MODULE 5
LAND-USE CHANGE & FORESTRY

5. LAND-USE CHANGE & FORESTRY

5.1 Introduction

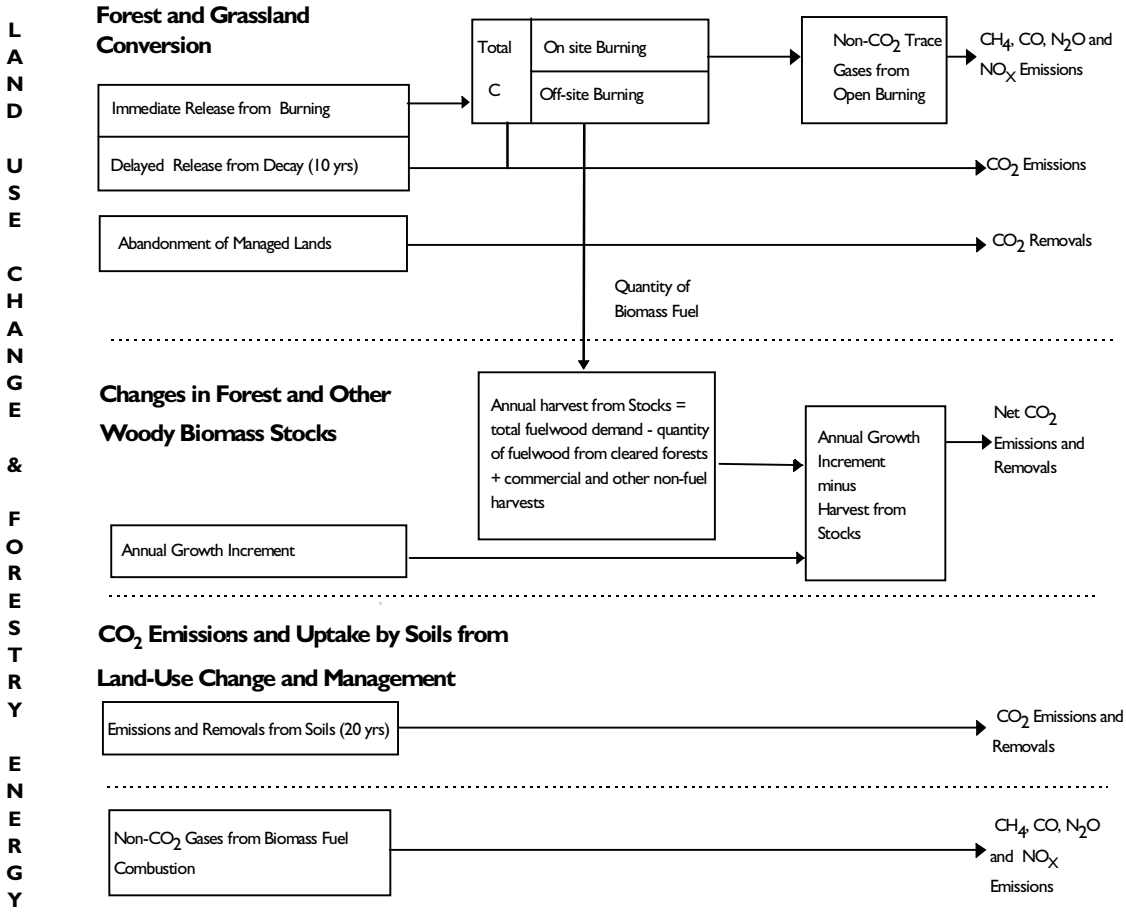
The priority calculations of emissions from land-use change and forestry focus upon three activities which are sources or sinks of carbon dioxide. It must be pointed out that there are inherently large uncertainties or errors associated with these calculations. Future work will develop guidance for estimating and expressing these errors. One of these activity types is also a source of non-CO_2 trace gas (CH_4, CO, N_2O, and NO_x) emissions, and these are also calculated here. NMVOCs are not treated here, although it is recognised that forests are a potential anthropogenic source of these gases.

On a global scale the most important land-use changes and management practices that result in CO_2 emissions and uptake are:

- changes in forest and other woody biomass stocks
- forest and grassland conversion
- abandonment of managed lands

The immediate release of non-CO_2 trace gases from the burning associated with forest/grassland conversion is also calculated. These calculations are very similar to calculations of non-CO_2 trace gas emissions from burning of savannas and agricultural residues (in the Agriculture module, Chapter 4). Calculations of non-CO_2emissions from biomass fuel combustion is done in the Energy Module. The present module deals with the sources and sinks of greenhouse gases from biomass and soil.

FIGURE 5-1 : RELATIONSHIPS AMONG CATEGORIES



The diagram above illustrates the relationships between the categories in this module and also with biomass fuel combustion in the Energy module. The key linkages are:

1 To estimate CO_2 emissions from burning during forest/grassland conversion it is only necessary to know the total amount of biomass burned as a result of that land conversion in the particular year of the inventory.

2 Total biomass burned must be divided into *on-site* and *off-site* (i.e., fuelwood) because the type of burning affects the emissions of non-CO_2 trace gases such as methane, and therefore different emissions factors may be applied to open burning (on-site) and to fuelwood use (off-site).

3 Countries which have good statistics on direct harvesting of all types of woody biomass and all uses of biomass for fuel should use these data. In many countries, significant amounts of wood removed from forests and other biomass stocks (primarily for domestic use) are not included in commercial harvest statistics. These countries can use statistics of fuelwood consumption published by the FAO. These statistics are based on household and other fuel consumption surveys, scaled to population, in order to estimate annual demand for fuelwood and other traditional fuels. This information can be used **instead of or in combination with** commercial harvest and sales statistics.

Fuelwood consumption information is used in two ways:

- for estimating non-CO_2 trace gas emissions from biomass fuel combustion.
- total wood consumption, corrected to deduct any wood which has come from forest and grassland conversion (CO_2 already accounted for) is also a key input for calculating net CO_2 emissions or removals due to changes in forest and other woody biomass stocks.

5.2 Changes in Forest and Other Woody Biomass Stocks

5.2.1 Introduction

This submodule deals with the emissions or removals of carbon (and carbon dioxide) due to changes in forest and other woody biomass stocks affected by human activity.

5.2.2 Data Sources

FAO Yearbooks of Forest Products (annual)

There are also a number of international data bases with country-specific statistics, as well as studies of individual countries. These include:

Forest Resources Assessment 1990: Tropical Countries (FAO, 1993).

The Forest Resources of the Temperate Zones (ECE/FAO, Geneva, 1992).

For a fuller bibliography, see *The IPCC Greenhouse Gas Inventory Reference Manual.*

CATEGORIES OF WOODY BIOMASS

Village, farm or urban trees and other afforestation programmes are included to allow users to account for biomass in trees outside normal forests. These may be important for fuelwood accounting in some countries. Users must provide all data for these categories.

5.2.3 Methodology

To calculate the net uptake of CO_2, the annual increment of biomass in plantations, forests which are logged or otherwise harvested, the growth of trees in villages, farms and urban areas and any other significant stocks of woody biomass, is estimated.

Wood harvested for fuelwood, commercial timber and other uses is also estimated as significant quantities may be gathered informally for traditional fuelwood consumption. In this case the commercial statistics should be supplemented by FAO fuelwood consumption data.

The net carbon uptake due to these sources is then calculated. If the figure is positive then this counts as a removal of CO_2, and if the figure is negative, it counts as an emission. Finally, the net carbon uptake/emission is expressed as CO_2.

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING TOTAL CARBON CONTENT IN ANNUAL GROWTH OF LOGGED AND PLANTED FORESTS

Use WORKSHEET 5-1 CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS at the end of this module to record inventory data.

1 For each type of biomass stock, enter the Area of Forest/Biomass Stocks in kilohectares (kha) in lower column A.

2 For dispersed (non-forest) trees (e.g., urban, village and farm trees), enter the number of trees (in 1000s of trees) in lower column A.

3 For each type of forest, enter the Annual Growth Rate (in tonnes of dry matter per hectare) in column B.

The default statistics in Tables 5-1 or 5-6 can be used if national data are not available. Using defaults would result in highly uncertain national estimates.

TABLE 5-1
AVERAGE ANNUAL ACCUMULATION OF DRY MATTER AS BIOMASS IN PLANTATIONS

Forest Types		Annual Increment in Biomass (tonnes dm/ha/year)
Tropical	*Acacia spp.*	15.0
	Eucalyptus spp.	14.5
	Tectona grandis	8.0
	Pinus spp	11.5
	Pinus caribaea	10.0
	Mixed Hardwoods	6.8
	Mixed Fast-Growing Hardwoods	12.5
	Mixed Softwoods	14.5
Temperate	Douglas fir	6.0
	Loblolly pine	4.0

Note: These are average accumulation rates over expected plantation lifetimes; actual rates will depend upon the age of the plantation.

The data for the temperate species are based upon measurements in the United States. Data on other species and from other regions should be supplied by individual countries (as available).

Additional temperate estimates by species and country can be derived from data in ECE/FAO (1992), assuming that country averages of net annual increment for managed and unmanaged lands are reasonable approximations for plantations.

4 For other non-forest trees, enter the Annual Growth Rate in kilotonnes of dry matter per thousand trees in column B, i.e., take average growth rate per tree and multiply by 1,000.

5 For each type of forest/grassland, multiply the Area of Forest/Biomass Stocks by the Annual Growth Rate to give the Annual Biomass Increment in kilotonnes of dry matter. Enter the result in column C.

6 For non-forest trees, multiply the Number of Trees by the Annual Growth Rate to give the Annual Biomass Increment in kilotonnes of dry matter. Enter the result in column C.

7 For each type of biomass stock, enter the Carbon Fraction of Dry Matter.

The default value is 0.5 for all biomass, if specific values are not available.

8 Multiply the Annual Biomass Increment by the Carbon Fraction of Dry Matter to give the Total Carbon Uptake Increment. Enter the result in column E.

9 Add the figures in column E and enter the total in the Total box at the bottom of the column.

USING COMMERCIAL HARVEST STATISTICS

Commercial harvest statistics are often provided for the commercial portion of the biomass only, in cubic metres (m^3) of roundwood. In this case the harvested amounts must be adjusted in two ways to reflect the values needed for the emissions/removals calculations. The volume of biomass expressed as m^3 must be converted to mass of dry matter expressed as tonnes (t dm).

- The default conversion ratio is 0.5 t dm/m^3.

In addition, an expansion ratio can be applied to account for the non-commercial biomass (limbs, small trees etc.) harvested with the commercial roundwood and left to decay. The following default ratios can be used:

- Undisturbed forests 1.75
  Logged forests 1.90
  Unproductive forests 2.00

If the forest type from which commercial roundwood has been harvested is known, the appropriate ratio can be applied. The value for logged forests could be used as a general default. More detailed formulae for deriving expansion ratio as a function of pre-harvest biomass density are discussed in the *Reference Manual*.

If both conversion and expansion are needed, they can be combined by using ratios which are the product of the two:

Forest type	*t dm total biomass/ m^3 commercial roundwood*
Undisturbed forests	*0.88*
Logged forests	*0.95*
Unproductive forests	*1.0*

Some harvest statistics are provided on a total biomass basis (expansion ratios already applied) or may be provided in mass of dry matter rather than volume. It is important that users determine carefully the nature of the values in their sources of commercial harvest data, then apply the appropriate conversions or expansions to get total biomass harvested. This can be:

a volume to mass conversion alone

b expansion from commercial to total mass of dry matter

c a combination of both (*a* and *b*)

STEP 2 ESTIMATE THE AMOUNT OF BIOMASS HARVESTED

1 Enter the amount of the Commercial Harvest in thousands of cubic metres in column F.

These values should be taken from local sources. FAO published values can be used as defaults. See the margin box *Using Commercial Harvest Statistics*.

2 Enter the Biomass Conversion/Expansion Ratio in tonnes of dry matter per cubic metre (t dm/m^3) in column G if necessary.

3 Multiply the Commercial Harvest by the Biomass Conversion/Expansion Ratio (if necessary) to give the Total Biomass Removed in Commercial Harvest in kilotonnes of dry matter. Enter the result in column H.

4 Enter Total Fuelwood Consumed (including wood for charcoal production) from FAO fuelwood consumption statistics.

5 Enter the quantity of Total Other Wood Use in kilotonnes dm in column J.

If any wood is removed but is not accounted for in harvest statistics for commercial harvest or fuelwood consumption it can be entered here.

6 Add the Total Fuelwood Consumed (column I) to the Total Biomass Removed in Commercial Harvest (column H) and Total Other Wood Use (column J) to give Total Biomass Consumption. Enter the result in column K. Sum this column and enter the result in the Totals box at the foot of the column.

7 Enter Wood Removed From Forest Clearing (total figure from column M, Worksheet 5-2, sheet 3, Quantity of Biomass Burned Off Site) at the bottom of column L.

8 Subtract Wood Removed From Forest Clearing from Total Biomass Consumption to give Total Biomass Consumption From Stocks in kilotonnes of dry matter. Enter the result in the box at the bottom of column M.

STEP 3 CONVERT WOOD HARVESTED TO CARBON REMOVED

1 Enter the Carbon Fraction in column N (the general default value for live biomass is 0.5).

2 Multiply Total Biomass Consumption From Stocks (column M) by Carbon Fraction (column N) to give Annual Carbon Release (in kilotonnes of carbon). Enter the result in column O.

STEP 4 ESTIMATE THE NET ANNUAL AMOUNT OF CARBON UPTAKE OR RELEASE

1 Subtract Annual Carbon Release (column O) from Total Carbon Increment (column E) to give Net Annual Carbon Uptake or Release. Enter the result in column P.

2 Multiply the Net Annual Carbon Uptake or Release (column P) by 44/12 to give the Annual CO_2 Removal (if a positive value) or Emission (if a negative value). Enter the result in column Q.

3 For summary reporting purposes and for consistency with other emission/removal categories, it is necessary to reverse the sign of these results, to express emissions as a positive value and removals as negative.

5.3 CO_2 Emissions from Forest and Grassland Conversion

5.3.1 Introduction

Forest and grassland conversion to permanent cropland or pasture is primarily an activity of the tropics. Tropical forest clearing is usually accomplished by cutting undergrowth and felling trees followed by burning biomass on-site or as fuelwood. 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 per cent) is converted to charcoal which resists decay for 100 years or more, and the remainder is released instantaneously into the atmosphere as CO_2.

Where conversion of forest and grassland to permanent cropland and pasture occurs outside the tropics, the basic calculations should still be the same.

Carbon is also lost from the soils after conversion, particularly when the land is cultivated. Conversion of grasslands into cultivated lands also results in CO_2 emissions, mainly from soils. Estimates of carbon emissions from these practices in Section 5.6.

5.3.2 Data Sources

To carry out the inventory task in this section you need the following forest/grassland area statistics.

Forest/grassland areas converted to cropland and pasture, by type over two time periods:

- the inventory year
- the past ten years

Satellite images, aerial photography and land-based surveys are all possible sources of data.

There are also a number of international data bases with country-specific statistics, as well as studies of individual countries. These include:

Forest Resources Assessment 1990: Tropical Countries (FAO, 1993). Summary tables for tropical countries are included in the *Workbook*.

The Forest Resources of the Temperate Zones, (ECE/FAO, Geneva, 1992).

For a fuller bibliography, see *Reference Manual*.

5.3.3 Methodology

Three sets of calculations are used to produce estimates of CO_2 emissions due to forest/grassland conversion:

- Carbon dioxide emitted by burning aboveground biomass (*immediate* emissions, occurring in the year of conversion)
- Carbon dioxide released by decay of aboveground biomass (*delayed* emissions, occurring over a ten-year period)
- Carbon dioxide released from soil (calculated in Section 5.6).

The totals are added together to arrive at total for carbon released from vegetation. Total carbon released is then converted to CO_2 emissions.

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING BIOMASS CLEARED

Use WORKSHEET 5-2 FOREST AND GRASSLAND CONVERSION, at the end of this module to record inventory data. You should do this for each forest/grassland type:

1 Enter the figures for Area Converted Annually in kilohectares in column A. Default values for tropical forests from FAO, reported by the forest categories in Box 2 and Table 5-1 of the *Reference Manual* are shown in Table 5-4.

See also Technical Appendix, Chapter 5 of the *Reference Manual* for a discussion of other international sources of data.

2 Enter the figures for Biomass Before Conversion in tonnes of dry matter per hectare (t dm/ha) in column B. Default values are shown in Tables 5-5 and 5-6.

3 Enter the figures Biomass After Conversion in tonnes of dry matter per hectare (t dm/ha) in column C.

This figure includes any biomass not fully cleared (default value = 0) plus regrowth in agricultural use. The default value is 10 tonnes dry matter per hectare if annual crops; and can be significantly higher if woody perennials (e.g., coffee, rubber trees) are planted (see *Reference Manual)*.

TABLE 5-4
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Africa									
Countries	Wet			Moist With Short Dry Season			Moist With Long Dry Season		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Angola				3123.3	2904.5	21.9	9717.9	9037.3	68.1
Botswana									
Burundi							50.6	47.0	0.4
Cameroon	8386.0	8020.5	36.5	8573.2	8098.1	47.5	1987.5	1793.6	19.4
Cape Verde									
Central African Rep.	706.3	706.3		11095.2	10504.7	59.0	18400.9	17761.8	63.9
Chad							4414.0	3932.2	48.2
Congo	7794.8	7667.1	12.8	12393.0	12197.9	19.5			
Benin				847.1	838.4	0.9	3903.1	3344.5	55.9
Equatorial Guinea	915.7	882.2	3.3	965.4	929.6	3.6			
Ethiopia									
Djibouti									
Gabon	1228.2	1154.5	7.4	18170.0	17080.0	109.0			
Gambia							85.5	79.1	0.6
Ghana				3910.9	3575.9	33.5	6581.0	5575.5	100.5
Guinea	388.3	384.7	0.4	1204.3	1119.8	8.5	5820.0	5060.2	76.0
Ivory Coast				8537.0	7519.2	101.8	3482.8	3312.1	17.1
Kenya				12.9	12.9				
Liberia	948.0	892.5	5.5	3939.1	3740.8	19.8			
Madagascar	4780.9	4506.7	27.4				4190.9	3777.1	41.4
Malawi							3397.9	2947.7	45.0
Mali							4082.8	3705.6	37.7
Mauritania									
Mozambique				965.9	903.0	6.3	6180.5	5623.0	55.7
Namibia									
Niger									
Nigeria	1269.1	1196.6	7.2	6371.4	5983.5	38.8	6649.1	6027.5	62.2
Guinea-Bissau				129.4	129.4		2050.9	1892.0	15.9
Zimbabwe									
Rwanda									
Senegal							2766.9	2585.9	18.1
Sierra Leone	805.2	756.1	4.9	883.3	829.4	5.4	296.5	278.4	1.8
Somalia									
Sudan				2149.3	1797.5	35.2	12456.1	10674.9	178.1
Tanzania				667.7	626.0	4.2	15738.5	13502.2	223.6
Togo				320.5	293.1	2.7	1214.0	1025.2	18.9
Uganda							1229.0	1090.8	13.8
Burkina Faso							2265.1	2112.5	15.3
Zaire	64047.7	60436.6	361.1	42769.1	40380.1	238.9	5446.7	4829.0	61.8
Zambia							24221.2	21676.1	254.5
TOTAL	91270.0	86603.9	466.6	127027.8	119463.4	756.4	146629.2	131691.0	1493.8

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Africa									
Countries	Dry			Montane Moist			Montane Dry		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Angola	7761.8	7218.1	54.4	3401.3	3163.1	23.8			
Botswana	3098.9	2940.4	15.8						
Burundi				59.8	56.8	0.3	136.2	128.8	0.7
Cameroon	637.8	584.5	5.3	1897.7	1767.4	13.0			
Cape Verde									
Central African Rep.	845.8	816.8	2.9	806.3	772.2	3.4			
Chad	5285.5	5024.3	26.1						
Congo									
Benin	894.1	764.4	13.0						
Equatorial Guinea				14.9	14.3	0.1			
Ethiopia	2065.8	2007.6	5.8	5524.2	5347.9	17.6	838.3	824.9	1.3
Djibouti									
Gabon									
Gambia	19.0	17.5	0.1						
Ghana	438.2	403.8	3.4						
Guinea				145.4	127.6	1.8			
Ivory Coast				77.6	72.7	0.5			
Kenya	18.8	18.8		725.4	678.0	4.7	240.0	230.2	1.0
Liberia				0.2	0.2	0.0			
Madagascar	2424.5	2219.3	20.5	4985.4	4596.2	38.9			
Malawi	191.0	165.6	2.5	422.1	372.7	4.9			
Mali	4954.6	4547.6	40.7						
Mauritania									
Mozambique	10881.1	10162.9	71.8	14.0	13.1	0.1			
Namibia	2607.3	2520.9	8.6						
Niger	190.4	190.4							
Nigeria	1444.6	1380.1	6.4	267.4	243.2	2.4			
Guinea-Bissau									
Zimbabwe	8258.8	7729.4	52.9	73.3	68.6	0.5			
Rwanda				137.5	134.0	0.3	30.7	29.9	0.1
Senegal	1845.8	1716.3	12.9						
Sierra Leone				26.3	24.7	0.2			
Somalia									
Sudan	19514.6	17757.2	175.7	600.3	502.3	9.8	235.9	217.3	1.9
Tanzania	13677.7	12374.6	130.3	3054.7	2705.2	34.9	367.8	329.5	3.8
Togo	36.9	34.5	0.2						
Uganda				4701.0	4281.5	42.0	763.1	698.2	6.5
Burkina Faso	1643.8	1533.1	11.1						
Zaire	118.2	111.0	0.7	8138.5	7448.3	69.0	76.4	69.8	0.7
Zambia	11347.8	10287.7	106.0	361.6	337.5	2.4			
TOTAL	100202.7	92526.9	767.6	35434.9	32727.3	270.8	2688.3	2528.5	16.0

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Continental and Insular South and South-East Asia

Countries	Wet			Moist With Short Dry Season			Moist With Long Dry Season		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Bangladesh	895.5	572.2	32.3				249.5	197.3	5.2
Bhutan	186.3	176.0	1.0						
Brunei	476.4	458.3	1.8						
Myanmar	13709.9	12093.8	161.6				12123.8	10426.7	169.7
Sri Lanka	263.2	247.0	1.6				705.8	605.3	10.1
India	8723.4	8228.5	49.5				7422.8	7044.7	37.8
Indonesia	104211.8	93949.9	1026.2	3284.0	3005.3	27.9	457.8	360.8	9.7
Cambodia	1873.0	1689.3	18.4				4002.9	3610.4	39.3
Laos	4356.4	3960.2	39.6				4969.9	4542.4	42.7
Malaysia	20028.0	16338.8	368.9						
Nepal	647.9	608.7	3.9				1382.8	1300.1	8.3
Pakistan							15.4	10.9	0.5
Papua New Guinea	30244.2	29323.5	92.1	727.2	705.0	2.2			
Philippines	6610.2	4214.2	239.6	919.6	593.6	32.6	1442.1	1004.0	43.8
Singapore	4.4	4.4							
Thailand	4589.9	3081.6	150.8				7189.3	5231.7	195.8
Vietnam	3371.6	2894.5	47.7				3939.1	3381.6	55.7
TOTAL	200192.2	177840.6	2235.2	4930.9	4303.9	62.7	43901.3	37715.9	618.5

Countries	Dry			Montane Moist			Montane Dry		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Bangladesh									
Bhutan				2360.9	2230.4	13.1			
Brunei									
Myanmar	393.4	351.1	4.2	6588.8	5941.8	64.7			
Sri Lanka	988.1	836.1	15.2	57.6	57.3	0.0			
India	28393.5	26252.3	214.1	9159.0	8803.8	35.5	116.4	116.4	
Indonesia	80.0	72.9	0.7	13555.9	12083.2	147.3			
Cambodia	7506.8	6770.7	73.6	94.5	92.7	0.2			
Laos	2473.5	2267.0	20.7	2667.5	2403.5	26.4			
Malaysia				1517.6	1244.3	27.3			
Nepal	39.3	37.1	0.2	2691.2	2361.2	33.0			
Pakistan	5.9	4.2	0.2	824.5	583.3	24.1	1186.4	839.3	34.7
Papua New Guinea	430.4	417.2	1.3	5538.4	5369.8	16.9			
Philippines				2019.4	2019.4				
Singapore									
Thailand	4382.6	3159.1	122.3	1726.1	1262.9	46.3			
Vietnam	1108.5	951.6	15.7	1263.3	1084.5	17.9			
TOTAL	45801.9	41119.2	468.3	50064.4	45538.0	452.6	1302.8	955.7	34.7

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Central and South America and Caribbean

Countries	Wet			Moist With Short Dry Season			Moist With Long Dry Season		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Antigua And Barbuda							10.0	9.8	0.0
Bahamas							153.7	123.8	3.0
Bolivia				23967.7	21453.8	251.4	16024.9	14128.2	189.7
Brazil	301722.3	291596.6	1012.6	95197.0	87729.1	746.8	118943.9	109353.2	959.1
Belize	1798.0	1755.4	4.3				238.4	238.4	
Colombia	49682.6	47455.3	222.7	705.7	549.5	15.6	4347.1	3551.0	79.6
Costa Rica	842.2	625.1	21.7				0.0	0.0	0.0
Cuba	125.3	113.8	1.1				1372.6	1246.8	12.6
Dominica	47.3	44.1	0.3						
Dominican Republic	451.8	340.9	11.1				362.3	273.3	8.9
Ecuador	8572.4	7149.9	142.3	1619.5	1350.8	26.9	381.0	317.8	6.3
El Salvador	40.8	32.6	0.8				15.3	12.2	0.3
French Guyana	7996.2	7993.5	0.3	3.1	3.1				
Grenada							3.6	5.5	-0.2
Guadeloupe	95.5	92.5	0.3						
Guatemala	3820.1	3402.9	41.7				730.5	730.5	
Guyana	11671.1	11671.1		1217.9	1176.1	4.2	4039.8	3901.4	13.8
Haiti	7.4	4.5	0.3				14.3	8.8	0.6
Honduras	1597.5	1285.9	31.2				542.4	436.6	10.6
Jamaica	259.4	122.2	13.7				240.7	113.4	12.7
Martinique	45.0	42.8	0.2						
Mexico	2717.6	2440.8	27.7				13091.1	11110.3	198.1
Nicaragua	4477.8	3712.2	76.6				419.6	347.8	7.2
Panama	2136.6	1801.8	33.5				67.6	66.5	0.1
Paraguay				843.2	473.0	37.0	7681.4	5564.2	211.7
Peru	41501.0	40358.0	114.3	12679.3	12298.8	38.1			
Puerto Rico	42.8	49.4	-0.7				130.7	150.6	-2.0
St. Kitts and Nevis							13.0	13.2	0.0
St. Lucia	7.7	4.5	0.3						
St. Vincent	12.7	10.3	0.2				0.3	0.2	0.0
Surinam	9490.2	9405.3	8.5	1086.7	1044.5	4.2	4317.7	4317.7	
Trinidad and Tobago	191.8	155.0	3.7						
Venezuela	21073.8	19601.8	147.2	3434.7	2978.1	45.7	15403.0	12487.3	291.6
TOTAL	470426.8	451267.9	1915.9	140754.7	129056.7	1169.8	188544.9	168508.6	2003.6

TABLE 5-4 (CONT.)
FOREST AREA (1000 HA) AND RATES OF CONVERSION (RC, 1000 HA/YR) FOR TROPICAL COUNTRIES

Central and South America and Caribbean									
Countries	Dry			Montane Moist			Montane Dry		
	1980	1990	RC	1980	1990	RC	1980	1990	RC
Antigua and Barbuda									
Bahamas	58.7	47.3	1.1	7.8	6.3	0.2			
Bolivia	8261.6	7345.5	91.6	7253.1	6339.6	91.3	51.7	45.5	0.6
Brazil	31989.0	28862.5	312.6	49963.7	43565.2	639.9			
Belize				9.8	2.4	0.7			
Colombia	21.9	18.0	0.4	2971.8	2486.3	48.6	4.8	3.7	0.1
Costa Rica				1081.1	802.5	27.9			
Cuba	2.5	2.3	0.0	321.5	292.0	2.9	65.9	59.9	0.6
Dominica									
Dominican Republic				553.8	417.8	13.6	60.1	45.3	1.5
Ecuador	52.2	43.5	0.9	3716.6	3099.9	61.7			
El Salvador				98.5	78.5	2.0			
French Guyana									
Grenada									
Guadeloupe									
Guatemala				463.3	91.7	37.2	24.0		2.4
Guyana				1667.7	1667.7				
Haiti	0.0	0.0	0.0	14.6	9.0	0.6	1.6	1.0	0.1
Honduras				3442.4	2770.9	67.1	138.2	111.2	2.7
Jamaica	0.2	0.1	0.0	5.7	2.7	0.3	1.5	0.7	0.1
Martinique				0.0	0.0				
Mexico	1886.8	1590.3	29.6	9909.6	8903.9	100.6	25070.0	22356.8	271.3
Nicaragua				2356.1	1953.3	40.3			
Panama				1556.3	1248.6	30.8			
Paraguay	8305.2	6794.1	151.1	54.1	27.3	2.7			
Peru	22.8	18.8	0.4	15742.9	14692.3	105.1	102.0	84.9	1.7
Puerto Rico				104.6	120.5	-1.6			
St. Kitts and Nevis									
St. Lucia									
St. Vincent									
Surinam									
Trinidad and Tobago									
Venezuela	326.6	221.9	10.5	11400.2	10371.8	102.8	25.9	17.8	0.8
TOTAL	50927.5	44944.3	598.3	112695.2	98950.1	1374.5	25545.7	22726.8	281.9

Source: Data are from FAO (1993) and M. Lorenzini (pers. comm., 1996). Forest areas and rates of conversion are divided into the same land categories as in Box 2 and Table 5-1 in the *Reference Manual.*

TABLE 5-5
DRY MATTER IN ABOVEGROUND BIOMASS IN TROPICAL FORESTS
(TONNES DM/HA)

Tropical Forests						
	Wet	Moist with Short Dry Season	Moist with Long Dry Season	Dry	Montane Moist	Montane Dry
	R > 2000	2000>R>1000		R<1000	R>1000	R<1000
Africa	300	140	60-90	20-55	105	40
Asia:						
Continental	225	185	100	75	190	no data
Insular	275	175	no data	little to none exist	255	none exist
America	295	no data	90	105	150	50

R= annual rainfall in mm/yr.

Sources: See, *Reference Manual* (Table 5-4), additional biomass estimates for different forest types and disturbance classes, by climatic zones within countries are given in Table 5-5 in the *Reference Manual*

TABLE 5-6
DRY MATTER IN ABOVEGROUND BIOMASS IN TEMPERATE AND BOREAL FORESTS
(TONNES DM/HA)

Temperate Forests	Coniferous	220-295
	Broadleaf	175-250
Boreal Forests	Mixed broadleaf/coniferous	40-87
	Coniferous	22-113
	Forest-tundra	8-20

Sources: See *Reference Manual*

4 Subtract the figures in column C from the figures in column B to produce the figure for Net Change in Biomass Density in tonnes of dry matter per hectare and enter the result in column D.

5 Multiply the Area Converted Annually (in kilohectares) by the Net Change in Biomass Density (in tonnes per hectare) to calculate the Annual Loss of Biomass for each forest/grassland type in kilotonnes of dry matter (kt dm). Enter the results in column E.

STEP 2 ESTIMATING CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS ON-SITE

1 Enter figures for the Fraction of Biomass Burned On Site by forest/grassland type in column F (see side-box).

2 Multiply the Annual Loss of Biomass (in kilotonnes) by the Fraction of Biomass Burned on Site to calculate the Quantity of Biomass Burned On Site (in kilotonnes of dry matter) for each forest/grassland type. Enter the result in column G.

3 Enter the Fraction of Biomass Oxidised on Site in column H (default fraction 0.9).

4 Multiply Quantity of Biomass Burned on Site (in kilotonnes of dry matter) by the Fraction of Biomass Oxidised on Site to calculate the Quantity of Biomass Oxidised on Site (in kilotonnes of dry matter). Enter the figures in column I.

5 Enter the Carbon Fraction of the Aboveground Biomass (burned on site) in column J (default value 0.5).

6 Multiply the Quantity of Biomass Oxidised on Site (in kilotonnes of dry matter) by the Carbon Fraction of the Aboveground Biomass to calculate the Quantity of Carbon Released (in kilotonnes carbon). Enter the results in column K.

7 Total the figures in column K and enter the figure in the Subtotal box at the bottom of column on the Worksheet.

This Subtotal will be used later to estimate emissions of other gases from burning on-site. (Worksheet 5-3)

FRACTIONS

Various fractions are used in calculating the emissions from forest/grassland conversion.

- Fraction biomass burned on-site and off-site.
- Fraction left to decay. This is the portion of the biomass which is simply left to decay and so releases gases at a slower rate.
- Fraction which oxidises during burning. This is the fraction of burned biomass which actually oxidises instead of turning to charcoal.

STEP 3 ESTIMATING CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS OFF-SITE

1 Enter the Fraction of Biomass Burned off Site in column L.

2 Multiply the Annual Loss of Biomass (in kilotonnes of dry matter) from column E by the Fraction of Biomass Burned off Site to calculate the Quantity of Biomass Burned off Site (in kilotonnes of dry matter) for each forest/grassland type. Enter the result in column M.

3 Total the figures in column M and enter the figure in the Subtotal box at the bottom of the column on the Worksheet.

4 Enter the Fraction of Biomass Oxidised off Site for each forest/grassland type in column N (default value 0.9).

5 Multiply Quantity of Biomass Burned off Site (in kilotonnes of dry matter) by the Fraction Oxidised to calculate the Quantity of Biomass Oxidised off Site (in kilotonnes of dry matter). Enter the figures in column O.

6 Enter the Carbon Fraction of the Aboveground Biomass (burned off site) in column P (default value 0.5).

7 Multiply the Quantity of Biomass Oxidised off Site (in kilotonnes of dry matter) by the Carbon Fraction of the Aboveground Biomass to

calculate the Quantity of Carbon Released (in kilotonnes). Enter the results in column Q.

8 Total the figures in column Q and enter the figure in the Subtotal box at the bottom of the column on the Worksheet.

STEP 4 ESTIMATING TOTAL CARBON RELEASED BY BURNING ABOVEGROUND BIOMASS ON- AND OFF-SITE

1 Add the subtotal for the Quantity of Carbon released from Biomass Burned On-Site in column K to the subtotal for the Quantity of Carbon released (from Biomass Burned Off-Site) in column Q. The result is the Total Carbon Released (from on and off site burning). Enter the result in the Subtotal box at the bottom of column R.

STEP 5 ESTIMATING CO_2 RELEASED BY DECAY OF ABOVEGROUND BIOMASS

1 Enter figures for Average Area Converted (average over ten years) for each forest/grassland type in column A.

For default values, you can use Table 5-4 as the conversion rates are the average over the 10-year period 1980-1990.

2 Enter the average Biomass Before Conversion in tonnes of dry matter per hectare (t dm/ha) in column B. Default values are provided in Tables 5-5 and 5-6.

3 Enter the average Biomass After Conversion in tonnes of dry matter per hectare (t dm/ha) in column C. This figure includes any biomass not fully cleared (default value is 0) and biomass in agricultural use. (The default value is 10 tonnes dry matter per hectare.)

4 Subtract the value in column C from the value in column B to produce Net Change in Biomass Density in tonnes of dry matter per hectare. Enter the results in column D.

5 Multiply the Average Area Converted (10-Year Average) in kilohectares (column A) by the Net Change in Biomass Density in tonnes dry matter per hectare (column D) to calculate the Average Annual Loss of Biomass (aboveground) for each forest/grassland type in kilotonnes of dry matter (kt dm). Enter the results in column E.

6 Enter Fraction Left to Decay (10-Year average) in column F (see side-box).

7 Multiply the Average Annual Loss of Biomass for each forest/grassland type by the Fraction Left to Decay to calculate the Quantity of Biomass Left to Decay. Enter the result in column G.

8 Enter the Carbon Fraction in Aboveground Biomass in column H (default fraction 0.5).

9 Multiply the Quantity of Biomass Left to Decay (column G) by the Carbon Fraction (column H) to calculate Carbon Released from Decay of Aboveground Biomass. Enter the figures in column I.

10 Add the figures in column I and enter the total in the Subtotal box at the bottom of the column.

STEP 6 ESTIMATING TOTAL CO_2 EMISSIONS FROM FOREST AND GRASSLAND CONVERSION

1 Enter the total for Immediate Release from Burning (contained in the subtotal box of column R in Worksheet 5-2, sheet 3) in column A.

2 Enter the total for Delayed Emissions from Decay (contained in the subtotal box of column I in Worksheet 5-2, sheet 4) in column B.

3 Add the figures in columns A and B to calculate the Total Annual Carbon Release (in the Inventory Year from clearing over a 10 year period). Enter the result in column C.

4 Multiply the Total Annual Carbon Release by 44/12 to convert it into the Total Annual CO_2 Release (in Gg). Enter the result in column D.

ESTIMATING FRACTION LEFT TO DECAY

In the Amazon, *Fraction Left to Decay* is typically about 0.5 but this varies greatly by region. Country experts must provide this value.

There is a relationship between the fraction left to decay here and the fraction burned on and off site. For a given year the fraction burned, the fraction left to decay (and possibly a fraction harvested as commercial timber or other non-fuel use) should sum to 1.0, accounting for all biomass cleared. Because the burning and decay portions are averaged over different time periods in the methodology, the relationship need not be precise. However, assumptions made for these different fractions should be consistent.

Furthermore, in countries where fuelwood is critically short no wood may be left on site to burn or decay.

5.4 On-site Burning of Forests: Emissions of Non-CO_2 Trace Gases

5.4.1 Introduction

All burning of biomass (e.g., fuelwood, dung) for energy and of savannas and agricultural wastes is a significant source of CH_4, N_2O, CO and NO_x. Net CO_2 emissions from forest/grassland conversion were calculated in Section 5.3 above. Emissions of non-CO_2 trace gases from on-site burning of forests are calculated here.

5.4.2 Methodology

The method relies on estimation of the gross carbon flux based on work done in Section 5.3 of this *Workbook*.

CH_4 and CO are estimated as ratios to carbon fluxes emitted during burning. Total nitrogen content is estimated based on the nitrogen-carbon ratio. N_2O and NO_x are estimated as ratios to total nitrogen.

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Use WORKSHEET 5-3 ON-SITE BURNING OF FORESTS to enter data for this submodule.

STEP 1 ESTIMATING NITROGEN RELEASED

1 Enter the estimate of Quantity of Carbon Released from on-site burning of forests (in kilotonnes carbon) in column A.

Use the figure in column K of Worksheet 5-2, sheet 2, *Forest and Grassland Conversion*.

2 Enter the Nitrogen-Carbon Ratio of Biomass Burned in column B.

The general default value is 0.01.

3 Multiply Quantity of Carbon Released by the Nitrogen-Carbon Ratio to give the Total Nitrogen Released. Enter the total in kilotonnes of nitrogen in column C.

STEP 2 ESTIMATING NON-CO_2 TRACE GAS EMISSIONS

1 Enter Trace Gas Emissions Ratios in column D.

Refer to Table 5-7 for non-CO_2 trace gas emissions ratios.

TABLE 5-7
EMISSION RATIOS FOR OPEN BURNING OF FORESTS

Compound	Ratio
CH_4	0.012 (0.009-0.015)
CO	0.06 (0.04-0.08)
N_2O	0.007 (0.005-0.009)
NO_x	0.121 (0.094-0.148)

Note: Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of C) relative to mass of total carbon released from burning (in units of C). Those for nitrogen compounds are expressed as the ratios of nitrogen released as N_2O and NO_x relative to the nitrogen content of the fuel (in units of N).

See *Reference Manual* for sources.

2 Multiply Quantity of Carbon Released (column A) by the emissions ratio for CH_4 to give the Amount of CH_4 released. Enter the amount in kilotonnes of C in column E.

3 Multiply Quantity of Carbon Released (column A) by the emissions ratio for CO to give the Amount of CO released. Enter the amount in kilotonnes of C in column E.

4 Multiply the Total Nitrogen Released (column C) by the emissions ratio for N_2O to give the Amount of N_2O Released. Enter the amount in kilotonnes of N in column E.

5 Multiply the Total Nitrogen Released (column C) by the emissions ratio for NO_x to give the Amount of NO_x Released. Enter the amount in kilotonnes of N in column E.

6 Multiply the figures in column E by the conversion ratios[1] in column F to give total for the release of CH_4, CO, N_2O and NO_x. Enter the results in Gg, which is the same as kilotonnes, in column G.

5.5 Abandonment of Managed Lands

5.5.1 Introduction

This submodule deals with net-CO_2 removals in biomass accumulation resulting from the abandonment of *managed* lands. Managed lands include:

- Cultivated lands (arable land used for the cultivation of crops)
- Pasture (land used for grazing animals)

Carbon accumulation on abandoned lands is sensitive to the type of natural ecosystem (forest type or grasslands) which is regrowing. Therefore abandoned lands regrowing should be entered by type. For grasslands the default assumption is that net accumulation aboveground is zero.

Because regrowth rates become slower after a time, the periods considered are:

- Land abandoned during the 20 years prior to the Inventory Year (i.e., 1990)
- Land abandoned between 20 and 100 years ago (i.e., before 1970 and after 1870)

When managed lands are abandoned, carbon may or may not reaccumulate on the land. Abandoned areas are therefore split into those which reaccumulate carbon and those which do not regrowth or which continue to degrade.

Only natural lands which are regrowing towards a natural state should be included. Lands which do not regrow or degrade should be ignored in this calculation.

As with forest and grassland conversion, effect of forest regrowth on soil carbon is dealt with in Section 5.6 of the *Workbook*.

---

[1] The molecular weight ratios given above for the emitted gases are with respect to the weight of nitrogen and carbon in the molecule. Thus for N_2O the ratio is 44/28 and for NO_x it is 46/14. NO_2 has been used as the reference molecule for NO_x.

5.5.2 Methodology

Two sets of calculations are used to estimate CO_2 removals from biomass regrowth and soils recovery. They relate to the quantity of land abandoned and the length of time for which it has been abandoned:

- Annual carbon uptake in aboveground biomass (land abandoned in the last twenty years)
- Annual carbon uptake in aboveground biomass (land abandoned for between twenty and a hundred years, if applicable).

These are then totalled and the carbon uptake is converted into CO_2 removals.

Completing the Worksheet

Use WORKSHEET 5-4 ABANDONMENT OF MANAGED LANDS at the end of this module to record inventory data.

STEP 1 CALCULATE ANNUAL CARBON UPTAKE IN ABOVEGROUND BIOMASS (LAND ABANDONED IN THE LAST TWENTY YEARS)

1 Enter the Total Area Abandoned and Regrowing for the last twenty years (in kilohectares) in column A.

There are no default data for these figures.

2 Enter the Annual Rate of Aboveground Biomass Growth (in tonnes dry matter per hectare) in column B. See Table 5-8 for default values.

3 Multiply the Total Area Abandoned and Regrowing (column A) by the Annual Rate of Aboveground Biomass Growth (column B) to give the Annual Aboveground Biomass Growth (in kt dm). Enter the result in column C.

4 Enter the Carbon Fraction of Aboveground Biomass in column D (default fraction 0.5).

5 Multiply the Annual Aboveground Biomass Growth (column C) by the Carbon Fraction of Aboveground Biomass (column D) to give the Annual Carbon Uptake in Aboveground Biomass. Enter the result in column E.

6 Add the figures in column E and enter the total in the Subtotal box at the bottom of the column.