changed to shrublands. In 1998, total area of shurblands already reached 2,023,600 ha.

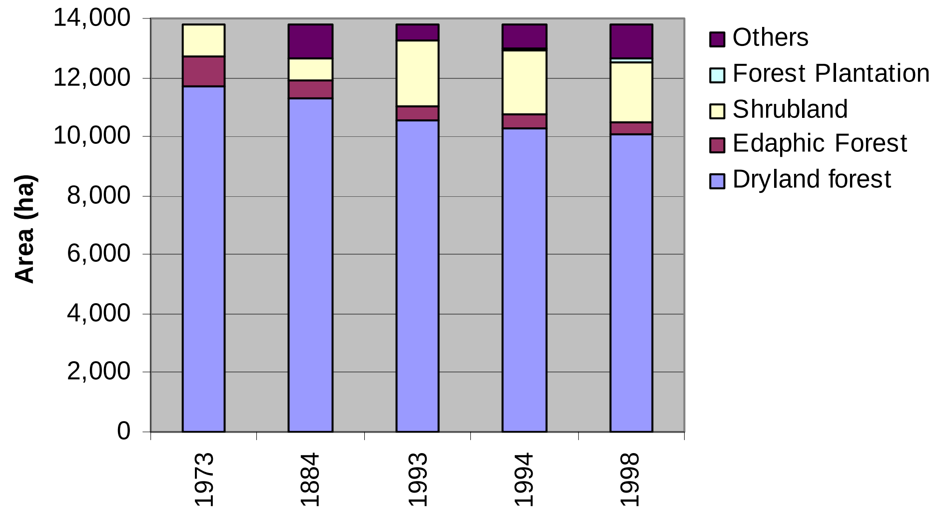

Figure 1. The changes in forest area from 1973 to 1998 (developed from World Bank/FAO/UNDP, 1996; MAFF and World Bank, 1999)

A detailed assessment of land use, land use change and forest using satellite in the period of between 1992 and 1996 has been done by DoFW (1999) up to a district level. An analysis on provincial data showed that the deforestation occurred in all forest types and all provinces, except in Tonle Sap lake, Krong Kep and Phnom Penh (Area of forest and non-forest in the two years is presented in Appendix 2 and 3). The higest rate occurred in Koh Kong, i.e. 6,140 ha per year (Figure 2). In term of percent to total forest area of 1992/93, provinces which have deforestation rate of more than 2% per year were Banteay Meanchey, Prey Veng, Svay Rieng, and Takeo. The rates in these four provinces were 2.48; 3.24; 7.61 and 13.31% respectively. In total, the annual lost of forest cover in Cambodia in the period of 1992 and 1996 was about 46,234 ha per year or equivalent to about 1.82% per year.

Many studies have indicated that the rate of deforestation in many countries was closely related to the population density (e.g. Murdiyarso *et al*., 2000; Kaimowitz, 1997), as the higher the population, the more lands and foods required for their activities and life. Using forest cover changes data that occurred in the period of between 1992 to 1996 (MoFW, 1999), and 1998 population density in each province (NIS, 1999), the relationship between these two variables were analysed. It was found that the relationship between deforestation rate and population density was not strong. However, there is an indication that the deforestation increased as the population density increased (Figure 3).

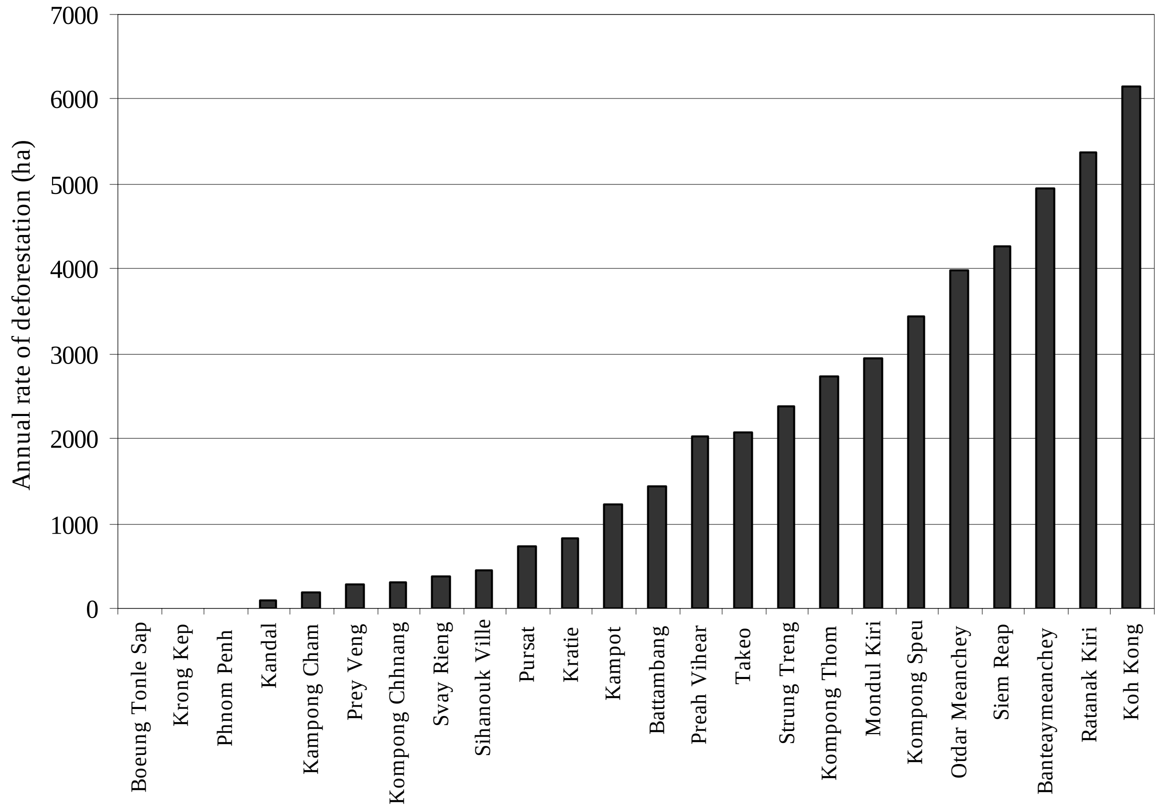

Figure 2. Rate of deforestation in the 24 provinces (Calculated from DoFW, 1999)

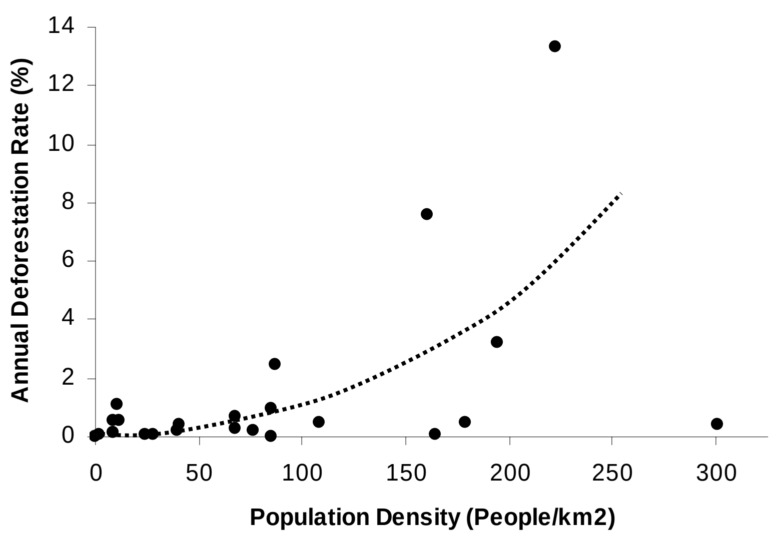

Figure 3. Relationship between rate of deforestation and population density in Cambodia (Calculated from DoFW, 1999 and NIS, 1999)

Without proper management and better reforestation program, Cambodian forest may disappear in the near future. Past data indicated that rate of reforestation was much lower than rate of deforestation. The reforestation program was actually started by the Department of Forestry and Wildlife (DoFW) in 1985 (Hang Sun Tra, 2000). The rate of planting varied from year to year, i.e. between 289 ha and 897 ha per year. Total degraded land and forests that have been reforested up to 1998 was only 85,000 ha, or less than annual rate of deforestation that occurred in the period of between 1984-1994. Common tree species in the reforestation program were Acacia, Eucalyptus and Teak. Rubber plantation is also included in the forest plantations. High proportion of the forest plantation is under rubber plantation.

For 2001-2005, the DoFW planned to reforest about 6 million hectares of degraded forestlands. Sites for implementing the program are being studied. The program will be implemented in three forms, namely: (1) tree planting for timber production at a rate of 50,000 ha/year, (2) tree planting in National Arbor Day at a rate of 120 ha/year, and (3) tree planting through people participation and forestry community, at a rate of 16,000 ha/year. Considering past data, DoFW may not be able to achieve the target. The main constraint will be financial matter. Thus, without any financial support from international funding, either through bilateral, multilateral or international convention fund, it would be difficult for Cambodia to maintain its forest.

Conversion of forest to other land use will lead to GHG emissions either through biomass burning or decay process. Based on the satellite assessment, it was suggested that forest were converted mainly to agriculture activities either using permanent or non-permanent system (shifting cultivation). In the satellite data, area of shifting cultivation was identified as mosaic cropping (this land may generate naturally into secondary forest). Some of the agriculture land was also established in wood-/shrubland evergreen area. In the period of 1992 and 1996, area of wood/shrubland used for other uses, in particular for establishment of agriculture area was about 13,024 ha/year, while the rate of increase of agriculture land and mosaic cropping was about 80,060 ha/year. This suggests that more than 80% of agriculture area were established from the conversion of forest area. The Annual change of agriculture land and mozaic cropping within the period is presented in Figure 4.

Table 7. . . . . ⁄覲 毿 **Wood Products**

Harvesting wood will lead the GHG emissions as biomass left in the forests after harvesting will be decomposed, while biomass taken out from the forests will be burnt as fuel wood or used for making other wood products. Thus, data on volume of harvested wood as well as fuel wood consumptions are required for developing the GHG inventory. World Bank/FAO/UNDP (1996) estimated that since 1990, fuel wood consumption of Cambodian household is about 6 million cubic meters per year. About 50% of this demand is from forests while another half from garden or other sources.

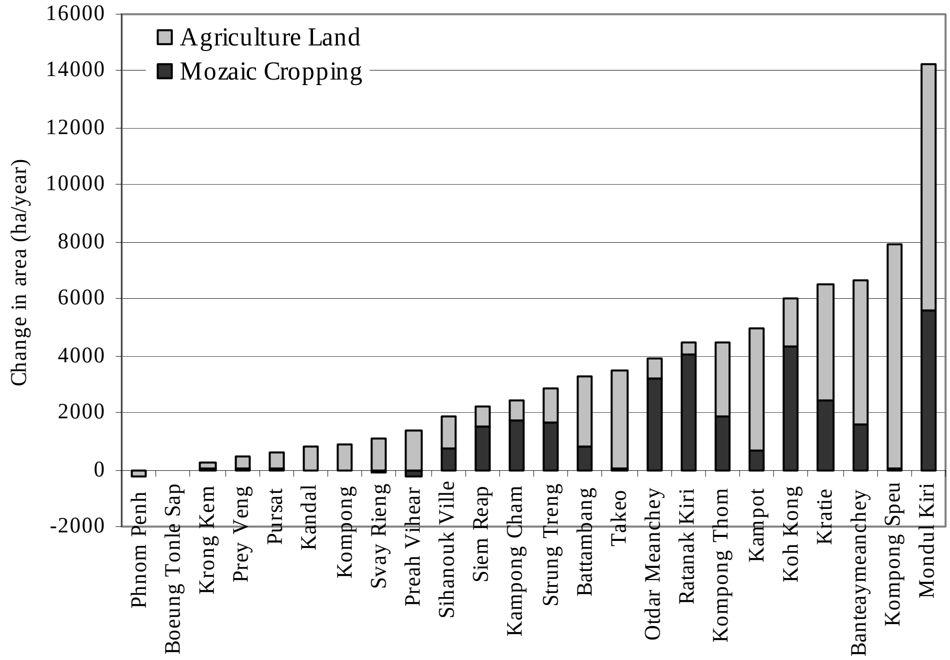

Figure 4. Annual change in agriculture land and mosaic cropping in the period of 1992/93 to 1996/97 (calculated from DoFW, 1999)

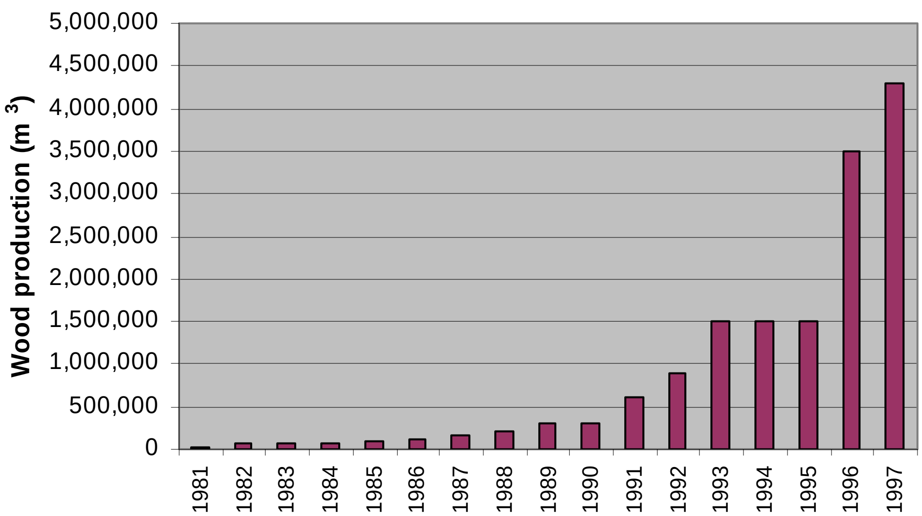

Figure 5. Wood production from 1981-1997. Data before 1996 taken from WB/UNDP/FAO (1996) and the last two years data from Henderson (1999)

Rate of timber harvesting from natural forests increased tremendously in the last five year (Figure 5). Prior to the 1990s, the rate of timber extraction was less than 0.5 million m^3

per year, and after 1990 it was over 0.5 million m^3 and reached 1.5 million m^3 in 1995. The recent estimate showed that the rate of timber extraction after 1995 increased very sharply from 1.5 million m^3 per year to about 4.0 million m^3 per year (Henderson, 1999).

Based on the above discussion, it is suggested that the main activity data for LULUCF in Cambodia are:

1. Area of secondary forests for each forest type;
2. Area of abandoned lands that are regenerated naturally (mosaic cropping);
3. Development of forest plantations, agroforests and community forests in degraded forest/lands;
4. Conversion of shrublands and forests into agriculture lands;
5. Formation of shrublands or degraded forest/lands; and
6. Wood extraction rate.

Table 8. . . . . ⊬覞 髟 **Emissi on Factors**

Emission factors in LULUCF do not necessary mean factors used to estimate emission from particular activities, but they also refer to factors for estimating carbon sequestration. Two keys emission factors for LULUCF in Cambodia are mean annual increment and fraction of harvested biomass that are not used for producing products. In connection with activity data mentioned in section 3.1, the specific key emission factors for LULUCF are:

2. Mean annual increment of the secondary forest for each forest type;
3. Mean annual increment of trees used in forest plantations, agroforest and community forest;
4. Biomass of forest and grassland that are converted into agriculture lands and biomass left after the conversion; and
5. Biomass of agriculture lands.

Studies on the emission factors in Cambodia are very limited. Most of tree growth data are presented in the form of diameter growth using units of cubic meter per year per hectare or cm per year. Nophea *et al.* (undated) stated that for evergreen forest, annual growth rate varied from 0.21 to 0.67 m^3/ha/year, mixed forest was between 0.08 and 0.37 m^3/ha/year. Similarly, data on aboveground biomass are also not available. Most of biomass data are presented in the form of volume of the standing stock. For evergreen forest, it was estimated that the commercial standing stock for trees with diameter of more than 10 cm, was between 192 and 230 m^3/ha, for mixed forest was between 52 and 60 m^3/ha, and for deciduous forest was about 60 m^3/ha and for mix forest was about 150 m^3/ha. Data on biomass before and after conversion were rarely available.

IV. METHOD FOR ESTIMATING MEAN ANNUAL BIOMASS INCREMENT AND ABOVEGROUND BIOMASS

4.1. Mean Annual Biomass Increment

Based on Boer *et al.* 2002, there are three approaches can be used for estimating the mean annual biomass increment:

- **<u>Approach 1:</u>** the annual biomass increment can be estimated by using assumption that the difference of wood volume between virgin (WV_{VF}) and logged-over (WV_{LOF}) forest is total wood volume accumulated in one year cycle (35 year).

  $$AMI_{LOF} = ((WV_{VF} - WV_{LOF})/Rotation)*WD*BEF$$

  Where: WD is wood density (t/m^3). In general, the default value of WD for Asian forest is $0.65 t/m^3$ and BEF is biomass expansion factor. Indonesia used BEF of 1.5.

- **<u>Approach 2:</u>** the annual biomass increment is estimated based on stand yield table (SY). Total stand biomass is estimated by multiplying stand yield (SY) with Biomass Expansion Factor (BEF) and correction factor (CF, ratio between stand yield table and observed data collected through forest inventory[2]), then divided by age of stand:

  $$MAI = (SY*CF*BEF)/(age\ of\ stand)$$

- **<u>Approach 3:</u>** the annual biomass increment can be estimated based on data on mean annual diameter increment as it is usually reported by forest companies. This data can be converted into annual biomass increment using following steps:

  - Estimate the wood volume of tree of logged-over forest from initial diameter (D).
  - Estimated the wood volume of tree after growing (initial diameter plus the annual diameter increment) using the allometric equation. Annual diameter increment can be estimated from diameter of tree.
  - Estimate wood volume per hectare by multiplying wood volume with number of tree per hectare according to their diameter class.
  - Calculate mean annual wood volume increment by taking the difference between total volume of tree after growing and volume of initial wood.
  - Calculate mean annual biomass increment by multiplying mean annual wood volume increment with biomass expansion factor and wood density.

[2] The correction factor is normally determined every 5-10 years, and the values ranged between 0.7 and 1.1, depending on the intensity of forest management/thinning and degree of forest disturbance. Normally, plantation forest which has a correction factor of less than 0.3 is considered as very open-forest and hence it must be replaced at the end of its rotation.

4.2. Aboveground Biomass

There are two approaches for estimating the biomass density for woody formations based on existing forest inventory data. The first approach is based on the volume over bark (VOB) of tree, while the second approach is using biomass regression equations. These regression equations are mathematical functions that relate oven-dry biomass per tree as a function of a single or a combination of tree dimension.

- ***Approach 1: Biomass density based on inventoried volume data (Stand Yield Table)***

The primary data needed for this approach is VOB (Volume Over Bark of tree). Inventory volume must include all trees, whether presently commercial or not, with a diameter of 10 cm at breast height (Brown, 1997). The equation for the AGB density is as follows:

$$\text{Aboveground biomass density (t/ha)} = VOB \times \rho \times BEF_A$$

WD is volume-weighted average wood density (the oven-dry biomass per m^3 green volume). It is expressed in units of mass of wood per unit of volume at 12% moisture content. A regression equation to convert wood density based on 12% moisture ($\rho_{12\%}$) to wood density based on oven-dry mass and green volume (ρ) is as follows (Reyes et al., 1992):

$$\rho = 0.0134 + 0.800\ \rho_{12\%}\ ;\ (r^2 = 0.99;\ \text{number of data points } n = 397)$$

Then the weighted average wood density value is calculated as follows:

$$\rho = \{(V_1/V_t)^*\ \rho_1 + (V_2/V_t)^*\ \rho_2 + \ldots\ldots.. + (V_n/V_t{}^*\rho_n)$$

V_1, V_2 …..V_n = volume of species 1, 2, ….. to the n^{th} species; Vt = total volume; ρ_1, ρ_2, …..ρ_n = wood density of species 1, 2, …..to the n^{th} species.

If these data are not available, the rough estimate of arithmetic mean of the ρ for Asian trees is 0.57 t/m^3 (Brown, 1997). BEF_A is biomass expansion factor (see Section 2.2).

Brown (1997) reported that there is no model for calculating biomass expansion factors for native conifer forests is available at present because of the general lack of sufficient data for the type of analysis performed for the broadleaf forests. However, one would expect that BEF_A for tropical pine forests would vary less than for broadleaf forests because of the generally similar branching pattern exhibited by different species of pine trees. Volumes of these stands ranged from 64 to 331 m^3/ha, where the BEF_A based on biomass of the main stem ranged from 1.05 to 1.58, with a mean of 1.3 (standard error of 0.06. A value of BEF_A of 1.3 can be used for biomass estimation of pine forests, whereas sufficient data is not available for doing estimation.

- ***Approach 2: Biomass Density Based on Stand Tables***

Another estimate of biomass density is derived from the application of biomass regression equations to stand tables. The method basically involves estimating the biomass per average tree of each diameter (diameter at breast height, dbh) class of the stand table, multiplying by the number of trees in the class, and summing across all classes. A key issue is the choice of the average diameter to represent the dbh class. For small dbh classes (10 cm or less), the mid-point of the class has been used (e.g., Brown et al. 1989).

There are several types of regression equations to estimate the AGB (in kg). The widely used equations are (Hairiah and Sitompul, 2000):

Polynomial model: $AGB=a_0+a_1D+a_2D^2+\ldots+a_nD^n$, and
Allometric models: $AGB= aD^b$ or $AGB= aD^bH$

Where a, b and c are parameters of the equations which are varied with tree species and location and D is dbh (in cm) and H is height of tree (m). The allometric models: $AGB=aD^b$ can be presented in the form of:

$$AGB = \exp\{a + b \ln(D)\}.$$

Brown (1997) has provided general equations that can be applied to estimate above ground biomass of trees at different climate regimes, if no local information available. The equations are presented in Table 5. She further suggested that for wider diameter classes, the quadratic-mean-diameter of a dbh class would be better to be used in the equation. Then, if basal area for each dbh class is known, the quadratic-mean-diameter (QSD) of trees in the class, or the dbh of a tree of average basal area in the class, should be used instead. To calculate the QSD, first divide the basal area of the diameter class by the number of trees in the class to find the basal area of the average tree. Equation for estimating the dbh from basal area is as follows:

dbh = 2 x {square root (basal area/3.142)}.

Allometric equations of some of agriculture perennial crops, namely palms, coffee and banana. The equations are:

Palm: $AGB = 4.5 + 7.7\ H$; $R^2 = 0.90$ (Frangi and Lugo, 1985)

Coffee: $\mathrm{Exp}(AGB) = 0.67134 + 0.00072208\ \mathrm{Exp}(H/0.40531445)$; $R^2=0.94$ (Winrock, 1998)

Banana: $AGB = 185 +882\ [\log(H)/H^2]/1000$; $R^2=0.99$ (Marquez (1998)

Table 5. Biomass regression equations for estimating biomass of tropical trees. Y= biomass per tree in kg, D = dbh in cm, and BA = basal area in cm^2

Equation Number	Climatic zone	Equation	Range in dbh *(cm)*	Number of trees	Adjusted r^2
1	DRY	Y = exp{-1.996+2.32*ln(D)}	5-40	28	0.89
2		Y =10^{-0.535+log_{10} (BA)}	3-30	191	0.94
3	MOIST	Y = 42.69-12.800(D)+1.242(D^2)	5-148	170	0,84
4		Y = exp{-2.134+2.530*ln(D)}			0.97
5	WET	Y = 21.297-6.953(D)+0.740(D^2)	4-112	169	0.92
6	Conifer forest	Y = exp{-1.170+2.119*ln(D)}	2-52	63	0.98

Note: Dry zone (rainfall is considerably less than evapotranspiration or annual rainfall is less than 1500 mm with distinct dry season. It was recommended to use equation 1 in region with annual rainfall of more than 900 mm and equation 2 in regions with annual rainfall of less than 900 mm; Moist zone (rainfall is between 1500-4000 m with a few month dry season or no dry season); Wet zone (rainfall always exceed evapotranspiration and no dry season). Equations 1-5 can also be used for plantation, however, it is better to check the validity of the equations using local data (Brown, 1997).

V. IMPROVEMENT OF ACTIVITY DATA

5.1. Methodology

Improvement of activity data such as land use and forest cover by type can be done through satellite image analysis. DoFW (1999) has done forest cover assessment using 15 LANDSAT TM IMAGES of 1993 and 1997 (Number 12850, 12750, 12650, 12550, 12851, 12751, 12651, 12551, 12451, 12752, 12652, 12552, 12452, 12753, and 12653). This data had been used in developing the national GHG inventory.

The Forest Cover Assessment done by the Department of Forestry and Wildlife was done up to district level (DoFW, 1999). However, in developing the National Greenhouse Gas Inventory, the data used were national level data. In addition, forest types considered in the analysis only included the major category and there was also no separation between undisturbed (*climax forest*) and disturbed forests. All forests are assumed to sequester carbon. In fact, forests that reach *climax stage* may not sequester carbon any longer as rate of photosynthesis may be the same as the rate of respiration. Therefore, separation between undisturbed and disturbed forest in the analysis is very important for reducing the uncertainty. This analysis assessed the variation of area of disturbed forest between provinces and their fraction relative to total forest area.

5.2. Result and Discussion

Land Use, Land Use Change and Forestry (LULUCF). Large fraction of Cambodian forest has been disturbed by human activities such as logging, shifting cultivation, developing agriculture land etc. In the Forest Cover Assessment done by DoFW (1999), forests that have been disturbed due to human activities were indicated as disturbed forests or mosaic. These disturbed forests will grow naturally back into the dense forest. However, the growing rate will depend on level of destruction, therefore, time needed to reach its original stage will vary from one to another. Heavily disturbed forests may have lower growing rate and require longer time to reach its original condition.

In this analysis, undisturbed forests are assumed to be the same with thick or dense forests. It may be possible that some of dense forests were also disturbed a number of years ago, but at present they have grown and back to their original condition. Crown cover and brief description of each forest type is given in Table 6, while total area of each forest category. Area of each forest types is in Tables 7.

Table 6. Crown cover and description of each forest type in Cambodia

No	Forest type/land use	Crown cover	Description/Comments
1	Evergreen dense	>70%	They usually contain multi-storied forests where trees keep their leaves during the whole year. They comprise the lowland tropical rainforests, the hill evergreen forests and the dry evergreen forests. A certain percentage of deciduous trees may be included as well and most deciduous forests may not be discernible from the evergreen forests. Coniferous forests (pines) may also be included because they could not be mapped as a separate class consistently.
2	Evergreen disturbed	20%-70%	
3	Evergreen mosaic	20%	
4	Mixed dense	>70%	They contain a variable percentage of evergreen and deciduous trees. The percentage of deciduous trees may vary from some 30 to some 70%. The variability of this class is high as it is stretching from the moist mixed deciduous forests to the mixed deciduous and to a more humid version of the dry deciduous forests. Some parts of dry evergreen forests are mapped in this class as well.
5	Mixed disturbed	20%-70%	
6	Mixed mosaic	20%-40%	
7	Undisturbed Deciduous	20%-40%	Deciduous forest is an open forest consisting of a few trees where most of their leaves are deciduous in dry season. These relatively species-poor, wholly deciduous forests are dominated by Dipterocarps and feature a sparse understorey subject to frequent fires.
8	Deciduous mosaic	20%-40%	
9	Mangrove	40%-50%	Tidal forest on the mud flats at the mouth of streams and along the shore of shallow bays. The dominant species are *Rhizophora conjugata* (Kongkang Nhy), *Rizophora mucronata* (Kongkang Chmul), *Ceriops sp*p., *Bruiera spp*., *Caralia sp.* and the families of Verbenaceae *(Avicennia sp*.), Sonneratiaceae, and Palmae *(Nypa fructican*s). *Rhizophora conjugata* and *Rhi. mucronat*a. *Rhizophora sp*p. reach a height of 15 to 20 m and diameters measured at 1.3 m high from ground vary from 30-40 cm, depending on natural factors (soil condition, location etc.). This forest is heavily degraded due to illegal logging for charcoal production. About 80% of this forest is already disturbed. The government has implemented mangrove reforestation program since 2000.
10	Inundated	20%-40%	This forest type is found in Cambodia around the Tonle Sap Lake. Most of the forests are low and disturbed. In many cases, there is only a mosaic remaining.
11	Forest Regrowth	20%-40%	Vegetation with tree height ranges between 5 m and 10 m[1]. It comprises areas with a continuous, usually dense layer of smaller trees. Stunted forests which grow very slowly due to poor site conditions may look similar to this category and therefore it is included in this class. The class 'forest regrowth' does not include other regrowth of shrubs, small bamboo or even very small trees growing directly after shifting cultivation. Differentiated between this class and woodland/shrubland on the basis of satelite images alone, is difficult.
12	Forest Plantation	N.A	Lands which are covered by tree plantation such as rubber, Eucalyptus, teak and pine. Only the area covered by tree layers were mapped.

Note: [1]Lands covered by forests normally have trees with height of more than 10 m. Source: Developed from DoFW (1998), Nophea *et al.* (undated) and Personal Communication with people from DoFW.

Table 7a. Area of Cambodian forest in 1992

Province	Evergreen		Mixed		Deciduous		Mangrove	Inundated	Forest Regrowth	Plantation
	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed				
	Hectares									
Battambang	7137	129659	14991	137706	165787	2916	0	109121	21183	0
Banteaymeanchey	401	38824	8237	24287	77319	19817	0	26	30978	0
Kandal	0	0	0	0	0	0	0	21161	202	0
Kompong Cham	6127	77957	4055	42029	22589	20116	0	14968	17863	60393
Kompong Chhnang	7517	12663	0	9908	101248	9635	0	20488	12370	0
Kompong Speu	18924	50337	0	6065	260248	409	0	0	20393	0
Kompong Thom	76352	337308	1675	26341	20394	4237	0	67533	113587	168
Kampot	40417	98182	0	5311	72692	643	2251	0	19918	0
Krong Kep	239	67	0	783	0	0	746	0	1439	0
Koh Kong	247445	679554	0	25003	17520	3966	62416	0	43047	203
Kratie	34512	225018	11992	149582	424872	52555	0	0	2660	7179
Mondul Kiri	69436	617462	26289	469149	1556246	186714	0	0	9541	14358
Phnom Penh	0	0	0	0	0	0	0	1118	0	0
Prey Veng	0	455	0	440	0	0	0	7557	412	211
Pursat	102092	286371	13744	111388	215384	14387	0	49823	18066	0
Preah Vihear	29637	175099	8486	226321	767883	15760	0	0	29074	0
Ratanak Kiri	19665	384340	17631	164250	324556	48317	0	0	49702	3780
Svay Rieng	0	3316	0	1686	0	0	0	25	0	0
Sihanouk Ville	173	67648	0	2616	17	0	12256	0	5104	372
Siem Reap	25881	188765	3549	103229	216336	1749	0	41110	36797	0
Stung Treng	25393	407590	0	154747	427352	45376	0	0	6824	0
Takeo	0	0	0	0	1238	0	0	13380	982	0
Odar Meanchey	12120	54859	12459	73740	186064	20717	0	0	797	0
Boeung Tonle Sap	0	0	0	0	0	0	0	3165	0	0
Cambodia	**723468**	**3835474**	**123108**	**1734581**	**4857745**	**447314**	**77669**	**349475**	**440939**	**86664**

Source: DoFW (1999)

Table 7b. Area of Cambodian forest in 1996

Province	Evergreen		Mixed		Deciduous		Mangrove	Inundated	Forest Regrowth	Plantation
	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed				
	Hectares									
Battambang	7137	128391	14680	136643	162970	3397	0	107780	20351	0
Banteaymeanchey	401	36189	8237	22481	75272	17618	0	26	14899	0
Kandal	0	0	0	0	0	0	0	20688	202	0
Kompong Cham	342	82955	3545	39863	21922	16654	0	14968	14346	70578
Kompong Chhnang	7517	12663	0	9841	100755	8671	0	20488	12370	0
Kompong Speu	18924	48609	0	6036	245146	1832	0	0	18600	0
Kompong Thom	70326	340991	1675	25862	20231	3832	0	67533	103281	168
Kampot	40417	99086	0	5311	69303	643	2251	0	16279	0
Krong Kep	239	67	0	783	0	0	746	0	1439	0
Koh Kong	236821	675410	0	24631	17520	3596	57582	0	32691	203
Kratie	30746	228785	11932	149382	421346	52368	0	0	2554	7179
Mondul Kiri	61904	622575	26169	466959	1547122	186190	0	0	9219	14358
Phnom Penh	0	0	0	0	0	0	0	1118	0	0
Prey Veng	0	64	0	440	0	0	0	6891	0	211
Pursat	102092	285497	13744	111340	215800	14387	0	49496	15241	0
Preah Vihear	29637	174902	8236	225506	758195	16838	0	0	28775	0
Ratanak Kiri	19621	373455	17306	158425	316982	52400	0	0	43436	3714
Svay Rieng	0	1428	0	1686	0	0	0	0	0	0
Sihanouk Ville	173	65917	0	2227	17	0	12256	0	4975	372
Siem Reap	22862	183640	3549	99805	212849	2328	0	39043	32044	0
Stung Treng	25393	405283	0	153673	413456	50782	0	0	6824	0
Takeo	0	0	0	0	128	0	0	4108	982	0
Odar Meanchey	12120	51676	10352	67638	174897	23379	0	0	797	0
Boeung Tonle Sap	0	0	0	0	0	0	0	3165	0	0
Cambodia	**686672**	**3817583**	**119425**	**1708532**	**4773911**	**454915**	**72835**	**335304**	**379305**	**96783**

Source: DoFW (1999)

DoFW (1999) has classified shrubland as non-forest (non-wood), even though some of this land contain trees. In general tree cover in this land is below 20% with height of less than 5 m. There are three categories of shrubland in Cambodia, i.e. shrubland evergreen, shrubland dry and shrubland inundated (see Appendix 1 for detail). In term of GHG inventory development, this land should be included since this land will sequester CO_2 from the atmosphere. As it is mentioned previously, other non-forest lands such as grassland and mosaic cropping may also sequester the CO_2 as these lands have some small growing trees. Thus, this land use categories also should be considered in the development of GHG inventory. In the initial national communication, the mosaic cropping was excluded. The area of the non-wood lands is presented in Table 8.

Table 8. Area of non-wood lands in Cambodia

Province	Wood-/Strubland		Grassland		Mosaic cropping	
	1992	1996	1992	1996	1992	1996
Battambang	166759	161730	102289	101777	5372	9359
Banteaymeanchey	98744	93699	68266	69180	1332	9220
Kandal	8078	4429	22946	17713	0	0
Kompong Cham	116583	113343	5083	4751	12564	21231
Kompong Chhnang	108792	106146	6128	6362	0	0
Kompong Speu	131071	109452	3074	2476	0	27
Kompong Thom	206115	199924	87437	88272	22583	31767
Kampot	40799	40230	10500	4129	4546	7892
Krong Kep	1907	1600	0	0	1373	1710
Koh Kong	105810	116417	21780	24995	4660	26402
Kratie	163018	145488	9083	7554	5369	17641
Mondul Kiri	517356	484764	47370	44769	26641	54610
Phnom Penh	409	409	723	723	0	0
Prey Veng	12535	13013	1808	1704	4583	4934
Pursat	113342	106540	28823	35901	4987	5284
Preah Vihear	95771	100356	3321	3419	14487	13450
Ratanak Kiri	112133	132955	2277	2277	65888	86167
Svay Rieng	21240	20421	0	0	15592	14968
Sihanouk Ville	14369	15111	4803	3792	4825	8464
Siem Reap	141098	136049	36420	56180	81376	88784
Stung Treng	67978	68238	1422	1422	6254	14450
Takeo	18789	15902	17391	10853	0	298
Odar Meanchey	89038	100396	13302	14694	31630	47575
Boeung Tonle Sap	1	1	722	808	0	0
Cambodia	**2351735**	**2286613**	**494968**	**503751**	**314062**	**464233**

Source: DoFW (1999).

In the Initial National Communication (MoE, 2002), the data on land use, land use change and forestry were derived from two different sources, i.e. World Bank/FAO/UNDP (1996) and MAFF/World Bank (1999). Thus there would different level of data uncertainty between the two sources and this would increae the uncertainty of the GHG emission and removal estimates. In this study, all data were derived from the same source, i.e. DoFW (1999).

Wood Harvest. In the Initial National Communication (MoE, 2002), total wood harvest in 1994 was estimated to be about 1.5 million m^3, similar to round wood production of 1993 and 1995 (see Figure 5). This data might not consider wood production from illegal logging, while many reports stated that illegal logging accounted for most of total round wood in Cambodia (Bottomley, 2000). New estimation made by Henderson (1999) regarding illegal logging showed that total round wood production in 1996 and 1997 from this logging were more than double of that of 1995 official data (see Figure 5). Therefore, in the improved LULUCF GHG inventory, this should be taken into account.

In this analysis, the estimation of total logging in 1994 was made based on historical round wood production and area of disturbed forests. Suppose, using conservative value a potential roundwood production from one-hectare forest is 20 m^3/ha, slightly higher than data used by Department of Forestry and Wildlife. DoFW (1998) stated that using assumption of 30 years cutting cycle, and mean annual increment of 0.33 m^3/ha/year, the sustainable extraction rate from the forest should be 15-20 m^3/ha. As forest concessionaires might not practice this, the higher value was used with cutting cycle of 35 years. Thus, it is assumed that the logged-over forest will be back to its original stage after 35 years.

Based on official data, the total wood production from 1960 to 1995 was about 8,766,000 m^3. If the potential production from one hectare is 20m^3, the total logged over forest area should be about 438,300 ha. In fact, total disturbed forest in 1995 was about 5,548,085 ha (disturbed evergreen and disturbed mixed forests). Suppose, we only adopt one third of this area if we assumed that most of the disturbance was not due to logging (e.g. for fuel wood consumption[3]), thus the total wood production should be about 20*1,849,362=36,987,233 m^3. Suppose, the annual wood production follows the similar pattern as the official data, then the total wood production in 1994 would be about 6,329,095 m^3. As the offical wood production is 1,500,000 m^3, thus illegal logging would account for about 4,829,095 m^3. Henderson (1999) reported that in 1997, the illegal logging reached 4,247,280 m^3 (see Appendix 4).

[3] About 92% of the Cambodian population use firewood and charcoal, primarily from natural foresta as well as trees outside forest areas. Fuel wood gathering contributes to forest degradation, especially in agriculture regions situated in limited wooded province (DoFW, 1998)

VI. IMPROVEMENT OF EMISSION FACTORS

6.1. Methodology

Type of emission factors covered in this study were mean annual increment and above ground biomass. The improvement of these data was carried out through literature review and field survey. The survey was done in seven sites in four different provinces. These include (1) Kirirom National Park (Kompong Speu province) representing undisturbed forest and (2) Ream National Park (Sihanouk ville) representing undisturbed forest, (3) Protected Landscape and Multiple Use Area (Tonle Sap Lake, Siem Reap province) representing disturbed forest, (4) Stung Forestry Community in Siem Reap representing the forest regrowth, and (5) Kompong Cham Plantation representing forest plantation. Forest types in these sites are "Mixed (semi-evergreen), Coniferous, Secondary, Inundated, Mangrove, and Forest Plantation. The general condition of the locations is presented in Appendix 5, while protocol for collecting and processing sampling in the survey is in Appendix 6.

In the survey, about 14 sample plots were developed, namely A, B, C, and D plots in Ream National Park, E and F plots in Kirirom National Park, G, H, I, and J plots in Siem Reap and K,L,M and N plots in Kompong Cham. Size of sample plots is $200m^2$. Number of trees and species measured as well as range of necromas weight in each plot are as follows:

Plot A (Ream National Park): mixed (semi-evergreen) forest:

- Measured live trees: total 38 trees, 9 species, diameter ranges from 5.2-47.8 cm and height range from 5.00-26.00 m.
- Collected destructive sampling with size $4m^2$: 5 sacks, coarse litters range from 1.65-4.00 kg, roots and biomass: 8.30 kg.

Plot B (Ream National Park): mixed (semi-evergreen) forest:

- Measured live trees: total 26 trees, 11 species, diameter ranges from 5.3 -47.8 cm and height range from 6.00-27.50 m, necromass range from 0.60-8.50 m.
- Collected destructive sampling with size $4m^2$: 8 sacks, coarse litters range from 1.3-7.00 kg, roots and biomass range from 0.7-3.3 kg.

Plot C (Ream National Park): mangrove forest:

- Measured live trees: total 74 trees, 4 species, diameter ranges from 5.0-32.2 cm and height range from 4.00-8.30 m.
- Collected destructive sampling with size $4m^2$: 4 sacks, roots and biomass range from 8.4-11.9 kg.

Plot D (Ream National Park): mangrove forest:

- Measured live trees: total 66 trees, 5 species, diameter ranges from 5.0-66.3 cm and height range from 3.50-10.00 m.

Plot E (Kirirom National Park): pine forest:

- Measured live trees: total 40 trees, 2 species, diameter ranges from 6.1-30.6 cm and height range from 7.50-24.70 m, necromass range from 0.29-8.00 m.
- Collected destructive sampling with size $4m^2$: 4 sacks, coarse litters range from 1.6-3.65 kg.

Plot F (Kirirom National Park): pine forest:

- Measured live trees: total 26 trees, 1 species, diameter ranges from 5.9-29.9 cm, and height range from 5.0-21.70 m.
- Collected destructive sampling with size $4m^2$: 4 sacks, coarse litters from 1.0-5.20 kg.

Plot G (Siem Reap): inundated forest:

- Plot G, total numbers of tree is 13, 1 species, diameter ranges from 5.6-23.1 cm and height of tree ranges from 2.50-9.20 m.

Plot H (Siem Reap): inundated forest:

- Plot H, total numbers of tree is 25, 3 species, diameter ranges from 6.4-19 cm and height of tree ranges from 5.00-13.00 m.

Plot I (Siem Reap): secondary forest:

- Plot I, total numbers of tree is 23, 1 species, diameter ranges from 5.50-33.2 cm and height of tree ranges from 5.10-16.50 meter.

Plot J (Siem Reap): secondary forest:

- Plot J, total numbers of tree is 29, 1 species, diameter ranges from 5.2-30.20 cm and height of tree ranges from 7.20-17.10 m.

Plot K (Kompong Cham): rubber plantation:

- Total numbers of tree is 13, 1 species, diameter ranges from 12.2-24.4 cm and height of tree ranges from 15.80-20.60 m.

Plot L (Kompong Cham): rubber plantation:

- Plot L, total numbers of tree is 14, only one species, diameter ranges from 6.1-33.00 cm and height of tree ranges from 11.6-22.1 m, the rubber trees were planted in 1987.

Plot M (Kompong Cham): Teak plantation (*Tectona gradis*):

- Plot M, total numbers of tree is 29, 1 species, diameter ranges from 11.50-22.00 cm and height of tree ranges from 14.3-17.4 m.

Plot N (Kompong Cham): *Tectona gradis*:

- Plot N, total numbers of tree is 16, only one species, diameter ranges from 14.30-24.30cm and height of tree ranges from 14.8-16.9 m, the trees were planted in 1988.

6.2. Result and Discussion

Above Ground Biomass. The aboveground biomass consists of live trees biomass, understorey and dead trees or necromas (see Appendix 7). The live tree biomass was not measured directly but it was estimated from diameter using developed allometric equations. It was found that number of trees with diameter of more than 5 m range between 13 and 74 trees per plot. The mean of diameter of trees between plot varies from 12.7cm and 35.7cm (Table 9; see Appendix 7 for detail).

As it is discussed in Chapter 4, the live tree biomass (LTB) can be estimated based on data on volume over bark (VOB), biomass expansion factor (BEF) and biomass density (ρ). In this analysis, BEF of evergreen, coniferous and secondary forests is assumed to be the same as that of secondary forest, i.e. 1.4 (taken from Ruhiyat *et al.*, 1995), teak is 1.25 (Hendri, 2000), rubber is assumed to the same as pine, i.e. 1.31 (taken from Boer *et al.*, 2000) and mangrove is about 1.4. The wood density of evergreen, coniferous and secondary forests is about 0.57 t/m^3 (Brown, 1997), while those of teak, mangrove and rubber are 0.70, 0.75, and 0.60 t/m^3 respectively. The equation is as follows:

Table 9. Range of diameter, total number and species of trees in the 14 plots

Plot	Tree num-ber	Species (number of trees)	Diameter			
			Max	Min	Mean	Stdev
A (Semi-evergreen)	38	*Flemingia stricta (16); Bauhinia bassacensis (4); Lithocarpus elegans (1); Leea indica (1); Buchanania arborescens (1); Mitrella mesnyi (1); Chhor-eung Morn (12); Neolitsea zeylanica (1); Tan Hork (1)*	47.8	5.2	26.5	30.1
B (Semi-evergreen)	26	*Flemingia stricta (6); Bauhinia bassacensis (8); Neolitsea zeylanica (2); Lithocarpus elegans (1); Knema globularia (1); Mitrella mesnyi (1); Diospyros hasseltii (1); Buchanania arborescens (1); Heritiera javanica (1); Tan Hork (2);Chhor-eung Morn (2)*	47.8	5.3	26.6	30.1
C (Mangrove)	74	*Rhizophora mucronata (48); Bruguiera sexangula (12); Tabon (12); Krabounh (2);*	32.2	5.0	18.6	19.2

Plot	Tree number	Species (number of trees)	Diameter			
			Max	Min	Mean	Stdev
D (Mangrove)	66	*Local name: Tabon (20); Rhizophora mucronata (20); Bruguiera sexangula (23); Local name: Kraboung (1); Lumnitzera littrorea (2);*	66.3	5.0	35.7	43.3
E (Coniferous)	40	*Pinus merkusii (39); Broussonetia billard (1);*	30.6	6.1	18.4	17.3
F (Coniferous)	26	*Pinus merkusii (26);*	29.9	5.9	17.9	17.0
G (Inundated forest)	13	*Barringtonia asiatica (13);*	23.1	5.6	14.4	12.4
H (Inundated forest)	25	*Barringtonia asiatica (23); Diploknema S.P, Madhuca elliptica (1); Local name: Paor (1);*	19.0	6.4	12.7	8.9
I (Secondary forest)	23	*Dipterocarpus costatus (23);*	33.2	5.5	19.4	19.6
J (Secondary forest)	29	*Dipterocarpus costatus (29);*	30.2	5.2	17.7	17.7
K (Rubber)	13	*Hevea brasiliensis (13);*	24.4	12.2	18.3	8.6
L (Rubber)	14	*Hevea brasiliensis (14);*	33.0	6.1	19.6	19.0
M (Teak)	29	*Tectona grandis (29);*	22.0	11.5	16.8	7.4
N (Teak)	16	*Tectona grandis (16);*	24.3	14.3	19.3	7.1

Note: Size of sampling plot is 200 m^2

$$LTB = VOB*BEF*\rho$$

Since the data on VOB of the trees in each forest are not available, thus these data should also be estimated using allometric equations. In Cambodia, no forest inventory was undertaken prior to preparation of the forest management plans and therefore no allometric equations for each forest type have been developed (DoFW, 1998; DoFW, 2000a). This study used Indonesian allometric equations relevance to each forest types. For future development, allometric equations for each forest types should be developed locally based on destructive sampling. This work should be prioritized since it is not only important for the further improvement of national GHG inventory but also for estimation of carbon stock potential of forest carbon projects.

The allometric equations used for estimating the VOB are as follows:

1. Evergreen, Coniferous and secondary forest: $VOB = 0.00007771*D^{2.267}$; R^2= 95% (Boer et al., 2000)
2. Mangrove and inundated: $VOB = 0.000107*D^{2.4}$; R^2 = 96 (Marlia, 1999)
3. Rubber (assumed the same as pine): $VOB = 0.0000478*D^{2.76}$; R^2=95% (Setiawan, 1996)
4. Teak: $VOB = 0.000838*D^{1.9386}$; R^2 = 96% (Pramugari, 1982).

The estimated dry weights of live tree (LTB), measured understorey and necromas are presented in Table 10.

Table 10 shows that the mean of total above ground biomass of evergreen forests, mangrove, coniferous, inundated forest, secondary forest, rubber, and teak are about 95, 144, 80, 50, 47, 100 and 185 t/ha respectively. These data may not reflect the total above ground biomass of the forests in Cambodia as the location selected for the survey were limited to only 14 locations with limited number of sample plots for each forest type (two sample plot for each forest type). For the future work, the study should be expanded to include more forest types in more locations at different level of degradation and more number of sample plots.

Table 10. Dry weight of understorey and necromas at the 14 plots

Plot	Understorey[1] (1)	Necromas[2] (2)	Live tree biomass[2] (3)	Total AGB (1+2+3)
	t/ha			
A (Semi-evergreen)	7.0 (4.5)		66.62	74
B (Semi-evergreen)	7.1 (4.7)	19.77	89.92	117
C (Mangrove)	13.5 (3.2)	-	75.75	89
D (Mangrove)	-	-	198.34	198
E (Coniferous)	4.3 (1.2)	1.22	96.93	102
F (Coniferous)	3.1 (2.3)		54.18	57
G (Inundated forest)	6.9 (9.1)	3.44	28.72	39
H (Inundated forest)	6.6 (9.5)		53.64	60
I (Secondary forest)	6.2 (8.2)		35.12	41
J (Secondary forest)	4.4 (5.1)		48.51	53
K (Rubber)	3.3 (1.0)		84.52	88
L (Rubber)	3.0 (1.0)		109.57	113
M (Teak)	5.2 (2.7)	6.54	203.25	215
N (Teak)	6.2 (0.6)		148.07	154

Note: Values in the brackets are standard deviations and calculated from field measurements. [2] Estimated from diameter using the allometric equations.

Mean Annual Increments. Based on data provided by Ashwell (1993 in Nophea *et al.*, undated), the mean annual increment of logged-over evergreen forest range from 0.21 to 0.67 m^3/ha/yr with mean of 0.33 m3/ha/yr. For logged-over deciduous forest, the mean annual increment ranged from 0.08 to 0.34 m^3/ha/yr with mean of about 0.19 m^3/ha/yr. If it is assumed that the wood density is 0.65 t/m^3 and the biomass expansion factor is 1.4 (Ruhiyat, 1995), the mean annual increments of logged-over evergreen forest, and logged-over deciduous forest are about 0.30 and 0.17 tB/ha/year respectively. Other study in Indonesia showed that the mean annual increment (MAI) of logged-over rain forest varied between 1.3 and 2.7 tB ha^{-1} yr^{-1} (Sutisna, 1997). The MAI could be increased up to 8.4 tB ha^{-1} yr^{-1} depending on tending intensity (Sutisna, 1997).

In this study, data on diameter growth of trees in sample plots were measured based on the measurement of diameter of tree in two different times (D_1 and D_2). The interval of the measurements was between 165 and167 days (I). The annual growth rate of the tree was calculated as follows:

$$\text{Annual growth rate of tree diameter at breast height} = (D_2 - D_1)*(365/I)$$

Where 365 the number of days in a year and subscripts 1 and 2 refers to time of measurement for time 1 and time 2 respectively. Similarly, change in height of the tree between the two periods is also used to estimate the annual growth rate of the tree height. The result of analysis is presented in Table 11.

Table 11. Mean and standard deviation of annual growth rate of tree diameter and tree height in the 14 plots

Plot	Forest type	Number of tree per plot	Diameter of tree at time-1 (D_1)[1]	Annual growth rate of tree diameter, dD (cm)	Height of tree at time-1, H_1 (m)[2]	Annual growth rate of tree height (m)
A	Semi evergreeen	38	12.96 (8.81)	1.14 (1.14)	10.61 (3.80)	0.92 (0.47)
B	Semi evergreeen	26	18.25 (11.2)	1.25 (1.02)	10.30 (4.52)	0.89 (0.56)
C	Mangrove	74	7.52 (3.76)	0.49 (0.67)	6.45 (1.00)	0.93 (0.39)
D	Mangrove	66	8.79 (7.92)	0.84 (1.11)	6.55 (1.61)	1.00 (0.49)
E	Coniferous	40	15.05 (6.58)	0.94 (0.68)	14.02 (4.72)	0.87 (0.47)
F	Coniferous	26	16.08 (6.90)	1.97 (4.61)	15.60 (5.62)	0.82 (0.50)
G	Inundated forest	13	Na	Na	Na	Na
H	Inundated forest	25	Na	Na	Na	Na
I	Secondary Forest	23	13.52 (6.64)	0.99 (1.04)	12.51 (2.89)	0.38 (0.21)
J	Secondary Forest	29	14.62 (5.91)	1.51(2.93)	11.99 (2.55)	0.42 (0.21)
K	Rubber plantation	13	18.67 (3.42)	0.78 (0.39)	18.90 (1.35)	0.64 (0.24)
L	Rubber plantation	14	18.33 (7.22)	0.71 (0.37)	18.21 (3.02)	0.57 (0.20)
M	Tectona grandis	29	16.77 (2.49)	0.77 (0.47)	15.88 (0.99)	0.54 (0.18)
N	Tectona grandis	16	19.33 (3.11)	1.23 (0.57)	15.88 (0.51)	0.65 (0.22)

Note: [1]Diameter at breast height; and [2]Height of the tree is measured from the soil surface to the top of the tree. Values in the brackets are standard deviations. Na is not available.

Annual growth rate of trees biomass (GRB) in each plot was estimated using Approach 3 described in Chapter 4. It can be written in the form of the following equation:

$$GRB = BEF * \rho * [\sum_{i=1}^{n} (a * D_i^{\ b})_2 - \sum_{i=1}^{n} (a * D_i^{\ b})_1]$$

Where subscripts 1 and 2 refer to the 1st and 2nd time of diameter measurement, n is number of tree per plot and i is tree number in the plot (see Appenidx 6). The estimated GRB is presented in Table 12.

Table 12. Annual growth rate biomass of trees biomass in each plot

Plot	Forest type	GRB (t/ha/year)	Plot	Forest type	GRB (t/ha/year)
A	Semi evergreeen	4.74	H	Inundated forest	-
B	Semi evergreeen	5.35	I	Secondary Forest	2.29
C	Mangrove	6.45	J	Secondary Forest	3.70
D	Mangrove	-	K	Rubber plantation	3.72
E	Coniferous	5.73	L	Rubber plantation	4.09
F	Coniferous	5.72	M	Tectona grandis	6.50
G	Inundated forest	-	N	Tectona grandis	6.55

Note: The estimates were the estimate of the biomass growth rate in the inventory year (2002).

As it is mentioned previously, data presented in Table 10-12 may not reflect the overall condition of Cambodian forest as the number of location and sample selected for this study was very limited. Thus this data should be treated as additional information that can be used for consideration in selecting aboveground biomass data and means annual increment of a forest type for GHG inventory development.

VII. UNCERTAINTY ANALYSIS

Figure 7. . . . . M ethodology

Estimates of Carbon emission or removals from any sectors may deviate greatly or insignificantly from the actual emissions or removal. This indicates that any estimate carries a certain level of uncertainty. There are many factors affecting uncertainty such as sampling error or limitations on instruments, expert judgment error and many others. Some sources of uncertainty may be easily to be characterized so that we can easily characterized estimates of the range of potential error. In some other cases, source of uncertainty may be difficult to be characterized.

In many National GHG Inventory reports, it was reported that estimates of carbon emissions or removal from LULUCF sectors might bear high degree of uncertainty. One of the main reasons is that most of activity data or emission factors used in the analysis are based on expert judgment or estimated from other available data. Therefore, uncertainty analysis for this sector is important. This analysis provides quantitative measures of the uncertainty of output values caused by uncertainties in the model itself and in its input values, and examine relative importance of these factors (IPCC, 2000).

In this study, the uncertainty of carbon emissions and removal estimates was assessed using Monte Carlo Analysis up to provincial level. The principle of Monte Carlo Analysis is to select random values of emission factor and activity data from within their individual probability density functions, and to calculate the corresponding carbon emission or removal values. This procedure is repeated many times and the results of each calculation run build up the overall emission probability density function (IPCC, 2000). Step of analysis is presented in Figure 6.

Following the Monte Carlo procedure, means and variance of activity data and emission factors are required as well as the statistical distribution of the data. In this study, the statistical distribution of the data is assumed to be normal. The activity data and emission factors used in this analysis were provided in chapters V and VI. Since the variance of activity data and emission factors are not available, approach to estimates these values are developed using a number of assumption. The assumptions are as follows:

1. Annual rate of forest conversion and land use change in the period of 1992-1996 is assumed to be the same (see Tables 7 and 8). Based on this assumption, the 1994 data according to forest category would be the means between data of 1992 and that of 1996.

2. Standard error (as a percentage of means) of forest area estimates from TM satellite data normaly ranges between 5% and 10% (personal communication with a staff from Cartography and GIS office at the Ministry of Environment). The error of the estimates is inversely related with the size of the area being assessed, thus the highest forest area would have smaller error while the lowest forest area might have the

highest error. Following this argument, we assumed that the standard deviation of forest area estimates are proportionally related with the size of the forest area, and the values ranges from 5% to 10% of the means. The smallest forest area will have error of about 0.1 of the estimate and the highest forest area will have error of about 0.05 of the estimate. In this study, it was found that the highest area is 1,742,960 ha. Thus the standard deviation of this estimated area is 0.05*1,742,960 ha = 87,148 ha. For area smaller than the higest value (say, *X*), the standard deviation of *X* would be equal to $(0.1 - \frac{X}{1,742,960} * 0.05) * X$

3. It was reported that the coefficient of variation for the main forest types of Cambodia from past inventory study was about 40-50% (DoFW, 1998). In this study we assumed that this value is applicable for all forest types. Thus, the standard deviations for biomass growth rates were assumed to be about 45% of the means.

4. The biomass growth rate of a given forest was estimated using weigthed average of biomass growth rate of disturbed and undisturbed forests.

5. In the initial national communication, the fraction of biomass burnt on site, off site and left to decay were assumed to be 40%, 10% and 50% respectively. In this study these values were modified based on available studies in the region. Palm et al. (1999) stated that in tropical countries, slash and burn technique were commonly practiced in shifting cultivation. Based on field measurement, it was found that fraction of biomass burned on site during the conversion was about 66% (Prayogo *et al.* in Hairiah and Sitompul, 1999) and off site is 10% and the remaining left to decay. Annual rate of forest/grassland conversion to agriculture land or for shifting cultivation was the annual mean of agriculture land development and the increase of mosaic cropping in the period of 1992 and 1996.

6. Land use and forest cover data published by DoFW (1999) did not clearly describe which forest types being converted into agriculture lands. Thus, this creates difficulty in determining amount of biomass before conversion. To solve this problem, we assumed that the proportion of each forest type used for agriculture development is proportional to the decrease in area of the corresponding forest. Following this assumption, the biomass before conversion (BBC) was estimated as follows:

$$BBC = \frac{1}{A} \sum_{i=1}^{n} A_i * B_i$$

Where A is total area reduction of all forest types, A_i is area reduction of forest-i^{th} and B_i is the biomass of forest-i^{th}. For example, in a given province area of evergreen, shrubland and grassland decreased for about 1000, 800 and 200 ha respectively and biomass of these lands were 100, 20 and 10 t/ha respectively. Suppose, the area of agriculture land increase by about 500 ha. Using the above equation, it was assumed that about 250 ha of the agriculture land is developed from the conversion of evergereen forest, while 200 ha is developed from the conversion of shurbland and

100 ha is developed from the conversion of grassland. Thus, the biomass before conversion would be about (10/20*100+8/20*20+2/20*10)=59 t/ha.

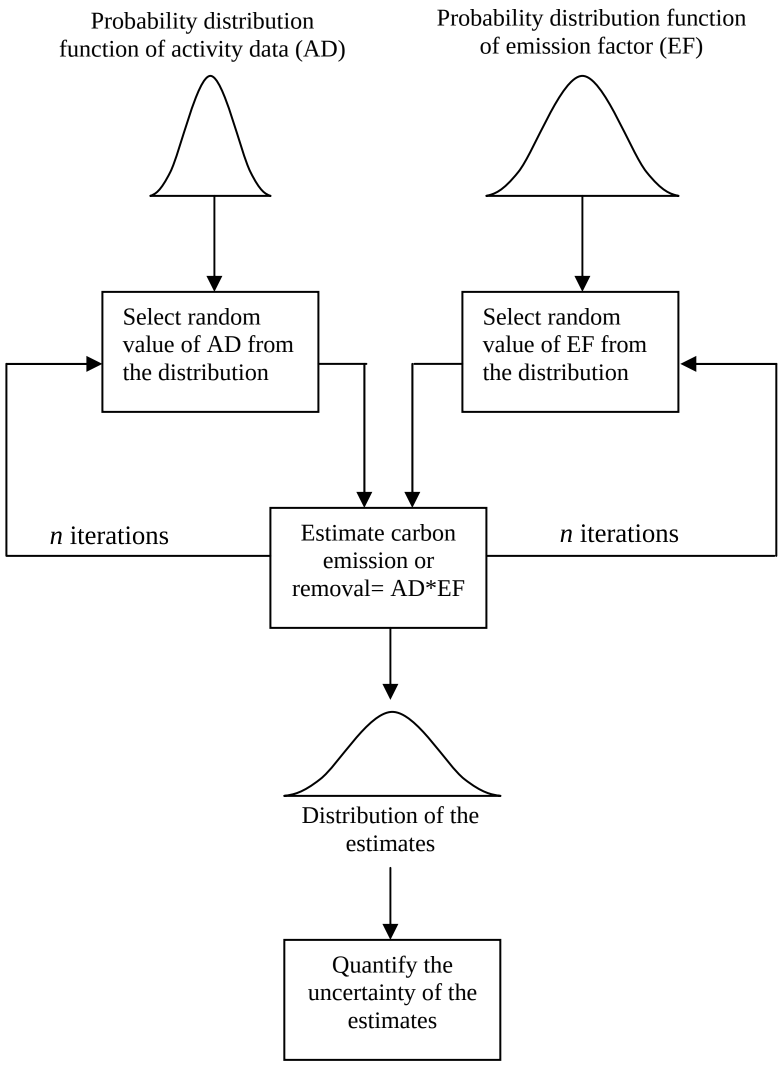

Figure 6. Step of uncertainty analysis using Monte Carlo technique (IPCC, 2000)

7. Total round wood production used in this study considered the illegal logging. Thus the data of total wood production from illegal logging need to be estimated. In this case, the total wood production from both legal and illegal logging was reestimated based on the historical wood production in the last 30 years and total reported area of disturbed forests from DoFW (1999) as described in Chapter 3. As the estimated wood production for 1994 was at national level, i.e. 6,329,095 m^3, the wood production in each province was estimated using the proportion of wood production of the 1997.

8. Data on fuel wood and charcoal consumption was available only for national level. Thus this data was disagregated into provincial data based on population density of

the corresponding province (NIS, 2001). In 1994, the fuel wood and charcoal consumption was about 5,398,000 ton (MIME, 1996). This was used in National GHG Inventory.

7.2 Result and Discussion

Biomass Growth Rate. Considering studies of Ashwell (in Nophea, undated), Sutisna (1997), the data resulted from this study (Table 12), new biomass growth rate for each forest types were developed as it shown in Table 13. The standard deviation of the biomass growth rate was calculated following assumption described above. In comparison with the biomass growth rate used in the Initial National Communication, the estimates used in this study were lower, since many reports stated that the biomass growth rate of disturbed forest, in particular logged-over forest were less than 2.0 t/ha/year. Furthermore, Aswhell (in Nophea, undated) gave much lower estimate for evergreen and deciduous (Table 13).

Table 13. Estimated of biomass growth rate of each forest types in Cambodia

Forest types	Initial NatCom (t/ha/year)	Estimated from Survey data (t/ha/year)	Other studies (t/ha/year)	Used in this study (t/ha/year)
Evergreen	3.00[1]		0.30[7],	2.5
Mixed (Semi-evergreen)	4.20[2]	5.04	1.71-2.96[8]	3.0
Deciduous	3.60[2]	n.a	0.17[7]	2.0
Forest Regrowth	2.83[3]	2.99	1.3-2.7[9]	2.5
Inundated	2.98[3]	n.a	n.a	2.0
Mangrove	3.00[4]	6.45	n.a	3.0
Plantation (rubber)	*6.68*[5]	5.20	3.3-25[10]	6.7
Shrubland	1.00[4]	n.a	n.a	1.0
Non-Forest/Agroforestry	5.84[3]	n.a	n.a	6.0
Wood-/Shrubland Evergreen	n.a	n.a	n.a	1.0
Wood-/Shrubland dry	n.a	n.a	n.a	0.7
Wood-/Shrubland Inundated	n.a	n.a	n.a	0.5
Mosaic of cropping<30%	n.a	n.a	n.a	1.5
Mosaic of cropping >30%	n.a	n.a	n.a	0.5
Grassland	0.50[6]	n.a	n.a	0.2
Bamboo	1.50	n.a	n.a	n.a

Source: [1] IPCC (1997);[2] FAO (1997); [3] LEAP RWEDP (1997); [4] Lasco and Pulhin (1999); [5] Boer *et al.*, (2001);[6] UNDP-ESMAP (1992); [7]Ashwell (in Nophea, undated); [8]Logged over forest (Boer *et al.,* 2001); [9]Sutisna (1997), and [10]Askari (2000).

Above Ground Biomass. Aboveground biomass used in this study was set lower than the ones used in the Initial National Communication. This was motivated by the fact that the estimates of biomass based on field survey were much lower than those used in the Initial National Communication (Table 14).

Table 14. Estimates of total aboveground biomass by forest types in Cambodia

Forest types	Initial NatCom	Estimated from Survey data	Other studies	Used in this study
Evergreen	295[1]		150[2]	200
Mixed (Semi evergreen)	370[1]	95	n.a	250
Deciduous	120[1]	n.a	n.a	100
Forest Regrowth	190[1]	47	32-230[3, 4]	120
Inundated	70[1]	50	15-342[4,5]	70
Mangrove	175	144	152-443[4]	150
Plantation	80	142	60-153[4]	100
Shrubland	70	n.a	~78[7]	70
Non-Forest/Agroforestry	n.a	n.a	30-207[6]	100
Wood-/Shrubland Evergreen	n.a	n.a	n.a	70
Wood-/Shrubland dry	n.a	n.a	n.a	50
Wood-/Shrubland Inundated	n.a	n.a	n.a	40
Mosaic of cropping<30%	n.a	n.a	~30[8]	30
Mosaic of cropping >30%	n.a	n.a	~100[8]	75
Grassland	n.a	n.a	2-7.6[5,9]	5

Source: [1]IPCC (1997); [2] FAO (1997); [3]Kiyono and Hastaniah (1997); [4]Wasrin *et al.*, (2000); [5]Utomo (1996); [6]Tomich et al. (1998); [7] Van Noordwijk *et al.*, (2000); [8]Murdiyarso & Wasrin (1996); [9]Palm et al., (1999); [10]Hairiah and Sitompul (2000). Note: ~ means around that value.

Wood Production. Using the assumption described in methodology (section 7.1), it was found that the estimate of wood production for 1994 at national level was about 6,329,095 m^3 and at provincial level is presented in Table 15.

Table 15. Total wood production in 1994 by province

No	Province	Wood production (m^3)	No	Province	Wood production (m^3)
1	Banteaymeanchey	132,458	13	Phnom Penh	0
2	Battambang	670,569	14	Prey Veng	0
3	Kandal	0	15	Pursat	247,365
4	Kompong Cham	166,401	16	Preah Vihear	96,860
5	Kompong Chhnang	213,688	17	Ratanak Kiri	466,786
6	Kompong Speu	372,538	18	Svay Rieng	0
7	Kompong Thom	337,007	19	Sihanouk Ville	0
8	Kampot	152,326	20	Siem Reap	5,365
9	Krong Keb	0	21	Stung Treng	307,120
10	Koh Kong	2,183,968	22	Takeo	0
11	Kratie	926,428	23	Odar Meanchey	0
12	Mondul Kiri	50,218	24		

Fuel Wood and Charcoal Consumption. Fuel wood is the main source of energy for cooking in Cambodia. A study conducted by NIS (1999) stated that 94.3% of population in rural areas uses firewood for cooking, 2.3% charcoal, 1.7% kerosene, 0.5% LPG and

1.2% others. While in the urban areas about 64.9 of population uses firewood, 22.5% charcoal, 2.8% kerosene, 9.1% LPG and 0.7 others. While, the average amount of fire-wood consumed per person is about 0.558 kg/day/cap and charcoal 0.36 kg/cap/day (equivalent to 0.648 kg firewood; FAO, 1998). Estimate of fuelwood consumption per province based on population is given in Table 16.

Table 16. Estimates of fuel wood and charcoal consumption by province in 1994

No	Province	Fuel Wood Consumption (ton)	No	Province	Fuel Wood Consumption (ton)
1	Battambang	355189	13	Phnom Penh	445083
2	Banteaymeanchey	268036	14	Prey Veng	511407
3	Kandal	468653	15	Pursat	165536
4	Kompong Cham	802465	16	Preah Vihear	53717
5	Kompong Chhnang	178691	17	Ratanak Kiri	35080
6	Kompong Speu	268584	18	Svay Rieng	242822
7	Kompong Thom	268584	19	Sihanouk Ville	66324
8	Kampot	263651	20	Siem Reap	372729
9	Krong Keb	15348	21	Stung Treng	30695
10	Koh Kong	38917	22	Takeo	380951
11	Kratie	116204	23	Odar Meanchey	37273
12	Mondul Kiri	12059	24		

This study made major change in the developing GHG inventory for LULUCF in comparison with inventory reported in the Initial National Coomunication. As it is described above, some of the activity data and emission factors used in this study have accommodated local data and other regional data. The IPCC default values seem to be overestimated. Thus they were not used in the analysis. In addition, the GHG inventory reported in the Initial National Communication may have double counting problem, in particular in module Forest and Grassland Conversion (module 5.2 of the IPCC).

Revised GHG Inventory. Using the activity data and emission factors presented above, the GHG inventory for forestry sector in each provice was estimated. The result of analysis shows that rate of GHG emission from forestry sector varied considerably between provinces (Table 17). Koh Kong was the provice with the highest CO_2 emissions, while Mondul Kiri was the province with the highest CO_2 sequestration. The CO_2 sequestration rate of Mondul Kiri province was much higher than the CO_2 emission, therefore, this province has significant role in offsetting carbon emission of other provinces. The error of the estimates also varied between provinces and between GHG types (Appendix 8). The error of the CO_2 removal estimates ranged from 16% to 38% with mean of about 26%, while error of the GHGs emission estimates were much smaller, i.e. between 1% and 22% with mean of about 6%.

In term of CO_2-equavalent, it was shown that more than half of provinces in Cambodia were already net emitter provinces in 1994 (Figure 7). The net emitter provinces were Battambang, Banteay Meanchey, Kandal, Kompong Cham, Kompong Chhnang, Kompong Speu, Kampot, Krong Kep, Koh Kong, Prey Veng, Svay Rieng, Takeo, and

Odar Meanchey. The total net CO_2-eq emission of these provinces was about 9,047 kt. The other provinces were found as net sinker provinces with total net carbon removal of about 16,266 kt CO_2-eq. This indicated that in 1994, forestry sector of Cambodia was still as net sinker. The total net sink was about 7,219 kt CO_2-eq. Thus, this sector could still offset partly the emission of other sectors.

Table 17. GHGs emission from forestry sector in 1994 by province

Province	CO_2 uptake (kt)	CO_2 emission (kt)	CH_4 emission (kt)	CO emission (kt)	N_2O emission (kt)	Nox emission (kt)
Battambang	-2276.297	2448.858	1.246	10.905	0.009	0.310
Banteay Meanchey	-685.187	2117.037	4.112	35.982	0.028	1.022
Kandal	-134.535	866.623	0.027	0.236	0.000	0.007
Kompong Cham	-1835.806	2114.661	0.930	8.139	0.006	0.231
Kompong Chhnang	-545.137	831.292	0.180	1.571	0.001	0.045
Kompong Speu	-613.207	1920.225	2.042	17.869	0.014	0.507
Kompong Thom	-2880.057	1783.858	1.847	16.160	0.013	0.459
Kampot	-701.969	1222.205	1.323	11.574	0.009	0.329
Krong Kep	-19.585	30.900	0.009	0.076	0.000	0.002
Koh Kong	-3964.194	5640.697	3.161	27.658	0.022	0.785
Kratie	-2539.392	2344.455	0.614	5.372	0.004	0.153
Mondul Kiri	-7751.445	781.142	2.057	18.003	0.014	0.511
Phnom Penh	-5.520	0.000	0.000	0.000	0.000	0.000
Prey Veng	-65.644	951.759	0.045	0.390	0.000	0.011
Pursat	-2601.557	874.857	0.171	1.497	0.001	0.043
Preah Vihear	-2661.835	601.029	0.944	8.260	0.006	0.235
Ratanak Kiri	-3331.389	2273.147	3.879	33.944	0.027	0.964
Svay Rieng	-64.705	477.577	0.102	0.892	0.001	0.025
Sihanouk Ville	-432.604	397.323	0.867	7.589	0.006	0.216
Siem Reap	-2139.436	926.206	0.729	6.376	0.005	0.181
Stung Treng	-3152.449	986.040	0.906	7.924	0.006	0.225
Takeo	-78.582	846.019	0.464	4.063	0.003	0.115
Odar Meanchey	-955.286	1126.676	3.329	29.130	0.023	0.827
Boeung Tonle Sap	-15.791	0.000	0.000	0.000	0.000	0.000
Total	-39451.609	31562.585	28.984	253.610	0.199	7.202

In comparison with GHG inventory reported in the Initial National Communication (NatCom), it was found that the improved GHG inventory gave lower estimates than those of the NatCom. The discrepancy between the improved and the NatCom was 39% for CO_2 removal, 30% for CO_2 emission and about 60% for non-CO_2 emissions (Table 18). In term of CO_2-eq, the net emission estimates were -7,219 kt and -17,908 kt for the improved inventory and the NatCom respectively. Thus the discrepancy was about 60%.

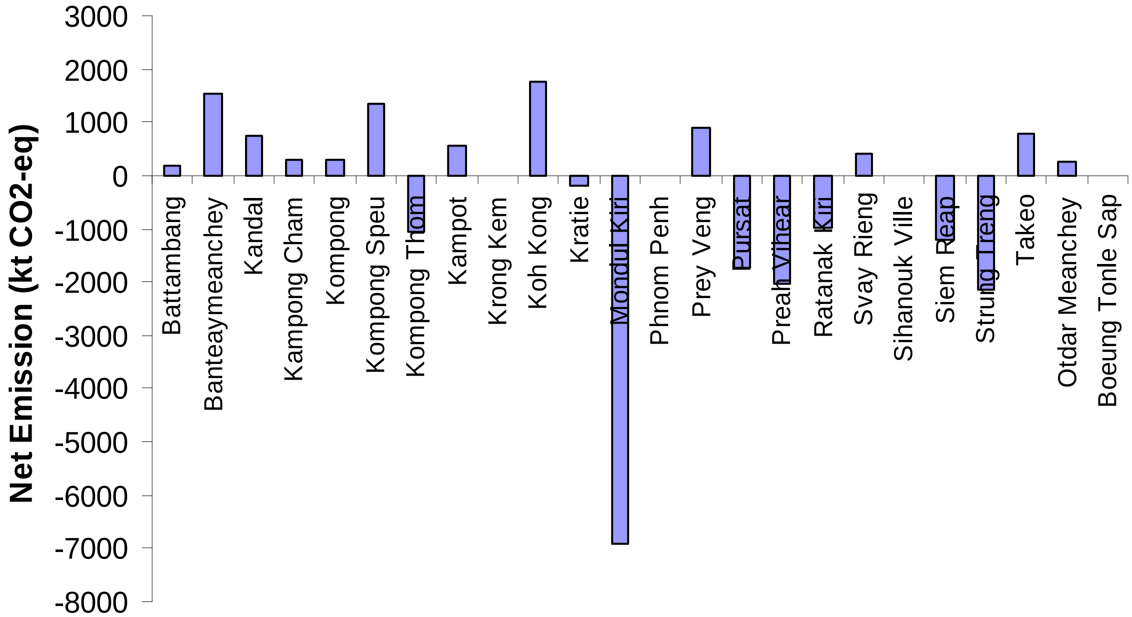

Figure 7. Net GHG emission in 1994 by province

Table 18. Comparison of 1994 GHG Inventory between National Communication and the Improved Inventory

	Removal (kt)	Emission (kt)				
	CO_2	CO_2	CH_4	CO	N_2O	NOx
Improved	-39,451.609	31,562.585	28.984	253.610	0.199	7.202
NatCom	-64,850.230	45,214.270	74.770	654.200	0.510	18.580
% Change of Natcom	39.2	30.2	61.2	61.2	60.9	61.2

VIII. CONCLUSION AND RECOMMENDATION

From this study, a number of conclusions that can be drawn are:

1. Area of forest by its types and area of forest being converted to other uses (deforestation rate) and annual growth rate of tree biomass are the most important activity data and emission factor that will determine greatly the accuracy of the GHG emission and removal estimates.

2. The improvement of the GHG inventory was made in three areas, namely forest area and rate of forest conversion estimates, annual growth rate of tree biomass, and level of analysis. The satellite data of 1992 and 1996 was used to estimate forest area and rate of forest conversion, and mean annual biomass increments were estimated based on data of other studies (in the country or neighbouring countries) and field measurement. The GHG inventory was developed on provincial basis not on national basis. The standard errors of the forest area estimates were estimated to be between 5% and 10%, while those of annual growth rate of tree biomass were about 45%.

3. The most important forest types that contribute significantly to carbon sequestration and emissions in Cambodia are logged Evergreen, Mixed&Coniferous, and Deciduous forests. These forest types cover most of Cambodian forest. Logging and forest conversion mostly occurred in these forest types.

4. The over-logged Evergreen, Mixed & Coniferous, and Deciduous forests were estimated to grow at a rate of about 2.5, 3.0 and 2.0 t/ha/year respectively. In comparison with other studies these rates are much higher. Therefore, the measurement of diameter growth rate of these forests and the measurement of tree biomass components using destructive sampling is recommended for the further improvement of the future National GHG Inventory.

5. Future plan of Department of Forestry and Wildlife (DoFW) to reforest about 6 million ha of degraded forestlands will give significant contribution to the increase of Carbon-sequestration in Cambodia. Considering past data, DoFW may not be able to achieve this target. Without any financial support from international funding, either through bilateral, multilateral or international convention fund, it would be difficult for Cambodia to maintain and improve its forest cover.

6. Rate of GHG emission in 1994 from forestry sector varied considerably between provinces. Koh Kong is a province with the highest CO_2 emissions, while Mondul Kiri was the province with the highest CO_2 sequestration. The error of the estimates also varied between provinces and between GHG types. The error of the CO_2 removal estimates ranged from 16% to 38% with mean of about 26%, while error of the GHGs emission estimates ranged from 1% to 22% with mean of about 6%.

7. In term of CO_2-equavalent, more than half of provinces in Cambodia were already net emitter provinces in 1994. The net emitter provinces were Battambang, Banteay Meanchey, Kandal, Kompong Cham, Kompong Chhnang, Kompong Speu, Kampot,

Krong Kep, Koh Kong, Prey Veng, Svay Rieng, Takeo, and Odar Meanchey. The total net CO_2-eq emission of these provinces was about 9,047 kt. The other provinces were as net sinker provinces with total net carbon removal of about 16,266 kt CO_2-eq. Thus in 1994, forestry sector of Cambodia was still as net sinker.

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APPENDICES

APPENDIX 1. LAND USE AND FOREST CLASIFICATION OF CAMBODIA

Department of Forestry and Wildlife has divided land use of Cambodia into two categories namely wood land and non-wood land (DoWF, 1999). Wood land is mainly dominated by forest and small fraction by forest plantation. Whereas non-wood land is dominated by agriculture land (about 50%) and shrubland (about 25%). Furthermore, forest can be divided into two main types, namely dryland forests and edaphic forests and these two forest types can be further divided into a number of sub-types (Figure A1; Nophea, undated). The following described briefly the description of each forest types and definition of non-wood lands.

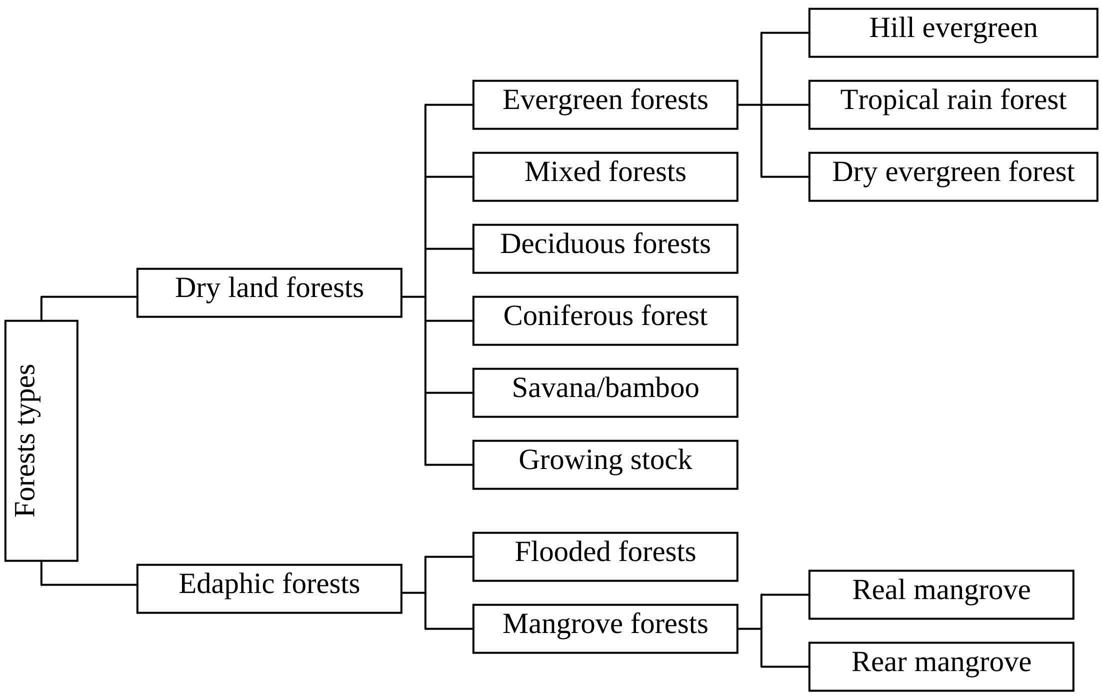

Figure A1. Forest Clasification of Cambodia (From Nophea, undated)

A. Wood Lands

1. Dryland Forests

1.1. *Evergreen Forest*: The Evergreen Forest is a multi-storey forest consisting of more than 80 percent trees of evergreen species with a canopy of 0.8-0.9. This forest type may be further divided into three subtypes: the hill evergreen forest, tropical rainforest and dry evergreen forest. It has been estimated that the average growing stock varies between 192-230 m^3 /ha with annual growth rates varying from 0.21-0.67 m^3 /ha/year.

1.1.1. Hill Evergreen Forest. These dense, higher elevation (more than 700 m above sea level) forests may be divided into those located in the coastal ranges and those in northern uplands. Because of the colder environment, frequent fogs, the violence of the summer winds, and the often shallow and poor soils, these forests often assume a stunted and irregular appearance. They are simple in structure with a single tree stratum to 20 meters rich in the Fagaceae genera *Lithocarpus, Castanopsis and Quercus. Cinnamomum, Litsaea* and the Myrtaceae genera *Syzygium* and *Trisania* frequently occurring in the northeastern uplands. *Dipterocarpus* are virtually absent. The undergrowth is very dense, featuring shrubs and tree-ferns. The eastern forests also feature Gnetum and the palms *Pinango, Arenga* and *Pandanus.* Hill evergreen forests possess a well-developed epiphytic flora.

1.1.2. Tropical Rainforest: These diverse, high, layered forests feature an irregular canopy with average heights of 30m dominated by Dipterocarps *Dipterocarpus costatus* (Cheur Til Nindeng*), Anisoptera glabra* (Pdeak*),Hopea odorata* (Korki Msave*), Shorea hypochra* (Korki Pnong) with the associated species of *Herrietiara javonica* (Khley*), Swintonia pierei* (Svay Chamring), and *Palaguium obovatum* (Chur Ni). Emergent trees may exceed 40 m in height. These trees have classical growth forms; long, narrow, cylindrical boles, sometimes with pronounced buttresses. Palms, lianas and a diverse array of smaller trees constitute a dense understorey. A dwarf forest type is associated with poorly drained depressions. The gymnosperms *Dacrydium pierrei* and *Podocarpus periifolius* are here associated with small to medium-sized Dipterocarps and numerous palms

1.1.3. Dry Evergreen Forest: These floristically and structurally heterogeneous forests occur in humid to sub-humid areas where the rainfall exceeds 1,200 mm per year and the dry season lasts three to five months. Emergent trees such as *Ficu*s, *Dipterocarpus alatu*s, *Shorea vulgari*s, *Anisoptera cochichinnensis* and *Tetrameles nudiflora* may exceed 40 m high. They possess cylindrical boles up to 20 m long, which give the forest a majestic aspect. The diverse continuous tree stratum is between 20 to 30 m high with no family clearly dominating. *Guttifer*a, *Ficu*s, *Irvingia malayan*a, *Sindora cochinchinnensi*s, *Pterocarpus pedatu*s, and *Pahudia conchinchinnensis* are commonly found.

1.2. Mixed Forest: Mixed forests have deciduous and evergreen tree species, where deciduous species represent more than 50 percent of the stand. These stands exhibit a closed structure during the wet season. They are almost completely deciduous and dominated by a few gregarious species such as *Lagerstroemia sp*p. and *Xylia dolabriformis* and numerous scattered associated species such as *Afzelia xylocarpu*s, *Pterocarpus pedatu*s, *Ceiba pentandr*a, *Irvingia oliver*i. The understorey is nearly always dominated by sparse or dense large bamboo (russey rhley). There are numerous subtypes associated with differing soil conditions or allied with other forest types. It has been estimated that the average growing stock varies between 52-60 m^3/ha with annual growth rates of 0.08-0.37 m^3/ha/year.

1.3. Deciduous Forest: Deciduous forest is an open forest consisting of a few trees where most of their leaves are deciduous in dry season. These relatively species- poor, wholly deciduous forests are dominated by Dipterocarps and feature a sparse understorey subject to frequent fires. The single-tree stratums generally feature tree diameters of less than 40 cm. They are widespread east of the Mekong River and north of the Great Lake at altitudes below 500 m. these forests exhibit marked variation in the dominance according to the soil type. They degrade into savannah with disturbance. Most characteristic species are resistant and have thick bark, such as *Dipterocarpus intricatus* (Trach), *D. obtusifolius* (Tbeng), *D. tuberculatus* (Khlong), *Shorea obtusa* (Rin Phum), *Terminalia tomentosa*(Chlik) and so on.

1.4. Savannah and Bamboo Forests: These open, secondary vegetation types are derived from the degradation of the dry Dipterocarps or mixed deciduous forest through over-exploitation or excessive fire. In extreme cases such as on the Chhlong Plateau or at Khula (North-East Thailand) all trees may be removed and replaced by shrubs and grasses. Bamboo-dominated areas may also derive from disturbed evergreen forests on rocky outcrops or steep slopes at high elevations.

1.5. Coniferous Forest: This type refers to pine forests that occur only on the Kirirom plateau where trees exceed 20m in height and possess boles of 50-60cm in diameter. However, pines are frequently associated with more fire-tolerant broad-leave trees such as species of Dipterocarpus and Shorea on certain summits and ridges along the southerly fall of the Cardomome ranges. They also occur in a variety of associations near Mondulkiri in the northeast, in lowland areas around the Great Lake such as in Kompong Thom and near Surin in Thailand (David a.). There is only one species of pine in Cambodia, the *Pinus merkusii*, known as SRAL in Khmer language.

1.6. Growing Stock of Dryland Forests: According to earlier field inventories and dendrometric analysis in the Cambodian forests, the volume over bark (VOB) of all living trees more than 10 cm DBH (Table 5) is 230 m^3/ha in the evergreen forest and only 60 m^3/ha in the deciduous forest, with the mixed forest being 150 m^3/ha. The volume potential available for cutting (VAC) of all marketable trees above 40 cm DBH (minimum diameters accepted by the market) are 80 m^3/ha in the evergreen forests, 30 m^3 /ha in the deciduous forests and 60 m^3/ha in the mixed forests.

2. Edaphic Forests

2.1. *Flooded Forests*: These forest types are found along the delta of the Mekong River, the great lake of Tonle Sap and other plain areas. The most characteristic species are *Cynometra saigonensis* (Ompelteak Prey) *Barringtonia acutongula* (Reang Phnum), *Coccoreas anisopodum* (Chrokeng) and so on with heights and diameters of less than 15 m and 50 cm, respectively. These forest types serve as shelters for fish breeding, protecting soil from erosion, and providing a wide range of environmental services. They are under the control of the Department of Fishery of MAFF. Thus, management practices in these forests are not available at the moment.

2.2. *Mangrove Forests*: Mangroves are distributed in only three provinces and one independent resort city, covering an area of 85,000 ha in 1993, of which 63,700 ha was distributed in Koh Kong, a southwestern province of Cambodia (Table 6). Cambodia's coastline extends some 435 km between the Thai and Vietnamese borders.

2.2.1. Real Mangrove: In most mangrove forests, different species dominate certain zones. The characteristic zonation pattern results from differences in the rooting and growth of seedlings and competitive advantages, which each species has along the gradient from mean sea level to above the high water lines. The dominant species in this forest type belong to the family of Rhizophoraceae, such as *Rhizophora conjugata* (Kongkang Nhy), *Rizophora mucronata* (Kongkang Chmul), *Ceriops sp*p., *Bruiera spp*., *Caralia sp.* and the families of Verbenaceae *(Avicennia sp*.), Sonneratiaceae, and Palmae *(Nypa fructicans*). The average annual growth rate of Cambodia's mangrove forests was estimated to be 7.2 m^3 /ha. In some areas this amount is as large as 9.2-9.9 m^3 /ha. *Rhizophora conjugata* and *Rhi. mucronat*a. *Rhizophora sp*p. reach a height of 15 to 20 m and diameters measured at 1.3 m high from ground vary from 30-40 cm, depending on natural factors (soil condition, location etc.), compared to 30 m high with diameter of 70 cm in Vietnam. Due to illegal logging in mangrove forests, the recent mangrove inventory shows that the growing stock of all standing trees within DBH greater than 5 cm is 98 m^3 /ha (Table 7). That amount is quite low, compared to growing stock in other countries.

2.2.2. Rear mangrove: The associated species of *Eugenia zeylanica* (Smach Dom), *Vatica s*p., *Randia tomentos*a, *Anacardium occidental* and *Cratoxylon sp.* are also found along Kompong Som Bay in Northern Koh Kong province up to the gulf of Thailand.

C. Non-Wood Land

DoFW (1998) defined lands that are not covered or covered by tree or vegetation with height of less than 5 m are considered as non-wood lands. Land use types under this category are as follows:

1. Wood-Shrub lands

1.1. Wood-Shrubland Evergreen: It is a mixture of shrubs, grass and trees. The tree cover is below 20%, or trees are less than about 5 meters high. Evergreen woodland and shrubland can be found mainly on shallow soils, on the top of mountains under climax conditions or as a result of non-sustainable land use. Theoretically there is a chance of it becoming forest again. Young regrowth after shifting cultivation is also included in this class when the shifting cultivation mosaic becomes invisible. There is usually a dense layer of shrubs and grass with some small trees and a significant proportion of bamboo.

1.2. Wood-Shrubland dry: It is a dry variant of class 'Wood-Shrubland Evergreen' and it can be found on the dry plains or on the plateaus of the southern part of the Lower Mekong Basin, as well as on dry sun-exposed slopes. In appearance it resembles a dry savanna.

1.3. Wood-shrubland Inundated: This class encompasses the degraded inundated areas around the Tonle Sap lake. There is often a dense layer of small trees, which cannot be classified as forest.

2. Mosaic of Cropping

This class contains a mixture of fields under cropping or in various stages of fallow with shrubs and regrowth. Regrowth of shifting cultivation areas after the land has been abandoned also contains young trees. If not cleared again, the chances of becoming forest are theoretically high. Mosaic of cropping can be further divided into two, namely the one which has cropping area of more 30% and the other one with cropping area of less than 30%.

3. Agriculture Land

This class contains permanent fields, mainly paddy fields, coffee and tea plantations, mixed agricultural land and other land uses where the agricultural component is the dominant. Small villages with orchards and trees may be included in the category.

4. Bamboo

This class comprises all large areas of dense bamboo visible on the satellite images used for the survey. Sparse bamboo coverage or small bamboo will not be discernible and will be included in one of the other classes. Small lots of bamboo resulting from degradation of mixed or evergreen forests will also not be included in this class.

5. Others

This class consists of a number of non-forest lands such as bare lands, rocks, urban, residential areas or other artificial cover that is visible on the images, water and wetland (swamps and marshes).

Appendix 2. Total area of forest by type and by province

Province	Evergreen		Mixed		Deciduous		Forest Regrowth		Inundated		Mangrove		Plantation	
	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97
Banteay Meanchey	39225	36590	32524	30718	97136	92890	30978	14899	26	26	0	0	0	0
Battambang	136796	135528	152697	151323	168703	166367	21183	20351	109121	107780	0	0	0	0
Boeung Tonle Sap	0	0	0	0	0	0	0	0	3165	3165	0	0	0	0
Kompong Cham	84084	83297	46084	43408	42705	38576	17863	14346	14968	14968	0	0	60393	70578
Kampot	138599	139503	5311	5311	73335	69946	19918	16279	0	0	2251	2251	0	0
Kandal	0	0	0	0	0	0	202	202	21161	20688	0	0	0	0
Koh Kong	926999	912231	25003	24631	21486	21116	43047	32691	0	0	62416	57582	203	203
Kompong Chhnang	20180	20180	9908	9841	110883	109426	12370	12370	20488	20488	0	0	0	0
Kompong Speu	69261	67533	6065	6036	260657	246978	20393	18600	0	0	0	0	0	0
Kompong Thom	413660	411317	28016	27537	24631	24063	113587	103281	67533	67533	0	0	168	168
Kratie	259530	259531	161574	161314	477427	473714	2660	2554	0	0	0	0	7179	7179
Krong Kep	306	306	783	783	0	0	1439	1439	0	0	746	746	0	0
Mondul Kiri	686898	684479	495438	493128	1742960	1733312	9541	9219	0	0	0	0	14358	14358
Odar Meanchey	66979	63796	86199	77990	206781	198276	797	797	0	0	0	0	0	0
Phnom Penh	0	0	0	0	0	0	0	0	1118	1118	0	0	0	0
Preah Vihear	204736	204539	234807	233742	783643	775033	29074	28775	0	0	0	0	0	0
Prey Veng	455	64	440	440	0	0	412	0	7557	6891	0	0	211	211
Pursat	388463	387589	125132	125084	229771	230187	18066	15241	49823	49496	0	0	0	0
Ratanak Kiri	404005	393076	181881	175731	372873	369382	49702	43436	0	0	0	0	3780	3714
Siem Reap	214646	206502	106778	103354	218085	215177	36797	32044	41110	39043	0	0	0	0
Sihanouk Ville	67821	66090	2616	2227	17	17	5104	4975	0	0	12256	12256	372	372
Stung Treng	432983	430676	154747	153673	472728	464238	6824	6824	0	0	0	0	0	0
Svay Rieng	3316	1428	1686	1686	0	0	0	0	25	0	0	0	0	0
Takeo	0	0	0	0	1238	128	982	982	13380	4108	0	0	0	0

Source: Calculated from DoFW (1999).

Appendix 3. Total area of non-forest by types and by province

Province	Wood/Scrublands		Grassland		Mosaic cropping		Agricultural land		Bare land		Urban/Residential		Others	
	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97	1992/93	1996/97
Banteay Meanchey	98744	93699	68266	69180	1332	9220	290200	315720	51	51	3016	3016	4411	4411
Battambang	166759	161730	102289	101777	5372	9359	290554	302931	431	431	2242	2242	11953	11953
Boeung Tonle Sap	1	1	722	808	0	0	60	60	0	0	0	0	246513	241563
Kompong Cham	116583	113343	5083	4751	12564	21231	470078	473443	4628	5933	4977	4977	23040	23928
Kampot	40799	40230	10500	4129	4546	7892	156307	177807	0	0	88	88	17307	9360
Kandal	8078	4429	22946	17713	0	0	221838	225854	750	750	1520	1541	33698	40188
Koh Kong	105810	116417	21780	24995	4660	26402	13847	22184	1585	2075	399	620	13873	15276
Kompong Chhnang	108792	106146	6128	6362	0	0	159599	164184	86	86	0	78	15183	16020
Kompong Speu	131071	109452	3074	2476	0	27	190299	229710	0	0	350	350	604	639
Kompong Thom	206115	199924	87437	88272	22583	31767	269932	283032	0	0	1186	1186	12759	12759
Kratie	163018	145488	9083	7554	5369	17641	73457	93765	4483	4483	1614	1614	31549	31595
Krong Kep	1907	1600	0	0	1373	1710	6712	7624	0	0	0	182	1439	1439
Mondul Kiri	517356	484764	47370	44769	26641	54610	154172	197476	8967	8967	3333	3333	65260	65351
Odar Meanchey	89038	100396	13302	14694	31630	47575	30524	33944	0	0	124	124	623	1392
Phnom Penh	409	409	723	723	0	0	27580	26506	0	0	2826	3314	3892	4479
Preah Vihear	95771	100356	3321	3419	14487	13450	43764	50571	62	62	181	181	320	366
Prey Veng	12535	13013	1808	1704	4583	4934	425299	427176	139	139	565	565	18879	25634
Pursat	113342	106540	28823	35901	4987	5284	174001	176552	0	0	711	711	3269	4338
Ratanak Kiri	112133	132955	2277	2277	65888	86167	9778	11729	353	353	253	253	32316	32316
Siem Reap	141098	136049	36420	56180	81376	88784	309747	313388	135	135	4788	4788	5013	5420
Sihanouk Ville	14369	15111	4803	3792	4825	8464	19932	25602	199	358	832	832	9125	5343
Stung Treng	67978	68238	1422	1422	6254	14450	16414	22559	2188	2641	314	314	30405	30794
Svay Rieng	21240	20421	0	0	15592	14968	224796	230201	0	0	298	298	32564	27570
Takeo	18789	15902	17391	10853	0	298	260378	277378	0	0	233	233	23972	36218

Source: Calculated from DoFW (1999).

Appendix 4. Estimated timber trade from illegal logging by province (m^3 of roundwood equivalent)

Province	Concession Operations	Collection of Illegal Fellings	Illegal Domestic and Export in Log Form	Illegal Sawnwood Domestic and Exports	Total Roundwood Equivalent	Total Roundwood Equivalent (percent)
Ratanakiri	447		300,000	12,800	313,247	7
Stung Treng		100	110,000	96,000	206,100	5
Kratie	105,900	183,800	140,000	192,000	621,700	15
Mondulkiri			14,500	19,200	33,700	1
Kompong Thom	68,400	25,200	75,000	57,556	226,156	5
Kompong Cham			45,000	66,667	111,667	3
Kompong Speu			10,000	240,000	250,000	6
Kompong Som	15,400			128,000	143,400	3
Kampot				102,222	102,222	2
Koh Kong	58,300	300	15,000	1,392,000	1,465,600	35
Battambang			250,000	200,000	450,000	11
Bantey Meanchey				88,889	88,889	2
Pursat			70,000	96,000	166,000	4
Preah Vihear			65,000	0	65,000	2
Siem Reap						0
Others		3,600		0	3,600	0
Total	248,447	213,000	1,094,500	2,691,333	4,247,280	
Percent	6	5	26	63		100

Source: Henderson (1999).

Appendix 5. Condition of Sites Selected for the Survey

1. Kirirom National Park

Kirirom National Park is located between 11.14’05 N and 11.23’04 N and between longitude 100.16’27 E and 113.58’45 E, Southwest of Phnom Penh. Access to the area is from Trang Tro Yeung, 87 km from Phnom Penh on National Highway N°4. The road to the plateau is off the right, and is market with a sign. The central area of Kirirom is about 26 km from Trang Troyeung, of which 10 km is flat road, and 16 km climbing the escarpment of the high altitude plateau.

The central area of Kirirom is 114 km from Phnom Penh, 147 km from Sihanoukville, and 74 km from the province capital of Kompong Speu on national Highway N°4. The boundaries of the Kirirom are extends to:

- The foothills of the range of hills called Phnom Kam Vicheviet and Phnom Koam Klang in the North;
- Chambok Commune, Phnom Srouch district, Kompong Speu Province in the East;
- The hills of Phnom Prak and Phnom Mabal Dom Rey in the South;
- The hills of Phnom Doantrie and Phnom Phrom, in Koh Kong Province in the West.

The area to be designated as a national park, called Preah Soramriddh Koh Somak Park (hereafter referred to as the ‘park area’), is 35,000 ha in area, which is part of the total area of Kirirom, as described above. The forest represent in the survey is coniferous “pine forest” in Kirirom National Park.

2. Ream National Park

Preah Sihanouk National Park (Ream) is located in Prey Nop District within the Sihanoukville, South-Western Cambodia. Situated in the communes (sub-districts) of Ream; O Oknha Heng, Boeng Ta Prum and O' Chrouv the park lies on the coast of the Gulf of Thailand adjacent to National Route No. 4. It is 194 kilometers from Phnom Penh and 18 kilometers to the East of the provincial city of Sihanoukville. The park lies within the area circumscribed by longitude 103º37’- 103º50’E, and latitude 10º24’-10º35’N. The approximate center of the protected area is the National Grid Reference 595635.

The park is bounded to the North by National Highway No.4 between the communes of Ream and O Oknha Heng; to the West by the provincial road Nº 45 running southwards from Ream commune and the provincial airport to the coast at Ream Naval Base; and to the East by a dirt road running in the South-Easterly direction from O Oknha Heng commune immediately to the East of Prek Cham watercourse fishing village of Koh Khchang. The park incorporates the island of Koh Thmei, and the smaller island of Koh Ses which lies closely adjacent to Cambodia’s maritime border with Vietnam.

Preah Sihanouk National Park, covering 21,000ha, is a coastal park encompassing a wide range of habitats. The site is dominated by the estuary of the Prek Toek Sap, which features extensive areas of mangrove and associated rear mangrove forests and mudflats. The forest represent in the survey is semi-evergreen and mangrove forests in Ream National Park.

3. Siem Reap Multiple Use Area

Chong Kneas. The site is located approximately 10 km from the Siem Reap town to the South. As indicated by GPS, the site has the UTM number of 372858:1467429. The forest represent in the survey is inundated forest.

Stung Community Forestry. The site is located East of Siem Reap town in Stung village, Sotrnokum district. GPS indicated UTM number of 390853:1476378 for this site. It is a degraded Dipterocarps forest. The forest represent in the survey is secondary forest.

4. Kompong Cham Forest Plantation

Chup Rubber Plantation. The site is located approximately 25 km from the Kompong Cham town, due to the East as indicated by GPS, the site has the UTM number of 1324575. The forest represent in the survey is rubber plantation.

Tectona Grandis Forest in Dung Tung Plantation. The site is located approximately 45 km from the Kompong Cham town, due to the East. The map shows that the site is located in latitude and longitude between $12^0$586 and $105^0$1315. The forest represent in the survey is *Tectona grandis* (Meysak) plantation.

The important data for developing GHG inventory in LULUCF sector include converted area per forest type, mean annual increment of trees, above ground biomass of natural forests, biomass expansion factors, biomass density, fraction biomass burnt on site/off site and decay. Among these parameters, the most important data are converted forest area, mean annual increment, wood harvest and biomass density of each forest type. Less accurate estimates to these data will lead to underestimation or overestimation of the GHG uptake/emission.

Appendix 6. Sampling Protocol Used in the Survey

Protocol for sampling followed the procedures developed by Hairiah *et al.* (1999). The sampling protocols are for: (i) live tree biomass, (ii) tree necromas, (iii) destructive sampling, and (iv) measurement of mean annual increments.

1. Sampling Protocol for Live Tree Biomass.

Sampling Locations. Locations for sampling are natural forests (undisturbed and disturbed forest. The disturbed forest can be logged over-forest or slash and burnt forest (forest after burnt).

*Equipment*s: line for center of transect (40 m long), stick to measure width (2.5 m long), wooden stick of 1.3 m length, knife, measurement tape (for measuring diameter which include the factor π) and Hagameter (for tree height). If the last two instruments are not available, use formula such as diameter formula and Like Triangle "Petakar" with Proportion (tree height, see Appendix 1).

Procedure. Set out two 200 m^2 quadrats (5m x 40m)[4], by running a 40 m line through the area and then sampling the trees >5cm diameter that are within 2.5m of each side of the line, by checking the distance to the central of the line (Figure 1). For each tree, the diameter is measured at 1.3m above the soil surface (called, diameter at breast height, DBH), except where trunk irregularities at that height occur or trees branch occur below the height measurement (1.3m). For the first case, height of measurement should be higher and all branches with diameter >5cm are measured and then calculate the equivalent diameter as SQRT (ΣD^2). For the second case, just measured all branches with diameter >5cm at the measurement height (1.3m) and then calculate the equivalent diameter as SQRT (ΣD^2). If tree >50cm diameter are present in the sampling plot, whether or not they are included in the transect, an **additional sample of 20m x 100m** is needed where all trees with diameter >30cm are measured. Thus in this case, in total we will have three rectangular plots, two plots with size of 5m x 40m and one plot with size of 20m x 100m.

The tree biomass in kg/tree for each tree can be estimated using an appropriate allometric equations.

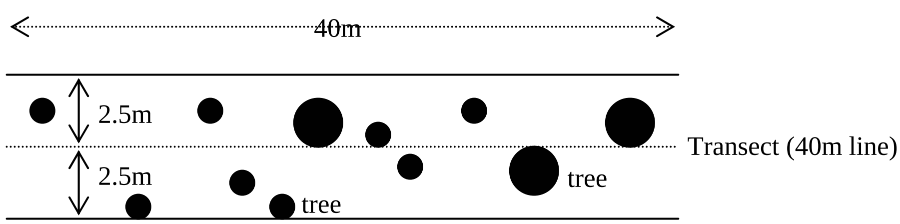

Figure 1. A 200 m^2 quadrat for sampling trees with diameter of more than 5cm.

[4] The two rectangular plots (5m x 40m = 200 m^2) should be selected within a forest area of at least 1 ha. The two plots should not fall in densest or least vegetation.

2. Sampling Protocol for Tree Necromass

Procedure. Within the plot of 200 m^2 (5mx40m) all trunk (unburnt part), dead standing trees, dead trees on the ground and stumps are sampled that have a diameter >5 cm and a length of >0.5 m. Their height (length) is recorded within the 5 m wide transect (see Figure 2) and diameter.

Calculation. For the **branched** structures an allometric equation is used (Table 1). For **unbranched** cylindrical structures, an equation is based on cylindrical volume, i.e. Biomass (kg) = $\pi D^2 H\rho/40$, where D is diameter (cm), H length (m) and ρ wood density (g cm^{-3}). The latter is estimated as 0.4 g cm^{-3} as default value, but it can be around 0.7 for dense hardwood, around 0.2 for very light species, and generally decreases during decomposition of dead wood laying on the soil surface.

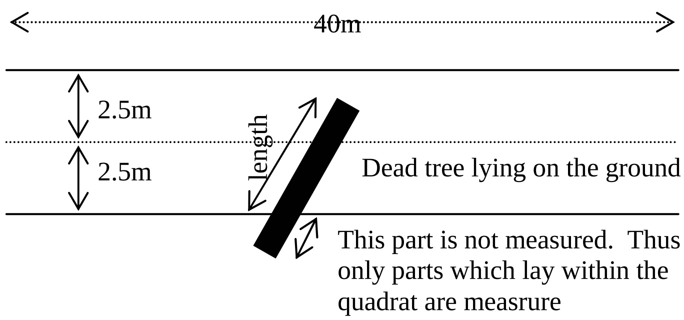

Figure 2. The 200 m^2 quadrat for sampling necromass (trunk, dead trees which have diameter >5 cm and a length of >0.5 m)

3. Sampling Protocol for Destructive Sampling

Equipment. Quadrat of 1m x 1m and 0.5m x 0.5m (Figure 3a) in the quadrat of 200 m^2, knives and/or scissors, scales (one allowing to weight up to 10 kg with a precision of 10 g for fresh samples and one with a 0.1 g precision for sub-samples), marker pens, plastic and paper bags, sieves with a 2 mm mesh size and trays.

Procedure. Locate sampling frames within the 40m x 5 m transect (the 200 m^2 quadrat) as indicated in Figure 3b, placing it once (randomly) in each quarter of the length of the central rope for 4 x (1m^2) or 8x(0.25m^2) samples.

Understorey Biomass. All vegetation less than 5 cm DBH is harvested within the 1m x 1m quadrat. Weight the total fresh sample (g m^{-2}),mix well and immediately take and weigh a composite fresh sub sample (~300 g), for subsequent oven drying.

Litter is samples within the same frames in two steps. **Coarse litter** (any tree necromass <5cm diameter and/or <50cm length, undecomposed plant materials or crop residues, all unburned leaves and branches) is collected in 0.5m x 0.5m quadrat (0.25m^2), on a randomly chosen location within the understorey sample. All undecomposed (green and brown) materials collected to a sample handling location. **Fine litter** (dark litter, including all woody roots which partly decomposed) in a 0-5 cm soil layer is taken and put in the sieves with a 2 mm mesh size for removing the soil parts. All fine litters are then put on the bags (For convenience, take the top soils and put on the bags for processing elsewhere).

Sample handling for destructive biomass and litter samples. **Biomass**: Dry the sub-sample at 80^{o}C for conversion to dry weight and for analysis of C, N, and its quality (lignin and polyphenolic concentration which influence the decomposition rate of organic materials); if oven capacity is limited, samples can be sun dried (in aventilated plastic shelve system) and only sub-samples processes in the oven. **Coarse litter**: To minimize containation with mineral soil, the sample should be soaked and washed in water; the floating litter is collected,sun dried and weighed, the rest is sieved on a 2 mm mesh sieve and added to the fine litter fraction. Depending on the total amount, a sub-sample can be taken at this stage forabtaining an 'oven-dry' correction (oven at 80^{o}C).As alternative to the washing procedure, samples can also be ashed (at 650^{o}C) to coorect formineral soil contamination. **Fine litter and roots**: The litter (incl.dead roots) and (live) root material collected on the 2 mm sieve (by dry sieving) is washed and dried. The soil passing through this sieve is collected as 0-5 cm sample for C_{org} or C-fraction analysis.

Calculation. Take the average pf the 8 samples to record the understorey and litter biomass for the transect replicate.

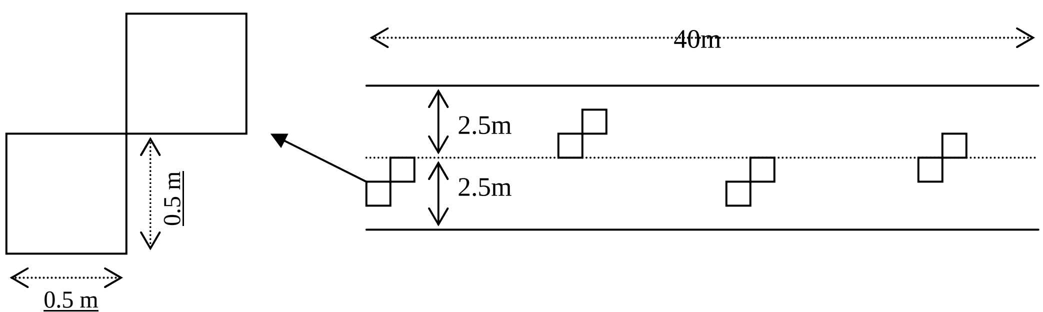

Figure 3. Design of a sampling frame, which can be used for 1m x 1m samples, orfortwo adjacent 0.5m x 0.5m samples (left) and Position of understorey sampling within a 40m x 5m vegetation transect (right)

4. Protocol for Measuring Annual Biomass Increment (cm Per Year)

Procedure. In the two quadrats of 200 m^2, all trees with diameter of more than 5 cm are labeled. After 6 months (end of the year) diameter and height of these labeled tree are measured again. The diameter different between first measurement and the second measurement indicates the diameter increment.

Appendix 7a. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot A (semi-evergreen forest)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Bauhinia bassacensis*	13.3	13.4	0.2186	7	7.4	0.8743
2	*Bauhinia bassacensis*	12.6	12.7	0.2186	9	9.3	0.6557
3	*Bauhinia bassacensis*	19.6	19.7	0.2186	8.2	8.65	0.9835
4	*Bauhinia bassacensis*	7.5	7.6	0.2186	10.5	10.75	0.5464
5	*Buchanania arborescens*	5.2	5.4	0.4371	6	6.2	0.4371
6	*Chhor-eung Morn*	7	7.5	1.0928	9.7	10	0.6557
7	*Chhor-eung Morn*	17.9	19.3	3.0599	11	11.7	1.5299
8	*Chhor-eung Morn*	47.8	48.1	0.6557	20.5	21	1.0928
9	*Chhor-eung Morn*	6.7	6.9	0.4371	9.45	9.6	0.3278
10	*Chhor-eung Morn*	7.3	7.4	0.2186	10.5	10.71	0.4590
11	*Chhor-eung Morn*	19.9	21.8	4.1527	12.5	13.2	1.5299
12	*Chhor-eung Morn*	21	21	0.0000	20.2	20.3	0.2186
13	*Chhor-eung Morn*	6.2	6.5	0.6557	8.5	8.7	0.4371
14	*Chhor-eung Morn*	9.9	10.2	0.6557	13	13.4	0.8743
15	*Chhor-eung Morn*	18.9	19.4	1.0928	18	18.45	0.9835
16	*Chhor-eung Morn*	31.5	31.9	0.8743	17.5	18.1	1.3114
17	*Chhor-eung Morn*	5.8	7.6	3.9341	7.2	8	1.7485
18	*Flemingia stricta*	7.9	8	0.2186	9.5	9.8	0.6557
19	*Flemingia stricta*	8.4	8.6	0.4371	11.5	11.6	0.2186
20	*Flemingia stricta*	6.6	7	0.8743	10.5	11	1.0928
21	*Flemingia stricta*	14.6	15.1	1.0928	10.5	11	1.0928
22	*Flemingia stricta*	19.3	20.8	3.2784	9.7	10.5	1.7485
23	*Flemingia stricta*	12.6	12.8	0.4371	9.6	10.1	1.0928
24	*Flemingia stricta*	13.6	14.2	1.3114	9.5	9.95	0.9835
25	*Flemingia stricta*	5.9	6.1	0.4371	8.5	8.65	0.3278
26	*Flemingia stricta*	6.6	6.9	0.6557	9.2	9.43	0.5027
27	*Flemingia stricta*	7.2	7.3	0.2186	7.8	8.15	0.7650
28	*Flemingia stricta*	5.4	5.4	0.0000	8.9	8.91	0.0219
29	*Flemingia stricta*	5.9	6.2	0.6557	8.7	9.19	1.0710
30	*Flemingia stricta*	6.3	6.7	0.8743	8.8	9.08	0.6120
31	*Flemingia stricta*	7.7	8.2	1.0928	9.8	10.15	0.7650
32	*Flemingia stricta*	6.5	7.1	1.3114	7.5	8.2	1.5299
33	*Flemingia stricta*	15.6	16.9	2.8413	9.3	9.9	1.3114
34	*Leea indica*	21.5	23	3.2784	11.2	11.9	1.5299

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
35	*Lithocarpus elegans*	6.9	7	0.2186	5	5.6	1.3114
36	*Mitrella mesnyi*	19.8	20.9	2.4042	9.1	9.85	1.6392
37	*Neolitsea zeylanica*	25.2	26.1	1.9671	20.5	20.8	0.6557
38	*Tan Hork*	10.8	11.6	1.7485	9.5	10.1	1.3114
	Average	12.96	13.48	1.14	10.61	11.03	0.92
	Stdev	8.81	8.95	1.15	3.81	3.80	0.47

Appendix 7b. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot B (semi-evergreen forest)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Bauhinia bassacensis*	11.3	11.9	1.3273	11.3	11.65	0.7742
2	*Bauhinia bassacensis*	28.4	28.8	0.8848	11.5	11.75	0.5530
3	*Bauhinia bassacensis*	12.0	12.3	0.6636	8	8.4	0.8848
4	*Bauhinia bassacensis*	41.7	42.8	2.4333	8.2	9	1.7697
5	*Bauhinia bassacensis*	14.5	14.7	0.4424	9	9.3	0.6636
6	*Bauhinia bassacensis*	19.3	19.9	1.3273	8.5	8.7	0.4424
7	*Bauhinia bassacensis*	18.3	18.9	1.3273	7.8	8.6	1.7697
8	*Bauhinia bassacensis*	16.8	17	0.4424	7.7	7.9	0.4424
9	*Buchanania arborescens*	18.5	19	1.1061	11.2	11.45	0.5530
10	*Choeng morn*	9.5	9.8	0.6636	7.8	8	0.4424
11	*Choeng morn*	6.0	6.7	1.5485	8	8.8	1.7697
12	*Diospyros hasseltii*	23.7	23.7	0.0000	14.5	14.52	0.0442
13	*Donghok*	38.4	39.3	1.9909	19.5	20.1	1.3273
14	*Donghok*	47.8	48.2	0.8848	27.5	27.9	0.8848
15	*Flemingia stricta*	21.6	22.2	1.3273	12	12.6	1.3273
16	*Flemingia stricta*	7.1	7.7	1.3273	7.5	7.8	0.6636
17	*Flemingia stricta*	5.7	5.8	0.2212	6.5	6.6	0.2212
18	*Flemingia stricta*	23.2	24.9	3.7606	11.1	11.9	1.7697
19	*Flemingia stricta*	16.8	17.6	1.7697	9.5	10.4	1.9909
20	*Flemingia stricta*	21.1	22.6	3.3182	9	9.3	0.6636
21	*Heritiera javanica*	6.4	6.4	0.0000	8.5	8.7	0.4424
22	*Knema globularia*	5.3	5.3	0.0000	6	6.2	0.4424
23	*Lithocarpus elegans*	24.6	26	3.0970	11.5	11.85	0.7742
24	*Mitrella mesnyi*	18.0	18.2	0.4424	7.1	7.4	0.6636
25	*Neolitsea zeylanica*	6.8	7.6	1.7697	11.2	11.85	1.4379
26	*Neolitsea zeylanica*	11.7	11.9	0.4424	7.5	7.7	0.4424
	Average	18.25	18.82	1.25	10.30	10.71	0.89
	Stdev	11.21	11.39	1.02	4.52	4.55	0.56

Appendix 7c. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot C (Mangrove)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Bruguiera sexangula*	5.1	5.2	0.2199	5.8	6.3	1.0994
2	*Bruguiera sexangula*	6	6	0.0000	6.5	6.8	0.6596
3	*Bruguiera sexangula*	7.6	7.6	0.0000	7	7.8	1.7590
4	*Bruguiera sexangula*	6.6	6.7	0.2199	7.5	7.84	0.7476
5	*Bruguiera sexangula*	8.7	8.8	0.2199	7.5	7.88	0.8355
6	*Bruguiera sexangula*	6.6	6.6	0.0000	6.8	7.1	0.6596
7	*Bruguiera sexangula*	9.8	9.8	0.0000	7.6	7.8	0.4398
8	*Bruguiera sexangula*	6.3	6.3	0.0000	7	7.2	0.4398
9	*Bruguiera sexangula*	5.4	5.4	0.0000	5	5.4	0.8795
10	*Bruguiera sexangula*	5.1	5.4	0.6596	6.3	7	1.5392
11	*Bruguiera sexangula*	6.5	6.6	0.2199	7.9	8.2	0.6596
12	*Bruguiera sexangula*	5.6	5.7	0.2199	6.5	6.8	0.6596
13	*Krabounh*	5.5	5.5	0.0000	7.1	7.6	1.0994
14	*Krabounh*	6	6	0.0000	7.4	7.9	1.0994
15	*Rhizophora mucronata*	9.9	10.8	1.9789	5.5	5.65	0.3298
16	*Rhizophora mucronata*	6.8	7.7	1.9789	6	6.5	1.0994
17	*Rhizophora mucronata*	7.5	7.7	0.4398	5.3	5.8	1.0994
18	*Rhizophora mucronata*	5.2	5.2	0.0000	5.5	5.65	0.3298
19	*Rhizophora mucronata*	7.7	7.8	0.2199	6	6.35	0.7696
20	*Rhizophora mucronata*	5	5.1	0.2199	5.2	6	1.7590
21	*Rhizophora mucronata*	6.1	6.2	0.2199	4.8	5.3	1.0994
22	*Rhizophora mucronata*	6	6.1	0.2199	5	5.8	1.7590
23	*Rhizophora mucronata*	6.3	6.4	0.2199	5.5	6	1.0994
24	*Rhizophora mucronata*	6.6	6.7	0.2199	6.3	6.5	0.4398
25	*Rhizophora mucronata*	8.8	8.9	0.2199	5.5	5.8	0.6596
26	*Rhizophora mucronata*	8.1	8.3	0.4398	6.3	6.4	0.2199
27	*Rhizophora mucronata*	5.2	5.3	0.2199	5	5.3	0.6596
28	*Rhizophora mucronata*	8.9	9	0.2199	5.14	5.6	1.0114
29	*Rhizophora mucronata*	6.8	7.2	0.8795	4	4.6	1.3193
30	*Rhizophora mucronata*	4.7	5.4	1.5392	5.4	5.8	0.8795
31	*Rhizophora mucronata*	7.5	8.2	1.5392	5.6	6.1	1.0994
32	*Rhizophora mucronata*	8	8.1	0.2199	5.8	6.3	1.0994
33	*Rhizophora mucronata*	8.5	8.5	0.0000	5.5	5.75	0.5497
34	*Rhizophora mucronata*	8.6	8.7	0.2199	6.5	7	1.0994
35	*Rhizophora mucronata*	6.5	6.7	0.4398	4.8	5.35	1.2093

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
36	*Rhizophora mucronata*	8.6	8.8	0.4398	7.3	7.95	1.4292
37	*Rhizophora mucronata*	7.7	7.9	0.4398	7	7.8	1.7590
38	*Rhizophora mucronata*	6	6.1	0.2199	6.2	6.5	0.6596
39	*Rhizophora mucronata*	5	5.1	0.2199	5.8	6.2	0.8795
40	*Rhizophora mucronata*	6.8	7.3	1.0994	6.5	6.9	0.8795
41	*Rhizophora mucronata*	5.3	5.3	0.0000	6	6.45	0.9895
42	*Rhizophora mucronata*	5.6	5.8	0.4398	6.3	6.65	0.7696
43	*Rhizophora mucronata*	5.1	5.2	0.2199	6	6.45	0.9895
44	*Rhizophora mucronata*	6.5	6.7	0.4398	6.6	6.8	0.4398
45	*Rhizophora mucronata*	8.2	8.2	0.0000	6.5	6.75	0.5497
46	*Rhizophora mucronata*	7.5	7.6	0.2199	7.1	7.4	0.6596
47	*Rhizophora mucronata*	6.7	6.8	0.2199	6.8	7.15	0.7696
48	*Rhizophora mucronata*	6	6.1	0.2199	6.5	6.95	0.9895
49	*Rhizophora mucronata*	6.1	6.2	0.2199	5.3	5.8	1.0994
50	*Rhizophora mucronata*	6.5	6.7	0.4398	6.5	6.9	0.8795
51	*Rhizophora mucronata*	6.9	7.1	0.4398	6.5	7.3	1.7590
52	*Rhizophora mucronata*	7.1	7.1	0.0000	4.5	4.52	0.0440
53	*Rhizophora mucronata*	6	6	0.0000	7.5	7.65	0.3298
54	*Rhizophora mucronata*	7.5	7.7	0.4398	7.5	7.92	0.9235
55	*Rhizophora mucronata*	6.4	6.5	0.2199	6.8	7.4	1.3193
56	*Rhizophora mucronata*	6.3	6.3	0.0000	5.8	6	0.4398
57	*Rhizophora mucronata*	8	8.2	0.4398	6.5	6.8	0.6596
58	*Rhizophora mucronata*	6.9	7.1	0.4398	7.3	7.65	0.7696
59	*Rhizophora mucronata*	5.8	6.1	0.6596	6.5	6.7	0.4398
60	*Rhizophora mucronata*	5.8	5.9	0.2199	6.3	6.8	1.0994
61	*Rhizophora mucronata*	5.5	5.6	0.2199	5.5	6.1	1.3193
62	*Rhizophora mucronata*	6.4	6.4	0.0000	6	6.4	0.8795
63	*Tabon*	22.1	22.6	1.0994	7.1	7.7	1.3193
64	*Tabon*	12.3	13.7	3.0783	8.3	8.88	1.2753
65	*Tabon*	6.9	7	0.2199	7.5	7.9	0.8795
66	*Tabon*	10.5	10.8	0.6596	8	8.4	0.8795
67	*Tabon*	32.2	33.3	2.4187	8	8.6	1.3193
68	*Tabon*	11.3	11.4	0.2199	8	8.4	0.8795
69	*Tabon*	12	13.2	2.6386	7.6	8.2	1.3193
70	*Tabon*	7.5	8	1.0994	8	8.2	0.4398
71	*Tabon*	6.6	6.9	0.6596	7.8	8.3	1.0994
72	*Tabon*	6.9	7.1	0.4398	8	8.5	1.0994
73	*Tabon*	7	8.1	2.4187	7.8	8.35	1.2093

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
74	*Tabon*	5.3	5.4	0.2199	7.5	8.15	1.4292
	Average	7.52	7.74	0.49	6.45	6.87	0.93
	Stdev	3.76	3.91	0.67	1.00	1.02	0.39

Appendix 7d. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot D (Mangrove)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Bruguiera sexangula*	7.1	7.2	0.2212	7.2	7.8	1.3273
2	*Bruguiera sexangula*	7.3	7.6	0.6636	7.9	8.1	0.4424
3	*Bruguiera sexangula*	7.9	8.2	0.6636	7.5	7.85	0.7742
4	*Bruguiera sexangula*	7	7.2	0.4424	7.2	7.3	0.2212
5	*Bruguiera sexangula*	6.9	7	0.2212	6.5	7.2	1.5485
6	*Bruguiera sexangula*	6.5	6.5	0.0000	6.5	7.2	1.5485
7	*Bruguiera sexangula*	5.7	5.7	0.0000	6	6.1	0.2212
8	*Bruguiera sexangula*	6.7	6.8	0.2212	6.5	7	1.1061
9	*Bruguiera sexangula*	6	6	0.0000	6	6.5	1.1061
10	*Bruguiera sexangula*	5.1	5.1	0.0000	7	7.2	0.4424
11	*Bruguiera sexangula*	5.1	6	1.9909	6.5	7	1.1061
12	*Bruguiera sexangula*	5.2	7	3.9818	7	7.9	1.9909
13	*Bruguiera sexangula*	10.5	10.6	0.2212	5.1	6	1.9909
14	*Bruguiera sexangula*	7	8.1	2.4333	6.5	6.9	0.8848
15	*Bruguiera sexangula*	6	6.2	0.4424	4	4.2	0.4424
16	*Bruguiera sexangula*	8.8	9.2	0.8848	4.5	5.1	1.3273
17	*Bruguiera sexangula*	5.2	5.4	0.4424	4	4.7	1.5485
18	*Bruguiera sexangula*	5.1	5.1	0.0000	4.5	4.85	0.7742
19	*Bruguiera sexangula*	6.1	6.2	0.2212	4.5	4.9	0.8848
20	*Bruguiera sexangula*	6.6	6.8	0.4424	6.5	6.8	0.6636
21	*Bruguiera sexangula*	6.3	6.3	0.0000	4.3	4.8	1.1061
22	*Bruguiera sexangula*	5.6	5.6	0.0000	3.5	4	1.1061
23	*Bruguiera sexangula*	6.9	7.1	0.4424	5.5	5.9	0.8848
24	*Krabornh*	8.9	9.3	0.8848	10	10.2	0.4424
25	*Lumnitzera littrorea*	7.2	7.5	0.6636	8.5	8.6	0.2212
26	*Lumnitzera littrorea*	14.5	14.5	0.0000	8.6	9.15	1.2167
27	*Rhizophora mucronata*	6.4	6.5	0.2212	6	6.7	1.5485
28	*Rhizophora mucronata*	6.1	7.8	3.7606	5.5	6.2	1.5485
29	*Rhizophora mucronata*	5.7	5.9	0.4424	6.5	6.9	0.8848
30	*Rhizophora mucronata*	6.1	6.3	0.4424	6	6.15	0.3318
31	*Rhizophora mucronata*	8.6	8.9	0.6636	9.5	10.1	1.3273
32	*Rhizophora mucronata*	7.6	7.7	0.2212	9.5	9.8	0.6636
33	*Rhizophora mucronata*	5.3	5.4	0.2212	6.5	6.8	0.6636
34	*Rhizophora mucronata*	7.1	7.3	0.4424	9	9.1	0.2212
35	*Rhizophora mucronata*	5.1	5.1	0.0000	6	6.1	0.2212

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
36	*Rhizophora mucronata*	6.6	6.8	0.4424	7	7.3	0.6636
37	*Rhizophora mucronata*	6.6	7.8	2.6545	6.5	6.8	0.6636
38	*Rhizophora mucronata*	6.5	7.8	2.8758	6.7	7	0.6636
39	*Rhizophora mucronata*	10	10	0.0000	7	7.1	0.2212
40	*Rhizophora mucronata*	5.1	5.1	0.0000	6	6.1	0.2212
41	*Rhizophora mucronata*	5.8	5.9	0.2212	5.5	5.8	0.6636
42	*Rhizophora mucronata*	6	6	0.0000	5.5	6.2	1.5485
43	*Rhizophora mucronata*	5.3	5.3	0.0000	4.2	4.6	0.8848
44	*Rhizophora mucronata*	5.5	6.6	2.4333	7	7.8	1.7697
45	*Rhizophora mucronata*	14.6	15	0.8848	4.5	5	1.1061
46	*Rhizophora mucronata*	8.6	9	0.8848	4.5	5.2	1.5485
47	*Tabon*	16.7	17.1	0.8848	9.5	10.1	1.3273
48	*Tabon*	24.3	25.5	2.6545	9.5	10.25	1.6591
49	*Tabon*	6.3	6.3	0.0000	9.4	9.9	1.1061
50	*Tabon*	6.7	7.2	1.1061	8.5	9.1	1.3273
51	*Tabon*	12.7	12.7	0.0000	8.5	8.85	0.7742
52	*Tabon*	64.3	66.5	4.8667	8.7	9.25	1.2167
53	*Tabon*	5.4	5.9	1.1061	7	7.5	1.1061
54	*Tabon*	6	6.3	0.6636	8	8.2	0.4424
55	*Tabon*	14.6	14.7	0.2212	7	7.2	0.4424
56	*Tabon*	5.5	5.5	0.0000	6.5	7.05	1.2167
57	*Tabon*	14.4	14.8	0.8848	7	7.28	0.6194
58	*Tabon*	5.1	5.1	0.0000	4.2	5.01	1.7918
59	*Tabon*	19.8	20.7	1.9909	6.5	7.3	1.7697
60	*Tabon*	13.9	14.2	0.6636	7	7.4	0.8848
61	*Tabon*	6.4	6.8	0.8848	7	7.6	1.3273
62	*Tabon*	13.5	15	3.3182	7.5	8.2	1.5485
63	*Tabon*	6	6.1	0.2212	5.5	6.15	1.4379
64	*Tabon*	7	8	2.2121	4.5	5.2	1.5485
65	*Tabon*	5	5.6	1.3273	4.6	5.1	1.1061
66	*Tabon*	6.9	6.9	0.0000	5.5	5.9	0.8848
	Average	8.79	9.17	0.84	6.55	7.01	1.00
	Stdev	7.92	8.17	1.11	1.61	1.58	0.49

Appendix 7e. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot E (Coniferous)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Broussonetia billardii*	9.1	9.2	0.2253	6.5	6.6	0.2253
2	*Pinus merkusii*	20.5	21.1	1.3519	16.15	16.62	1.0590
3	*Pinus merkusii*	13	13.2	0.4506	15.1	15.6	1.1265
4	*Pinus merkusii*	22.6	22.7	0.2253	17.5	17.8	0.6759
5	*Pinus merkusii*	16.5	16.5	0.0000	15	15.1	0.2253
6	*Pinus merkusii*	10.7	11	0.6759	15.1	15.28	0.4056
7	*Pinus merkusii*	23.2	24	1.8025	18.1	18.71	1.3744
8	*Pinus merkusii*	17	17.6	1.3519	16.5	16.98	1.0815
9	*Pinus merkusii*	19	19.1	0.2253	16.5	16.7	0.4506
10	*Pinus merkusii*	30.6	31.4	1.8025	19.5	20.12	1.3969
11	*Pinus merkusii*	7.3	8.4	2.4784	8.65	8.97	0.7210
12	*Pinus merkusii*	9.2	9.4	0.4506	10.1	10.3	0.4506
13	*Pinus merkusii*	13	13	0.0000	13.9	14	0.2253
14	*Pinus merkusii*	9	9.2	0.4506	9	9.11	0.2478
15	*Pinus merkusii*	10.4	11	1.3519	9.6	10.22	1.3969
16	*Pinus merkusii*	23.7	24.5	1.8025	18.5	19.3	1.8025
17	*Pinus merkusii*	6.2	6.6	0.9012	7.5	7.87	0.8336
18	*Pinus merkusii*	26.8	27.5	1.5772	19.7	20.2	1.1265
19	*Pinus merkusii*	16.8	17.3	1.1265	21.7	22.15	1.0139
20	*Pinus merkusii*	6.1	6.7	1.3519	15	15.6	1.3519
21	*Pinus merkusii*	9.1	9.1	0.0000	8.6	8.8	0.4506
22	*Pinus merkusii*	25.6	26.1	1.1265	19.7	20.25	1.2392
23	*Pinus merkusii*	8.2	8.2	0.0000	7.5	7.55	0.1127
24	*Pinus merkusii*	22.5	23.2	1.5772	19.8	20.4	1.3519
25	*Pinus merkusii*	10	10.5	1.1265	7.5	7.91	0.9238
26	*Pinus merkusii*	13	13.3	0.6759	16.6	16.92	0.7210
27	*Pinus merkusii*	15.6	16.3	1.5772	18.5	19.15	1.4645
28	*Pinus merkusii*	9	9	0.0000	7.5	7.6	0.2253
29	*Pinus merkusii*	9.2	9.7	1.1265	8.9	9.4	1.1265
30	*Pinus merkusii*	8.8	8.9	0.2253	7.3	7.35	0.1127
31	*Pinus merkusii*	26.8	27	0.4506	19.5	19.8	0.6759
32	*Pinus merkusii*	7.2	7.5	0.6759	7.1	7.61	1.1491
33	*Pinus merkusii*	18	18.3	0.6759	19.7	20.1	0.9012
34	*Pinus merkusii*	16	16.2	0.4506	18.5	18.85	0.7886
35	*Pinus merkusii*	11	11.6	1.3519	16	16.5	1.1265

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
36	*Pinus merkusii*	17	17.4	0.9012	18	18.3	0.6759
37	*Pinus merkusii*	11.1	11.3	0.4506	10.6	10.75	0.3380
38	*Pinus merkusii*	15.7	16.6	2.0278	12.5	13.15	1.4645
39	*Pinus merkusii*	22.1	23.1	2.2531	14.8	15.6	1.8025
40	*Pinus merkusii*	15.2	15.8	1.3519	12.4	12.8	0.9012
	Average	15.05	15.46	0.94	14.02	14.40	0.87
	Stdev	6.58	6.69	0.68	4.72	4.81	0.47

Appendix 7f. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot F (Coniferous)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Pinus merkusii*	11.9	12	0.2267	10.5	10.7	0.4534
2	*Pinus merkusii*	13.6	14	0.9068	17.5	17.8	0.6801
3	*Pinus merkusii*	8.2	8.5	0.6801	17.3	17.7	0.9068
4	*Pinus merkusii*	13.2	13.5	0.6801	17.3	17.6	0.6801
5	*Pinus merkusii*	5.9	6.1	0.4534	7.5	7.6	0.2267
6	*Pinus merkusii*	7.2	7.3	0.2267	7	7.2	0.4534
7	*Pinus merkusii*	20.1	20.5	0.9068	17.5	17.9	0.9068
8	*Pinus merkusii*	15.5	15.6	0.2267	17.3	17.4	0.2267
9	*Pinus merkusii*	22	22.6	1.3602	21.65	21.95	0.6801
10	*Pinus merkusii*	17.8	18.7	2.0404	17.5	18.3	1.8137
11	*Pinus merkusii*	16	16	0.0000	17.5	17.6	0.2267
12	*Pinus merkusii*	15	16.1	2.4938	18.5	18.9	0.9068
13	*Pinus merkusii*	24.6	25.1	1.1335	21.6	22	0.9068
14	*Pinus merkusii*	26.1	27.7	3.6273	20.1	20.88	1.7683
15	*Pinus merkusii*	21.5	21.9	0.9068	21.5	21.8	0.6801
16	*Pinus merkusii*	17.2	18	1.8137	11.5	12.1	1.3602
17	*Pinus merkusii*	15.7	16.1	0.9068	16.5	16.89	0.8842
18	*Pinus merkusii*	20.9	22.5	3.6273	21.9	22.6	1.5870
19	*Pinus merkusii*	29.9	30.3	0.9068	20.6	20.97	0.8388
20	*Pinus merkusii*	20.5	21	1.1335	19.2	19.8	1.3602
21	*Pinus merkusii*	29.2	30	1.8137	22.6	23.2	1.3602
22	*Pinus merkusii*	11	11.4	0.9068	5.3	5.8	1.1335
23	*Pinus merkusii*	11.8	11.9	0.2267	7.5	7.8	0.6801
24	*Pinus merkusii*	8	8	0.0000	9.6	9.62	0.0453
25	*Pinus merkusii*	7.7	7.7	0.0000	5	5.01	0.0227
26	*Pinus merkusii*	7.7	18.3	24.0311	15.65	15.92	0.6121
	Average	16.08	16.95	1.97	15.60	15.96	0.82
	Stdev	6.90	6.95	4.61	5.62	5.72	0.50

Appendix 7g. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot G (Inundated forest)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Barringtonia asiatica*	13.6			9.2		
2	*Barringtonia asiatica*	13.6			2.5		
3	*Barringtonia asiatica*	17.3			3.5		
4	*Barringtonia asiatica*	23.1			7.8		
5	*Barringtonia asiatica*	18.1			6.5		
6	*Barringtonia asiatica*	9.8			7.1		
7	*Barringtonia asiatica*	15			6.2		
8	*Barringtonia asiatica*	8			6.4		
9	*Barringtonia asiatica*	8.9			3.5		
10	*Barringtonia asiatica*	5.6			6.7		
11	*Barringtonia asiatica*	7.6			5.5		
12	*Barringtonia asiatica*	10.9			5.4		
13	*Barringtonia asiatica*	8.8			4.1		
	Average	12.33			5.72		
	Stdev	5.03			1.91		

Appendix 7h. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot H (Inundated forest)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Diploknema S.P, Madhuca elliptica*	19			13.4		
2	*Diploknema S.P, Madhuca elliptica*	7.2			5		
3	*Barringtonia asiatica*	12			7.6		
4	*Barringtonia asiatica*	14.8			6.2		
5	*Barringtonia asiatica*	11			4.6		
6	*Barringtonia asiatica*	11.7			5.2		
7	*Barringtonia asiatica*	15.8			6.3		
8	*Barringtonia asiatica*	12.4			8.1		
9	*Barringtonia asiatica*	10.9			5.2		
10	*Barringtonia asiatica*	18.6			9.1		
11	*Barringtonia asiatica*	11.5			8.2		
12	*Barringtonia asiatica*	15.16			7.7		
13	*Barringtonia asiatica*	13.5			9.1		
14	*Barringtonia asiatica*	15.8			8.2		
15	*Barringtonia asiatica*	11.8			8.4		
16	*Barringtonia asiatica*	15.2			7.7		
17	*Barringtonia asiatica*	11.2			6.3		
18	*Barringtonia asiatica*	8.5			5.6		
19	*Barringtonia asiatica*	18			9.2		
20	*Barringtonia asiatica*	10.6			8.1		
21	*Barringtonia asiatica*	11.6			6.3		
22	*Barringtonia asiatica*	15			10.1		
23	*Barringtonia asiatica*	14.6			8.5		
24	*Barringtonia asiatica*	6.4			3.5		
25	*Barringtonia asiatica*	9.9			8.1		
	Average	12.88			7.43		
	Stdev	3.29			2.08		

Appendix 7i. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot I (Secondary forest)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Dioterocarpus costatus*	16.8	17.1	0.8359	14.5	14.61	0.3065
2	*Dioterocarpus costatus*	11.4	11.5	0.2786	14.2	14.23	0.0836
3	*Dioterocarpus costatus*	10.4	10.4	0.0000	13.8	13.9	0.2786
4	*Dioterocarpus costatus*	18.8	19.2	1.1145	15.1	15.3	0.5573
5	*Dioterocarpus costatus*	6.7	7.1	1.1145	11.1	11.2	0.2786
6	*Dioterocarpus costatus*	9.5	9.5	0.0000	11.2	11.2	0.0000
7	*Dioterocarpus costatus*	11.3	11.3	0.0000	12.5	12.59	0.2508
8	*Dioterocarpus costatus*	13	13.1	0.2786	13.8	13.9	0.2786
9	*Dioterocarpus costatus*	14.8	15.5	1.9504	14.2	14.4	0.5573
10	*Dioterocarpus costatus*	9.3	9.5	0.5573	12.7	12.8	0.2786
11	*Dioterocarpus costatus*	5.5	5.8	0.8359	6.2	6.5	0.8359
12	*Dioterocarpus costatus*	7	7	0.0000	11.1	11.2	0.2786
13	*Dioterocarpus costatus*	8.1	8.5	1.1145	11.4	11.5	0.2786
14	*Dioterocarpus costatus*	7.5	7.7	0.5573	11.3	11.5	0.5573
15	*Dioterocarpus costatus*	18.7	19	0.8359	14.7	14.9	0.5573
16	*Dioterocarpus costatus*	20.7	21.4	1.9504	15.2	15.45	0.6966
17	*Dioterocarpus costatus*	12.4	13.6	3.3435	5.1	5.1	0.0000
18	*Dioterocarpus costatus*	19.3	19.7	1.1145	15.2	15.35	0.4179
19	*Dioterocarpus costatus*	23.6	23.8	0.5573	15.3	15.5	0.5573
20	*Dioterocarpus costatus*	14.6	15	1.1145	12.3	12.4	0.2786
21	*Dioterocarpus costatus*	12.1	12.2	0.2786	12.1	12.3	0.5573
22	*Dioterocarpus costatus*	6.2	6.5	0.8359	8.2	8.3	0.2786
23	*Dioterocarpus costatus*	33.2	34.7	4.1794	16.5	16.7	0.5573
	Average	13.52	13.87	0.99	12.51	12.64	0.38
	Stdev	6.64	6.87	1.04	2.90	2.92	0.21

Appendix 7j. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot J (Secondary forest)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Dipterocarpus costatus*	13.4	13.5	0.2808	13.5	13.7	0.5615
2	*Dipterocarpus costatus*	30.2	30.4	0.5615	17.1	17.43	0.9265
3	*Dipterocarpus costatus*	13.9	14	0.2808	15.3	15.39	0.2527
4	*Dipterocarpus costatus*	16.7	16.8	0.2808	15.2	15.32	0.3369
5	*Dipterocarpus costatus*	11.4	11.5	0.2808	10.5	10.65	0.4212
6	*Dipterocarpus costatus*	29.3	29.5	0.5615	16.7	16.93	0.6458
7	*Dipterocarpus costatus*	14.5	14.5	0.0000	11.2	11.4	0.5615
8	*Dipterocarpus costatus*	8.1	8.3	0.5615	11.2	11.3	0.2808
9	*Dipterocarpus costatus*	10.3	10.4	0.2808	11.4	11.52	0.3369
10	*Dipterocarpus costatus*	14.9	15.3	1.1231	10.7	10.8	0.2808
11	*Dipterocarpus costatus*	9.9	10	0.2808	11.8	11.95	0.4212
12	*Dipterocarpus costatus*	13.4	13.5	0.2808	10.5	10.64	0.3931
13	*Dipterocarpus costatus*	12.3	12.6	0.8423	10.4	10.45	0.1404
14	*Dipterocarpus costatus*	20.4	20.6	0.5615	15.2	15.27	0.1965
15	*Dipterocarpus costatus*	8.4	8.5	0.2808	10.7	10.9	0.5615
16	*Dipterocarpus costatus*	20.7	22.6	5.3346	15.8	16.01	0.5896
17	*Dipterocarpus costatus*	7.6	7.9	0.8423	7.2	7.4	0.5615
18	*Dipterocarpus costatus*	15.6	15.6	0.0000	12.5	12.7	0.5615
19	*Dipterocarpus costatus*	8.5	8.5	0.0000	8.1	8.1	0.0000
20	*Dipterocarpus costatus*	12.2	12.6	1.1231	12.5	12.67	0.4773
21	*Dipterocarpus costatus*	20.3	22	4.7731	12.8	13	0.5615
22	*Dipterocarpus costatus*	14.9	15.3	1.1231	12.7	12.81	0.3088
23	*Dipterocarpus costatus*	19	19.1	0.2808	13.2	13.3	0.2808
24	*Dipterocarpus costatus*	12.1	17.5	15.1615	12.5	12.64	0.3931
25	*Dipterocarpus costatus*	11	11.7	1.9654	10.5	10.6	0.2808
26	*Dipterocarpus costatus*	11.6	11.8	0.5615	10.2	10.2	0.0000
27	*Dipterocarpus costatus*	19.7	20.4	1.9654	10.6	10.9	0.8423
28	*Dipterocarpus costatus*	18.6	19	1.1231	10.5	10.7	0.5615
29	*Dipterocarpus costatus*	5.2	6.3	3.0885	7.2	7.36	0.4492
	Average	14.62	15.16	1.51	11.99	12.14	0.42
	Stdev	5.91	6.00	2.93	2.55	2.58	0.21

Appendix 7k. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot K (Rubber plantation)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Hevea brasiliensis*	12.2	12.3	0.2765	15.8	16.1	0.8295
2	*Hevea brasiliensis*	22.6	22.9	0.8295	17.7	17.9	0.5530
3	*Hevea brasiliensis*	24.4	24.9	1.3826	18.1	18.4	0.8295
4	*Hevea brasiliensis*	17.9	18.4	1.3826	19.6	19.8	0.5530
5	*Hevea brasiliensis*	19	19.2	0.5530	19.1	19.3	0.5530
6	*Hevea brasiliensis*	20.8	21.2	1.1061	19.6	19.8	0.5530
7	*Hevea brasiliensis*	13	13.2	0.5530	18.5	18.8	0.8295
8	*Hevea brasiliensis*	16	16.2	0.5530	18.6	18.8	0.5530
9	*Hevea brasiliensis*	17.8	17.9	0.2765	18.6	18.9	0.8295
10	*Hevea brasiliensis*	19.8	20.2	1.1061	20.6	21	1.1061
11	*Hevea brasiliensis*	20.3	20.5	0.5530	18.3	18.4	0.2765
12	*Hevea brasiliensis*	19.6	20	1.1061	20.6	20.7	0.2765
13	*Hevea brasiliensis*	19.3	19.5	0.5530	20.6	20.8	0.5530
	Average	18.67	18.95	0.79	18.90	19.13	0.64
	Stdev	3.42	3.51	0.39	1.36	1.34	0.24

Appendix 7l. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot L (Rubber plantation)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Hevea brasiliensis*	26.4	26.7	0.8295	19.6	19.8	0.5530
2	*Hevea brasiliensis*	23.3	23.8	1.3826	22.1	22.4	0.8295
3	*Hevea brasiliensis*	6.1	6.2	0.2765	11.6	11.8	0.5530
4	*Hevea brasiliensis*	12.9	13.1	0.5530	16.6	16.7	0.2765
5	*Hevea brasiliensis*	24.6	24.9	0.8295	19.8	20	0.5530
6	*Hevea brasiliensis*	16.3	16.5	0.5530	19.6	19.9	0.8295
7	*Hevea brasiliensis*	13.3	13.4	0.2765	14.6	14.7	0.2765
8	*Hevea brasiliensis*	22.5	22.7	0.5530	19.5	19.7	0.5530
9	*Hevea brasiliensis*	15.6	15.8	0.5530	14.7	14.9	0.5530
10	*Hevea brasiliensis*	13	13.1	0.2765	17.4	17.7	0.8295
11	*Hevea brasiliensis*	12.7	12.9	0.5530	17.2	17.4	0.5530
12	*Hevea brasiliensis*	22.9	23.2	0.8295	21.3	21.5	0.5530
13	*Hevea brasiliensis*	33	33.4	1.1061	21.5	21.6	0.2765
14	*Hevea brasiliensis*	14	14.5	1.3826	19.4	19.7	0.8295
	Average	18.33	18.59	0.71	18.21	18.41	0.57
	Stdev	7.22	7.30	0.37	3.02	3.04	0.20

Appendix 7m. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot M (Tectona grandis)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Tectona grandis*	16.8	16.9	0.2808	14.3	14.5	0.5615
2	*Tectona grandis*	18.4	18.9	1.4038	14.7	14.9	0.5615
3	*Tectona grandis*	13.7	13.7	0.0000	14.6	14.8	0.5615
4	*Tectona grandis*	16	16.1	0.2808	14.5	14.6	0.2808
5	*Tectona grandis*	11.5	11.8	0.8423	14.9	15.1	0.5615
6	*Tectona grandis*	14.5	14.8	0.8423	15.3	15.6	0.8423
7	*Tectona grandis*	16.5	16.6	0.2808	15.3	15.5	0.5615
8	*Tectona grandis*	15.1	15.5	1.1231	16.8	17	0.5615
9	*Tectona grandis*	16.2	16.8	1.6846	17.2	17.3	0.2808
10	*Tectona grandis*	16.3	16.6	0.8423	17.1	17.2	0.2808
11	*Tectona grandis*	21	21.1	0.2808	16.3	16.5	0.5615
12	*Tectona grandis*	18.3	18.5	0.5615	17.4	17.7	0.8423
13	*Tectona grandis*	13.9	14.2	0.8423	17.3	17.5	0.5615
14	*Tectona grandis*	15.2	15.3	0.2808	16.8	17	0.5615
15	*Tectona grandis*	15.9	16.2	0.8423	17.1	17.3	0.5615
16	*Tectona grandis*	14.3	14.5	0.5615	16.8	17.1	0.8423
17	*Tectona grandis*	19.5	19.7	0.5615	15.9	16.2	0.8423
18	*Tectona grandis*	13.4	13.7	0.8423	15.8	16	0.5615
19	*Tectona grandis*	22	22.3	0.8423	16.1	16.3	0.5615
20	*Tectona grandis*	19.3	19.8	1.4038	15.2	15.5	0.8423
21	*Tectona grandis*	17.9	18.4	1.4038	16.3	16.5	0.5615
22	*Tectona grandis*	19.5	19.8	0.8423	14.9	15.1	0.5615
23	*Tectona grandis*	18.2	18.5	0.8423	15.3	15.5	0.5615
24	*Tectona grandis*	16.2	16.2	0.0000	16.2	16.3	0.2808
25	*Tectona grandis*	14.6	14.9	0.8423	14.5	14.7	0.5615
26	*Tectona grandis*	17.7	18.2	1.4038	17.1	17.2	0.2808
27	*Tectona grandis*	20.3	20.9	1.6846	16.5	16.6	0.2808
28	*Tectona grandis*	15.5	15.7	0.5615	14.8	14.9	0.2808
29	*Tectona grandis*	18.7	18.8	0.2808	15.7	15.9	0.5615
	Average	16.77	17.05	0.77	15.89	16.08	0.54
	Stdev	2.49	2.53	0.47	1.00	1.00	0.18

Appendix 7n. Diameter and height of trees, and estimated growth rate of the tree diameter and tree height in plot N (Tectona gradis)

No	Scientific Name	Diameter, Dbh (cm)		Estimated growth rate of tree diameter	Height (m)		Estimated growth rate of tree height
		Time-1	Time-2		Time-1	Time-2	
1	*Tectona grandis*	23.9	24.6	1.9654	16.4	16.6	0.5615
2	*Tectona grandis*	19.2	19.8	1.6846	16.1	16.3	0.5615
3	*Tectona grandis*	14.3	14.8	1.4038	14.8	14.9	0.2808
4	*Tectona grandis*	17.9	18.6	1.9654	14.9	15.1	0.5615
5	*Tectona grandis*	22	22.6	1.6846	16.5	16.8	0.8423
6	*Tectona grandis*	18.3	18.5	0.5615	16.2	16.5	0.8423
7	*Tectona grandis*	24.3	24.8	1.4038	16.5	16.7	0.5615
8	*Tectona grandis*	20.2	20.4	0.5615	16.3	16.5	0.5615
9	*Tectona grandis*	19.5	19.7	0.5615	15.7	15.9	0.5615
10	*Tectona grandis*	19.8	20.2	1.1231	15.4	15.7	0.8423
11	*Tectona grandis*	17	17.7	1.9654	15.8	16	0.5615
12	*Tectona grandis*	22.3	22.7	1.1231	16.2	16.5	0.8423
13	*Tectona grandis*	14.7	15	0.8423	16.1	16.4	0.8423
14	*Tectona grandis*	21.9	22.5	1.6846	15.9	16.3	1.1231
15	*Tectona grandis*	14.7	14.8	0.2808	15.7	15.9	0.5615
16	*Tectona grandis*	19.4	19.7	0.8423	15.7	15.8	0.2808
	Average	19.34	19.78	1.23	15.89	16.12	0.65
	Stdev	3.12	3.19	0.57	0.51	0.55	0.22

Appendix 8. Percent error of the GHGs emissions and removal estimates by province

Province	CO_2 uptake	CO_2 emission	CH_4 emission	CO emission	N_2O emission	NOx emission
Battambang	21.0	1.1	7.1	7.5	0.0	7.1
Banteay Meanchey	18.8	5.4	8.8	8.7	0.0	8.8
Kandal	30.4	0.1	0.0	8.3	na	0.0
Kompong Cham	22.8	1.0	7.5	7.4	0.0	8.7
Kompong Chhnang	16.3	0.7	11.1	10.2	na	0.0
Kompong Speu	21.5	3.4	10.3	10.1	0.0	9.8
Kompong Thom	27.2	2.7	8.1	8.2	0.0	21.5
Kampot	32.4	3.0	9.1	8.7	0.0	9.1
Krong Kep	20.0	0.0	0.0	12.5	na	na
Koh Kong	36.9	1.3	7.3	7.3	0.0	7.6
Kratie	23.9	0.7	8.2	8.6	na	6.7
Mondul Kiri	24.4	6.8	8.3	8.2	0.0	7.8
Phnom Penh	33.3	na	na	na	na	na
Prey Veng	22.7	0.1	0.0	10.3	na	0.0
Pursat	27.9	0.7	11.8	10.7	na	0.0
Preah Vihear	27.8	4.8	9.6	9.7	0.0	8.7
Ratanak Kiri	27.0	4.9	9.0	9.0	0.0	9.4
Svay Rieng	23.1	0.6	10.0	9.0	na	0.0
Sihanouk Ville	33.0	5.3	6.9	7.5	0.0	9.1
Siem Reap	21.9	1.7	6.8	6.9	0.0	5.6
Stung Treng	28.6	2.2	7.7	7.4	0.0	8.7
Takeo	24.1	1.7	8.7	9.6	na	8.3
Odar Meanchey	24.5	7.7	8.0	8.2	0.0	8.3
Boeung Tonle Sap	37.5	na	na	na	na	na