National System of Greenhouse Gas Reporting for Forest and Nature Areas under UNFCCC in The Netherlands

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ABSTRACT

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The Netherlands as being a Party to the United Nations Framework Convention on Climate Change (UNFCCC) has the obligation to design and operationalise a national system for the Land Use, Land-Use Change and Forestry sector (LULUCF). This report presents such a semi dynamic system at Tier 2 for forests and other nature terrains (trees outside forests, heathland, peats, and sandy areas) in The Netherlands. With this system a full account for carbondioxide and other greenhouse gas balance is presented and recalculated for 1990 – 2002.

Keywords: Dutch National system, Kyoto Protocol, UNFCCC, forest, Netherlands

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Preface

The Netherlands as being a Party to the *United Nations Framework Convention on Climate Change* (UNFCCC) has the obligation to design and operationalise a national system for the Land Use, Land-Use Change and Forestry sector (LULUCF). This report presents such a semi dynamic system at Tier 2 for forests and other nature terrains (trees outside forests, heathland, peats, and sandy areas) in The Netherlands.

With this system a full account for carbondioxide and other greenhouse gas balance is presented and recalculated for 1990 – 2002 at a Tier 2 level. These figures have been submitted in the NIR of 2005.

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Summary

The Netherlands as being a Party to the *United Nations Framework Convention on Climate Change* (UNFCCC) has the obligation to design and operationalise a national system for the Land Use, Land-Use Change and Forestry sector (LULUCF). This report presents such a semi dynamic system for forests and other nature terrains (trees outside forests, heathland, peat, and sandy areas) in The Netherlands.

With this system a full account for carbondioxide and other greenhouse gas balance is presented and recalculated for 1990 – 2002 at a Tier 2 level. These figures have been submitted in the NIR of 2005. The carbon balance for living biomass, dead wood, litter and soil organic carbon is presented for forests remaining forests and for other land uses changing to and from forests.

The land use changes between 1990 and 2000 showed that The Netherlands has an annual deforestation of 2504 ha (0.7% of the forest area) and an afforestation of 3124 ha. Deforestation led in total over the thirteen years of 1990 – 2002 to an emission of 11.2 million ton CO_2 compensated by only 1.9 million ton CO_2 due to afforestation.

The net sink of all processes of the forest and other nature terrains balance is very stable through time around an average of 1.74 million ton of CO_2 per year with a standard deviation of 88 kton. The sink is to a large extent determined by the balance between growth of forest remaining forest and the harvest. Newly added processes in this new National System are significant as well, but they compensate each other. The sources from deforestation and N_2O emissions (around 900 ktonne CO_2) are for two thirds compensated by the sinks from afforestation, dead wood, soil C changes due to land use changes, and trees outside the forest.

1 Introduction

The Netherlands as being a Party to the *United Nations Framework Convention on Climate Change* (UNFCCC) has the obligation to design and operationalise a national system (Article 5 of the UNFCCC) for the Land Use, Land-Use Change and Forestry sector (LULUCF). One of the elements of such a system is an inventory system for greenhouse gases for the forest and nature types of land use. Good Practice Guidance (GPG) for such an inventory, monitoring, and reporting system was prepared by the Intergovernmental Panel on Climate Change (IPCC 2003) and specifically deals with the forest sector as a single sector. Other types of nature (heath, wetlands, sand dunes, etc) are dealt with in GPG under either grasslands, wetlands or other lands.

Currently the Netherlands reports only some land use types and activities to the UNFCCC (Spakman et al. 1997, Olivier et al. 2003, Klein Goldewijk et al. 2004). These are the carbon sinks from changes in forest biomass (Category 5A), and the N_2O and CH_4 emissions from agricultural soils (Category 5E). It is clear that this current level of reporting will not suffice the new requirements.

Here we describe the approaches, methods, data and results for the Dutch National System for forest and nature areas.

2 Approach used for the national System for forest and nature areas

For the year 2000 The Netherlands reported a sink of 1413.26 Gg CO_2 (1.4 Mton CO2) for category 5A ('Changes in Forest and other Woody Biomass Stocks') (Klein Goldewijk et al. 2004). This was the only sub-category reported in Category 5 of that year. Out of the total national emissions reported for that year (169.3 Mton CO2), the sink comprised 0.8%. This, nor the trend in the sink (Figure 2.1.), would justify it to make the forest sector a Key Category [1]. Therefore the forest sector was reported based on IPCC defaults methods and data, whereby one nationally derived stem increment was converted to whole tree biomass based on one IPCC biomass expansion factor.

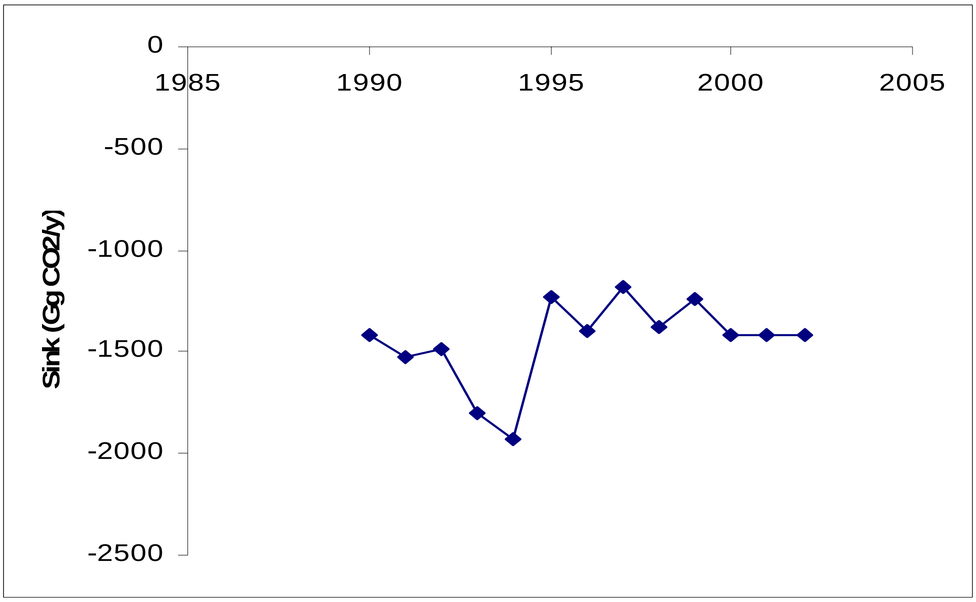

Figure 2.1. Trend in the forest biomass sink as reported for the Netherlands in the old system (Klein Goldewijk et. al. 2004)

However, a couple of reasons arose that require elaboration of the work for the forest sector reporting:

- Requirements as described by the Marrakesh Accords to set up a National System;
- Additional reporting requirements for Kyoto lands starting as of 2008;
- Existence of a detailed and ongoing geo-referenced forest inventory system (Figure 2.2);

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[1] Key category's: A category that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both.

- Reviews of Category 5A from National Communications made by the UNFCCC secretariat stating that many Parties report this category in a poor way and lack almost all background material (UNFCCC 2004) (FCCC/SBSTA/2004/INF.7);
- The Netherlands has the most intensively managed biosphere in the world;
- The whole land use sector (incl. livestock) in the Netherlands comprises a significant share of the total emissions with respectively 13%, 55% and 42% of total emissions of CO_2, N_2O, and CH_4;
- The obligation to report as accurately as possible;
- The political sensitivity of this category in international negotiations.

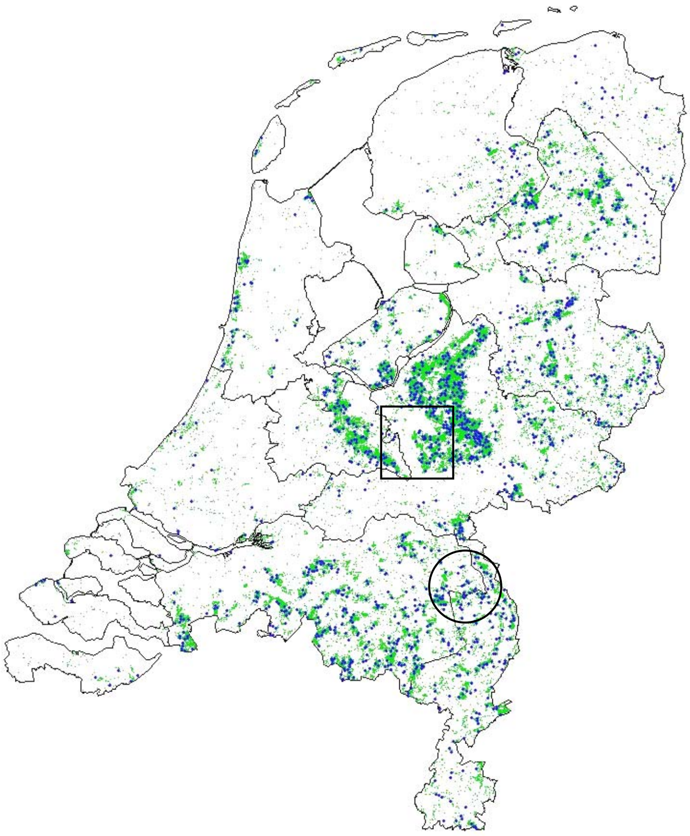

Figure 2.2. The Netherlands' forest map for 2000 (green shaded) and the location of the 1441 forest inventory plots (indicated by blue dots). The square is the location of Figure 6.3 and the circle the location of Figure 3.2. and 6.4

These items together were reason for the Netherlands to start an initiative to strive towards improvement of the reporting. The steering Committee (WEB sinks) e.g. initiated studies into so called white spots in reporting (Kuikman et al. 2004) and into an overview of available data (Nabuurs et al. 2003). Based on these it was decided to report the forest and nature areas from now on [2] at Tier 2 level. Tier 2 applies the same basic approach as Tier 1 (stock change) but applies detailed emission factors and activity data which are defined by country specific data for the most important land uses and activities. Higher resolution activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialised land use categories (IPCC 2003). In comparison to a Tier 3 method, the current system mainly lacks a full dynamic and a full geographically explicit approach. However on the most important pools (living biomass of forest remaining forest), the approach is clearly a Tier 3.

The approach chosen follows the IPCC 1996 Revised Guidelines and its updates in the Good Practice Guidance. Namely a carbon stock change approach based on inventory data (Equation 3.2.4. in IPCC GPG 2003) subdivided to appropriate pools and land use types. The pools distinguished are aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon (Figure 2.3.). For litter and soil organic carbon in 'forest remaining forest' and for biomass in other nature terrains it is assumed that the stock does not change. Therefore no sink is calculated, only the present stock.

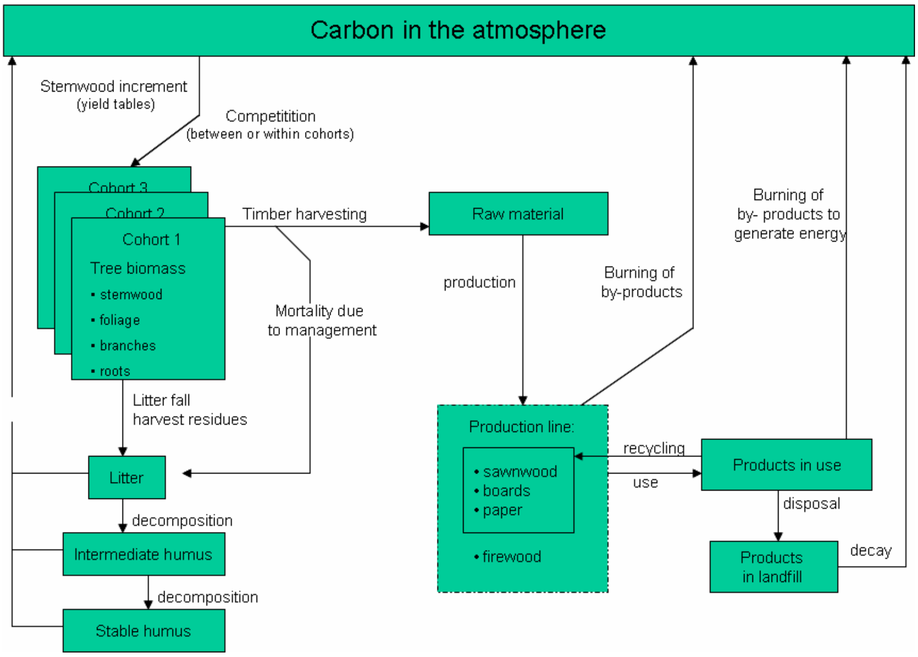

Figure 2.3. The carbon cycle of a managed forest and wood products system. The Dutch national system follows these pools and fluxes distinguished by aboveground biomass, belowground biomass, litter, dead wood, and soil organic carbon

In short the Dutch National system consists of land use maps combined (partly through a stepwise modeling approach) with a wide variety of databases. Some of

[2] NIR 2005, covering up to the year of 2002

these databases rely on ongoing monitoring, some are based on former monitoring results or derived from literature (Figure 2.4.).
The basis is formed by the land use maps for 1990 and 2000. Out of these, the land use change matrices are derived. For 'Forest remaining Forest' the land use is combined with the national forest inventory database (MFV for 2000 and HOSP for 1990), which stemvolume data are converted to whole tree carbon through selection of allometric equations from a large European equation and biomass database.
For 'Other lands converted to Forest' a rather simple calculation is carried out that assesses the losses or gains of biomass in the same year per transition. For these areas that fall under a transition a simple soil C balance is assessed. Additional sources of information are used for other nature terrains, soil organic carbon, litter, non CO_2 gases, and wood products.

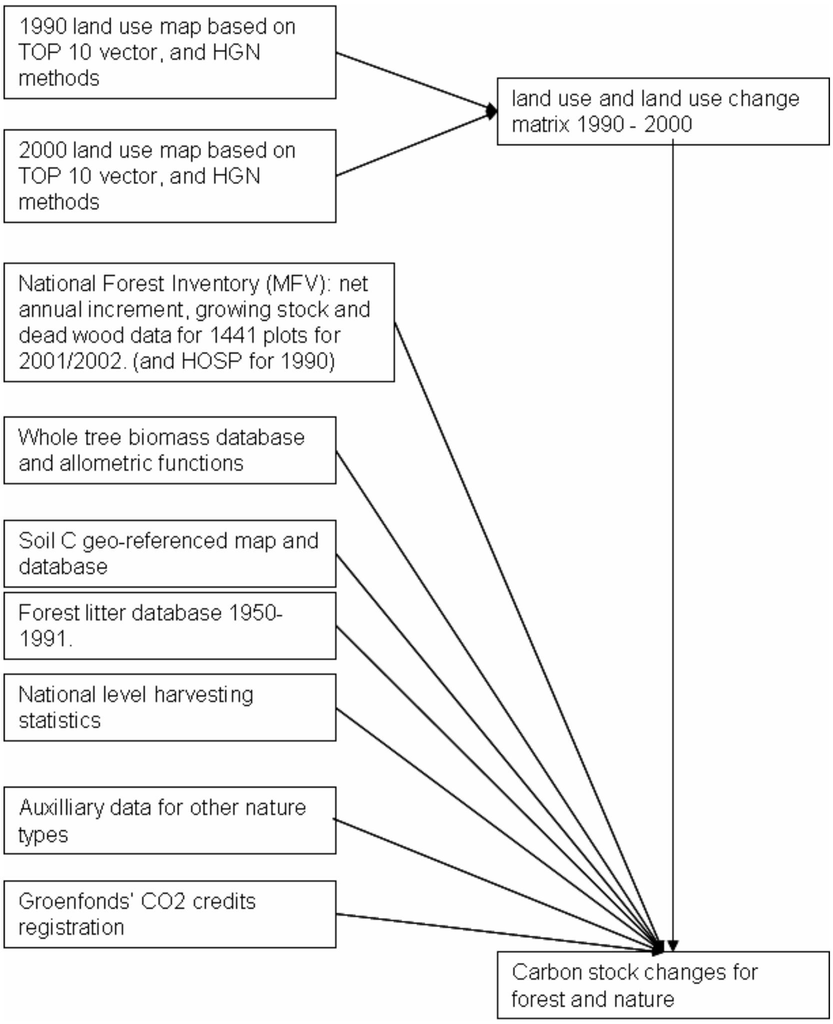

Figure 2.4. Data sources of the Dutch National System for greenhouse gas reporting of forest and nature areas

3 Methods and data for area determination

3.1 Introduction

From Nabuurs et al. (2003) it appeared that several methods for forest area assessment for the Netherlands had been applied in the past (Figure 3.1.). It was concluded that the most accurate assessment had been done based on the topographical maps (Kramer and Knol 2005). So, forest and nature area determination approach 3 as described in Good Practice Guidance (IPCC 2003, p. 2.12), was applied. This means that from two detailed geographically explicit maps (1990 and 2000), a land use and land use change matrix is derived.

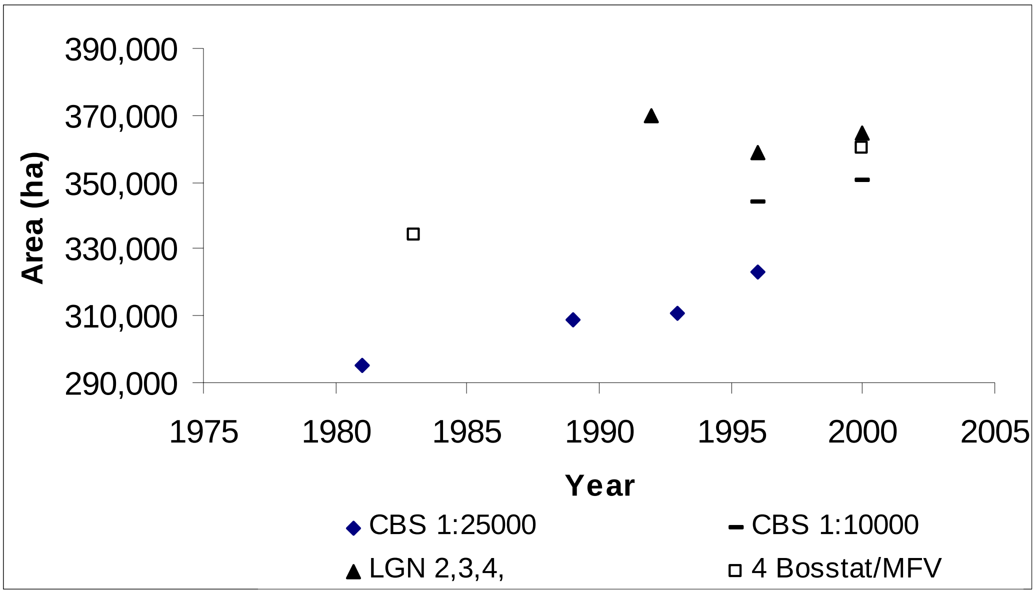

Figure 3.1. Estimates for forest area in The Netherlands based on various sources. 'LGN' are satellite derived data, 'CBS' is the Dutch statistical bureau represented here by estimates based on two scales of maps. '4 bosstat' is the area statistic for the fourth Dutch forest statistic carried out in 1983, and 'MFV' is the latest forest map based on a polygon conversion of the 1:10,000 topographical maps. For the Dutch National system (current report) a methodology comparable to the 'MFV' was used

Therefore, following procedure was applied: digital scans of the 1990 maps were made; the results are grids of 2.5 x 2.5 m. These were scaled up to 25 x 25 meter grids. The 2000 map was already available in 25x25 m grids. However, both of these maps still held methodological differences and differences based on coloring used in the hard copy maps. These were corrected for (Kramer and Knol 2005). Based on criteria, definitions, and preferred land use classes, the final runs were made to derive the digital maps.

3.2 Deriving the land use maps 1990 - 2000 (HGN [3])

The topographical maps of 1990 and 2000 served as the basis (Fig 3.2). However these maps are based on a combination of aerial photographs and intensive field work. Therefore not all sheets that form a map are inventoried in the same year. However all sheets are inventoried in between 1988 and 1992. The sheet inventoried as close as possible to 1990 was always chosen. If the choice was arbitrary (e.g. sheets of both 1988 and 1992 available), then the sheet closest to the average of all sheets (just after 1990) was chosen.

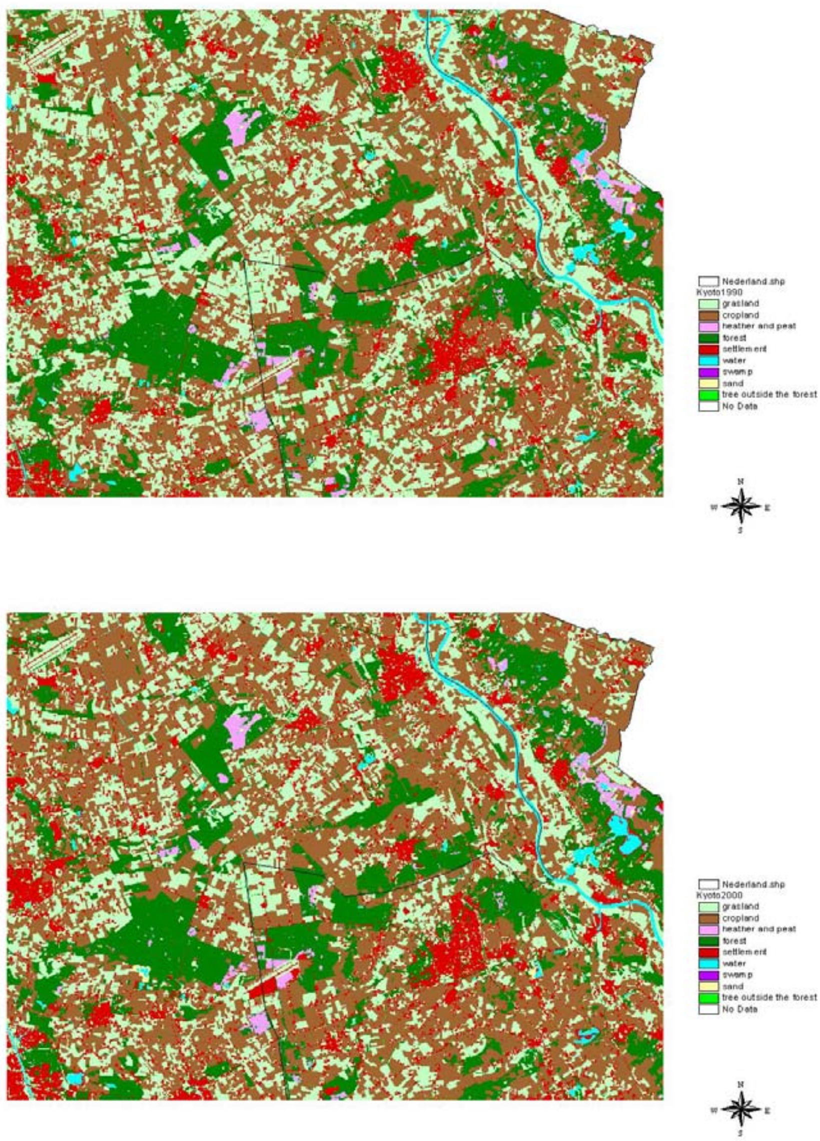

Figure 3.2. Example of the HGN land use map in 1990 (top) and 2000 (bottom) of a typical rural area. These are the digitized 25x25 m grid based maps corrected for methodological differences and color coding differences. See for the location in The Netherlands Figure 2.2. The deforestation and afforestation of this area is given in Figure 6.4.

[3] HGN: Historisch Grondgebruik Nederland

3.2.1 Preparation

Each sheet was scanned at 300 dpi with 24 bit RGB color depth. The scans were georeferenced according to the Dutch triangle system 'RijksDriehoekstelsel'. The results are scans with pixels of 2.5 x 2.5 meters.

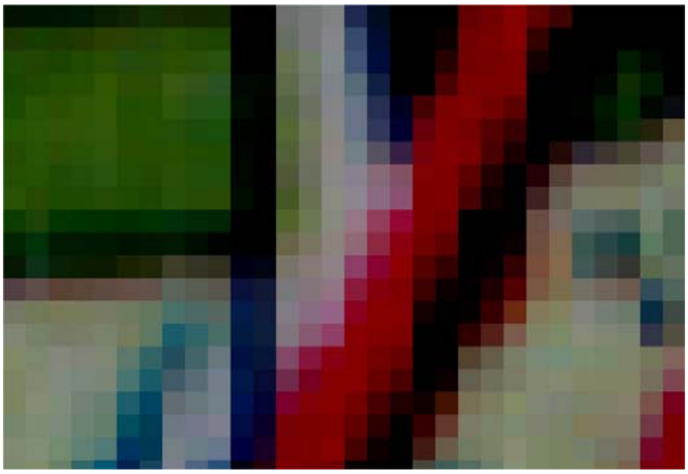

Figure 3.3 Part of a scan with pixels of 2.5x 2.5 meters

3.2.2 Classification

Generic classification
The methods described below are very comparable to the methods used by Knol et al. (2004) for their historical land use (HGN) map of the Netherlands for 1900. As a first step, colors are defined on the basis of distinguished colors from the maps. The map is taken as the truth. As little as possible visual interpretation is done. To change the scans into a classified database, the *supervised classification* of Erdas/Imagine 8.4 was used. This means that for each class, relevant pixels are appointed. On the basis of the RGB color depth, the programme searches for neighbouring pixels. A profile of such a class is thus set up. Then all pixels are compared to the profile and assigned to a class. Pixels that are not assigned to a class will be treated in the next step 'aggregation'.

Specific classification
Some land use forms do not have a unique color code on the original maps, e.g. cropland and buildings in cities. These are then distinguished based on the CBS land use statistics which allow the delineation of the built-up area.

3.2.3 Aggregation

Main aim of aggregation is to assign pixels which were left un-assigned in the 'generic classification'. It appeared that an aggregation to 25x25 meter pixels takes care of practically all un-assigned pixels (Kramer en Knol 2005). For each 25 m pixel, the majority class of the 2.5 m pixels is assigned to the 25 x 25 m cell. Especially in transition areas and in line-shaped elements, the heterogeneity within the 25 m pixel appeared to be large. Table 3.1 shows the results for area by land use when using different aggregation levels. The number of cells assigned to forest varied in this way from a minimum of 4968 cells to 5623, a difference of 13%. Based on these tests, it was chosen to use the 25 m resolution pixels (for details see Kramer and Knol 2005).

Table 3.1. Number of cells assigned to a certain land use when using different aggregation techniques for the sheet 'Lochem'

	12.5 m	**12,5 m**	**25m**	**50m**	**50m**	**50m**	**50m**
	Filter	**without filter 1990**	**without filter 1990**	**1983 4th statistic**	**HGN 1990**	**(Dirkse et al. 2000)**	**HGN 1990> 1 cel**
	1990			**vector converted to grid**	**12.5 to 50 meter**	**vector converted to grid**	**Single cells removed**
Grasland	28789	28237	29041		29842		
Cropland	11905	11706	12188		12436		
Heather	47	44	41		36		
Forest	**5623**	**5351**	**5553**	**4968**	**5318**	**5143**	**5150**
City	0	0	0				
water	710	636	669		625		
Other urban	1084	1043	1172		1282		
Roads	1505	1447	1002		305		
Houses	326	318	240		155		

In the aggregation as much as possible of the resolution was maintained. So, if a small patch of cropland (<1/16 ha) occurs within a forested area, it is maintained as a patch of cropland. This also means that small patches of forest (<0.5 ha) within agricultural land are maintained as 'trees outside the forest'. Table 3,2 gives the distinguished land use classes and the comparable class in the Good Practice Guidance

Table 3.2. Land use classes as defined in the historical land use map of the Netherlands and the equivalent land use class in Good Practice Guidance

HGN Basis	**HGN sub division**	**GPG classes**
Forest	Forest according to forest definition	Forest
	Trees outside the forest	Forest
	Heather/peat and other nature terrains	Forest
Grassland		Grassland
Cropland / bare soil		Cropland
Settlement	Settlement	Settlement
	Road	Settlement
Water		Other
Reed swamp		Wetland
Sand	Bare coastal dune	Other
	Beach	Other
	Inland sand dune	Other

4 Methods and data for forest biomass and dead wood stock changes

4.1 Carbon balance of living biomass in 'Forest remaining forest'

4.1.1 Basic data

The basic approach follows the IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry where a stock change approach is suggested. The basic assumption is that the net flux can be derived from converting the change in growing stock volume in the forest to carbon. Either as basic data the stock at two points in time is known, or the stock at one point is known plus the increment in consecutive years. Calculations for the living biomass carbon balance are carried out at the plot level. The Dutch National Forest Inventory has been used for this. This was available for two periods: a) 1988-1992, the so called HOSP data, and b) 2001-2002, the MFV data. HOSP plot level data (2007 plots ~ 400 plots per year) for growing stock volume, increment, age, tree species, height, tree number and dead wood were used for the 1990 situation. Forward calculation with these data was applied to the year 1999.

MFV plot level data for growing stock volume, increment, age, tree species, height, tree number and dead wood were used. In total 1440 plot recordings with forest cover were available for the years 2001 and 2002. MFV continues in 2004 as well with another 900 plots, with litter layer thickness as well. MFV data were used as one set of data. I.e. the resulting carbon balance is applied to the year 2000, 2001 and 2002.

4.1.2 Additional data

Although HOSP had completed two inventory cycles, where harvesting data were obtained, these were only used at the national level where they are often complemented by other sources. Therefore national data as given in Table 4.1. were used.

The national level harvest was artificially assigned to plots as thinnings based on criteria that plots may meet. The criteria are: age > 110, or growing stock more than 300 m^3 ha^{-1}. In these cases a thinning of 9% was carried out in the plot. No clearcuts were carried out. This was done for several reasons: 1) clearcuts are hardly carried out anymore in the Netherlands, 2) carrying out forward calculation with hypothetical clearcuts with no information of regeneration type from the single inventory cycles leads to highly uncertain forest development. Therefore it was decided to carry out the forward calculations with thinnings only.

Table 4.1. National level wood production data

Year /period	1000 m3/y	Type of felling	Reference
1990	313	Final cut	Daamen. 1991.
1990-1994	1196	Thinning	Daamen. 1994.
1991-1995	1568	Thinning and final cut from production forest plus outgrown coppice, and other	Daamen. 1996.
1992-1996	1339	production forest plus outgrown coppice, and other	Daamen. 1997.
1993-1997	1455	production forest plus outgrown coppice, and other	Daamen. 1998.
1995- 1999	1397	HOSP forest plus additional forest	Daamen. 2000.

For the conversion from volumetric dimensions to whole tree biomass, we relied on the COST E21 (2003) database on biomass equations. For validation and choice of the equation we made use of the biomass database collected by Van Hees (pers comm.). See figure 4.1. and 4.2. for Scots pine. See appendix 1 for the list of equations and selection criteria.

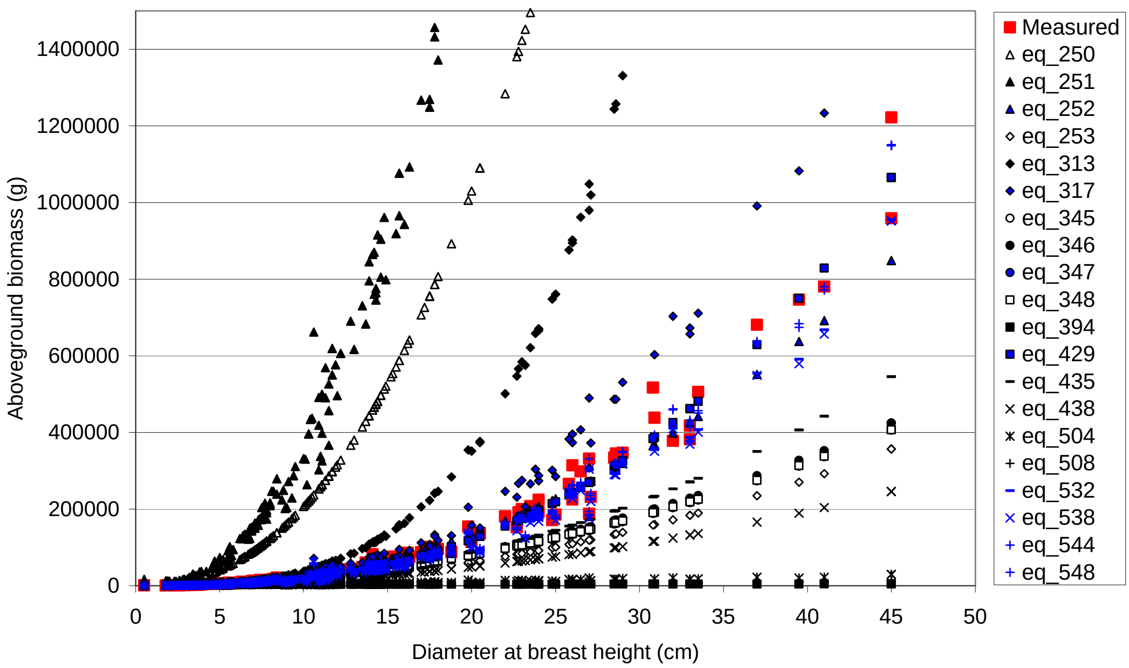

Figure 4.1. Example of equation application (DBH against dry matter) against measured data for Scots pine. Based on this, equation 544 was chosen with an R2 of 0.98

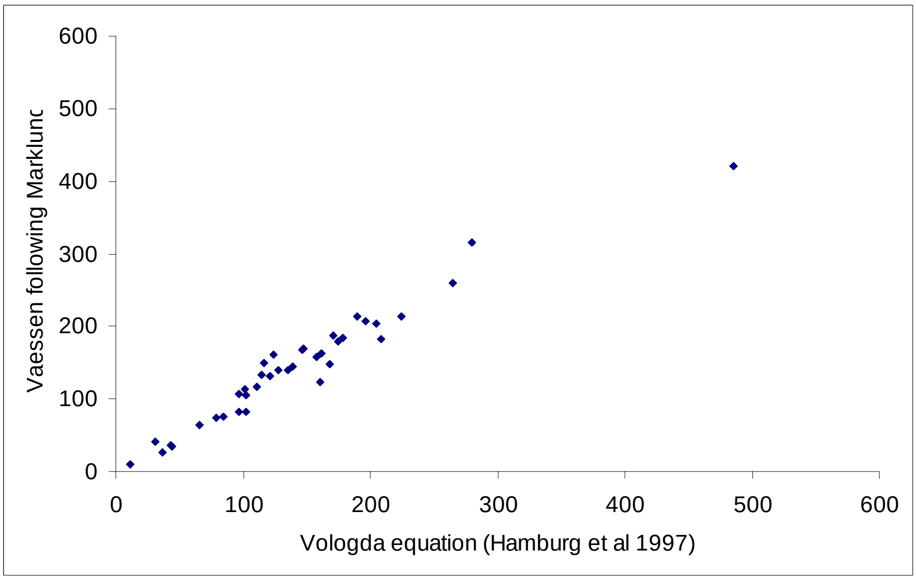

Figure 4.2. Results of equation 544 (Hamburg et al. 1997) plotted against results of the locally validated equation (Vaessen)

4.1.3 Calculation method

Following calculations are carried out to derive the annual carbon balance from the HOSP and MFV data and to forward calculate the balance.

Living biomass

Allometric relations are used to calculate above- and below ground biomass from volumetric or structural dimensions. Most allometric equations, and all allometric equations in this study, are based on tree diameter at breast height and/or tree height. We used the relations of Jansen et al.(1996) to extrapolate height growth and to calculate tree diameter from tree height and volume. Based on current dominant height and age, the limit of dominant height is calculated with:

$$h_{dom}(t) = S \times (1 - e^{-c_7 \times t})^{c_8}$$
$$\Leftrightarrow S = h_{dom}(t) / (1 - e^{-c_7 \times t})^{c_8}$$

(Jansen et al., 1996)

with:

t	age of the plot (year of recording – regeneration year) (years)
$h_{dom}(t)$	dominant height at age t (m)
S	limit of $h_{dom} \rightarrow \infty$ (m)
c_7, c_8	species specific constants ($year^{-1}$, -)

Both height and volume at age t+1 can then be calculated:

$$h_{dom}(t+1) = S \times (1 - e^{-c_7 \times (t+1)})^{c_8}$$

$$V_{tree}(t+1) = \frac{V_{plot}(t) + Ic_{V\ plot}(t)}{N_{trees}}$$

with

$V_{tree}(t+1)$	average single tree volume at age t+1 (m^3)
$V_{plot}(t)$	plot volume at age t ($m^3\ ha^{-1}$)
$Ic_{Vplot}(t)$	annual volumetric increment at age t ($m^3\ ha^{-1}\ y^{-1}$)

With the height and volume, the average diameter can be calculated:

$$V_{tree} = D_{tree}{}^{a} \times H_{tree}{}^{b} \times e^{c}$$

$$\Leftrightarrow \ln(V_{tree}) = a \times \ln(D_{tree}) + b \times \ln(H_{tree}) + c$$ (Jansen et al., 1996)

$$\Leftrightarrow \ln(D_{tree}) = \frac{1}{a} \times (\ln(V_{tree}) - b \times \ln(H_{tree}) - c)$$

With

V_{tree}	Average single tree volume (m^3)
D_{tree}	Diameter of average single tree (cm)
H_{tree}	Average single tree height (m)
a,b,c	species specific constants

The dominant height is assumed to be representative for all trees in the plot. The small underestimation in diameter that occurs as a result of this, is assumed to be negligible. The above and belowground total biomass is then derived with the equations as obtained from the COST E21 database. A validation was carried out based on the database of Van Hees (pers comm.).

$$M_{AB} = f_1(D,H)$$

$$M_{BG} = f_2(D,H)$$

$$M_{tree} = M_{AB} + M_{BG}$$

with:

M_{AB}	aboveground tree biomass (kg DW)
M_{BG}	belowground tree biomass (kg DW)
M_{tree}	total tree biomass (kg DW)

The resulting net flux (NEP, because it is assumed that all litter decomposes the same year) is derived from the tree mass at time t and t+1 and the carbon content of dry mass (50%).

$$\Delta C(trees)_{plot} = \frac{\left(M_{tree}(t) - M_{tree}(t+1)\right)}{\Delta t} \times N_{trees} \times F_{carbon}$$

with:

$\Delta C(trees)_{plot}$	net C flux in living biomass per plot (kg C $ha^{-1}y^{-1}$)
$M_{tree}(t)$	Total tree biomass at time t (kg DW)
N_{trees}	number of trees (ha^{-1})

F_{carbon}	carbon content (kg C kg^{-1} DW)
Δt	Time between t and t+1 (jaar)

Thinning

Thinning was carried out in all plots that met the criteria for thinning (age > 110 years or growing stock more than 300 m^3 ha^{-1}) and the total volume harvested was distributed over the plots proportional to growing stock volume. This yielded the volume to harvest per plot and, divided by the average stem volume per tree, a number of trees to be thinned from each plot. The net C flux due to thinning is then calculated from the number of trees thinned, the average biomass of a single tree and the carbon content of dry mass.

Dead wood

The net C flux to dead wood is the remainder of the input of dead wood due to mortality minus the decay of dead wood. It is reasonable to believe that a net build up may exist, because Dutch forestry is only since one decade paying attention to dead wood. The mortality rate was assumed to be a fixed fraction of the standing volume (0.4% y^{-1}). MFV data provide a current stock of dead wood volume (both lying and standing) of 6.6% of the living wood volume. HOSP data only provide standing dead wood volume, and since these were recorded around 1990, it was assumed that the amount of lying dead wood was negligible. Leaves and roots were not taken into account for the built up of dead wood, as it was assumed that these rather small litter fractions decomposed within one year.

The decay of dead wood is determined by the total time needed to fully decompose (Hees & Clerkx 1999). The wood density varies strongly during this decomposition, but was assumed to be 50% of the basic wood density of the living trees (Table 4.2).

Table 4.2. Basic wood density values for live biomass. Dead wood values were assumed to be half of live values (IPCC 2003)

Species	Basic Wood Density (kg DM/fresh volume)
Acer spp	560
Alnus spp	510
Betula spp	670
Fagus sylvatica	700
Fraxinus excelsior	680
Larix spp	500
Picea spp	440
Pinus other	550
Pinus sylvestris	500
Populus spp	440
Pseudotsuga menziesii	540
Quercus spp	700
Coniferous other	450
Broadleaved other	600

This resulted in the following calculations for the net C flux to dead wood:

$$\Delta C(deadwood)_{plot} = OutC(deadwood)_{plot} - InC(deadwood)_{plot}$$

$$InC(deadwood)_{plot} = M_{tree}(t) \times N_{trees} \times F_{carbon} \times F_{mortality}$$

$$OutC(deadwood)_{plot} = \left(\frac{V_{Dead\_S}}{TBP_S} + \frac{V_{Dead\_L}}{TBP_L} \right) \times WD_{Dead} \times F_{carbon}$$

with

$\Delta C(deadwood)_{plot}$	net C flux in dead wood mass per plot (kg C $ha^{-1}y^{-1}$)
$InC(deadwood)_{plot}$	C input into dead wood from dying trees (kg C $ha^{-1}y^{-1}$)
$OutC(trees)_{plot}$	C loss per plot due to decomposition of dead wood(kg C $ha^{-1}y^{-1}$)
$M_{tree}(t)$	total living tree biomass at time t (kg DW)
N_{trees}	number of living trees (ha^{-1})
F_{carbon}	carbon content of dry mass (kg C kg^{-1} DW)
$F_{mortality}$	mortality (y^{-1})
$V_{Dead\_S,L}$	volume of standing resp. lying dead wood
$TBP_{S,L}$	period for total decay of dead wood, standing and lying
WD_{Dead}	density of dead wood

Forward calculations and scaling up

Following the previous procedure, the carbon fluxes for the recorded inventory years of HOSP and MFV were calculated. For HOSP, we repeated the procedure for the years 1991-1999, assuming that net annual increment (Ic_{Vplot}) and maximal height (S) did not change for the plots during this period. Calculated changes in other variables (e.g. growing stock volume, decreasing tree numbers due to thinning, dead wood) were taken into account for the next year's calculations.

If any necessary data were missing for a plot, or the data showed large inconsistencies, the plot was discarded from the data set. To derive a national total, the representative area of each plot was used. These are given by the inventory data and varied between less than 0.5 ha to almost 730 ha. These representative areas were multiplied with the net flux of the respective valid plots and total net fluxes were summed and divided by the total representative area of valid plots. This average national flux per hectare was multiplied with the total area of forests in The Netherlands to obtain the national net carbon flux in forests remaining forests.

4.2 Carbon balance of living biomass when land use changes

During land use changes large pulses of emissions can occur. Then afterwards, the total carbon system and especially soils adapt to the new situation where there may be less or more litter input to the soil then in the previous situation. The IPCC (2003) gives a default period of 20 years for the soil to reach an equilibrium again with the litter input. However, IPCC also notes that this is a relatively short period, but chosen because of its practicability.

Here we follow a static approach to quantify the carbon implications of land use changes. Non-CO_2 emissions are assumed negligible. The static approach implies that at the time of e.g. deforestation it is assumed that the total carbon stock in living biomass is lost in the same year. Always the Dutch average forest biomass carbon stock is used (on average 71 Mg C ha^{-1}), as the sampling density of the national inventory was not dense enough to assess the carbon stock of the actual deforested lot.

For afforestations it is assumed that half of the carbon uptake factor applies as was found on average for the existing forest. This was the only reasonable assumption as specific data of each afforested lot were not available. In the future more specific data for each afforest lot will become available through the registration at the 'Groenfonds'.

For soil carbon stock changes after land use change it is assumed that the average carbon stock in the soil under the new and old land use are the same (De Groot et al. 2003).The soils database was not geographically explicit enough to accurately derive the soil carbon stock at the specific site where the land use change took place. Furthermore, accurate information on soil C changes after land use change was lacking for the Netherlands. Therefore it was simply assumed that the soil C stock stays the same. For the total area of a land use type as a whole however, the total stock under this land use can change in time, because of area changes.

4.3 CH4, N2O and other GHG's balance in forest remaining forest

N_2O

N_2O emissions occur through a variety of nitrogen related processes in forest soils (Lindner et al. 2004). They are further modified through N deposition, fertilization and other human induced forest management acts. Table 4.3. gives an overview of some measurements. The variety in N_2O emissions is large, both in time and space.

Table 4.3. Compilation of published N_2O-emission rates from soils of temperate forest ecosystems, aggregated into forest types from Papen and Butterbach-Bahl (1999)

	Mean annual fluxes (kg N_2O-N ha^{-1} yr^{-1})	Short-term fluxes (μg N_2O-N m^{-2} h^{-1})
Spruce	+0.1 – +2.2	-3 – +70
Douglas Fir	+0.1 – +0.7	-1 – +50
Pine	+0.01 – +0.4	-1 – +53
Beech	+0.4 – +7.8	-8 – +550
Mixed, Oak-Beech, etc.	+0.02 – +0.9	-4 – +92

Taking into account that approximately 40% of the Dutch forests consists of Scots pine, 10% spruce, 10% Douglas fir. 20% beech and the rest may resemble the mixed oak beech forest of the table 4.3 above, we come to an average N_2O-N emission for the Dutch forests of 0.229 kg N_2O-N ha^{-1} y^{-1}. This totals an emission of 82584 kg N_2O-N [4] y^{-1} or 25.6 kton CO_2 eq.

CH_4

It is widely believed that well aerated forest soils are significant sinks for atmospheric CH_4 whereas water saturated forest soils such as gley soils, riparian forest soils or forested bogs and fens can also be significant sources of CH_4 (IPCC 2003, Lindner et al. 2004). Although Lindner et al (2004) provide a European average sink of methane of -0.2 kg CH_4 ha^{-1} y^{-1}, the uncertainty around this mean is too large to give an estimate for Dutch forest with any certainty.

Other GHG's

Since forest fires are limited to approximately 200 ha per year (UN-ECE/FAO 2000) in The Netherlands, it was assumed that CO, NOx, and VOC emissions are negligible.

4.4 Biomass data for other nature terrains

Other nature terrains in The Netherlands consist mainly of trees outside the forest, heathland, inland sand dunes, coastal dunes, swamp and peat areas. It is assumed that in all of these terrains the living biomass carbon stock does not change. For heathland an average carbon stock in living biomass of some 8 tonne C ha^{-1} is reasonable. For swamp and peat areas we only assess the carbon stock in the soil organic matter following Kuikman et al. (2003).

For trees outside the forest, permanent crops, vineyards, orchards etc we follow the previous National Inventory Reports (NIR) where a change in stock was assumed to occur only if an area change occurs. We thus merely copy the results of these NIR report.

4.5 Wood products

For wood products it is assumed that they decompose in the same year as harvesting, i.e. not net build up of carbon in wood products in use is assumed. Neither is import or export of products taken into account.

[4] GWP of N_2O = 310

5 Methods and data for soil carbon stock changes

5.1. Forest remaining forest

Kuikman et al. (2003) give available databases and comes up with a geographically explicit soil C map for the Netherlands overlain on the LGN3 land use map. In addition the soil analysis database of Van den Burg (1999) was investigated. This database holds soil organic matter content data for 50,000 measurements from soil samples taken between 1950 and 1990 from mostly the mineral soil of 0 – 30 cm depth. The locations were not geographically explicit available, nor were the soil bulk densities. This complicated the analyses, and had to be aborted as a workable option. ICP litter and mineral soil data were used by Kuikman et al (2003) and were therefore already incorporated in their analysis.

Another option to dynamically model the living biomass dynamics with soil organic matter dynamics (e.g. with CO2FIX for every MFV plot) had to be aborted because of data constraints as e.g. the soil carbon stock at each MFV plot. Therefore we fully rely and only copy here the results of Kuikman et al (2003) for soil organic carbon, and use the equations by Van den Burg (1999) to assess litter carbon stocks for each MFV plot.

We assume that carbon stocks of soil organic carbon in mineral soil and in litter do not change over the time period analysed here. Therefore, for land uses that remain the same we only give a stock assessment of soil organic carbon that is actually a copy of Kuikman et al. (2003). For litter we applied the equations as given by Van den Burg (1999) to the MFV plots. This gives a litter C stock assessment as visualized in Figure 5.1.

For losses of carbon from drained peatlands, Kuikman et al (2003) give a national total of 4.8 – 7 million tonnes CO_2 per year. However, they acknowledge that this is a rough estimate only, where by far most of the emissions occur in peat soils in agricultural use. Even the available estimate of peat soil area vary between 294,000 and 450,000 ha. These differences are partly caused by methodological problems, but also by actual changes in area of peat soils through time. Pleijter (2004) showed that in a case area, the area of peat soils decreased by 47% between 1980 and 2003. Given these uncertainties, and the fact that only 5.8% of the forests is situated on peat soils, we do not estimate the loss of carbon from drained peatland soils.

5.1 Other land uses converted to and from forest

For soil C stock changes due to land use changes De Groot et al (2005) combined the land use changes map as derived here (chapter 3) with the soil C map of Kuikman et al. (2003). For assessing new carbon stocks in relation to land use it was assumed that all of the carbon is transferred to the new land use. Over the time frame studied here, it was furthermore assumed that the soil C does not reach a new equilibrium in relation to the new land use. Thus, the stock at the site stays the same; only per land use the total stock may change, because of area changes. Results are given in chapter 6.

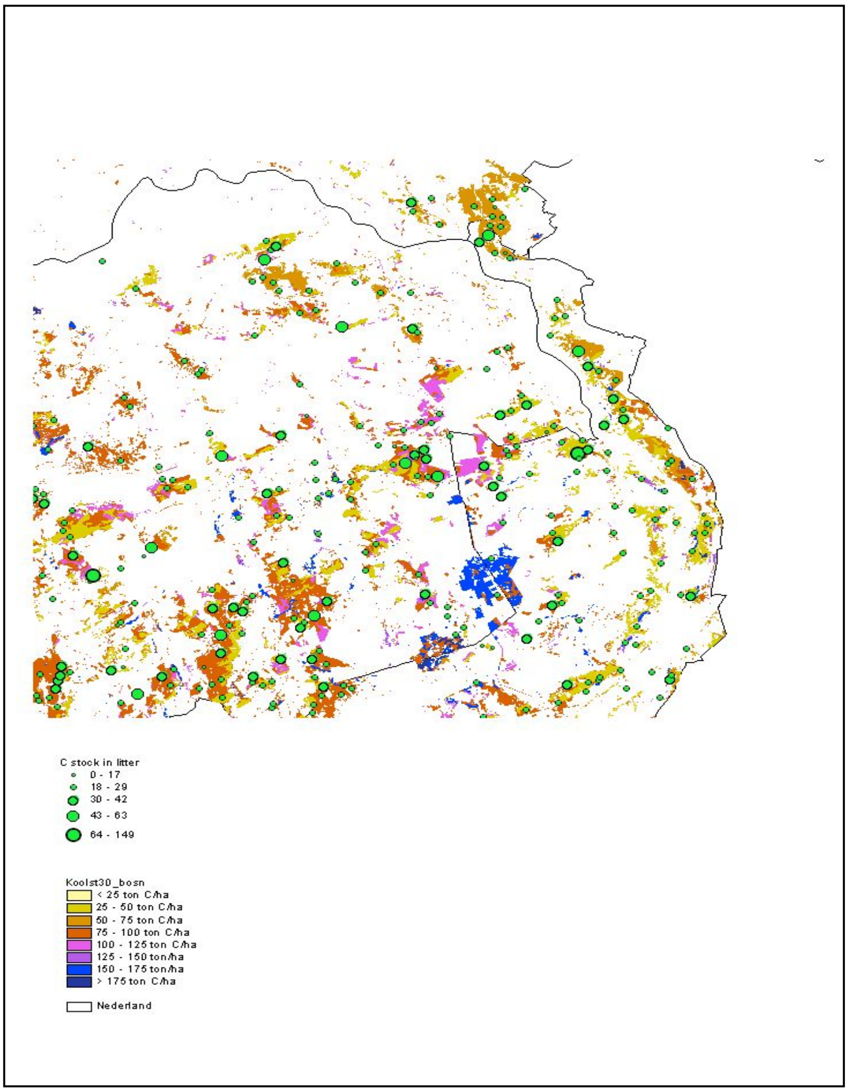

Figure 5.1. Section of the soil organic carbon map (polygons from Kuikman et al. 2003) with estimates of the litter layer carbon stock indicated by dots for each inventory plot. The latter are derived from equations given by Van den Burg (1999). The area is the same as depicted in Figure 3.2.

6 Results for the forest sector carbon balance 1990 - 2002

6.1 Forest remaining forest

A mere visualization of sources and sinks (NBP) per MFV plot for 2000 is given in Figure 6.1. A strong variation in space is clearly visible. This variation in space is also translated into a strong variation between years per plot. Where a harvest takes place in one year, a regrowth will occur the next year. The strongest sink (trees, dead wood and harvesting taken into account) amounted to -3.7 tonne C y^{-1}, and the strongest source amounted to 7.1 tonne C y^{-1}. Overall national results are given in Figure 6.2.

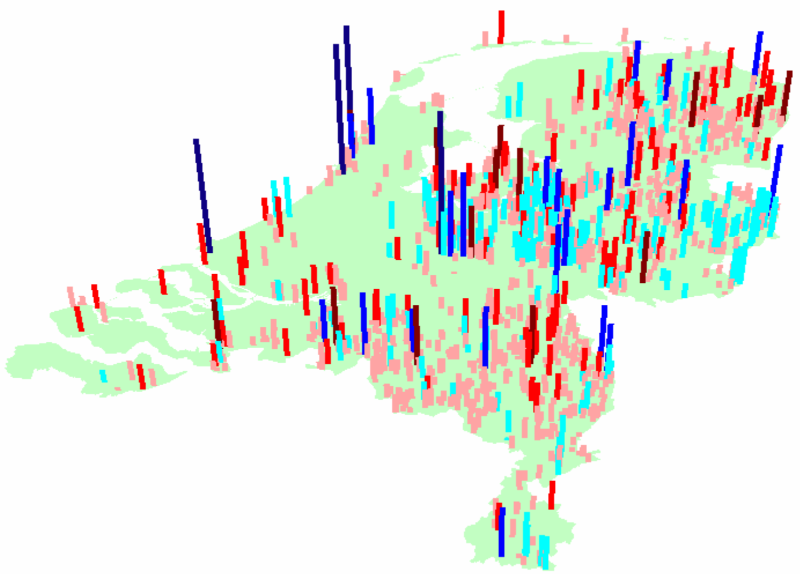

Figure 6.1. Net flux (NBP) as assessed for each MFV data point for the whole of the Netherlands (blue = source due to harvesting, red = sink). This 3D map is a mere visualization of the spatial distribution of sinks and sources

The results for 'forest remaining forest' show a very stable sink in the Dutch forest (Fig 6.2). The average sink from growth of live trees lies around -3.9 million tonnes CO_2 with a variation of 65 ktonne.

Figure 6.2. Temporal development of the sink in live trees and the emissions from harvesting

Harvesting fluctuates a bit more, but gives an average emission of 2 million tons CO_2 with a variation of 134 kton.

6.2 Land use changes

The land use change matrix with gross transitions between classes is given in Table 6.1 for 1990-2000. The net changes in land use are summarised in Table 6.2. The calculations of emissions and sinks have been carried out with the gross changes as given in Table 6.1. The tables show that in The Netherlands land use changes are significant. In total 642,000 ha have changed in land use between 1990 and 2000; which is 15% of the land ! One third of these changes are between cropland and grassland, whereby grassland loses a net 113,000 ha. However, also concerning forests, the changes are quite large: The Netherlands deforests annually 2504 ha (0.7% y^{-1}), and afforests 3124 ha. Figures 6.3. and 6.4 give regional examples that depict these changes. See chapter 7 for a discussion of these results concerning area change and appendix 2 for a validation in the field.

Table 6.1. Land use change matrix 1990 – 2000 between 9 main classes (in ha or ha/10 year). Horizontal summation gives the total land use area per class for 2000. It says for example that from 1990 to 2000, 10310 ha of forest were changed into grassland, and 10588 were changed from grassland into forest. All grayish marked cells are land use changes for which the soil C changes are assessed in the current report (Figure 6.6.). All encircled cells are land use changes that have to do with deforestation and afforestation and for which the carbon balance of biomass is presented in Figure 6.5.

in ha or ha/10 year	Grassland	Cropland	Heather/ peat	Forest	Settlement and roads	Water	Reed swamp	Sand/dunes	Trees outside the forest	
Grassland	1,166,930	158,174	828	10,310	26,971	6,990	2,070	1,287	3,131	1,376,690
Cropland	207,172	759,056	67	1,274	5,261	924	16	14	422	974,205
Heather/peat	854	671	43,193	2,898	280	272	19	647	152	48,986
Forest	10,588	10,356	4,906	334,821	4,125	620	87	555	2,254	368,313
Settlement and roads	91,131	43,681	363	9,013	387,622	3,484	81	590	4,164	540,129
Water	8,623	3,500	657	946	2,603	764,383	540	2,232	228	783,711
Sand/dunes	686	153	301	604	264	2,111	16	33,383	111	37,626
Trees outside the forest	3,821	1,584	226	3,130	2,168	302	22	101	11,460	22,813
	1,489,805	977,176	50,539	362,994	429,293	779,085	2,850	38,808	21,923	**4,152,473**

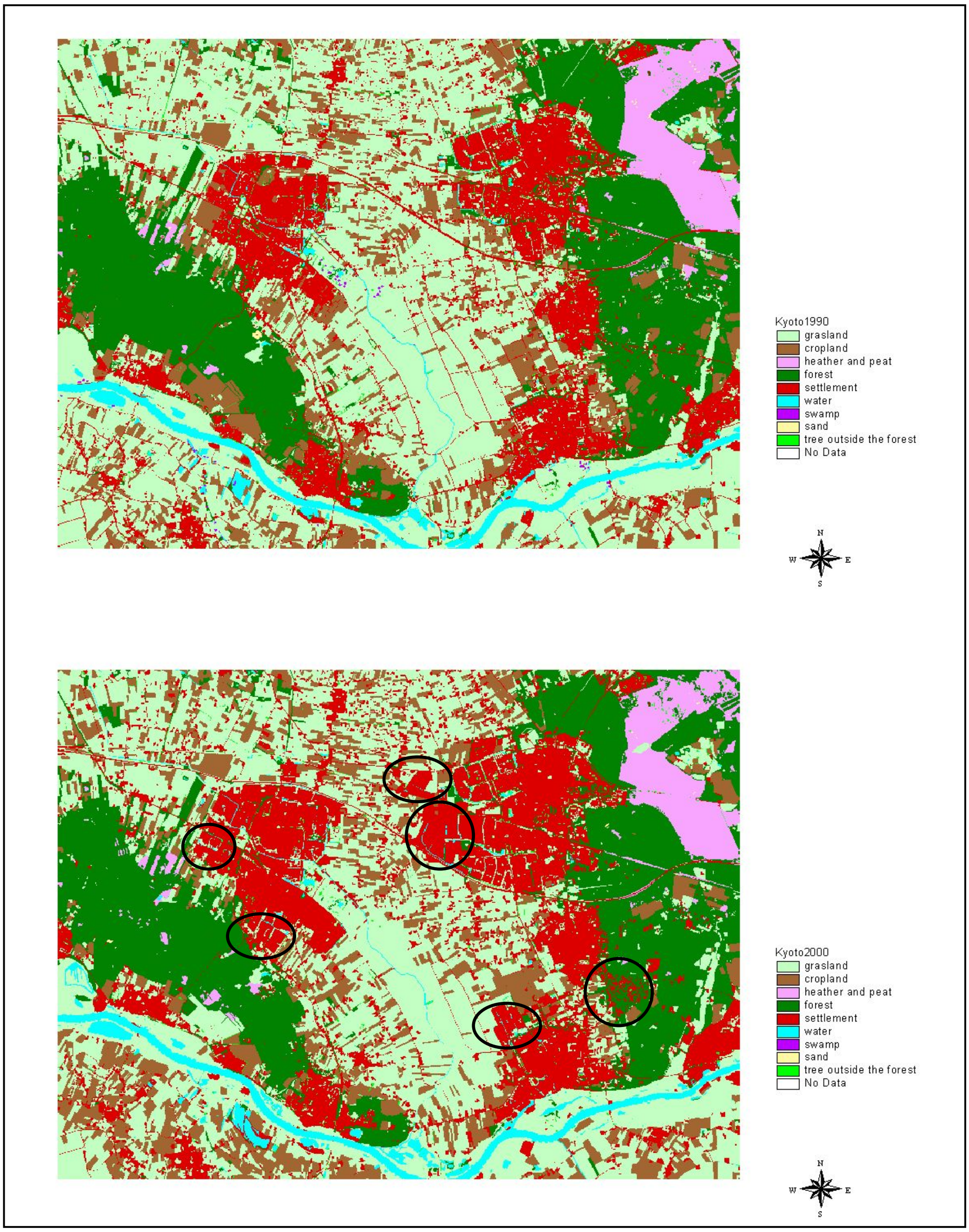

Figure 6.3. Example of the HGN land use pattern in 1990 (top) and 2000 (bottom). See for the location in the Netherlands the square in figure 2.2. Large settlement expansions (circles) are visible as well as a scattered increase of cropland at the expense of grassland

Table 6.2. *Net changes per 10 years in land use resulting from the gross changes as given in Table 6.1.*

	Ha	Ha	Difference
	1990	2000	Ha/ 10 year
Grassland	1,489,800	1,376,690	-113,110
Cropland	977,200	974,204	-2,995
Heather and peat	50,500	48,985	-1,514
Forest	363,000	368,312	5,313
Settlement	429,300	540,128	110,829
Water	779,100	783,711	4,611
Sand	38,800	37,626	-1,174
Trees outside the forest	21,900	22,813	913

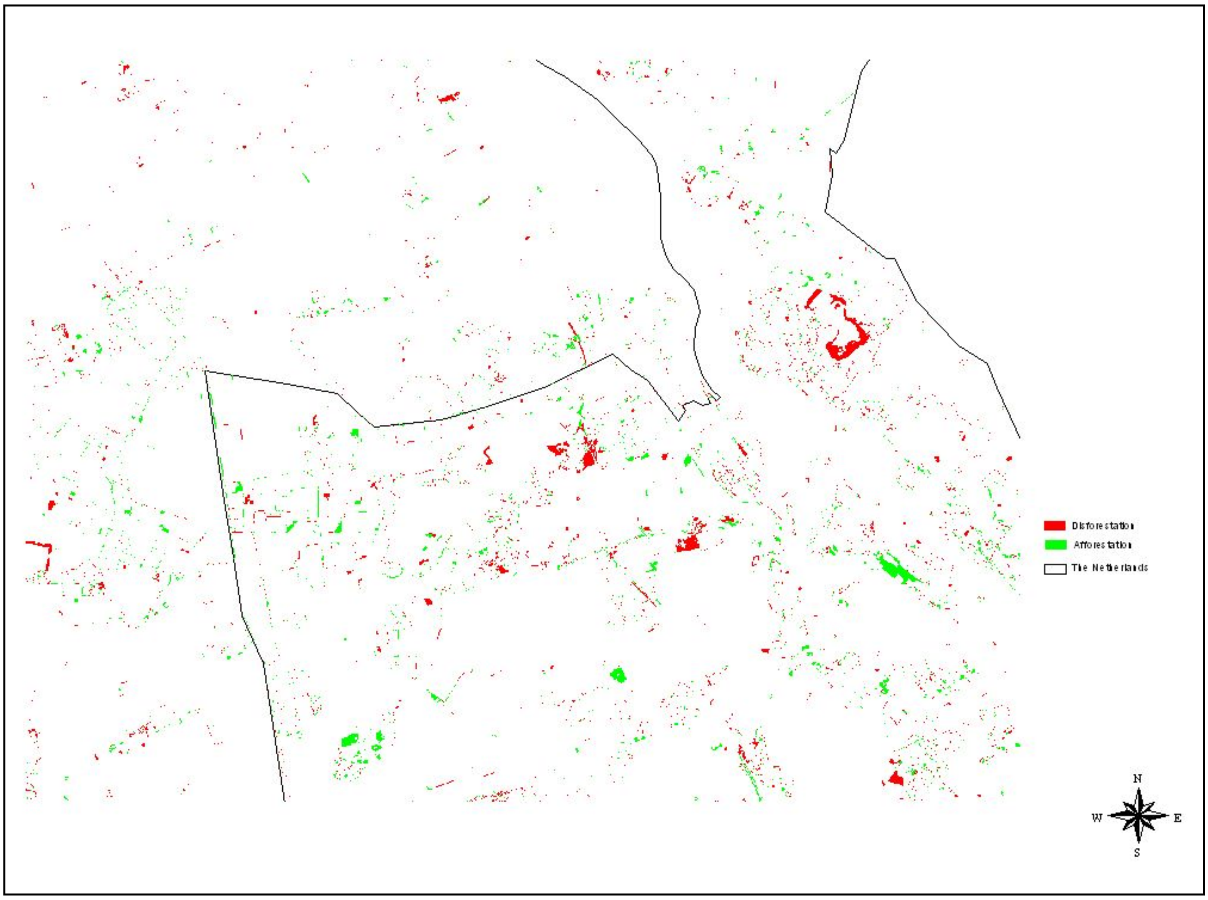

Figure 6.4. Deforestation and afforestation in the area of Figure 3.2 for 1990 – 2000 (red: deforestation, green: afforestation). See for the location in the Netherlands the circle in figure 2.2. A finely scattered pattern of afforestation and deforestation is visible

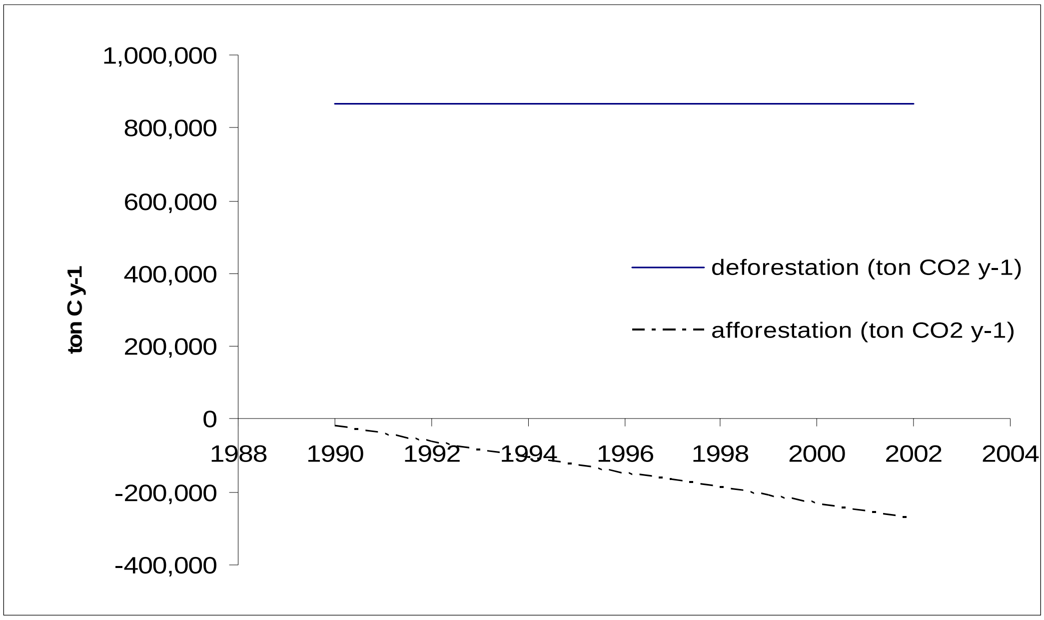

Figure 6.5. Living biomass balance of the deforestation and afforestation since 1990. Trends as derived from the land use change matrix up to 2000, were linearly extrapolated to 2002

By combining standing biomass estimates with deforested area, the emission as given in Figure 6.5. was derived. Deforestation in the Netherlands leads to an annual emission of 865 kton CO_2 y^{-1}. Deforestation led in total over the thirteen years of 1990 – 2002 to an emission of 11.2 million ton CO_2. The sink due to afforestation gradually increases as the area of afforestation increases, and led in total over 1990 – 2002 to a sink of 1.9 million tonne CO2.

6.3 Soil C stock changes under land use changes

Regarding the forest and other nature terrains only, and using the methods as given in section 5.2, we derived that the total soil C stock under forest and nature terrains will increase with 18.3 kton CO2 y^{-1}. This is not a real sink, only an allocation of soil C to the new land use. Forest area increases, so the total C stock under forest increases (De Groot and Kuikman in prep).

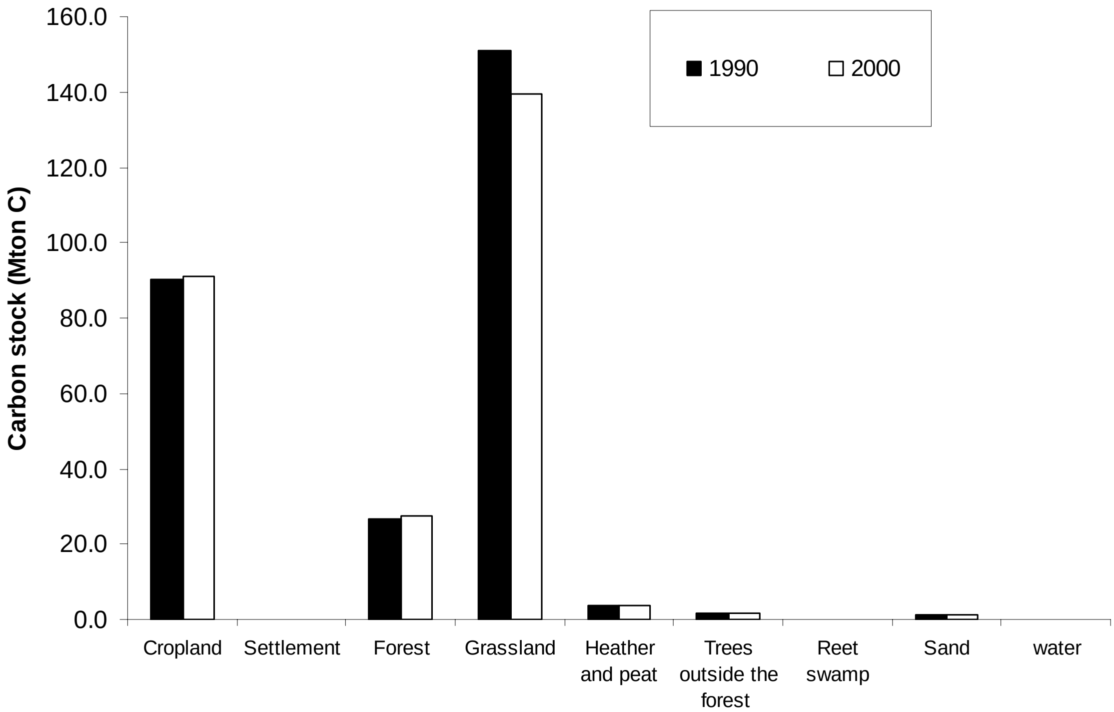

Figure 6.6. Soil C stocks per land use type in 1990 and 2000 as affected by merely land use changes (source De Groot and Kuikman)

An average N_2O-N emission for the Dutch forests of 0.229 kg N_2O-N ha^{-1} y^{-1} was derived from literature. This totals an emission of 82584 kg N_2O-N [5] y^{-1} or 25.6 kton CO_2 eq.

6.4 Other nature terrains and trees outside the forest

Merely the NIR 2004 was copied. No new methods were employed for the other nature terrains and trees outside forests. However, the estimate for the stock assessment of trees outside the forest might be different from the previous NIR reports, as the area estimate differs now (22 kha now versus 10 kha). No new estimate was made, as the uncertainty is too high, and as a mere stock assessment is not required.

[5] GWP of N_2O = 310

Table 6.3. NIR submission of 2002 for line plantations, orchards, and trees outside the forest (Klein Goldewijk et al. 2004)

	Area kha	Annual growth rate t dm/ha	Carbon uptake factor t C/ha	Carbon uptake increment (Gg C)
Non-Forest Trees *(specify type)*				57
forests<0.5 ha, coniferous	5	NA	IE	IE
forests<0,5 ha, broadleaved	5	NA	IE	IE
line plantations	66	NA	IE	IE
solitaires	2	NA	IE	IE
orchards	22	NA	IE	IE
nurseries	7	NA	IE	IE
total	**107**	NA	0.53	**57**

The previous NIR thus gave an uptake of 57 Gg C *44/12 = 209 kton CO_2 per year.

6.5 Total balance

Table 6.4. Overall results for carbon stock change estimates by category (negative is a sink) ton CO_2 y^{-1}

Year	Live trees	Dead wood	Harvest	Deforestation	Afforestation	soil C changes due to LUC	Trees outside the forest and line plantations	N2O
1990	-4,072,913	-333,588	2,110,171	865,644	-21,073	-18,333	-209,000	25,600
1991	-4,030,376	-334,122	2,027,655	865,644	-42,147	-18,333	-209,000	25,600
1992	-3,993,835	-334,809	1,895,420	865,644	-63,221	-18,333	-209,000	25,600
1993	-3,961,909	-335,862	1,853,943	865,644	-84,295	-18,333	-209,000	25,600
1994	-3,934,917	-336,934	1,875,658	865,644	-105,369	-18,333	-209,000	25,600
1995	-3,912,207	-337,789	1,901,291	865,644	-126,443	-18,333	-209,000	25,600
1996	-3,892,729	-338,434	1,910,902	865,644	-147,516	-18,333	-209,000	25,600
1997	-3,875,796	-338,947	2,088,959	865,644	-168,590	-18,333	-209,000	25,600
1998	-3,862,824	-338,676	1,995,018	865,644	-189,664	-18,333	-209,000	25,600
1999	-3,851,427	-338,733	2,017,830	865,644	-210,738	-18,333	-209,000	25,600
2000	-3,958,681	-335,507	2,213,834	865,644	-231,812	-18,333	-209,000	25,600
2001	-3,958,681	-335,507	2,213,834	865,644	-252,886	-18,333	-209,000	25,600
2002	-3,958,681	-335,507	2,213,834	865,644	-273,960	-18,333	-209,000	25,600

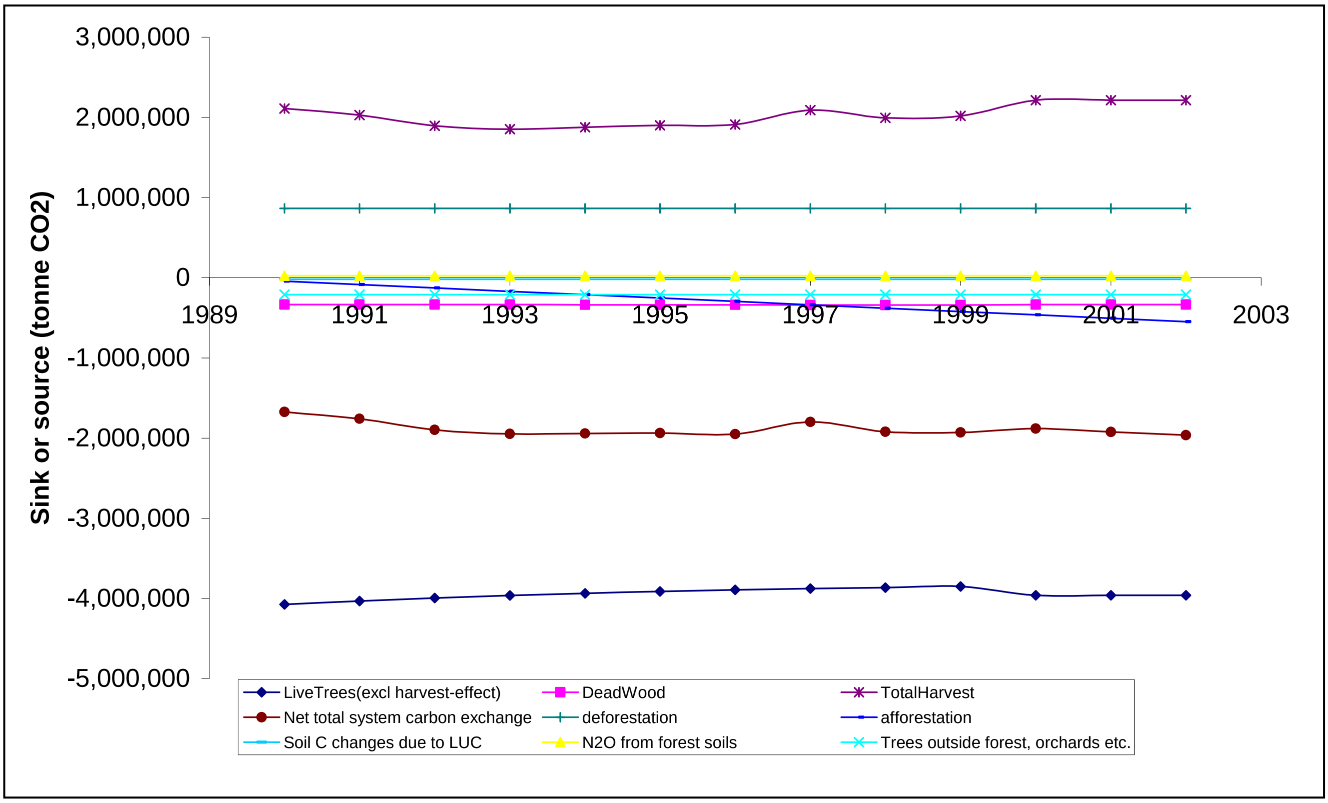

Figure 6.7. Temporal development of the components of the forest and other nature terrains carbon balance

The net sink of the forest and other nature terrains balance is very stable around an average of 1.74 million ton of CO_2 per year with a variation of 88 kton. The sink is to a large extent determined by the growth of forest remaining forest, and the harvest taking place in there. Newly added processes in this new National System are significant as well, but they compensate each other. The sources from deforestation and N_2O emissions (around 900 kton CO_2) are for two thirds compensated by the sinks from afforestation, dead wood, soil C changes, and trees outside forest.

7 Discussion and Conclusions

The current National System is a significant expansion of the previous reporting done by The Netherlands. Now, all pools and processes are followed for all forest and other nature terrains (Table 7.1).

*Table 7.1. Overview of methods and approaches per pool in the National System Forests. Uncertainty is estimated by classes: *: 0-10% standard deviation, **: 10- 30%, ***: 30-70%, ****: 70- >100%*

Land use	Pool or gas	Assessment	Uncertainty
Forest remaining forest			
	Living biomass in forest	Dynamically assessed and forward calculated	*
	Dead wood in forest	Dynamically assessed and forward calculated	**
	Litter	Only stock assessed; Assumed stock change does not occur	***
	Soil organic carbon	Only stock assessed; Assumed stock change does not occur, or in case of drained peats is too uncertain	***
	Wood products	Assumed stock change does not occur	**
	Non CO_2: Methane and Nitrous oxide	Nitrous oxide: Estimated from literature. Methane assumed negligible and too uncertain	***
	Non CO_2: CO, VOC, and NOx	Assumed negligible	****
	Living biomass other nature terrains	Assumed that stock only changes by area changes; copied from old NIR system	***
Other land uses changing to and from forest			
	Area change	Derived from two topographical maps	**
	Living biomass	Calculated based on average stock loss and average sink per hectare in existing forest for linearly interpolated land use changes	**
	Dead wood	Assumed stock changes are negligible	***
	Litter	Assumed stock changes are negligible	***
	Soil organic carbon	Stock change calculated based on area changes for linearly interpolated land use changes per land use type	***
	Wood products	Assumed stock change does not occur	***
	Non CO_2: Methane and Nitrous oxide	Assumed negligible	****
	Non CO_2: CO, VOC, and NOx	Assumed negligible	****
	Living biomass other nature terrains	Assumed that stock only changes by area changes; copied from old NIR system	***

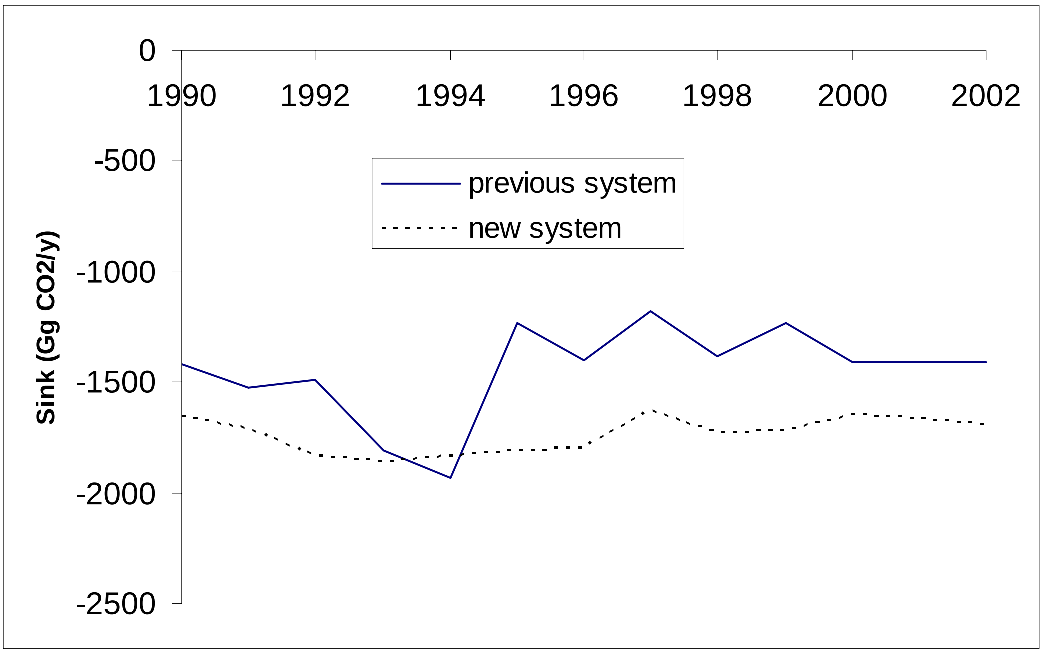

Figure 7.1. Comparison of the net sink estimate for category 5 for the Netherlands under the new system versus the old system

The uncertainty in the current system estimate was not formally assessed, but only estimated (Table 7.1). Largest uncertainty under 'forest remaining forest' occurs in the soil and litter pools, the non-CO_2 gases, and in the biomass of other nature terrains. Under the 'Other land uses changing to and from forest' practically all pools are estimated to show large uncertainty. Important for this compartment are the land use changes themselves. They were found to be very large (a deforestation of 2500 ha per year, and afforestation of 3100 ha per year); much larger than previously thought. On the one had this is not so strange; The Netherlands went through a fast economic growth in the 1990's, and large industrial and residential areas were build. Furthermore, we know that for farmers a rotational use of the land in grassland for a couple of years and then cropland for a coupe of years is normal. Therefore the large area changes between grassland and cropland are plausible as well, and may even be underestimations, because the rotation change may have taken place twice in the 10 year. However, some land use changes are more unlikely to take place, e.g. the 10,310 ha changing from forest to grassland, the 26,971 ha changing from settlement to grassland and the 4125 ha changing from settlement to forest. These are conversions that are not likely to take place, and could be the result of small methodological differences in drawing the hard copy topographical maps or a shift of grid cells. This, as well as the very fine pattern of deforestation and afforestation (Figure 6.4) are reason for concern and will be part of the validation of the HGN maps. However, where Annex I countries have looked at their gross changes of land use (not only the net afforestation), then a deforestation is found more often (Levy and Milne 2004)

Validation of the maps can be thought of in various ways: 1 is to simply visually check the maps and the land use changes with the hard copy version of the topographical maps; 2) is a validation in the field. The latter has been done

preliminary, by overlaying the grid cells of the HGN map with the field assessment of land use (Appendix 2). Out of the 1723 visited forest inventory plots, the HGN map was correct in 84%. I.e. out of all grids where HGN depicted a grid cell as 'forest', it was indeed forest in the field. However, in 2% of the cases there is reason for doubt: these are classified as forest in the HGN map, but are some other type of land use, but with still a possibility that the topographical map has shown some sort of forest vegetation (military, recreational, etc...).
But in another 2% of the cases HGN says a grid cell is forest, but where the field visit says it is clearly something else (settlement, industrial, ..). And in another 4% of the cases where HGN says a grid cell is grass, the field visit says it is clearly forest.

Based on the new system a larger sink was found: on average a sink of 1.74 milllion ton CO_2 was assessed compared to on average 1.4 in the old system. This is an average difference of 21 %. This difference is rather small because several of the processes that were added to the system compensate each other. The sources from deforestation and N_2O emissions (around 900 kton CO2) are for two thirds compensated by the sinks from afforestation, dead wood, soil C changes, and trees outside forest. Figure 7.1. shows the total results of the old system compared to the new one. The sink under the new system is larger and more stable. How this system will evolve in coming years will very much depend on harvesting levels.

Table 7.2. Comparison of estimates for the Dutch forestry sector C balance

	Flux (Million tonnes CO_2 y^{-1}) (negative is sink)	reference
New system	-1.74	Current report
Old system (reporting to UNFCCC)	-1.41	Klein Goldewijk et al. 2004
Reporting to UN-ECE	-1.47	UN-ECE/FAO 2000
Static bookkeeping of forest biomass	-1.21	Nabuurs & Mohren 1993.
Whole biosphere (cropland, grassland, peat, forests)	23.8	Janssens et al. 2004.
Dynamic forestry sector model (net sector exchange)	-1.5	Karjalainen et al. 2004

From Table 7.2. it appears that most estimates for the Dutch forestry sector are rather close to each other. With exception of the Janssens et al. paper, the highest estimate is 55% higher than the lowest. Janssens et al came up with a totally different number for the total Dutch biosphere because of large sources they found for cropland and drained peatlands (not included here). All other differences between the estimates of Table 7.2 can be explained from differences in pools included or methodological differences.

The new Dutch system results are in line with other submissions of the EU countries. In the past most countries only reported the carbon stock change in forest biomass and found a sink in category 5. However, those that do a reasonable assessment of their soils now, often show a large source for soils. This is the case for

France, Great Britain, Germany, Hungary, Italy, and Sweden. Only in the case of Poland and Slovak Republic, the soils appear to be a sink.

Improvements in the current system can be thought of. These may be:

- improvement in soil organic carbon and litter data
- improved ways for interpolating and projecting: the connection between CO2FIX and each MFV plot can be thought of.
- For Kyoto lands an improved and more accurate reporting will be needed: local data from Groenfonds registration can be thought of
- Formal QA/QC assessments will have to be made
- Sensitivity and uncertainty assessments need to be made, as well as validation of the land use changes

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Appendix 1. Equations used to derive total tree biomass

A range of allometric equations were available for most, but not for all, tree species or species groups. We only considered allometric equations developed in Europe, which calculate aboveground or belowground biomass based on either stem diameter, stem height or a combination of both. For those species or species groups where several equations were available, the equations were validated with biomass data from the database of van Hees et al (pers. comm.). Equations with the lowest sum of squares were selected. For species for which no such allometric equations were available for Europe, equations of another species were used. For species (groups) with no proper allometric equations available in Europe, we selected the allometric equations of other species for which their BEF's, according to Garcia et al. (2004), were closest in value to those of the species (groups) with no available allometric relations.

Table 1 Allometric equations used to calculate aboveground biomass from inventory data

Species group	Equation	Developed for	Country	Reference
Acer spp	$0.00029*D^{2.50038}$	Betula pubescens	Sweden	Johansson 1999a
Alnus spp	$0.00309*D^{2.022126}$	Alnus glutinosa	Sweden	Johansson 1999b
Betula spp	$0.00029*D^{2.50038}$	Betula pubescens	Sweden	Johansson 1999a
Fagus sylvatica	$0.0798*D^{2.601}$	Fagus sylvatica	The Netherlands	Bartelink 1997
Fraxinus excelsior	$0.41354*D^{2.14}$	Quercus robur & Quercus petraea	Austria	Hochbichler 2002
Larix spp	$0.0533*(D^2*H)^{0.8955}$	Picea abies	European Russia	Hamburg et al. 1997
Picea spp	$0.0533*(D^2*H)^{0.8955}$	Picea abies	European Russia	Hamburg et al. 1997
Pinus other	$0.0217*(D^2*H)^{0.9817}$	Pinus sylvestris	European Russia	Hamburg et al. 1997
Pinus sylvestris	$0.0217*(D^2*H)^{0.9817}$	Pinus sylvestris	European Russia	Hamburg et al. 1997
Populus spp	$0.0208*(D^2*H)^{0.9856}$	Populus tremula	European Russia	Hamburg et al. 1997
Pseudotsuga menziesii	$0.111*D^{2.397}$	Pseudotsuga menziesii	The Netherlands	Van Hees 2001
Quercus spp	$0.41354*D^{2.14}$	Quercus robur & Quercus petraea	Austria	Hochbichler 2002
Coniferous other	$0.0533*(D^2*H)^{0.8955}$	Picea abies	European Russia	Hamburg et al. 1997
Broadleaved other	$0.41354*D^{2.14}$	Quercus robur & Quercus petraea	Austria	Hochbichler 2002

Table 2 Allometric equations used to calculate belowground biomass from inventory data

Species group	Equation	Species	Country	Reference
Acer spp	$0.0607*D^{2.6748}*H^{-0.561}$	Betula pubescens	European Russia	Hamburg et al. 1997
Alnus spp	$0.0607*D^{2.6748}*H^{-0.561}$	Betula pubescens	European Russia	Hamburg et al. 1997
Betula spp	$0.0607*D^{2.6748}*H^{-0.561}$	Betula pubescens	European Russia	Hamburg et al. 1997
Fagus sylvatica	-3.8219*2.5382*ln(D)	Fagus sylvatica	France	Le Goff & Ottorini 2001
Fraxinus excelsior	$-1.551*0.099*D^2$	Quercus petraea	France	Drexhage et al. 1999
Larix spp	$0.0239*(D^2*H)^{0.8408}$	Picea abies	European Russia	Hamburg et al., 1997
Picea spp	$0.0239*(D^2*H)^{0.8408}$	Picea abies	European Russia	Hamburg et al., 1997
Pinus other	$0.0144*(D^2*H)^{0.8569}$	Pinus sylvestris	European Russia	Hamburg et al., 1997
Pinus sylvestris	$0.0144*(D^2*H)^{0.8569}$	Pinus sylvestris	European Russia	Hamburg et al., 1997
Populus spp	$0.0145*(D^2*H)^{0.8749}$	Populus tremula	European Russia	Hamburg et al., 1997
Pseudotsuga menziesii	$0.0239*(D^2*H)^{0.8408}$	Picea abies	European Russia	Hamburg et al., 1997
Quercus spp	$-1.551*0.099*D^2$	Quercus petraea	France	Drexhage et al. 1999
Coniferous other	$0.0239*(D^2*H)^{0.8408}$	Picea abies	European Russia	Hamburg et al., 1997
Broadleaved other	$-1.551*0.099*D^2$	Quercus petraea	France	Drexhage et al. 1999

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Appendix 2. Validation of the land use map through field visited forest inventory plots

To derive a first validation of the HGN land use map for 2000, the 1723 visited MFV forest inventory plots were overlain on the HGN map. The land use of these 1723 plots according to the field visit is given in the column, the land use according to the HGN map is given in the row.
Yellow marked are those plots that are classified as forest in the HGN map, and are truly forest in the field (84% correct at a 25x25 m grid). Light shading are those plots that are classified as forest in the HGN map, but are some other type of land use where there is still a possibility that the land use could be under forest (2%). However, this also leaves 2% where HGN says a grid cell is forest, but where the field visit says it is clearly something else (settlement, industrial, ..). This also leaves us with almost 4% where HGN says a grid cell is grass, but where the field visit says it is clearly forest) (dark shading).

	Land use according to HGN map in current study									
	Grassland	Cropland	Heather/peat	Forest	Settlement	Water	Sand	Trees outside forest	total	
Evenaged forest	35	5	5	957	2	1	2	1	1008	Daadwerkelijk bos in het veld
Conversion forestry			1	119					120	
Unevenaged forest	3		3	169	1				176	
Regeneration area				2					2	
Crooked beech tree forest				9			1		10	
Cover forest				9					9	
Estate forest				17	1				18	
Spontaneous forest	4	1	7	47	1		2		62	
Shrub with H < 8 m	1			2					3	
Temporary			1	1					2	
Unmanaged	1			17					18	
Lane	3		1	23	2				29	
Hedgerow	3			3					6	
Lane (2)	2	1		10					13	
Coppice	4			18					22	
Coppice on stems	1			3					4	
Other forest (not recreation)				15	2				17	
Recreation forest	2			15		2		1	20	
Landscape forest	4			26	4				34	
Agriculture	8	1		3	2			4	18	Geen bos in het veld
Settlement	4	1		17	9			1	32	
Industrial area				2	1				3	
roads, railroads	5	1		13	3				22	
Recreation area	7			3	3			1	14	
Permanent rcreation	2			7					9	
Water	1			4		2			7	
Nature area			7	13				1	21	
Sports terrain	4			2				1	7	
Military terrain	1			5			1		7	
Park, cemetary	1			7				1	9	
Landfill	1								1	
Totaal MFV veldwerk '01-'02	**97**	**10**	**25**	**1538**	**31**	**5**	**6**	**11**	**1723**	

Appendix 3. The Dutch NIR 2005 over 1990

Table App 4.1. Summary of sub-sources/sinks in Land-Use Change and Forestry (LUCF) in 1990 (IPCC category 5)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals
	(Gg)		
Total Land-Use Change and Forestry	**8,115.13**	**-5,220.93**	**2,894.20**
A. Changes in Forest and Other Woody Biomass Stocks	**2,110.17**	**-4,615.50**	**-2,505.33**
1. Tropical Forests	NO	NO	NO
2. Temperate Forests (1)	2,110.17	-4,615.50	-2,505.33
3. Boreal Forests	NO	NO	NO
4. Grasslands/Tundra	NO	NO	NO
5. Other	NE	NE	NE
B. Forest and Grassland Conversion (2)	**865.64**		
1. Tropical Forests	NO		
2. Temperate Forests *(Deforestation)*	865.64		
3. Boreal Forests	NO		
4. Grasslands/Tundra	NO		
5. Other	NE		
C. Abandonment of Managed Lands	**0.00**	**-21.07**	**-21.07**
1. Tropical Forests	NO	NO	NO
2. Temperate Forests *(Afforestation)*	NO	-21.07	-21.07
3. Boreal Forests	NO	NO	NO
4. Grasslands/Tundra	NO	NO	NO
5. Other	NE	NE	NE
D. CO_2 Emissions and Removals from Soil	**5139.31**	**-584.36**	**4,554,95**
1. Cultivation of Mineral Soils	NE	NE	NE
2. Cultivation of Organic Soils	4,246.00	NO	4,246.00
3. Liming of Agricultural Soils	183.15	NO	183.15
4. Forest Soils (3)	IE	IE	IE
5. Other (due to change in land use) (4)	710.16	-584.36	125,8
E. Other (6)	**NE**	**NE**	**NE**

(1) Temperate Forests include: forest, trees outside forests and dead wood.

(2) Include only the emissions of CO_2 from Forest and Grassland Conversion. Associated removals are reported under section D.

(3) Forest soils 5D4 is reported under 5D5 Other

(4) Include all emissions from land use and soils carbon stocks not reported under sections A, B and C.

Appendix 4. Forest definition as applied by the Netherlands

(Forest Land is land with woody vegetation and with tree crown cover of more than 20 per cent and area of more than 0,5 ha. The trees should be able to reach a minimum height of 5 m at maturity in situ. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; or of open forest formations with a continuous vegetation cover in which tree crown cover exceeds 20 per cent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 20 per cent or tree height of 5 m are included under forest, as areas normally forming part of the forest area which are temporally unstocked as a result of human intervention or natural causes but which are expected to revert to forest.
Forest Land also includes:
forest nurseries and seed orchards that constitute an integral part of the forest;
forest road, cleared tracts, firebreaks and other small open areas, all smaller than 6 m. within the forest;
forest in national parks, nature reserves and other protected areas such as those of special environmental, scientific, historical, cultural or spiritual interest, with an area of more than 0,5 ha and a width of more than 30m.;
windbreaks and shelterbelts of trees with an area of more than 0,5 ha and a width of more than 30m.;

This excludes tree stands in agricultural production systems for example in fruit plantations and agro forestry systems.

The current report includes reporting of forests under the definition as given above plus trees outside the forest as well as nature trains as heathlands, peats, etc.