Biodiversity and Climate Change Project - BIOCLIME

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Survey of biomass, carbon stocks, biodiversity, and assessment of the historic fire regime for integration into a forest monitoring system in the Districts Musi Rawas, Musi Rawas Utara, Musi Banyuasin and Banyuasin, South Sumatra, Indonesia

Work Package 1 draft report: Quality assessment report of ICRAF historic land cover change dataset

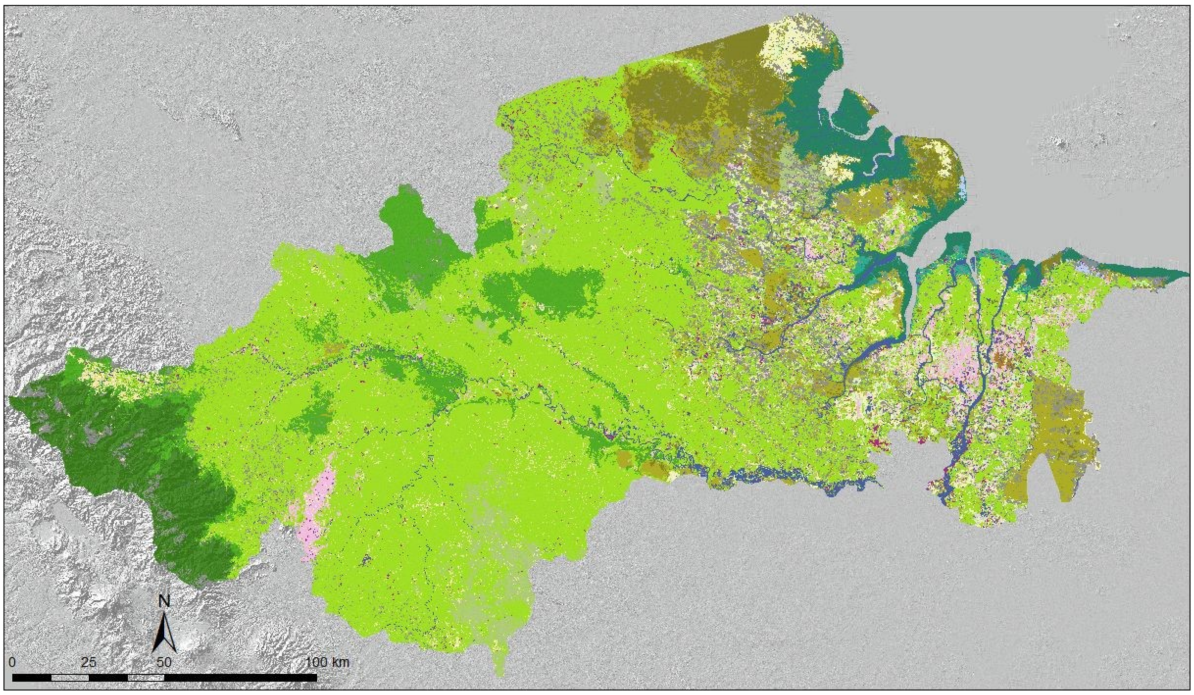

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Table of Contents

1 Introduction ... 3

2 Data used ... 3

3 Methodology ... 3

3.1 Preprocessing of the dataset ... 5

3.2 Assessment of land cover change and carbon emissions ... 8

3.2.1 Land cover change detection methodology ... 8

3.2.2 Carbon calculation for Land cover classes ... 8

3.2.3 Calculation of the deforestation rate for the study area**Error! Bookmark not defined.**

4 Results ... 9

4.1 Land cover classifications ... 9

4.2 Land cover change ... 15

4.3 Deforestation rate ... 19

4.4 Carbon stock maps ... 21

4.5 Carbon stock change ... 24

1 Introduction

With the Biodiversity and Climate Change Project (BIOCLIME), Germany supports Indonesia's efforts to reduce greenhouse gas emissions from the forestry sector, to conserve forest biodiversity of High Value Forest Ecosystems, maintain their Carbon stock storage capacities and to implement sustainable forest management for the benefit of the people. Germany's immediate contribution will focus on supporting the Province of South Sumatra to develop and implement a conservation and management concept to lower emissions from its forests, contributing to the GHG emission reduction goal Indonesia has committed itself until 2020.

One of the important steps to improve land-use planning, forest management and protection of nature is to base the planning and management of natural resources on accurate, reliable and consistent geographic information. In order to generate and analyze this information, a multi-purpose monitoring system is required.

This system will provide a variety of information layers of different temporal and geographic scales:

- Information on actual land-use and the dynamics of land-use changes during the past decades is considered a key component of such a system. For South Sumatra, this data is already available from a previous assessment by the World Agroforestry Center (ICRAF).
- Accurate current information on forest types and forest status, in particular in terms of aboveground biomass, carbon stock and biodiversity, derived from a combination of remote sensing and field techniques.
- Accurate information of the historic fire regime in the study area. Fire is considered one of the key drivers shaping the landscape and influencing land cover change, biodiversity and carbon stocks. This information must be derived from historic satellite imagery.
- Indicators for biodiversity in different forest ecosystems and degradation stages.

This work package report focuses on the first information layer listed above, the information on actual and historic land-use in the four BIOCLIME districts and the dynamics of land use changes in the past decades. The World Agroforestry Center ICRAF produced a historic time series of Land cover and land-use maps in the framework of the project LAMA-I. This dataset is provided by ICRAF for use in the Bioclime project. The present report summarizes the calculation of the historic land cover changes and associated associated carbon emissions in order to contribute to the calculation of reference emission levels (REL).

2 Methodology

Figure 1 shows the workflow applied in this work package. Land cover maps of the five points in time 1990, 2000, 2005, 2010 and 2014 provided by ICRAF in the framework of a collaboration between BIOCLIME and the LAMA-I project were the key dataset used for the analysis (see chapter 2.1). The datasets were put through a comprehensive quality assessment and an improved version was produced by ICRAF in order to address the outcomes of this assessment. Then the data went through a thematic processing which produced a classification translation key into the BAPLAN classification scheme, which is used in BIOCLIME. In a next step, a post classification change detection was conducted by overlaying the classification of two consecutive points in time for each change period, as well as for the overall change period 1990 – 2014. The stock difference method was then applied in companion with LiDAR derived

AGB values for the different land cover classes as Emission Factors (EFs) in order to calculate carbon stock and carbon stock change maps. Further, the drivers of deforestation and carbon emissions were analyzed from the change maps.
Based on the historic trends identified in carbon storage a carbon emission baseline was eventually derived.

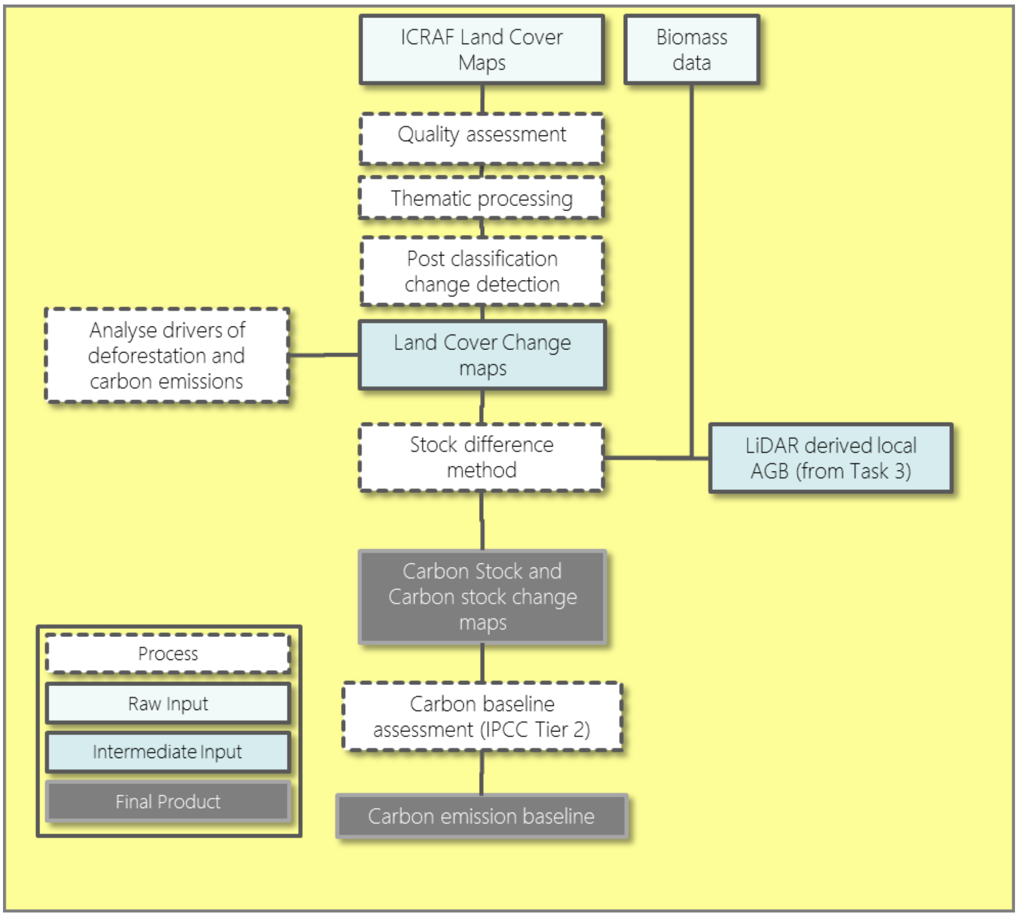

Figure 1: Workflow of the methodology applied in this work package.

2.1 Data used

The assessment is based on the historic land cover data time series in the version 3, as provided by ICRAF via ftp on 30 May 2016. The delivered database contains the following GIS layers. A technical report which documents the methodology and results, and a dedicated report on the results of the accuracy assessment was received together with an earlier version of the dataset (Version 2). Table 1 shows the data available for this work package.

Table 1: Datasets provided by ICRAF

Filename	Type	Format
LC1990_v3_48s.tif	Raster	GeoTIFF
LC2000_v3_48s.tif	Raster	GeoTIFF
LC2005_v3_48s.tif	Raster	GeoTIFF
LC2010_v3_48s.tif	Raster	GeoTIFF
LC2014_v3_48s.tif	Raster	GeoTIFF

GPS_accuracy_all.shp	Point Vector	Shapefile
lc_legend.lyr	Symbology	Layerfile
lc_legend.xlsx	Spreadsheet	MS Excel
Accuracy_Assessment_result.docx	Report	MS Word
Technical report_LAMA-I_TZ_AP_VA_18062015.pdf	Report	PDF

A detailed technical assessment of the Version 2 of the data was conducted and the results are summarized in the internal report "Quality assessment report of ICRAF historic land cover change dataset". The report proved a very high quality of the analysis conducted, however, identified a variety of shortcomings of Version 2. As a consequence, a follow up Version 3 of the data was produced by ICRAF, and all shortcomings adequately addressed. Most importantly, the Version three was now delivered in full Landsat resolution of 30 m which allows the exploitation of the data at maximum spatial scale.

2.2 Preprocessing of the dataset

Before the datasets could be changed for land cover classification, a data preprocessing had to be done in order to assure that the data is in the correct format and all preconditions for a multitemporal use of the data are met. The required processing steps are shown in Figure 2n.

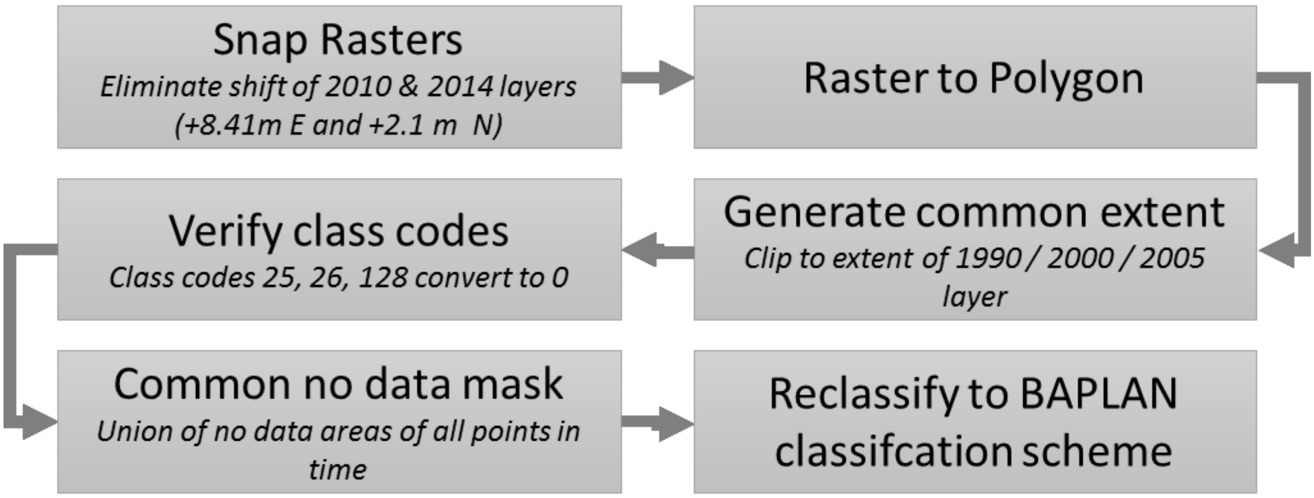

Figure 2: Preprocessing steps.

As a first step, the classification raster GIS files had to be brought into a common spatial grid in order to allow for a multitemporal overlay without spatial offsets between the dataset of the time series. It was found that the data layers of the years 2010 and 2014 have a slight spatial offset of the raster grid of 8.41 m to the East and 2.1 meters to the north. By modifying the map info of the raster layers, i.e. the geographic location of the dataset, a perfect matching of the rasters could be achieved. Figure 3 shows in a schematic way the off-set and the correction of the data.

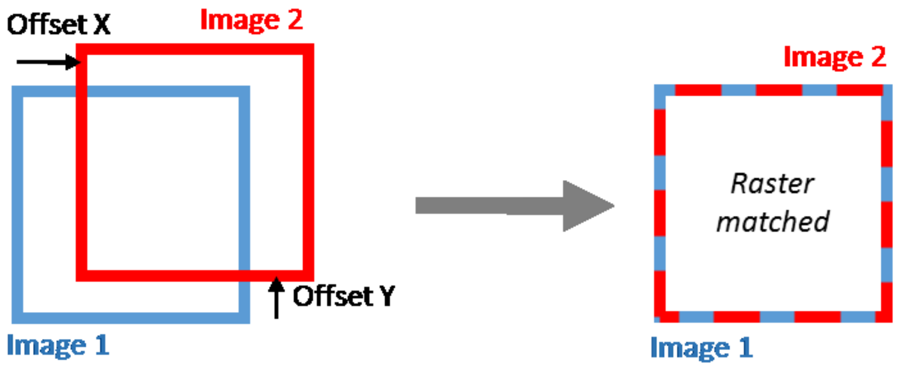

Figure 3: Matching of the rasters of two classification raster files by raster matching. The initial files had a spatial off-set of the pixels of 8.41 m to the East and 2.1 m to the North. The raster snapping allows a perfect spatial matching of the pixels and facilitates that overlaying pixels are in exactly the same location.

The second step is a the conversion of the raster files into polygon vector format. As the RSS change and carbon emission assessment tools are implemented in ArcGIS 10, the ESRI polygon shapefile format was chosen.

As the classification files differed very slightly in spatial extent (which is related to the slight spatial offset described above), the next step is the generation of layers with a common spatial extent. As the 1990, 2000 and 2005 layers were consistent in geolocation and spatial extent, those points in time were used as a reference, and the 2010 and 2014 were processed by the Clip tool in the ArcGIS toolbox.

The next step was the verification of the class codes of the data sets. The classification scheme contains 24 classes and 0 for No Data, however, the dataset also had the codes 25, 26, and 128. These features were all recoded to 0 in order to facilitate consistent class codes through all points in time.

Then, a common no data mask was generated for all points in time and then applied to the data. This step is necessary in order to facilitate a comparability of the maps in terms of spatial extent of the classes and carbon storage and emissions between the change periods from one point in time to another. In order to generate the mask, the No Data areas from each point in time was first extracted, then all No Data areas were merged and finally applied to all classification layers.

The last step in the preprocessing was the conversion of the ICRAF classification scheme to the BAPLAN classification scheme. This was done in order to facilitate the usability of the results of the study by the provincial forest administration for reporting onto the national level. In cooperation with ICRAF, a conversion key between the two classification schemes was designed, which is shown in Figure 4.

ICRAF Code	ICRAF Classification Scheme	Translation	BAPLAN Classification scheme	Indonesian name	Baplan Code
1	Undisturbed forest	↔	Primary dry land forest	Hutan lahan kering primer	2001
2	Logged over forest (High density)	↔	Secondary/ logged over dry land forest	Hutan lahan kering sekunder/ bekas tebangan	2002
3	Logged over forest (Low density)	↔			
4	Undisturbed swamp forest	↔	Primary swawp forest	Hutan rawa primer	2005
6	Undisturbed peat swamp forest				
5	Logged over swamp forest	↔	Secondary/ logged over swamp forest	Hutan rawa sekunder/ bekas tebangan	20051
7	Logged over peat swamp forest				
8	Undisturbed mangrove forest	↔	Primary mangrove forest	Hutan mangrove primer	2004
9	Logged over mangrove forest	↔	Secondary/ logged over mangrove forest	Hutan mangrove sekunder/ bekas tebangan	2007
10	Mixed garden	↔	Mixed dryland agriculture/mixed garden	Pertanian lahan kering campur semak / kebun campur	20092
12	Coffee agroforest				
11	Rubber agroforest				
14	Oil palm monoculture	↔	Tree crop plantation	Perkebunan/ Kebun	2010
15	Rubber monoculture				
16	Coconut monoculture				
13	Acacia plantation	↔	Plantation forest	Hutan tanaman	2006
19	Shrub	↔	Scrub	Semak belukar	2007
17	Rice field	↔	Rice fields	Sawah/ persawahan	20093
18	Annual crops	↔	Dry land agriculture	Pertanian lahan kering	20091
20	Grass	↔	Grass	Rumput	3000
21	Cleared land	↔	Open land	Tanah terbuka	2014
22	Settlement/Built-up area	↔	Settlement/ developed land	Pemukiman/ lahan terbangun	2012
24	Waterbody	↔	Water body	Tubuh air	5001
23	Fish pond	↔	Embankment	Tambak	20094

Figure 4: Conversion key between the ICRAF classification scheme and the BAPLAN classification scheme.

For the use in the RSS carbon modeling procedure, an additional simplified class code for the BAPLAN classes was introduced which is shown in Table 2.

Table 2: Simplified class codes for the BAPLAN classification scheme.

CODE	Class
1	Primary dry land forest
2	Secondary/ logged over dry land forest
3	Primary swawp forest
4	Secondary/ logged over swamp forest
5	Primary mangrove forest
6	Secondary/ logged over mangrove forest
7	Mixed dryland agriculture/mixed garden
8	Tree crop plantation
9	Plantation forest
10	Scrub
11	Rice field
12	Dry land agriculture
13	Grass
14	Open land
15	Settlement/ developed land
16	Water body
17	Embankment

2.3 Assessment of land cover change and carbon emissions

2.3.1 Land cover change detection methodology

To assess changes in biomass and carbon stock the stock difference method based on a post classification change detection method, was applied. **All change analysis, in particular the carbon change assessment and the assessment of net forest loss and deforestation rate, was conducted exclusively on areas which contain no "No data" in any of the classification time steps.** The classification results (land cover map) from two time periods are overlaid and the change vectors (from-to-changes from one class into another) between the two layers were determined.

Based on the biomass values assigned to the individual land cover classes, the change in biomass and carbon stock for each polygon was calculated. The creation of the change layer was done by a proprietary GIS routine, which is linked to a biomass database (see chapter **Error! Reference source not found.**).

Due to the high number of change vectors resulting from the intersection of two classifications (up to 24x24=576 possible change vectors) and the resulting complexity of the change map, coded labels were created that group several change vectors into meaningful classes. The change code table is shown in **Error! Reference source not found.** in the annex.

2.3.2 Carbon calculation for Land cover classes

The carbon values for the different land cover classes have been calculated based on the LiDAR AGB model developed in WP 3 and the procedure for the establishment of the carbon values is described in detail in the Work package report.

Table 3 shows the Classification legend and the assigned carbon values. A detailed report and the sources of the carbon values used for each class is appended to this document.

Table 3: Aboveground biomass and carbon values assigned to the land cover classes.

Land cover class	Map code	AGB [t ha-1]	Carbon [t ha-1]
Primary dry land forest	1	545	273
Secondary/ logged over dry land forest	2	256	128
Primary swawp forest	3	226	113
Secondary/ logged over swamp forest	4	74	37
Primary mangrove forest	5	198	99
Secondary/ logged over mangrove forest	6	44	22
Mixed dryland agriculture/mixed garden	7	105	53
Tree crop plantation	8	32	16
Plantation forest	9	40	20
Scrub	10	25	13
Rice field	11	10	5
Dry land agriculture	12	31	16
Grass	13	6,2	3
Open land	14	0	0
Settlement/ developed land	15	0	0
Water body	16	0	0
Embankment	17	0	0

In order to determine the deforestation rate all forest type classes were combined into a single "Forest" class and the other land cover classes were merged into a single "Non-forest" class. **"No data" values in any of the classifications were excluded from analysis.**
The deforestation rate was then calculated by the equation:

$$r = ((A2 - A1) * A1^{-1}) \; * \; \Delta t^{-1}$$

r = Deforestation rate
A1 = Forest area (ha) Time Step 1
A2 = Forest area (ha) Time Step 2
Δt = Time difference (yr) between the time steps

3 Results

3.1 Land cover classifications

Figure 5 to Figure 9 show the results of the land cover classification for the five points in time 1990, 2000, 2005, 2010 and 2014. The spatial extent of the different land cover classes in the five points in time is shown in Table 4
. Note that the maps and statistics show the land cover status before the application of the common No data mask.

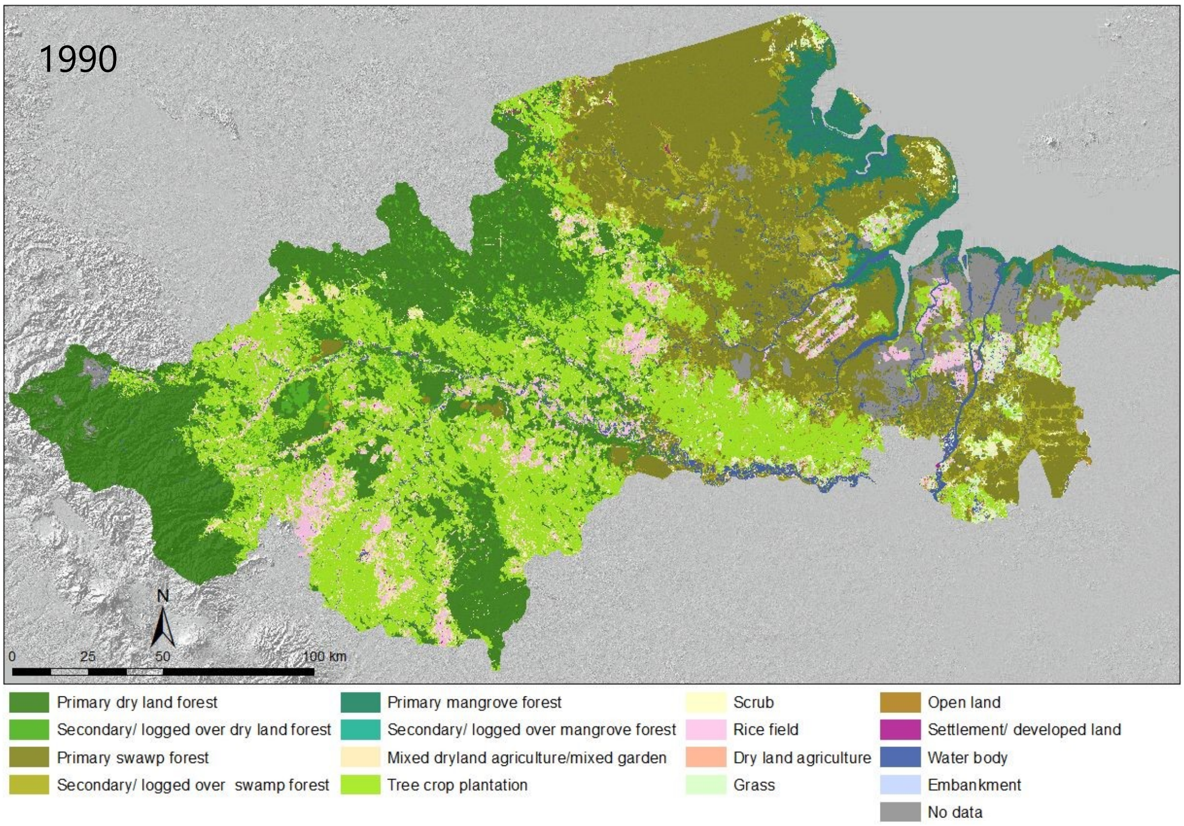

Figure 5: Land cover classification 1990

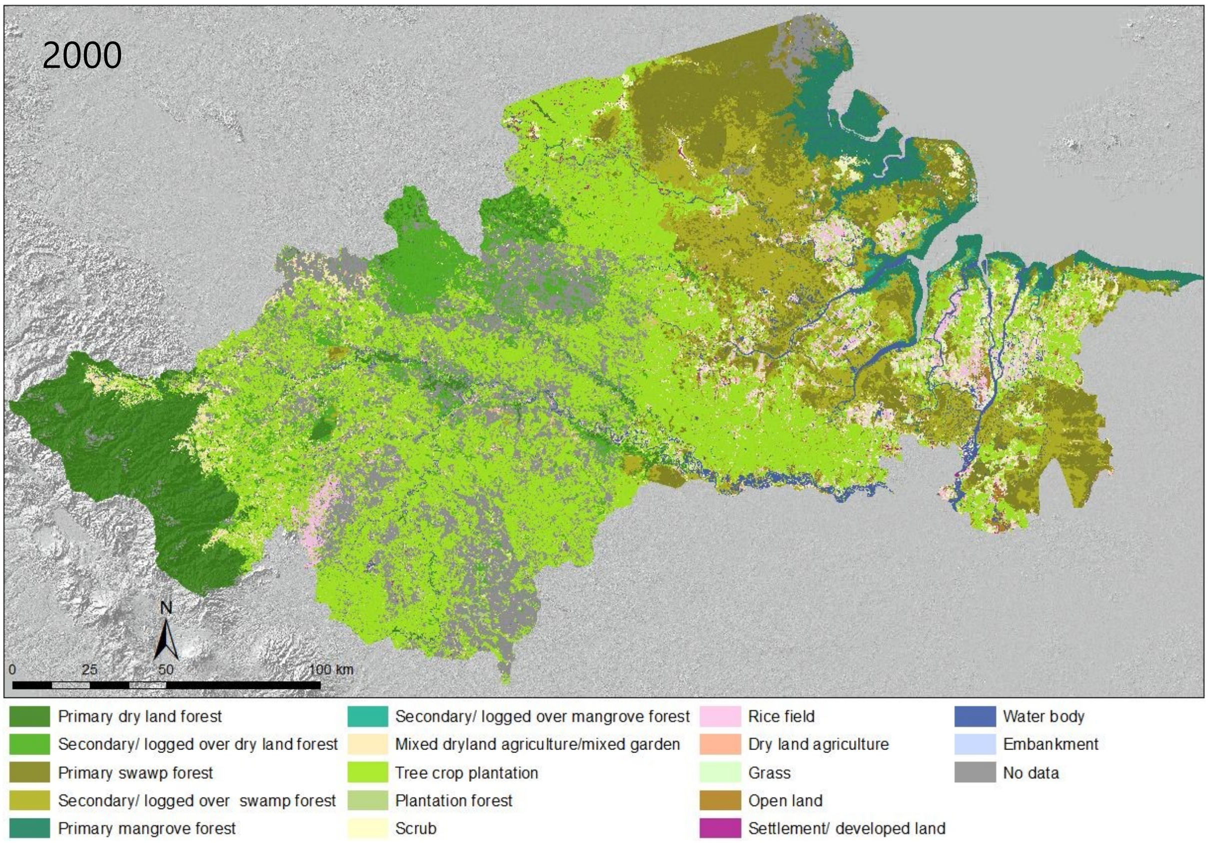

Figure 6: Land cover classification 2000

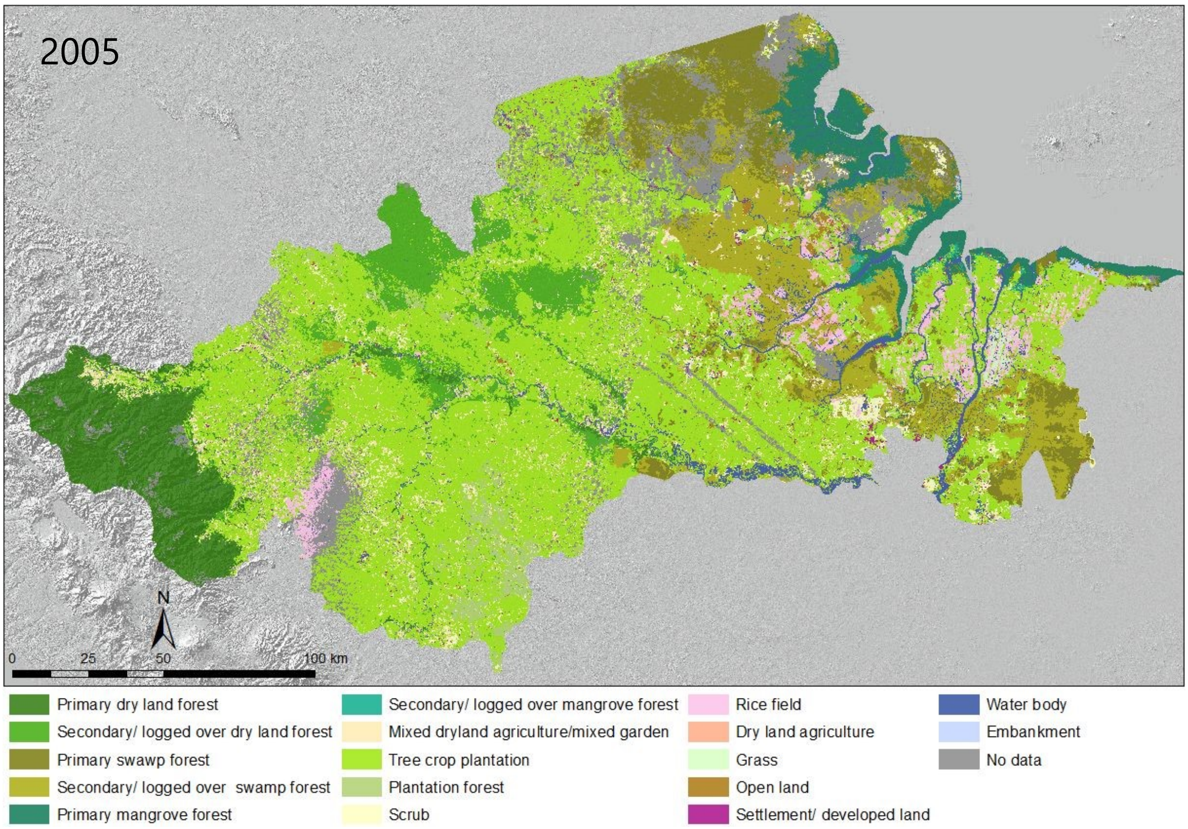

Figure 7: Land cover classification 2005

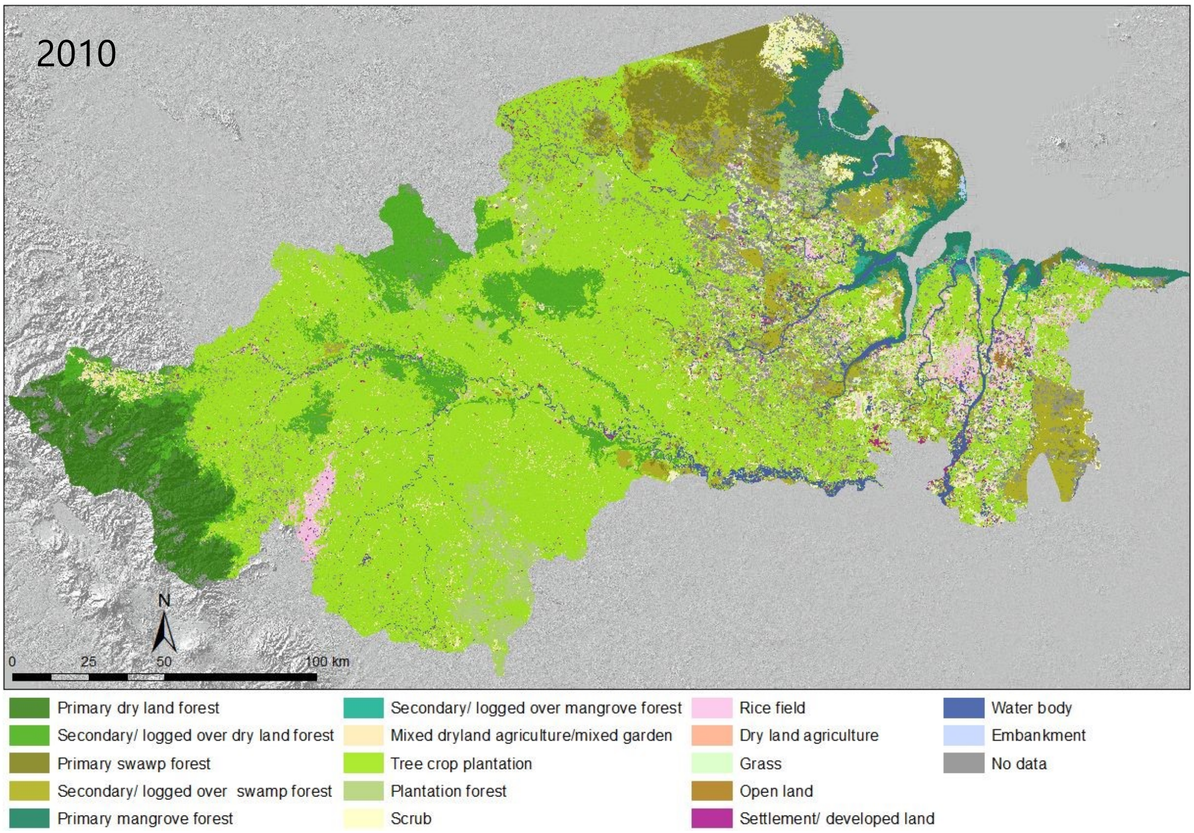

Figure 8: Land cover classification 2010

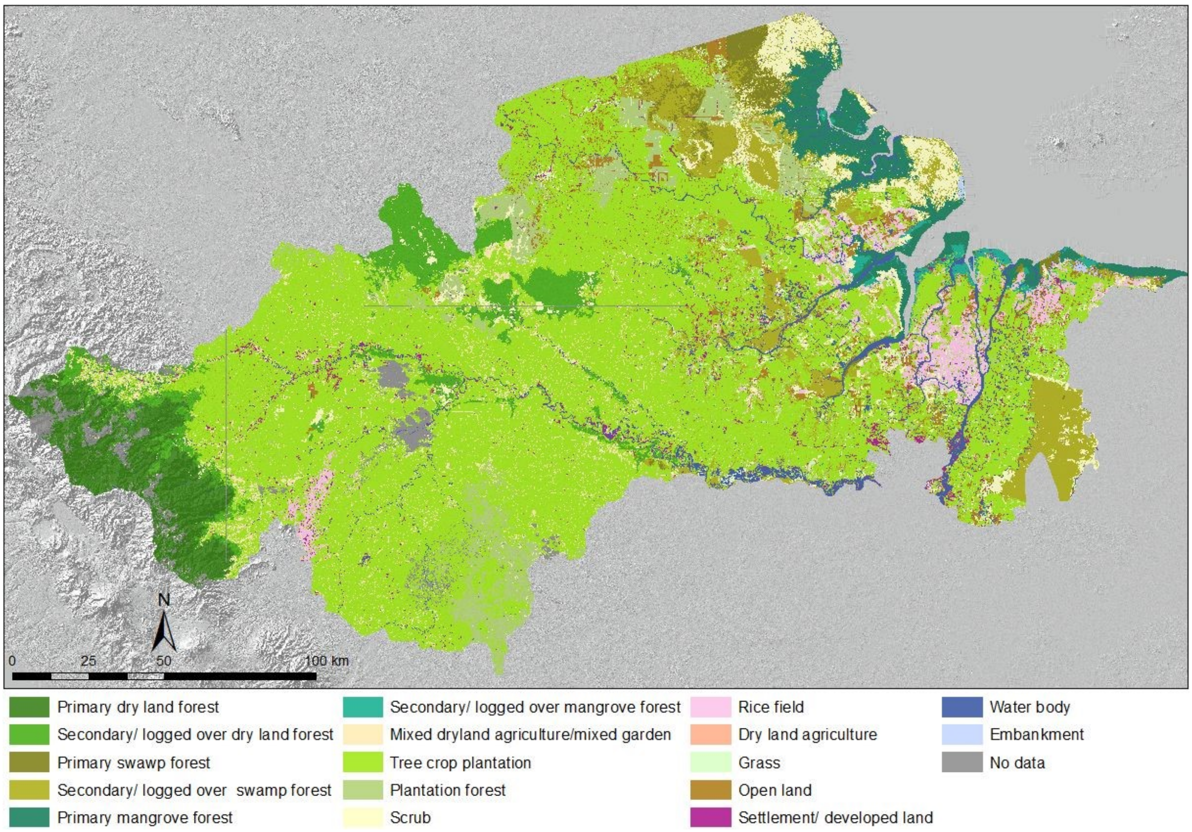

Figure 9: Land cover classification 2014

Table 4: Spatial extent of the different land cover categories in the five points in time.

Land Cover	Code	Area [ha]				
		1990	2000	2005	2010	2014
Primary dry land forest	1	871,563	289,632	260,314	193,063	171,254
Secondary/ logged over dry land forest	2	119,783	230,716	258,296	245,078	180,355
Primary swawp forest	3	859,638	397,310	256,148	167,487	47,206
Secondary/ logged over swamp forest	4	205,801	415,012	361,948	227,183	257,222
Primary mangrove forest	5	152,158	145,385	143,175	133,332	128,528
Secondary/ logged over mangrove forest	6	3,332	13,784	10,874	16,138	24,422
Mixed dryland agriculture/mixed garden	7	113,730	87,518	130,324	71,896	112,685
Tree crop plantation	8	1,007,473	1,348,775	1,675,992	1,954,907	2,075,566
Plantation forest	9	0	13,301	65,533	108,741	184,768
Scrub	10	68,633	99,263	99,247	101,408	177,000
Rice field	11	157,072	122,431	113,174	97,964	106,351
Dry land agriculture	12	3,453	7,109	13,391	32,236	1,629
Grass	13	48,768	26,898	14,206	63,618	45,259
Open land	14	6,395	28,996	22,220	12,524	93,848
Settlement/ developed land	15	7,909	11,722	19,034	28,494	58,899
Water body	16	109,532	109,526	109,526	109,532	109,532
Embankment	17	10	1,238	3,079	2,844	6,411
No data	99	129,469	516,101	308,239	298273.23	83,783
Sum		**3,864,718**	**3,864,718**	**3,864,718**	**3,864,718**	**3,864,718**

The following figure shows the common no data mask which was created by merging the no data areas of all five points in time. The total area of the common no data mask is 1,110,722 ha.

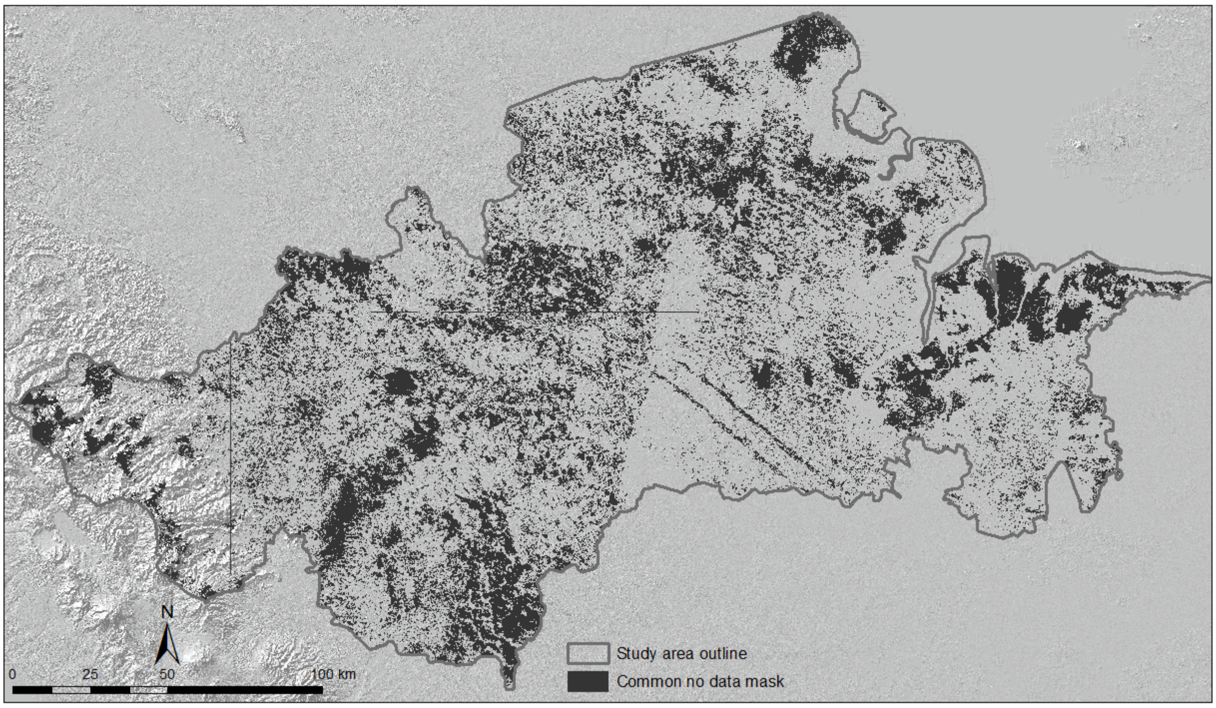

Figure 10: Common Nodata mask

The spatial extent of the land cover classes after the application of the common no data mask is shown in Table 5. These statistics form the basis for all further calculation of land cover changes and carbon emissions.

Table 5: Spatial extent of the different land cover categories after applying the common no data mask.

		Area [ha]				
Land Cover	**Code**	**1990**	**2000**	**2005**	**2010**	**2014**
Primary dry land forest	1	535,947	249,237	228,878	176,525	171,254
Secondary/ logged over dry land forest	2	86,219	211,542	173,755	178,190	136,500
Primary swawp forest	3	626,024	308,027	225,233	167,409	47,206
Secondary/ logged over swamp forest	4	156,004	279,509	280,437	187,474	189,734
Primary mangrove forest	5	145,296	140,039	139,139	133,332	128,528
Secondary/ logged over mangrove forest	6	2,597	6,654	6,781	11,420	13,579
Mixed dryland agriculture/mixed garden	7	54,025	66,681	86,243	46,081	75,986
Tree crop plantation	8	848,023	1,162,293	1,267,981	1,432,675	1,461,231
Plantation forest	9	0	13,301	34,243	56,704	107,682
Scrub	10	39,038	63,508	66,113	65,004	103,395
Rice field	11	99,119	90,402	86,901	77,084	72,310
Dry land agriculture	12	2,443	6,077	7,864	25,926	1,187
Grass	13	38,081	16,209	9,296	50,598	30,296
Open land	14	4,645	19,353	13,664	10,121	57,574
Settlement/ developed land	15	6,999	11,111	16,912	24,536	44,390

Water body	16	109,526	109,526	109,526	109,526	109,526
Embankment	17	10	529	1,030	1,392	3,619
Sum		**2,753,996**	**2,753,996**	**2,753,996**	**2,753,996**	**2,753,996**
No data		1,110,722	1,110,722	1,110,722	1,110,722	1,110,722
Total		**3,864,718**	**3,864,718**	**3,864,718**	**3,864,718**	**3,864,718**

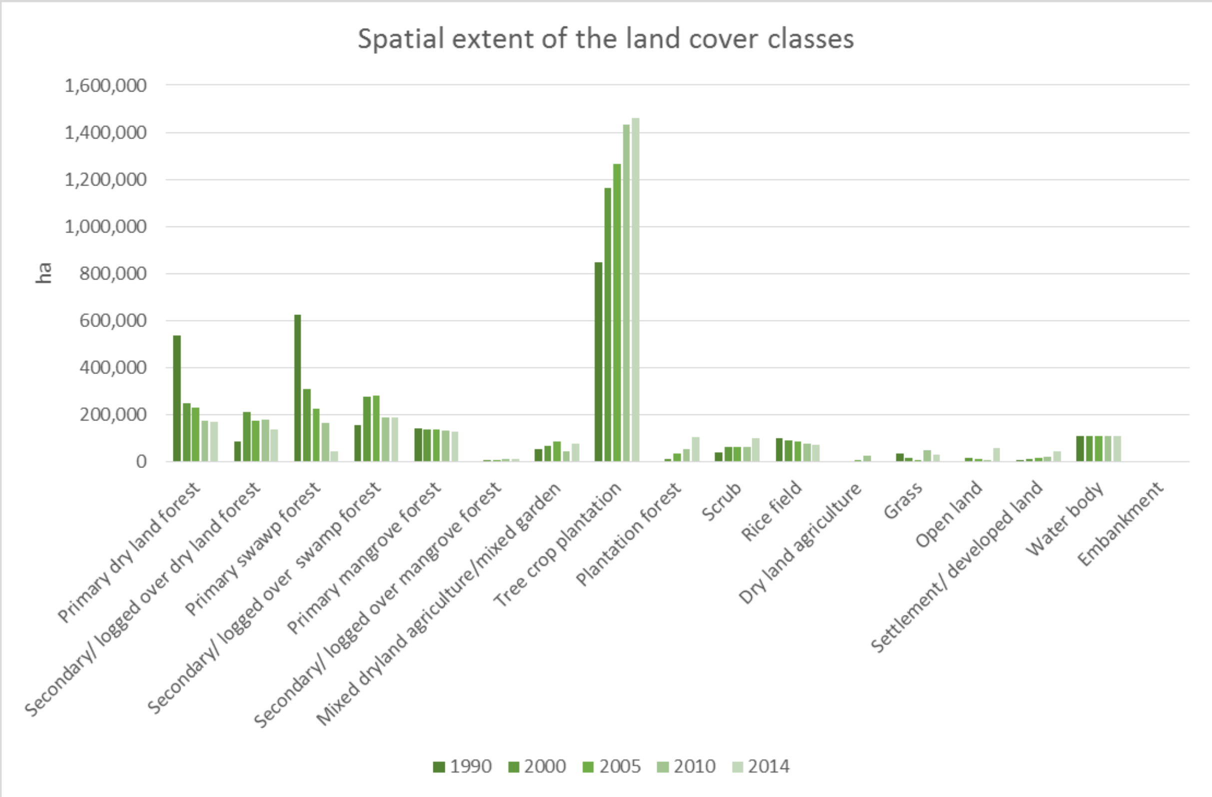

Figure 11: Spatial extent of the different land cover categories after applying the common no data mask

The most dominant land cover type in the study area was and is Tree crop plantation, occupying 848,023 ha in 1990 and expanding to 1,461,231 ha by 2014. The most abundant forest type in 1990 was Primary dryland forest with 535,947 ha, however this class lost about 68 % of its spatial extent until 2014 ending at 171,254 ha. Secondary dryland forest increased from 86,219 ha in 1990 to 211,542 ha in 2000, before decreasing until 2014. Primary peat swamp forest lost even more of its spatial extent, covering 626,024 ha in 1990, but only 47,206 ha in 2014. Large shares of these changes were due to forest degradation related to logging which is reflected by the increase of spatial extent of the Secondary/ logged over peat swamp forest. Most non forest classes experienced an increase in spatial extent, especially the plantation forest class, the mixed dryland agriculture class as well as the Settlement/ developed land class. A decrease in spatial extent was observed for the Rice field class.

3.2 Land cover change

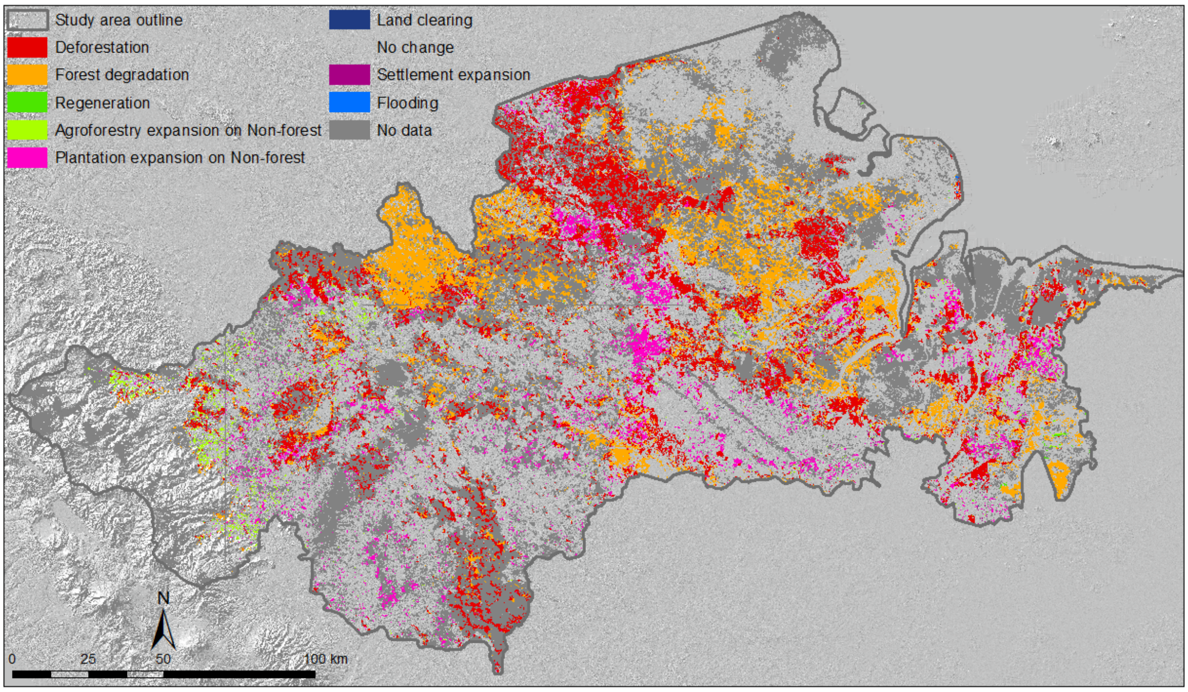

Figure 12: Land cover change map 1990 – 2000

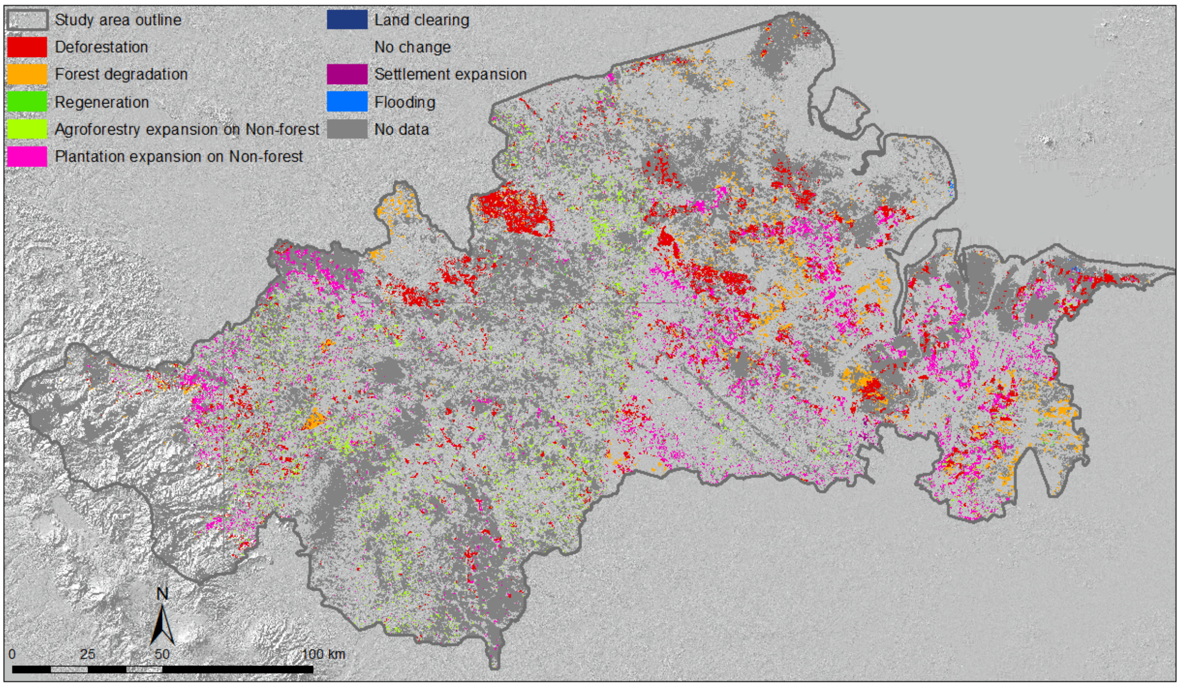

Figure 13: Land cover change 2000 – 2005

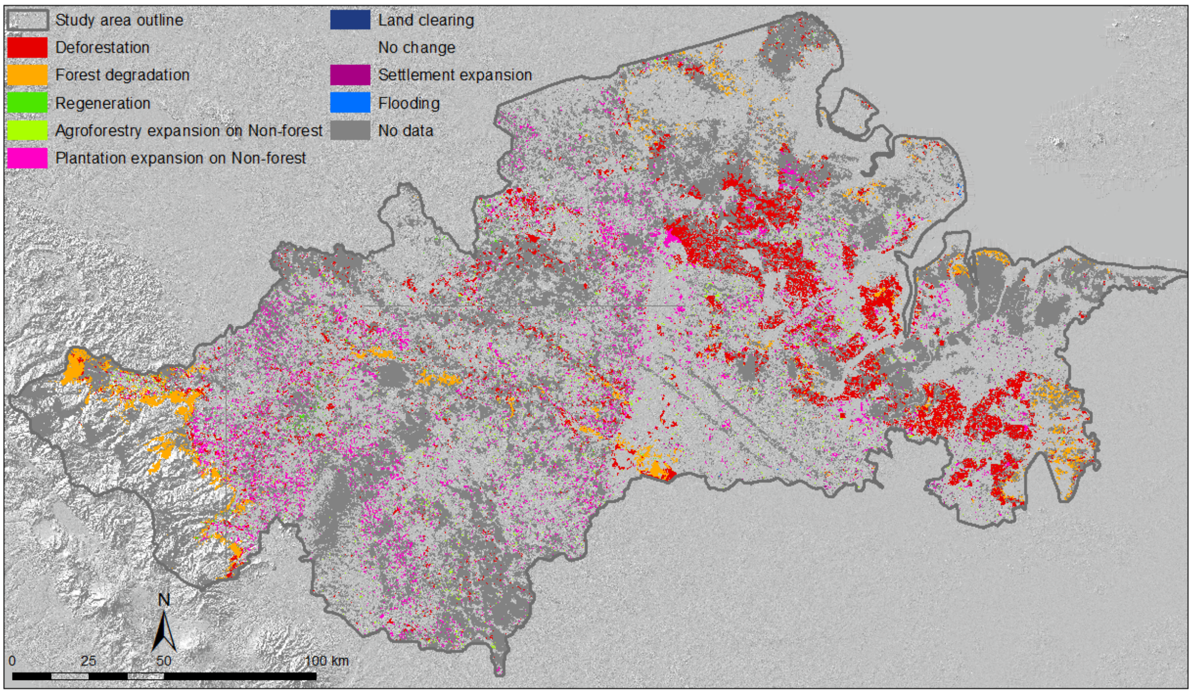

Figure 14: Land cover change 2005 – 2010

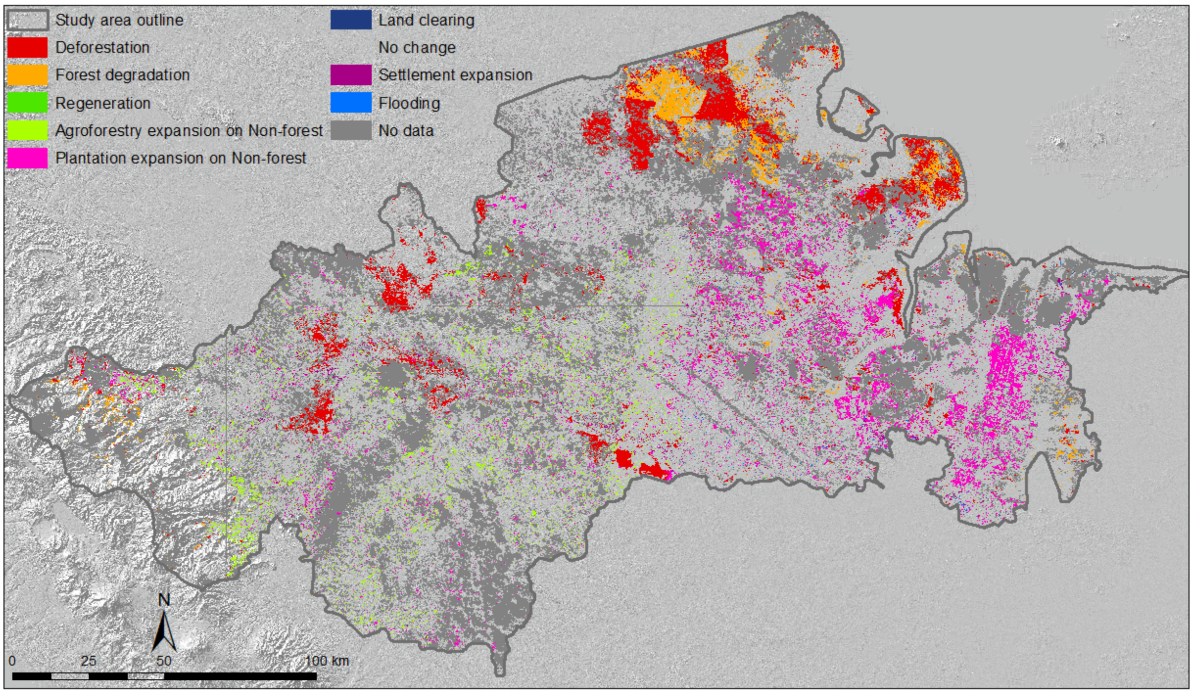

Figure 15: Land cover change 2010 – 2014

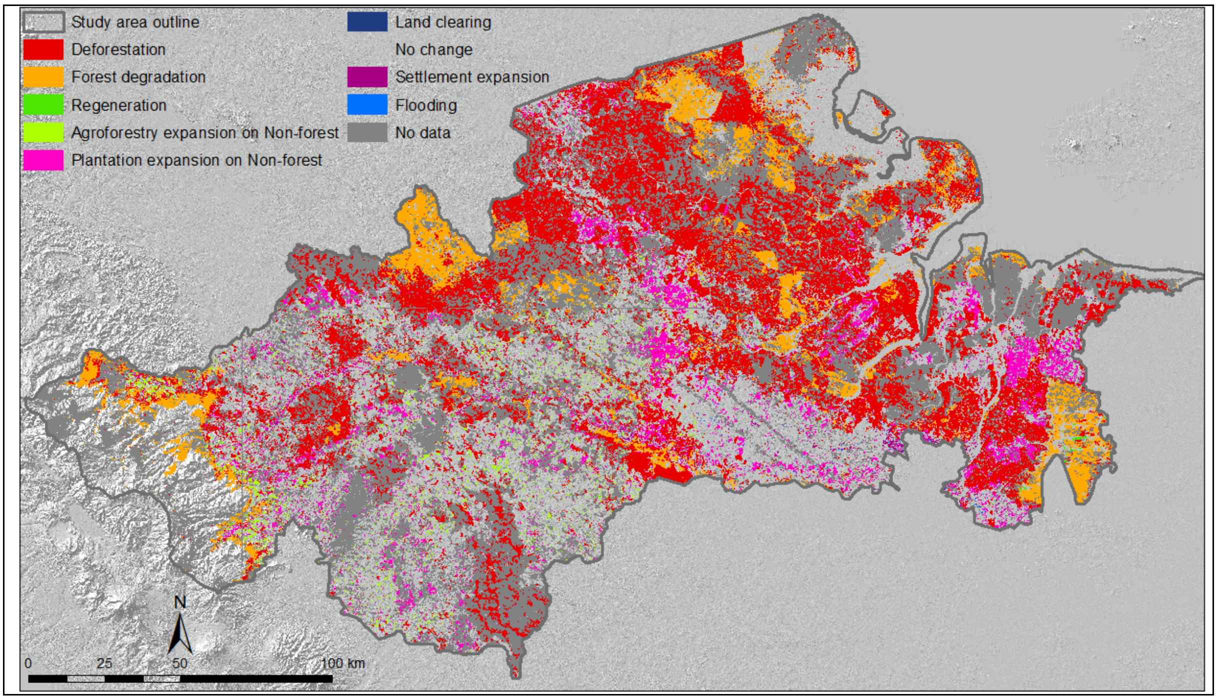

Figure 16: Land cover change 1990 – 2014

Figure 12 to Figure 16 show the land cover change maps for the five observation periods 1990 – 2000, 2000 – 2005, 2005 – 2010, 2010 – 2014 and 1990 – 2014. The change in spatial extent for the different land cover classes are shown in Table 6. As already indicated in chapter 3.1, the most intensive losses in spatial extent were observed for the classes Primary dryland forest and Primary peatland forest, amounting to -364,692 ha and -578,818 ha in the overall observation period 1990 – 2014, respectively. The highest increase in spatial extent was observed in the Tree crop plantation class, amounting to 613,208 ha, followed by Plantation forest with 107,682 ha in the period 1990 – 2014.

Table 6: Land cover change in the five observation periods.

Land Cover	Code	Area change (ha)				
		1990 - 2000	2000 - 2005	2005 - 2010	2010 - 2014	1990 - 2014
Primary dry land forest	1	-286,710	-20,358	-52,353	-5,271	-364,692
Secondary/ logged over dry land forest	2	125,322	-37,787	4,435	-41,689	50,281
Primary swawp forest	3	-317,997	-82,794	-57,824	-120,203	-578,818
Secondary/ logged over swamp forest	4	123,504	928	-92,963	2,260	33,730
Primary mangrove forest	5	-5,257	-900	-5,808	-4,804	-16,768
Secondary/ logged over mangrove forest	6	4,057	127	4,639	2,158	10,981
Mixed dryland agriculture/mixed garden	7	12,656	19,561	-40,161	29,904	21,960
Tree crop plantation	8	314,269	105,688	164,694	28,557	613,208
Plantation forest	9	13,301	20,942	22,460	50,978	107,682
Scrub	10	24,470	2,605	-1,109	38,391	64,357
Rice field	11	-8,717	-3,501	-9,817	-4,773	-26,808
Dry land agriculture	12	3,634	1,787	18,062	-24,739	-1,256
Grass	13	-21,872	-6,913	41,302	-20,302	-7,785
Open land	14	14,707	-5,689	-3,543	47,453	52,928
Settlement/ developed land	15	4,112	5,802	7,624	19,854	37,391
Water body	16	0	0	0	0	0

Embankment	17	519	500	363	2,227	3,608
Sum		**0**	**0**	**0**	**0**	**0**

Table 7: Spatial extent of the gross land cover changes in the five observation periods.

Change process	**1990 - 2000**	**2000 - 2005**	**2005 - 2010**	**2010 - 2014**	**1990 - 2014**
	Ha **%**	**Ha** **%**	**Ha** **%**	**Ha** **%**	**Ha** **%**
Deforestation	359,174 42.85%	142,904 36.74%	204,449 45.82%	168,093 37.38%	868,082 62.79%
Forest Degradation	326,720 38.98%	57,921 14.89%	78,060 17.50%	59,842 13.31%	275,702 19.94%
Plantation expansion on Non-forest	119,650 14.27%	121,109 31.14%	127,230 28.52%	142,116 31.60%	164,273 11.88%
Regeneration	2,094 0.25%	2,120 0.55%	4,576 1.03%	544 0.12%	2,796 0.20%
Settlement expansion	2,524 0.30%	4,951 1.27%	5,354 1.20%	17,894 3.98%	21,851 1.58%
Land clearing	449 0.05%	419 0.11%	135 0.03%	1,277 0.28%	340 0.02%
Agroforestry expansion on Non-forest	27,510 3.28%	59,052 15.18%	25,992 5.83%	57,667 12.82%	47,596 3.44%
Flooding	155 0.02%	462 0.12%	377 0.08%	2,289 0.51%	1,844 0.13%
Total Changes	**838,273**	**388,938**	**446,173**	**449,722**	**1,382,485**
No Change	**1,915,723**	**2,365,058**	**2,307,823**	**2,304,273**	**1,371,511**
Total	**2,753,996**	**2,753,996**	**2,753,996**	**2,753,996**	**2,753,996**

Table 7 and Figure 17 present a summary of the spatial extent of the different land cover change processes and the importance of those across the five observation periods. The importance of those changed intensively across time: While in the first period 1990 – 2000, deforestation and forest degradation were almost equal in importance (accounting for 43 % and 39 % of all observed changes), degradation declined to between 13 and 18 % in the following periods. The reason is that apart from areas with a strict protection status (such as the National parks), the majority of primary forest have already experienced degradation in the earliest observation period. At the same time, Plantation expansion on Non-forest increased significantly from 14 % (1990 – 2000) to approximately 29 – 31 % in the following periods. In the overall observation period 1990 – 2014, deforestation accounted for 63 % of all observed changes, forest degradation for 20 %, Plantation expansion on Non-forest for 12 % and Agroforestry expansion on Non-forest for 3.5 %.

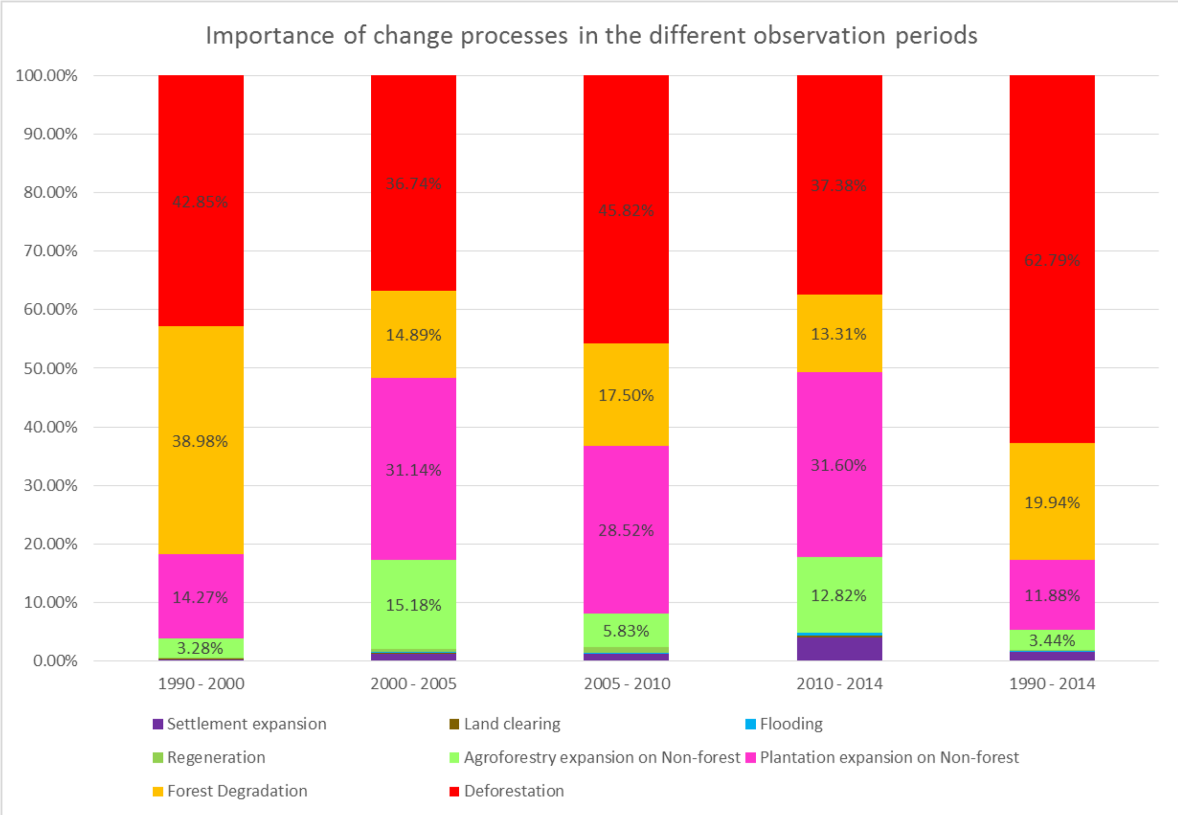

Figure 17: Importance of change processes in the different observation periods.

3.3 Deforestation rate

Table 8: Net forest loss in the five observation periods.

Net forest loss	1990 - 2000	2000 - 2005	2005 - 2010	2010 - 2014	1990 - 2014
ha	-357,080	-140,784	-199,873	-167,549	-865,286
%	-23.01%	-11.78%	-18.96%	-19.61%	-55.75%

Table 8 shows the net forest losses in the five observation periods. Between 1990 and 2000, 357,080 ha of forest have been lost which amounts to 23 % of the forest cover at the start of the observation period. In the following periods, another 140,784 ha (12 %), 199,873 ha (19 %) and 167,549 ha (20 %) have been lost. In the overall observation period 1990 – 2014, net forest loss amounted to 865,286 ha or 56 % of the forest cover of 1990.

Figure 18 shows the resulting annual deforestation rates in the study area in the five observation periods. It is interesting to note that the deforestation rates increased over time. While between 1990 and 2000, approx. 2.3 % of forest cover have been lost annually, this rate increased in the following periods up until 4.9 % per year. The reason is that while net forest loss remained on a more or less constant level (with a peak between 2005 and 2010), the spatial extent of forest cover diminished significantly. Therefore the relative rates increase over time. In the overall observation period 1990 – 2014 the annual deforestation rate averaged at 2.3 %.

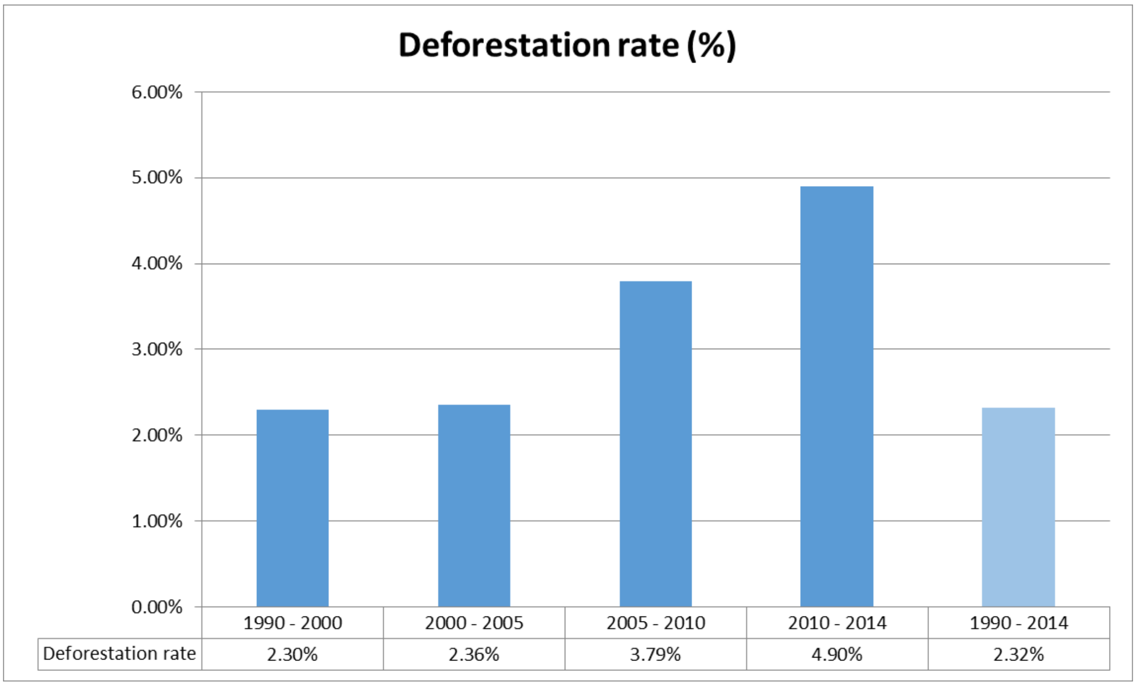

Figure 18: Annual deforestation rate in the five observation periods.

Figure 19 shows the analysis of deforestation drivers across the five observation periods. These varied significantly over time. While conversion to tree crop plantation remained the most important driver, its importance first increased from 67 % between 1990 and 2000 to 73 % between 2000 and 2005, before it started to decrease to 62 % (2005 – 2010) and then to 43 % (2010 – 2014). Overall, conversion to tree crop plantation accounted for 65 % of all deforestation between 1990 and 2014.

The second most important driver of deforestation over time was conversion to Scrub, which accounted for 9% (1990 – 2000), 6% (2000-2005), 10 % (2005 – 2010) and 25 % (2010 – 2014) of all deforestation. Conversion to plantation forest accounted for 2.5 % (1990 – 2000), 2.3 % (2000 – 2005), 2.6 % (2005 – 2010) and 14 % (2010 – 2014). In the overall period 1990 – 2014, this conversion amounted for almost 10 % of all deforestation. Less important drivers of deforestation in the overall period 1990 – 2014 were Conversion to Open land (5 %), Conversion to Rice field (4 %) and Conversion to mixed dryland agriculture (3 %).

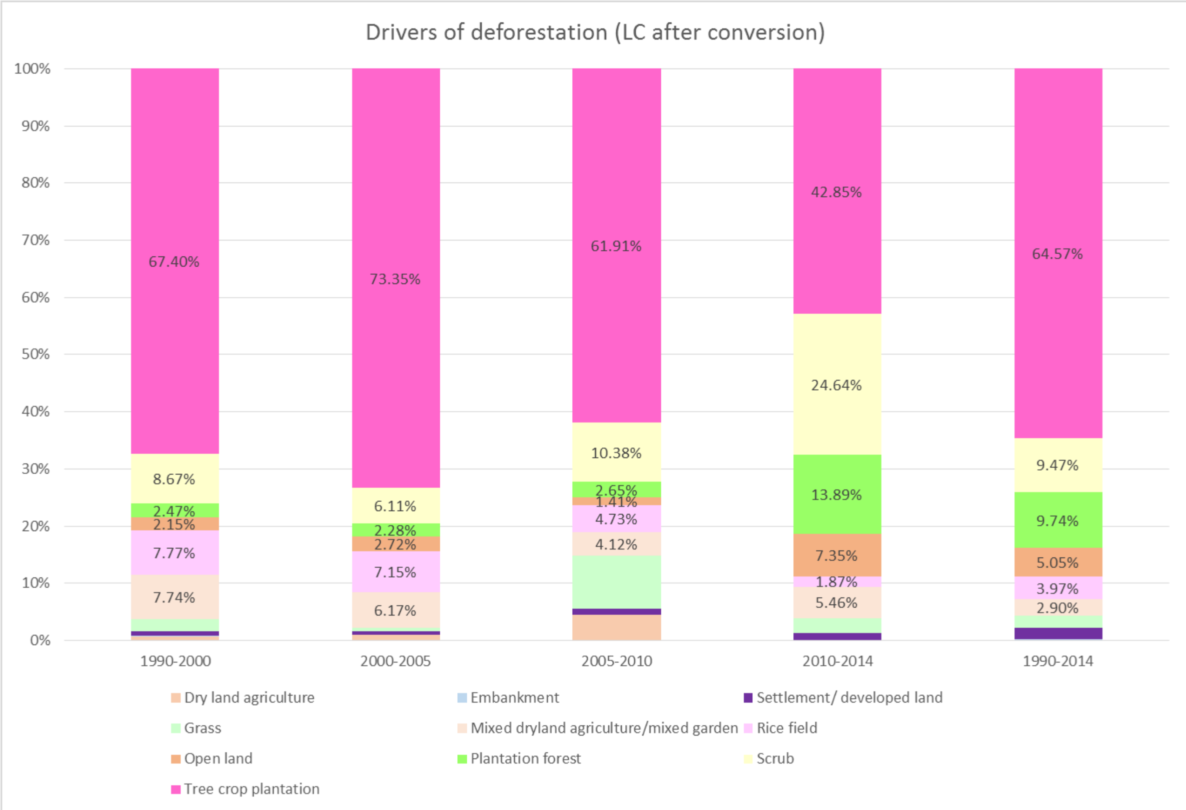

Figure 19: Drivers of deforestation

3.4 Carbon stock maps

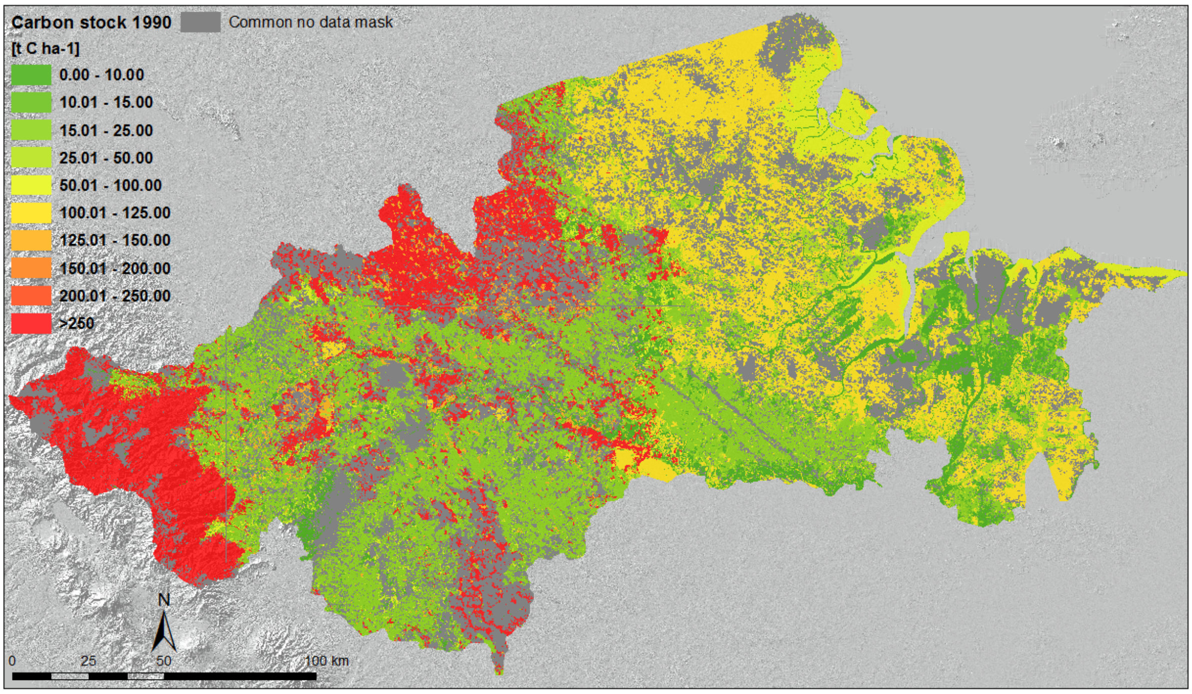

Figure 20: Carbon stock map 1990

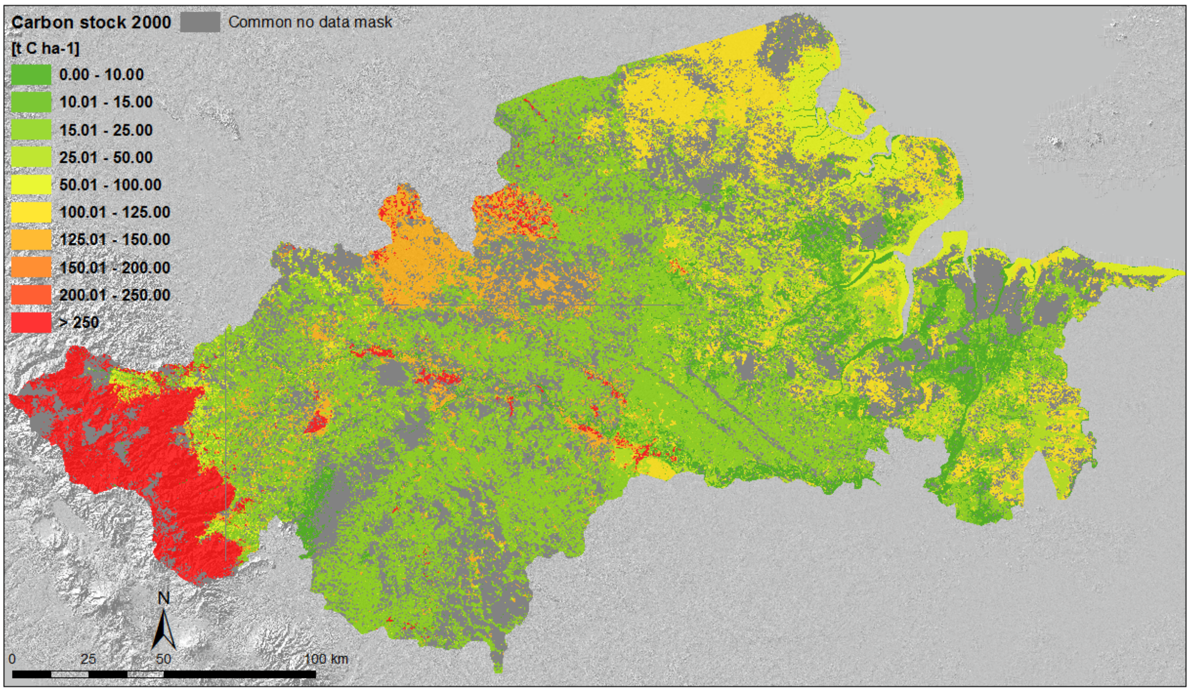

Figure 21: Carbon stock map 2000

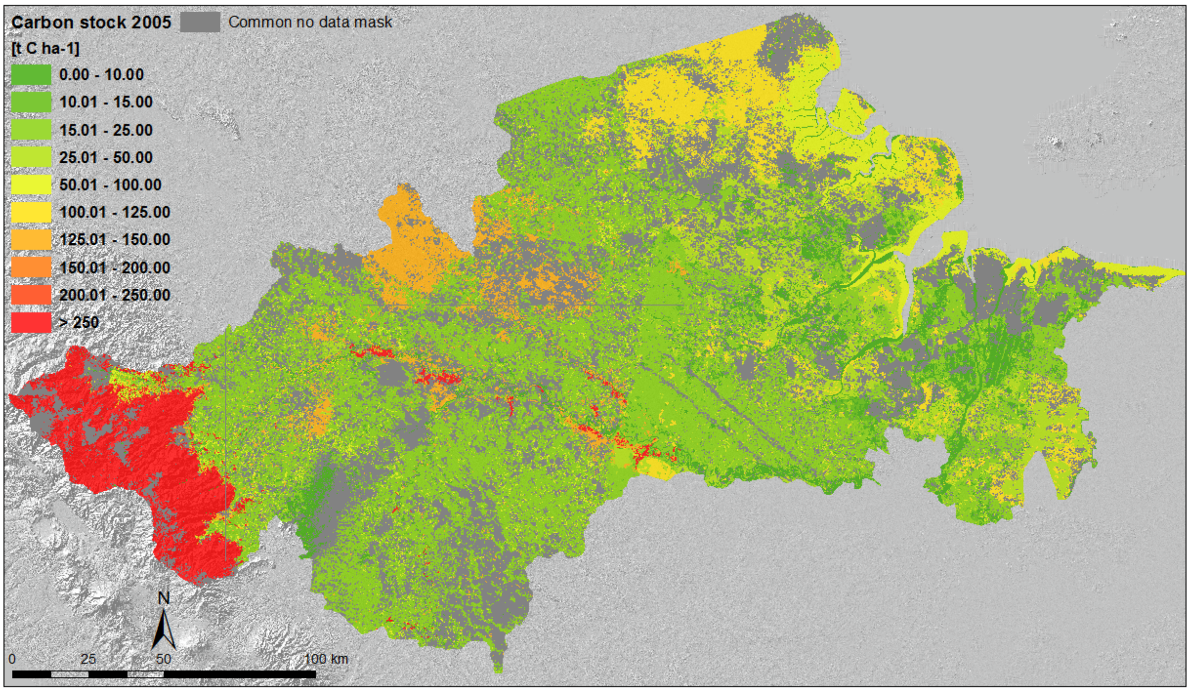

Figure 22: Carbon stock map 2005

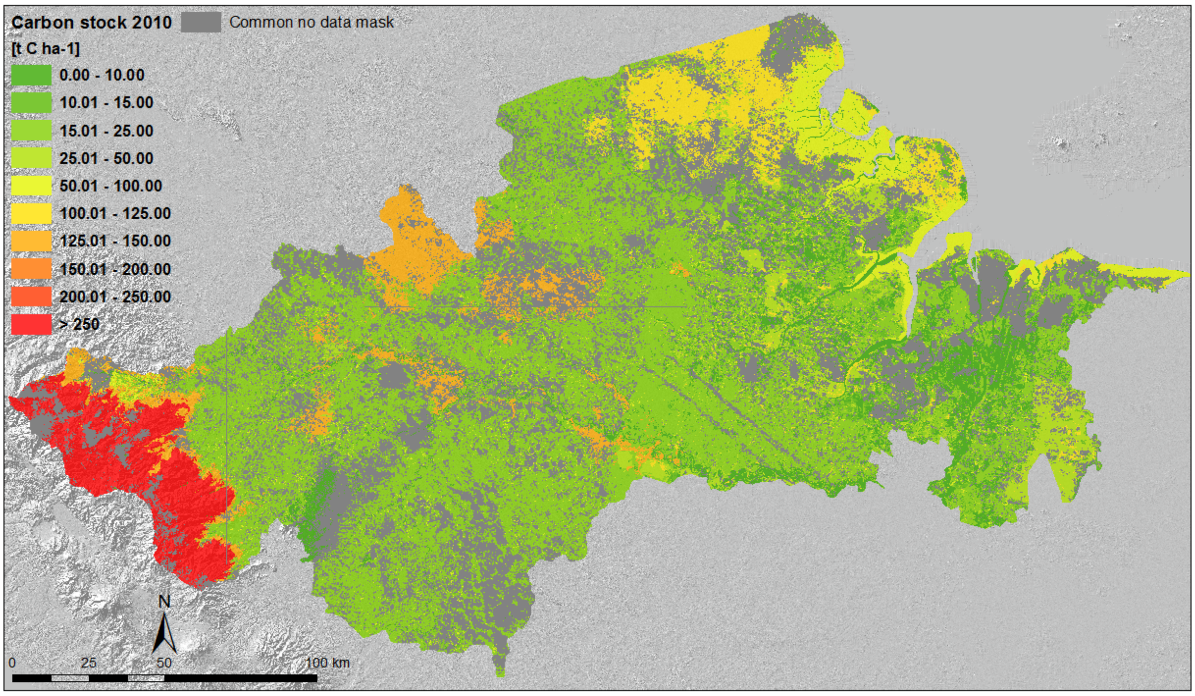

Figure 23: Carbon stock map 2010

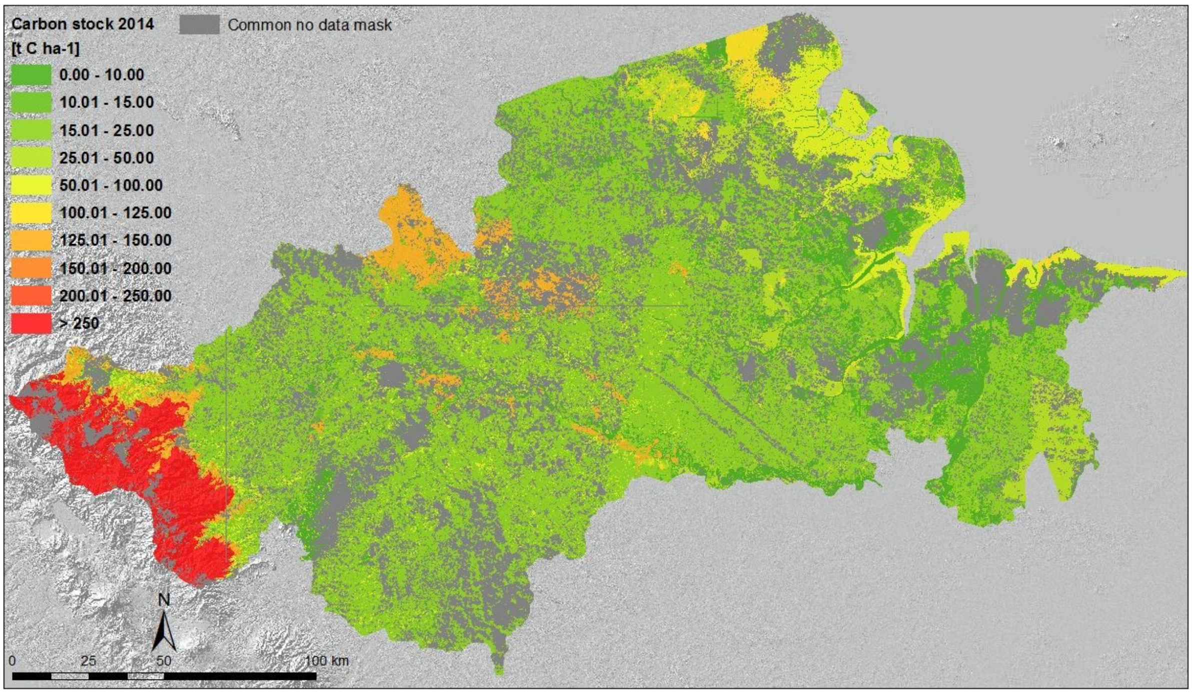

Figure 24: Carbon stock map 2014

Table 9: Carbon stock stored in the different land cover classes at the five points in time.

Land Cover	Code	Carbon stock [ha]				
		1990	**2000**	**2005**	**2010**	**2014**
Primary dry land forest	1	146,045,443	67,917,009	62,369,356	48,103,114	46,666,832
Secondary/ logged over dry land forest	2	11,036,091	27,077,322	22,240,581	22,808,287	17,472,038
Primary swamp forest	3	70,740,679	34,807,018	25,451,289	18,917,166	5,334,226

Secondary/ logged over swamp forest	4	5,772,165	10,341,828	10,376,160	6,936,543	7,020,166
Primary mangrove forest	5	14,384,304	13,863,889	13,774,807	13,199,862	12,724,300
Secondary/ logged over mangrove forest	6	57,139	146,393	149,191	251,250	298,729
Mixed dryland agriculture/mixed garden	7	2,836,328	3,500,771	4,527,736	2,419,276	3,989,247
Tree crop plantation	8	13,568,373	18,596,684	20,287,692	22,922,794	23,379,703
Plantation forest	9	0	266,013	684,860	1,134,070	2,153,637
Scrub	10	487,970	793,847	826,416	812,553	1,292,438
Rice field	11	495,594	452,011	434,506	385,418	361,552
Dry land agriculture	12	37,867	94,195	121,899	401,856	18,396
Grass	13	118,051	50,248	28,818	156,854	93,917
Open land	14	0	0	0	0	0
Settlement/ developed land	15	0	0	0	0	0
Water body	16	0	0	0	0	0
Embankment	17	0	0	0	0	0
Sum		**265,580,004**	**177,907,228**	**161,273,311**	**138,449,043**	**120,805,181**

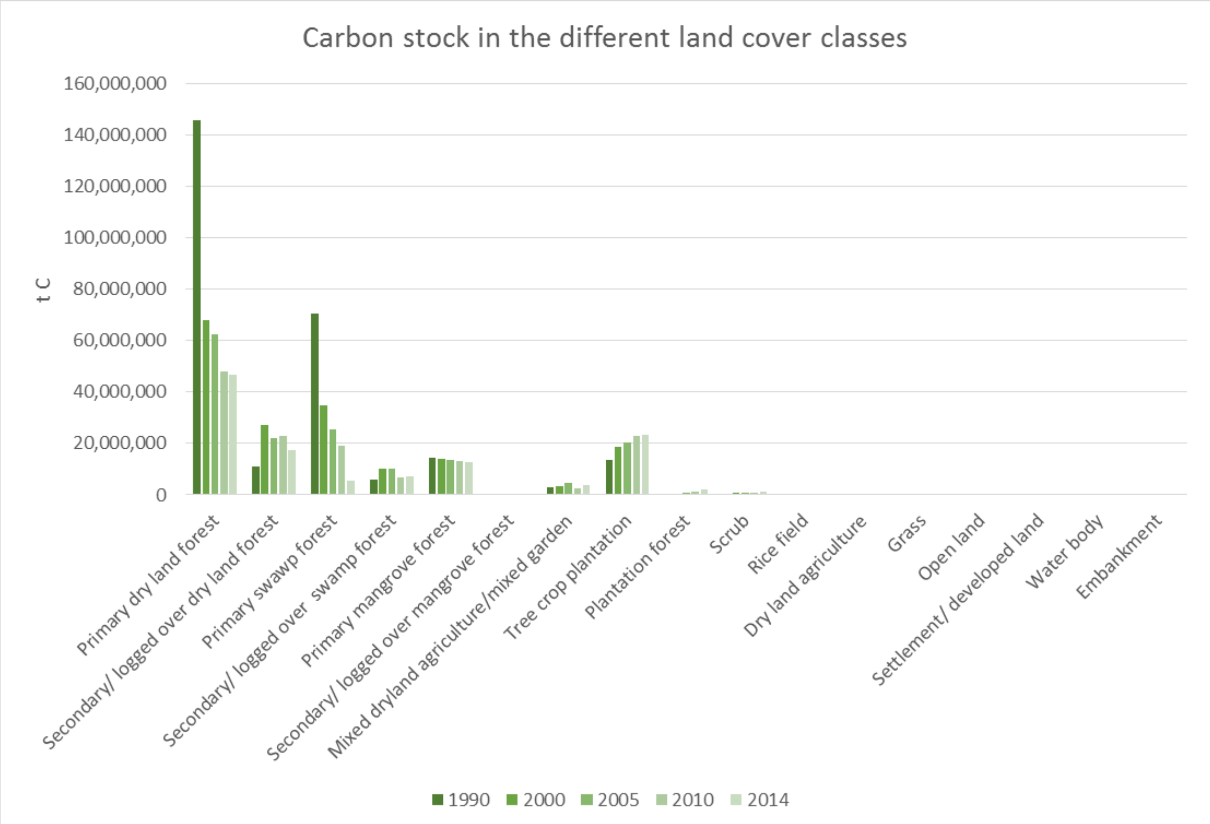

Figure 25: Aboveground carbon stock stored in the different land cover classes at the five points in time.

Table 9 and Figure 25 show the carbon stock stored in the different land cover classes over time. The majority of carbon was and is stored in the classes primary dryland forest amounting to 146,045,443 t C in 1990 and still 46,666,832 t C in 2014. The second highest carbon stock was observed in Primary peat swamp forest in 1990 with 70,740,679 t C, however, this declined to only 5,334,226 t C in 2014. Carbon storage in Primary mangrove forest remained almost constant over time. Carbon stocks in the secondary forest lasses (Dryland and peat) increased at first, but then decreased as well due to deforestation of secondary forests over time.

3.5 Carbon stock change

Table 10: Carbon stock change in the five observation periods.

		Carbon stock change t(C)				
Land Cover	**Code**	**1990 - 2000**	**2000 - 2005**	**2005 - 2010**	**2010 - 2014**	**1990 - 2014**
Primary dry land forest	1	-78,128,434	-5,547,653	-14,266,242	-1,436,282	-99,378,611
Secondary/ logged over dry land forest	2	16,041,231	-4,836,741	567,706	-5,336,248	6,435,948
Primary swamp forest	3	-35,933,661	-9,355,729	-6,534,123	-13,582,940	-65,406,453
Secondary/ logged over swamp forest	4	4,569,662	34,332	-3,439,617	83,623	1,248,001
Primary mangrove forest	5	-520,415	-89,082	-574,944	-475,562	-1,660,004
Secondary/ logged over mangrove forest	6	89,254	2,798	102,059	47,478	241,590
Mixed dryland agriculture/mixed garden	7	664,444	1,026,965	-2,108,460	1,569,971	1,152,919
Tree crop plantation	8	5,028,312	1,691,008	2,635,102	456,909	9,811,331
Plantation forest	9	266,013	418,847	449,210	1,019,567	2,153,637
Scrub	10	305,877	32,569	-13,863	479,886	804,468
Rice field	11	-43,583	-17,505	-49,087	-23,866	-134,042
Dry land agriculture	12	56,327	27,705	279,957	-383,460	-19,471
Grass	13	-67,803	-21,430	128,036	-62,937	-24,134
Open land	14	0	0	0	0	0
Settlement/ developed land	15	0	0	0	0	0
Water body	16	0	0	0	0	0
Embankment	17	0	0	0	0	0
Sum		**-87,672,776**	**-16,633,917**	**-22,824,268**	**-17,643,863**	**-144,774,823**

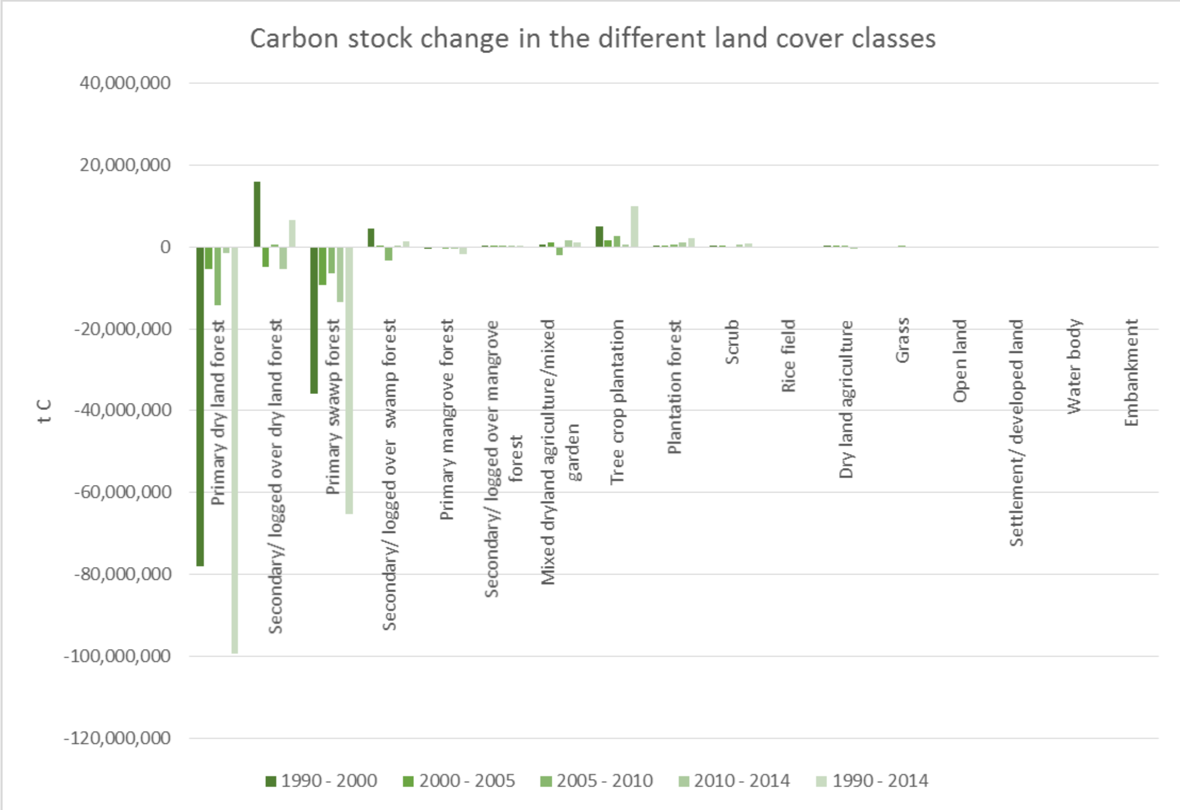

Figure 26: Carbon stock changes in the different land cover categories across the five observation periods.

Table 10 and Figure 26 show the carbon stock changes in the land cover classes across time. The most intensive carbon losses (in the overall observation period) were observed in Primary dryland forest amounting to -99,378,611 t C and in Primary peat swamp forest amounting to -65,406,453 t C. Compared to these enormous losses, the increases in carbon stock observed in the Tree crop plantation class (9,811,331 t C between 1990 and 2014) and Secondary Dryland Forest (6,435,948 t C) are considered minor.

Annual carbon stock changes are shown in Table 11.

Table 11: Annual carbon stock change in the five observation periods.

		Annual Carbon Emissions (t C yr-1)				
Land Cover	**Code**	**1990 - 2000**	**2000 - 2005**	**2005 - 2010**	**2010 - 2014**	**1990 - 2014**
Primary dry land forest	1	-7,812,843	-2,219,061	-2,853,248	-359,071	-4,140,775
Secondary/ logged over dry land forest	2	1,604,123	-1,934,696	113,541	-1,334,062	268,164
Primary swawp forest	3	-3,593,366	-3,742,292	-1,306,825	-3,395,735	-2,725,269
Secondary/ logged over swamp forest	4	456,966	13,733	-687,923	20,906	52,000
Primary mangrove forest	5	-52,042	-35,633	-114,989	-118,891	-69,167
Secondary/ logged over mangrove forest	6	8,925	1,119	20,412	11,870	10,066
Mixed dryland agriculture/mixed garden	7	66,444	410,786	-421,692	392,493	48,038
Tree crop plantation	8	502,831	676,403	527,020	114,227	408,805

Plantation forest	9	26,601	167,539	89,842	254,892	89,735
Scrub	10	30,588	13,027	-2,773	119,971	33,520
Rice field	11	-4,358	-7,002	-9,817	-5,967	-5,585
Dry land agriculture	12	5,633	11,082	55,991	-95,865	-811
Grass	13	-6,780	-8,572	25,607	-15,734	-1,006
Open land	14	0	0	0	0	0
Settlement/ developed land	15	0	0	0	0	0
Water body	16	0	0	0	0	0
Embankment	17	0	0	0	0	0
Sum		**-8,767,278**	**-6,653,567**	**-4,564,854**	**-4,410,966**	**-6,032,284**

Figure 27 shows the analysis of the drivers of carbon emissions, as derived from the carbon change matrices of the emission assessment. The driver analysis is based on the class into which the land cover was converted in the respective time period, and it shows the emissions (or removals) resulting from the conversion, as well as the source of the emissions (i.e. which class was converted and how large the emissions from this class are.
The highest emissions are caused by conversion into Tree crop plantation, accounting for almost 80 million tons of carbon emissions in the time period 1990 – 2014. The majority of those emissions (45 million t C) come from the conversion of Primary dryland forest, followed by approx. 25 million t C from the conversion of Primary peat swamp. The second highest emissions were caused by logging of primary dryland forest, amounting to 16 million t C, followed by the conversion to Plantation forest amounting to approx. 13 million t C. Logging of primary swamp forest caused another 11 million t C of carbon emissions.

The carbon change matrix underlying these results can be found in the annex.

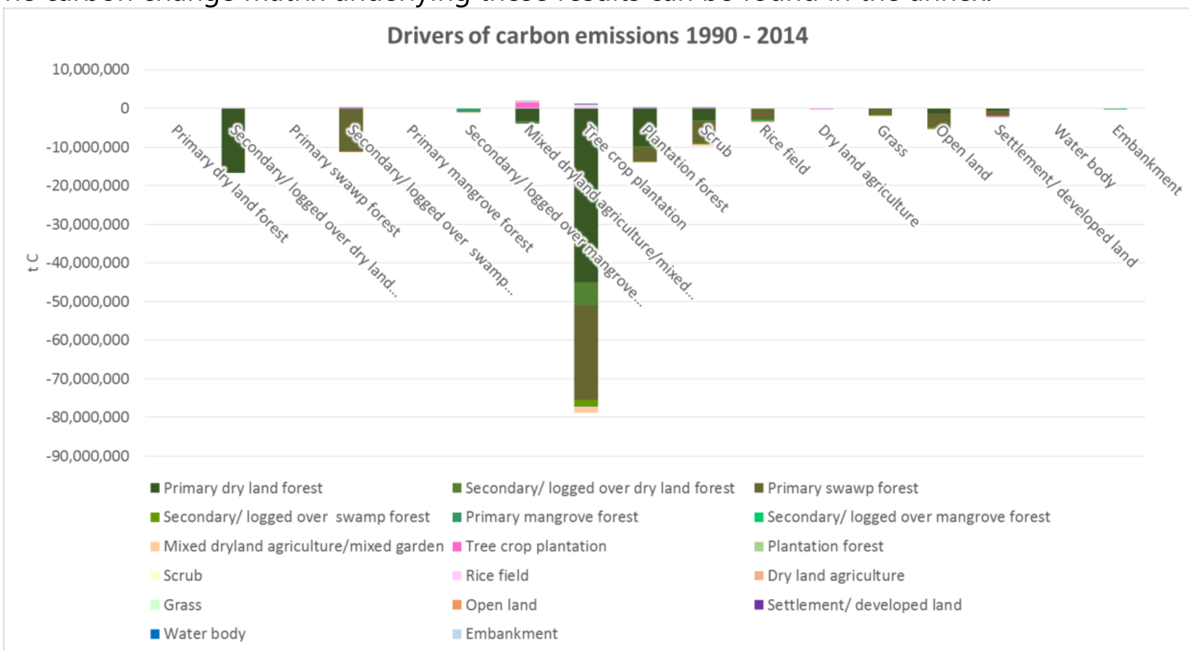

Figure 27: Drivers of carbon emissions

3.6 Carbon emission baseline

Based on the carbon stock maps shown in chapter 3.4, and the carbon stock statistics for the five points in time, a simple carbon emission baseline assessment was conducted. The basis for the assessment are the total carbon stocks in the study area as shown in Table 9. As there is no data available for 1995, this point in time was ignored in the trend analysis.
The baseline shown in Figure 28 is a simple mathematical projection of the carbon stock into the future by trend analysis. Different trend functions were tested on the data, and it was found that a logarithmic trend function provides the best curve fit and the most realistic future trend. The prediction was made until the year 2014. Projected carbon stock for 2014 is approximately 75,000,000 t C, i.e. predicted emissions in the next 50 years amount to approximately 50,000,000 t C. It has to be noted that this business-as-usual scenario is solely a mathematical projection of the historic trend in total carbon stock, and does not consider any other variables.

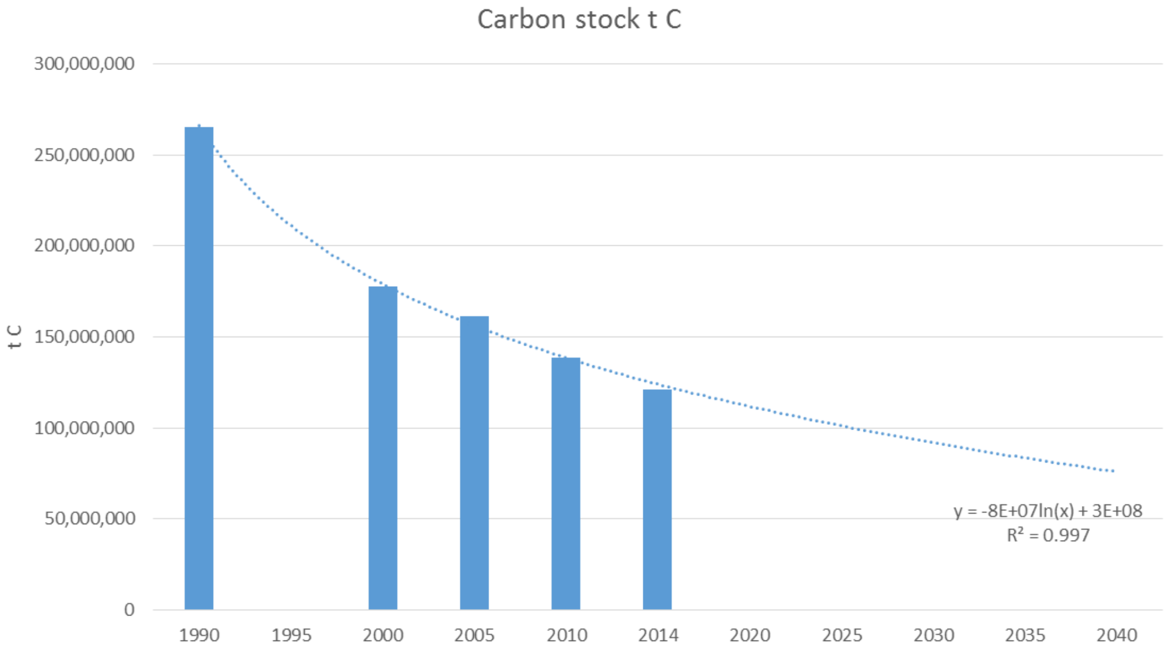

Figure 28: Development of total carbon stocks over time and carbon emission baseline.

4 Summary and conclusions

This report summarizes the results of the historic land cover and land cover change assessment and associated carbon emissions for the four districts Banyuasin, Musi Banyasin, Musi Rawas and Musi Rawas Utara for the time period 1990 – 2014. The assessment was carried out based on land cover data provided by ICRAF over a collaboration of the project Bioclime and LAMA-I. The ICRAF data was recoded to fit the BAPLAN classification scheme in use by the Indonesian Ministry of Environment and Forestry in order to make the results suitable for supporting the provincial forest administration and Government of South Sumatra in the reporting commitments of greenhouse gas emissions to the National level.
The results include a wide variety of geospatial datasets, ranging from the recoded land cover classifications, land cover change, deforestation statistics and maps, carbon stock maps and statistics, carbon stock change maps, carbon change statistics, as well as a simple way of projecting a carbon emission baseline up until 2040.
The study area in South Sumatra is dominated strictly by Tree crop plantations which constantly increased in spatial extent over the whole observation period by over 600,000 ha, culminating

at 1,461,231 ha in 2014. All forest types lost in spatial extent over the observation period, the most intense forest losses in absolute terms were found in Primary swamp forest (-578,818 ha) and Primary dryland forest (-364,692 ha). While the former was almost extent in 2014 (only 47,206 ha of former 626,024 ha left), the latter has retained 171,254 or 32 % of the original 535,947 ha. While significant parts of these losses were in the first observation window 1990 – 2000 due to logging and consequent conversion to Secondary forest, deforestation clearly dominated over time as a driver of primary forest loss. Land cover categories which increased in size include, aside from tree crop plantation, Plantation forest (+107,682 ha), Shrub (+64,357 ha), Open land (+52,928 ha), Settlement (+37,391 ha) and Mixed dryland agriculture/ mixed garden).

The analysis of change drivers revealed that Deforestation accounts for 63 % of all changes observed between 1990 and 2014, followed by forest degradation with 20 % and Plantation expansion on Non-forest with 12%.

Net forest loss amounted to 55 % or 865,286 ha in total over the whole observation period. Annual deforestation rates increased from 2.3 % yr-1 between 1990 and 2000 to 3.8 % yr-1 between 2005 and 2010 and then further to 4.9 % yr-1 between 2010 and 2014. This increase is due to varying but more or less constant net forest loss compared to ever decreasing forested areas.

The main driver of deforestation was found to be conversion to tree crop plantation accounting for 65 % of all deforestation. However, when observed through time, this driver lost importance since the period 2000 – 2005 with 74 % of all deforeations down to 43 %. This shows a trend in tree crop plantation development to move away from forested areas to the development of already deforested areas. Other important drivers of deforestation were "Conversion to shrub" and "Conversion to Plantation forest" accounting for approximately 10 % of all deforestation in the overall observation period.

The analysis of carbon stock distribution over time shows the highest carbon storage was and is found in primary dryland forest with 46,666,832 t C in 2014. However, the second highest carbon stocks are found in the tree crop plantation class which accounts for 23,379,703 t C in 2014 due to its dominant spatial extent in the AOI. Secondary dryland forest with 17,472,038 t C has the next highest carbon stocks followed by Primary Mangrove Forest with 12,724,300 t C.

The most intensive carbon losses were observed in the class Primary dryland forest, amounting to -99,378,611 t C followed by primary peat swamp forest with 65,406,453 t C. These intense losses were only partly compensated by carbon accumulation in Tree crop plantations amounting to 9,811,331 t C and Plantation forest (2,153,637 t C). Annual total carbon losses amounted totaled at -8,767,278 t C yr-1 in the period 1990-2000, constantly declining to -4,410,966 t C yr-1 in the period 2010 – 2014. The overall average 1990 – 2014 was -6,032,284 t C yr-1

The analysis of the drivers of carbon emissions showed that the main process causing emissions is the conversion into tree crop plantations which account for almost 80,000,000 t C in the observation period 1990 – 2014. The majority of those emissions came from the conversion of Primary dryland forest, followed by Primary swamp forest. The second highest emissions were caused from logging of Primary dryland forest, accounting for approximately 16,000,000 t C followed by the conversion to Plantation forest which produced another 13,000,000 t C. Logging of primary swamp forest caused another 11,000,000 t C.

A simple carbon emission baseline was drawn for the study area based on the historic development of total carbon stock and a trend analysis. The historic trend follows a logarithmic decline, which was projected forward until the year 2040. The projected carbon stock in the year 2040 amounts to approximately 75,000,000 t C which means the predicted emissions under a business as usual scenario amount to approximately 50,000,000 t C in the next 25 years, i.e. approximately 2,000,000 t C yr-1 as a long term annual average.

5 Outputs/ Deliverables

- Land cover classifications 1990, 2000, 2005, 2010, 2014 in the BAPLAN classification scheme, in Shapefile format
- Common No Data mask for the time period 1990 – 2014
- Land cover change, carbon stock, and carbon stock change for the time periods 1990 – 2000, 2000 – 2005, 2005 – 2010 and 2010 – 2014, in Shapefile format
- Land cover change, deforestation and GHG emission statistics, in Excel format

6 Annex

Table 12: Carbon change matrix for the time period 1990 – 2014.

	LandCover Carbon	2014																	
Class	**1990**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Sum**
Primary dry land forest	**1**	0	-16,662,045	0	-5,150	0	-23	-3,234,033	-45,076,302	-9,765,864	-3,117,348	-127,766	-16,284	-169,480	-1,267,084	-663,107	0	-1,594	**-80,106,079**
Secondary/ logged over dry land forest	**2**	0	0	0	-90	0	-19	-345,852	-5,908,321	-382,132	-352,609	-32,856	-1,073	-14,647	-98,024	-124,854	0	0	**-7,260,477**
Primary swawp forest	**3**	0	1,238	0	-11,275,781	0	-33,710	-290,774	-24,412,205	-3,605,377	-5,448,355	-2,701,684	-23,956	-1,502,502	-3,545,984	-1,057,253	0	-98,517	**-53,994,861**
Secondary/ logged over swamp forest	**4**	0	344	0	0	0	-300	11,382	-1,661,987	-54,730	-262,238	-256,245	-3,516	-133,384	-244,608	-131,555	0	-13,110	**-2,749,947**
Primary mangrove forest	**5**	0	23	0	-234	0	-889,271	-16,585	-80,556	-20,711	-164,855	-47,164	-541	-7,328	-38,224	-22,952	0	-51,117	**-1,339,517**
Secondary/ logged over mangrove forest	**6**	0	38	0	3	0	0	917	-1,734	-130	-3,163	-2,547	-28	-592	-1,297	-709	0	-580	**-9,823**
Mixed dryland agriculture/mixed garden	**7**	0	14,181	0	-1,678	0	-36	0	-1,670,830	-34,436	-24,332	-55,622	-1,199	-13,249	-17,870	-64,440	0	-3,308	**-1,872,818**
Tree crop plantation	**8**	0	50,319	0	5,802	0	25	1,532,850	0	70,174	-37,254	-128,395	-118	-61,410	-99,743	-178,550	0	-16,680	**1,137,021**
Plantation forest	**9**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Scrub	**10**	0	29,730	0	27,743	0	176	43,542	94,458	6,967	0	-8,625	45	-9,359	-13,471	-20,305	0	-4,674	**146,227**
Rice field	**11**	0	4,694	0	2,854	0	575	198,954	618,816	30,563	25,186	0	3,158	-6,174	-18,405	-25,577	0	-765	**833,879**
Dry land agriculture	**12**	0	91	0	37	0	0	2,894	894	338	-160	-970	0	-1,298	-785	-2,856	0	-106	**-1,921**
Grass	**13**	0	1,057	0	5,220	0	83	7,122	328,431	18,755	20,974	5,609	1,171	0	-5,687	-6,123	0	-436	**376,177**
Open land	**14**	0	138	0	909	0	2	2,580	24,333	7,594	11,139	1,111	117	1,464	0	0	0	0	**49,388**
Settlement/ developed land	**15**	0	334	0	37	0	0	2,632	13,880	376	297	63	6	39	0	0	0	0	**17,663**
Water body	**16**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Embankment	**17**	0	81	0	0	0	0	66	107	0	9	0	0	0	0	0	0	0	**263**
	Sum	**0**	**-16,559,777**	**0**	**-11,240,329**	**0**	**-922,497**	**-2,084,305**	**-77,731,017**	**-13,728,613**	**-9,352,711**	**-3,355,090**	**-42,218**	**-1,917,920**	**-5,351,183**	**-2,298,279**	**0**	**-190,886**	**-144,774,823**