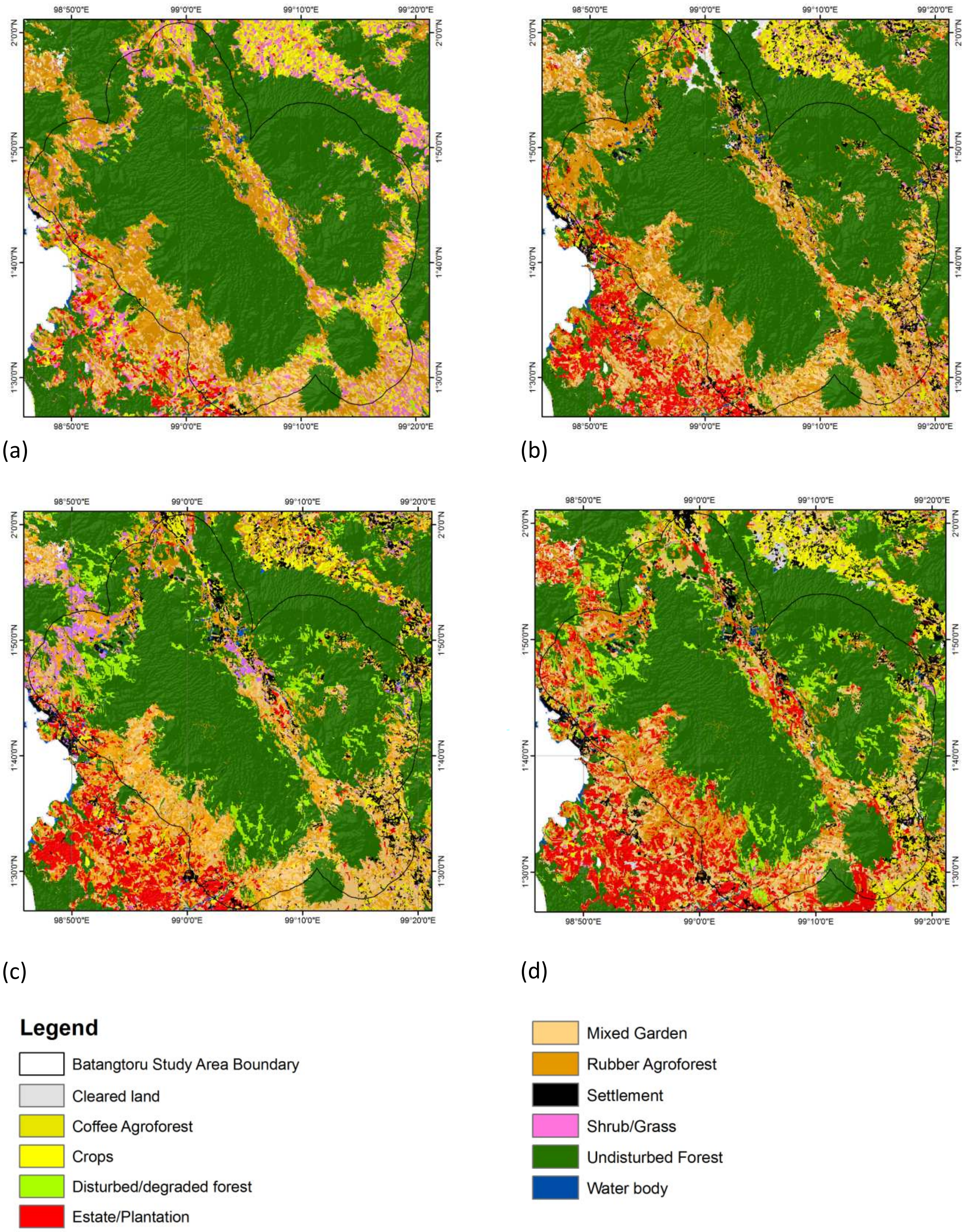


Figure 26. Land-cover maps of Batang Toru: (a) 1994; (b) 2001; (c) 2006; (d) 2009

Figure 26 shows the time-series land-cover maps of Batang Toru study area. The accuracy assessment was conducted by utilizing 173 'groundtruth' points on the 2009 map and the result indicates the accuracy level of 85.5% with the Khat statistics of 82% *(at $p=0.00001$).*

4.3.1.1 Forest-cover and land-cover dynamics in Batang Toru orangutan habitat

Within the orangutan habitat boundaries, forest unquestionably dominates, with a stable area of approximately 102 000–104 000 ha throughout 1994–2009, covering 94–95% of the total habitat area. Degradation occurred slightly in the forest area, amounting to 8000 ha and 9000 ha in 2005 and 2009 respectively. Anthropogenic land uses were observed in very small areas. Rubber agroforest appeared in relatively larger areas compared to other land uses of mixed gardens, plantations, coffee agroforest and crops. The areas of rubber agroforest were slightly decreasing throughout the periods of observation, that is, 4400 ha in 1994 to 3500 ha in 2009. Most of the agricultural and agroforest activities existed since the beginning of observation period (1994 map) (see also section 0).

4.3.1.2 Land-cover dynamics in the vicinity of orangutan habitat

For the entire study area, which included the 5-km-wide buffer around the orangutan habitat, forest still dominated, covering 151 000 ha (61%) of the entire area in 2009. Since 1994, the decrease of forest area was observed to be approximately 11 000 ha throughout the study period (from 162 000 ha in 1994 to 151 000 ha in 2009). Within the forested area, signs of degradation started to appear substantially on the 2006 map, similar to the trend in the core habitat area, with degraded forest areas increasing from 13 000 ha in 2005 to 17 000 ha in 2009 (see Table 29).

Table 29. Land-cover changes in Batang Toru study area, 1994–2009 (with the grouping for some minor classes)

Land-cover type	Area 1994 (ha)	Area 2001 (ha)	Area 2005 (ha)	Area 2009 (ha)
Undisturbed forest	159 470	152 126	140 294	133 563
Disturbed forest	3312	1372	13 205	17 513
Rubber agroforest	38 651	40 659	31 485	30 303
Mixed gardens	15 425	26 916	30 364	27 808
Other crops	15 506	7478	10 323	11 576
Plantation	1462	4787	4518	13 370
Other	12 430	11 712	16 044	11 900

Anthropogenic land uses have been observed since the beginning of the observation period (1994), dominated by rubber agroforest and mixed gardens (Table 29 and Figure 27(b); the red circles showing the emerging land-cover types). Mixed gardens in Batang Toru area were dominated by *kemenyan* and fruit-tree gardens (see section 0.3). *Kemenyan* gardens were normally located near forest while fruit-tree gardens were closer to settlement areas (Mulyoutami et al., this report). As for rubber, both agroforest systems and monoculture plantations existed (see also section 0.3.7). The areas of rubber agroforest decreased slightly from 2001 to 2009, that is, 40 000 ha to 30 000 ha, while mixed gardens increased from 15 000 ha in 1994 to 30 000 ha in 2005, before decreasing slightly to 28 000 ha in 2009. For tree-based agriculture–agroforest systems of rubber, coffee, mixed gardens (mainly *kemenyan* and durian) and plantations, the figures show variation between 61 000 ha and 74 000 ha during the observation periods. Oil palm plantations showed to appear into substantially larger areas only in 2009 observation (data not shown in the figures or tables).

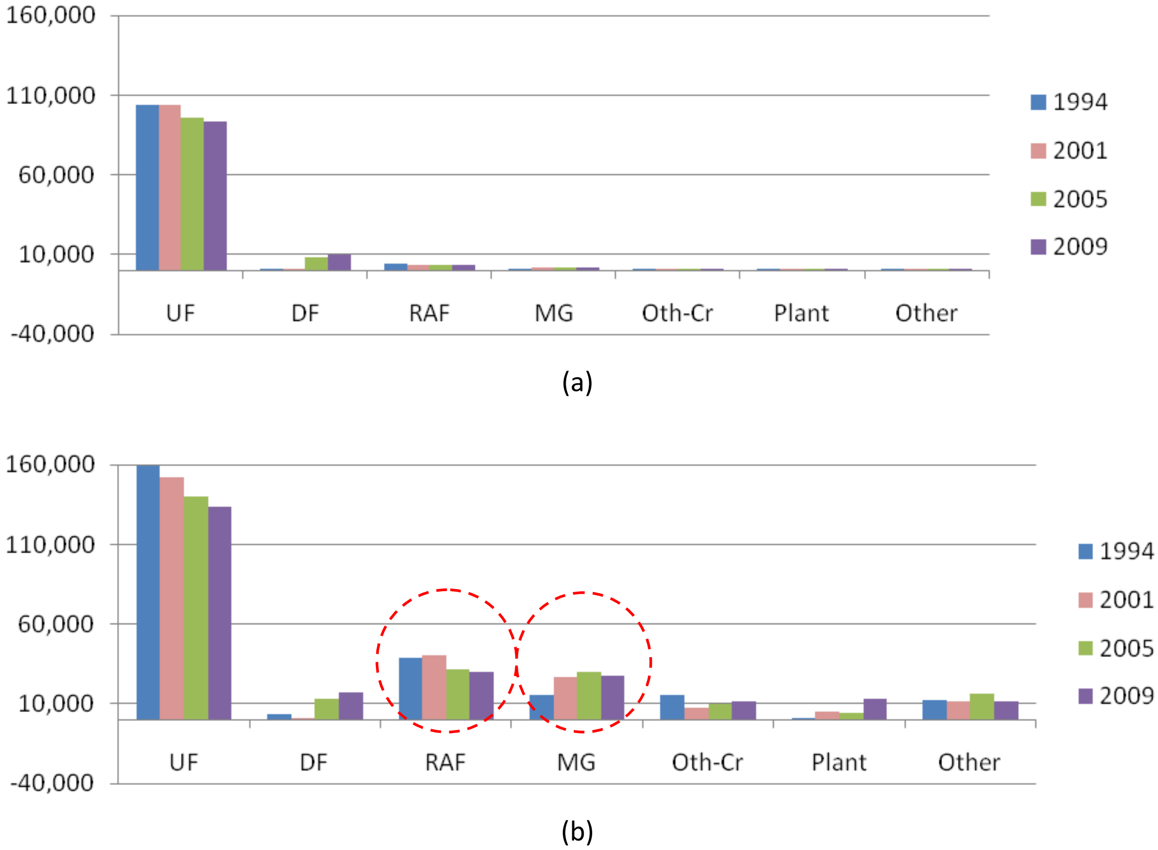


Figure 27. Land cover and changes from 1994 to 2009 in Batang Toru: (a) within orangutan habitat; and (b) in the entire study area. (Legend: UF=Undisturbed Forest, DF=Disturbed Forest, RAF=Rubber Agroforest, Oth-cr= other crops, incl. oil palm, coffee gardens, MG=Mixed Gardens, Est=Estate/Plantation, Other= other land-cover types, incl. shrubs, cleared land, settlement)

4.3.1.3 Aboveground carbon-stock (AGCS) and emissions for Batang Toru

The AGC density for both the entire study area and orangutan habitat alone are presented in Figure 28 and the maps in Figure 30. The AGC density in the orangutan habitat decreased from 235 t/ha in 1994 to 225 t/ha in 2009, while for the study area it decreased from 185 t/ha in 1994 to 174 t/ha. Throughout all observation periods, AGC density was always higher in orangutan habitat than that in the entire study area by approximately 50–55 t/ha. The annual rate of AGC decreases were less than 1% for both the core habitat and the entire study area.

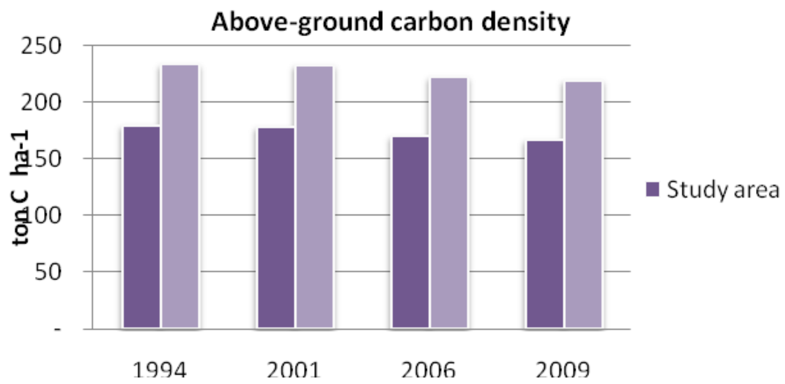


Figure 28. AGC density in Batang Toru

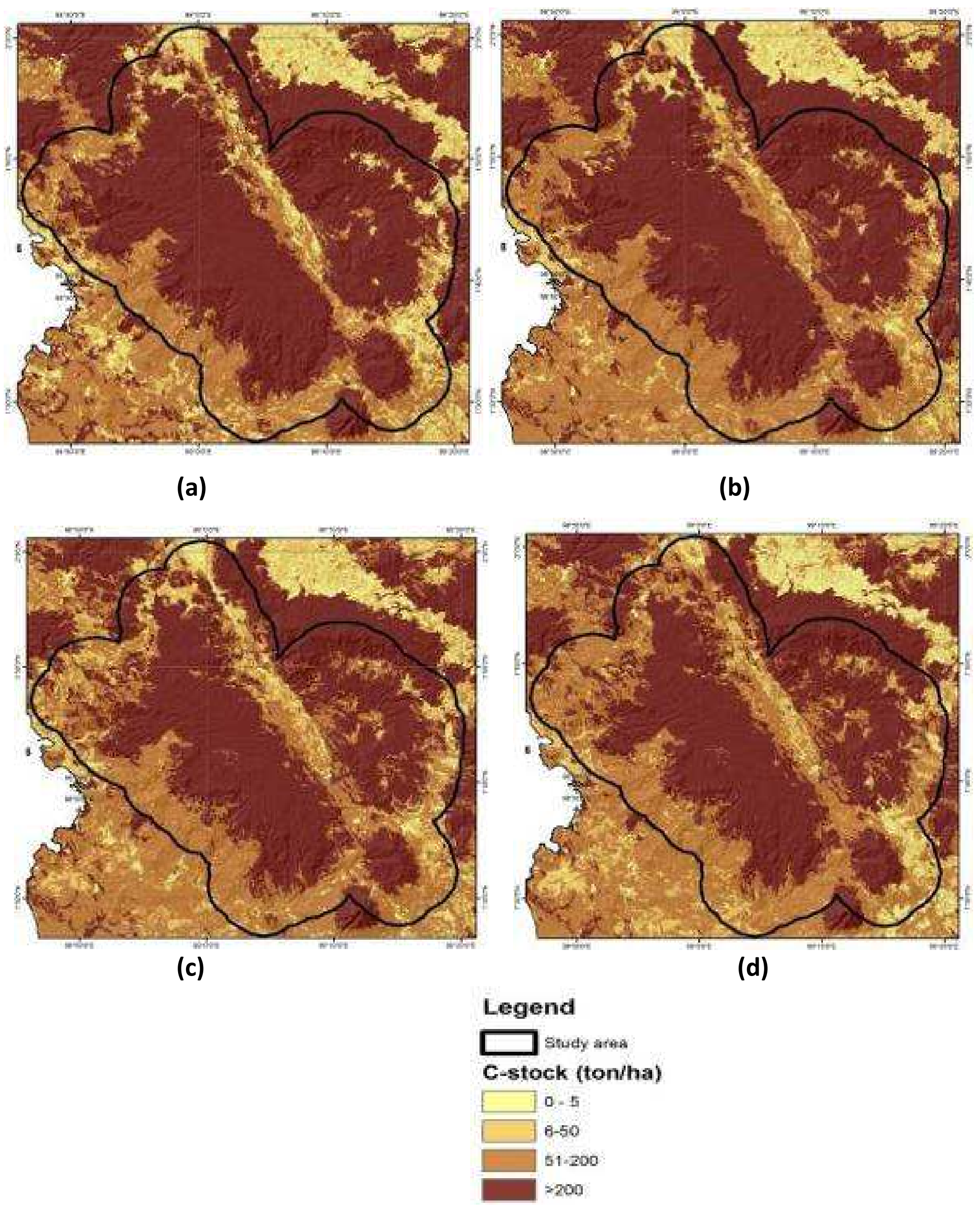


Figure 29. Maps of aboveground carbon-stocks in Batang Toru: (a) 1994; (b) 2001; (c) 2006; (d) 2009

For the entire Batang Toru area, there was an increase in total emissions ranging from 1.3 $MtCO_2e$/yr to 1.8 $MtCO_2e$/yr from 1994 to 2009, while for the core orangutan habitat emission rates ranged from 201 000 tCO_2e/yr to 546 000 tCO_2e/yr, with the highest in 2001–2006. The figures of emissions and sequestrations for each time series are presented in Table 30.

Table 30. Emissions, sequestrations and net emissions from 1990 to 2009, based on aboveground carbon-stock changes in Batang Toru study area

	1994-2001	2001-2006	2006-2009
Batang Toru Study area			
Emission - study area			
Total emission (ton CO2 eq.)	9,341,649	7,234,623	5,485,337
Annual emisssion (ton CO2 eq./yr)	1,334,521	1,446,925	1,828,446
Ave. ann. emission (ton CO2 eq./ha/yr)	5.40	5.86	7.40
Sequestration			
Total sequestration (ton CO2 eq.)	7,845,025	1,195,675	3,518,180
Annual sequestration (ton CO2 eq./yr)	1,120,718	239,135	1,172,727
Ave. ann. sequestration (ton CO2 eq./ha/yr)	4.54	0.97	4.75
Net emission- study area			
Total net emission (ton CO2 eq.)	1,496,624	6,038,948	1,967,157
Annual net emission (ton CO2 eq./yr)	213,803	1,207,790	655,719
Ave. ann. net emission (ton CO2 eq./ha/yr)	0.87	4.89	2.65
OU Habitat			
Emission - OU habitat			
Total emission (ton CO2 eq.)	1,410,112	2,731,405	958,361
Annual emisssion (ton CO2 eq./yr)	201,445	546,281	319,454
Ave. ann. emission (ton CO2 eq./ha/yr)	1.82	4.95	2.89
Sequestration			
Total sequestration (ton CO2 eq.)	1,065,493	75,622	84,369
Annual sequestration (ton CO2 eq./yr)	152,213	15,124	28,123
Ave. ann. sequestration (ton CO2 eq./ha/yr)	1.38	0.14	0.25
Net emission - OU habitat			
Total net emission (ton CO2 eq.)	344,618	2,655,784	873,991
Annual net emission (ton CO2 eq./yr)	49,231	531,157	291,330
Ave. ann. net emission (ton CO2 eq./ha/yr)	0.45	4.81	2.64

Emission factors from aboveground biomass changes in the orangutan habitat were highest during 2001–2006 (4.95 tCO_2e/ha/yr). which is attributed to the degradation in some areas of the forest edges (see Figure 26 (c) and (d)). Sequestration in orangutan habitats was small ranging between 0.14-1.38 tCO_2e/ha/yr . The highest sequestration (1.38 tCO_2e/ha/yr) took place in 1994-2001, during which the emission is the smallest (1.82 tCO_2e/ha/yr) resulting in the lowest net emission factor for that period (0.45 tCO_2e/ha/yr). For the entire study area, the trends of emission factors show slight but persistent increase throughout 1994–2009 (5.4 to 7.4 tCO_2e/ha/yr). However, by taking into account the sequestration, the pattern changes: net emission factor peaked during 2001–2006 (4.9 tCO_2e/ha/yr) and were low during 1994–2001 and 2006–2009 (see Figure 30).

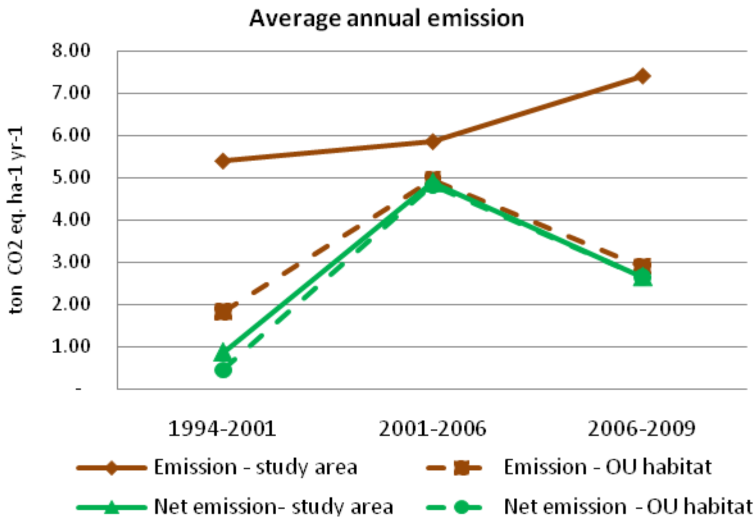


Figure 30. Emission factor and net emission factor based on aboveground biomass for Batang Toru study area and orangutan habitat

4.3.2 Tripa

The entire study area for Tripa covers an area of 102 040 ha. In Tripa, the land cover is categorised into 1) undisturbed forest; 2) disturbed forest; 3) agroforest/vegetation mosaics; 4) oil palm; 5) crops (including rice fields); 6) shrubs and grass; 7) rural settlement; 8) cleared land; 9) water body; and 10) no data (cloud and shadow). The characteristics of the major land-cover types observed in the field can be seen in Annex 2.

Time-series land-cover maps produced in this study can be seen in **Error! Reference source not found.**. The accuracy assessment was conducted by utilizing 62 'groundtruth' points on the 2009 map and the result indicates an accuracy level of 80.6% with the Khat statistics of 76.7% *(at p=0.00001).*

4.3.2.1 Land-cover types and the dynamics

Land cover in Tripa in the beginning year of observation (1990) was dominated by forest. Since more than 70% of the forest is on peat soil and/or peat swamp, for the remaining discussion in this report, 'forest' in Tripa mostly refers to these forest types. Forest covered 67 000 ha (65% of the area) in 1990 and decreased to 19 000 ha (18% of the total area) by 2009. The highest rate of forest conversion occurred 2005–2009 with almost 4000 ha of forest being lost annually to other uses. The observed annual rate of forest loss during the four periods of observation are 2-14 % per year[14], with the highest (14 %) taking place during the period 2005–2009.

[14] It applied the calculation of annual rate of deforestation by FAO (FAO, 1995)

Other land uses, reflecting human activities (that is, agriculture and agroforestry) are growing in many parts of the study area. The largest and most intensive development is that of oil palm plantations which started to appear substantially in 1995 (5884 ha). From 2005 to 2009, plantation areas doubled from 19 000 ha to 39 000 ha, showing the highest annual rate of 4900 ha per year, which is the highest compared to rates in the other observation periods. The conversion from forest to oil palm in that period (2005–2009) was approximately 1770 ha per year.

Other anthropogenic land uses are growing in less expansive fashion, comprising seasonal crops such as paddy rice and agroforest, which are located in the northern and eastern fringes of the study area.

The complete areas of changes of all the land-cover types in the Tripa study area are shown in table 31

Table 31Figure 32 (the ellipses) show those with largest changes during the observation periods.

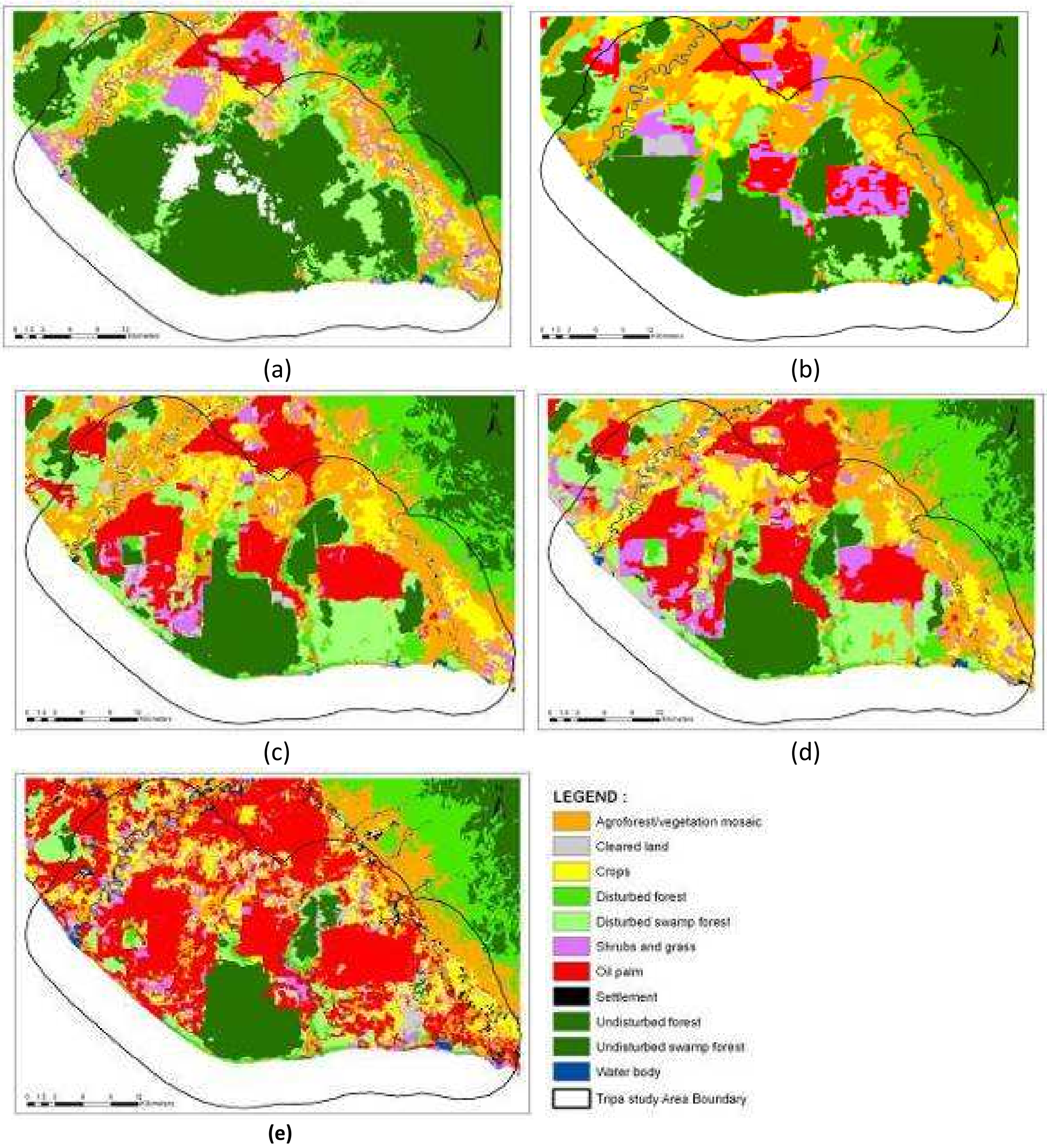


Figure 31. Land-cover maps of Tripa study area: (a) 1990; (b) 1995; (c) 2001; (d) 2005; (e) 2009

Table 31. Land-cover changes in Tripa study area, 1990–2009

Land-cover type	Area 1990 (ha)	Area 1995 (ha)	Area 2001 (ha)	Area 2005 (ha)	Area 2009 (ha)
Undisturbed forest	50 067	36 343	18 667	14 049	11 405
Disturbed forest	17 885	14 283	20 417	20 878	7570
Agroforest/vegetation mosaics	10 248	23 700	23 277	19 575	13 840
Oil palm	941	5884	17 908	18 606	38 568
Crops	9988	9197	10 182	12 676	13 244
Shrubs and grass	7727	5989	4773	9417	7017
Cleared land	643	1758	2125	1635	3867
Others (settlement, water, no data)	4543	4887	4693	5206	6531

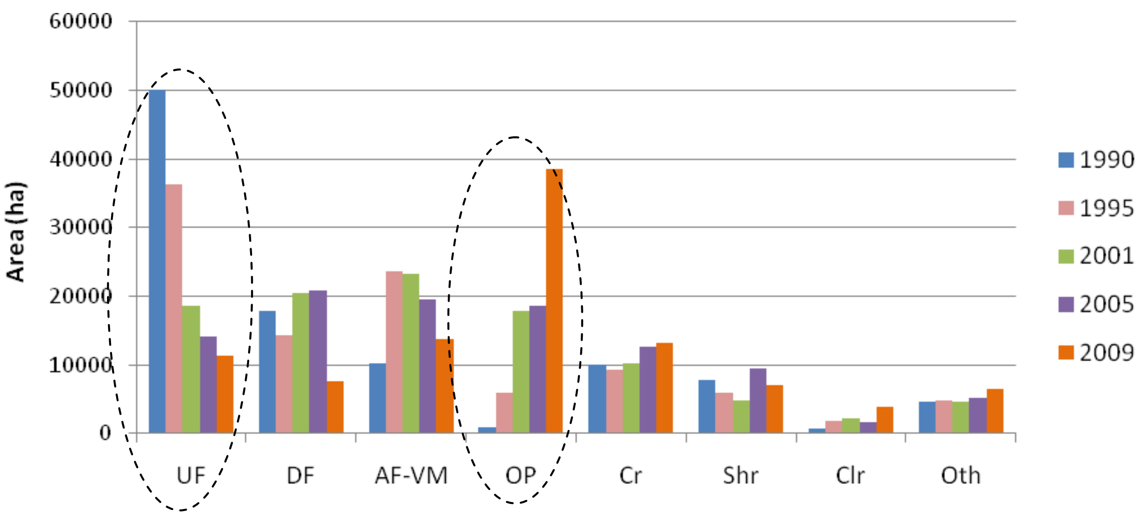


Figure 32. Changes in land cover in Tripa study area, 1990–2009 (Legend: UF=Undisturbed Forest, DF=Disturbed Forest, AF-VM=Agroforest/Vegetation mosaics, OP=Oil Palm, Cr=Crops (incl. rice), Clr=Cleared land, Oth = others (settlement, water, no data))

4.3.2.2 Forest conversion in Tripa Leuser Ecosystem Zone

Tripa–Leuser Ecosystem Zone (Tripa–KEL) map and Tripa HGU maps (YEL, pers. comm.) show an area of 60 316 ha and 48 000 ha respectively (see Figure 22(b)). The percentages of land-cover types within Tripa–KEL for 1995 (prior to KEL establishment), 2001 (immediately after KEL establishment) and 2009 (most current situation) can be seen in Figure 33.

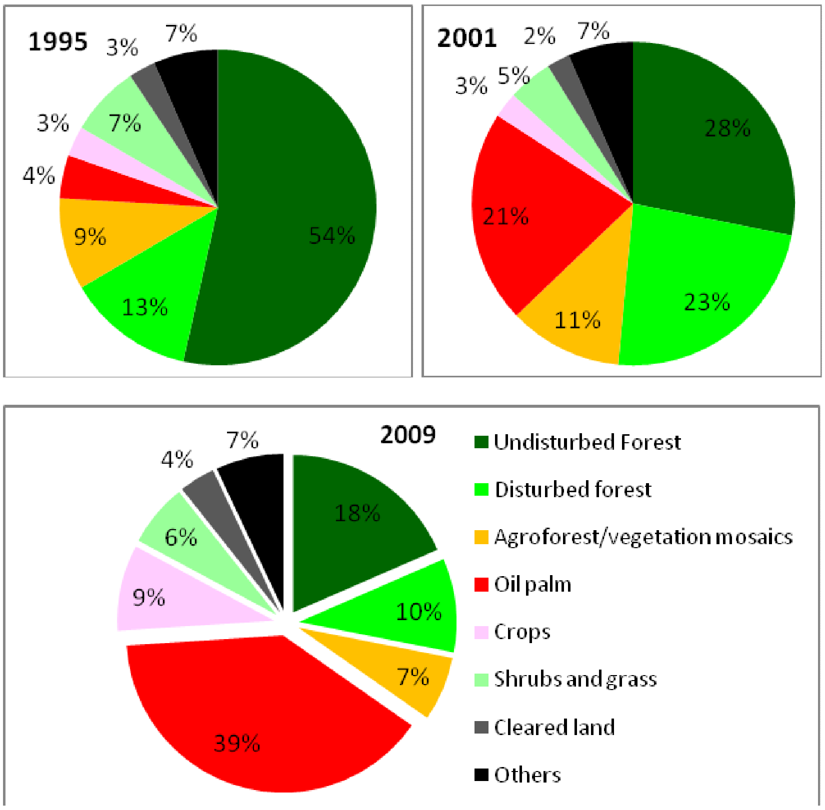


Figure 33. Percentages of land-cover types in Tripa–KEL for 1995, 2001 and 2009

In the mid-1990s, when most of the HGU concessions were issued (Minnimeyer, 2009), Tripa–KEL was dominated by undisturbed forest (54%), followed by low density/disturbed forest (13%), while oil palm covered 4% of the area. Three years after KEL establishment, as shown by the 2001 land-cover map, oil palm had expanded to 12 800 ha (21% of Tripa–KEL). By 2009, it grew to 23 600 ha (39% of Tripa–KEL), 6800 ha of which (9% of Tripa–KEL) was conversion from previously undisturbed forest, despite the designation as Leseur Ecosystem Zone (KEL) (Figure 33 and Table 32).

Table 32. Matrix of land-cover trajectory in Tripa–KEL in Tripa, 2001–2009

2001–2009	Forest (ha)	Agroforest/ mosaics (ha)	Oil palm (ha)	Crops (ha)	Shrubs (ha)	Cleared land (ha)	Others (ha)	Total 2001
Forest	16 896	1890	**6820**	2416	1075	1821	137	31 055
Agroforest/ mosaics	28	1399	2 651	1556	876	135	197	6842
Oil palm	3	170	**11 588**	202	890	24	6	12 881
Crops	1	247	311	596	344	13	25	1537
Shrubs	5	175	1527	345	457	176	2	2686
Cleared land	1	103	753	220	254	43	7	1380
Others	14	16	18	25	14	4	3846	3935
Total 2009	**16 948**	**3999**	**23 668**	**5359**	**3909**	**2215**	**4219**	**60 316**

By 2009, 17 000 ha of forest (28% of the area) was left intact in Tripa–KEL. Overall, the average rate of oil palm expansion since most HGU concessions were issued in the mid-1990s (1995 observation) to date (2009 observation) reached 1500 ha per year. By observing the period after KEL was established, that is, 2001–2009 observation, oil palm expansion within Tripa–KEL is only slightly lower: 1348 ha/yr. Specifically, conversion from forest to oil palm plantations involved 852 ha/yr in the period 2001–2009 (see Table 32). The last period of observation (2005–2009) showed the highest forest loss rate to oil palm plantations, 3300 ha/yr, as it covers the 'post-conflict' era.

4.3.2.3 Aboveground carbon-stock (AGCS) and emissions for Tripa

The aboveground carbon reference for Tripa is listed in Table 28 (see also Component B of this report). The average carbon-stock density in Tripa decreased from 125 t/ha in 1990 to 52 t/ha in 2009 while for Tripa–KEL, carbon density decreased from 158 t/ha in 1990 to 67 t/ha in 2009 (See Figure 34 and Figure 35).

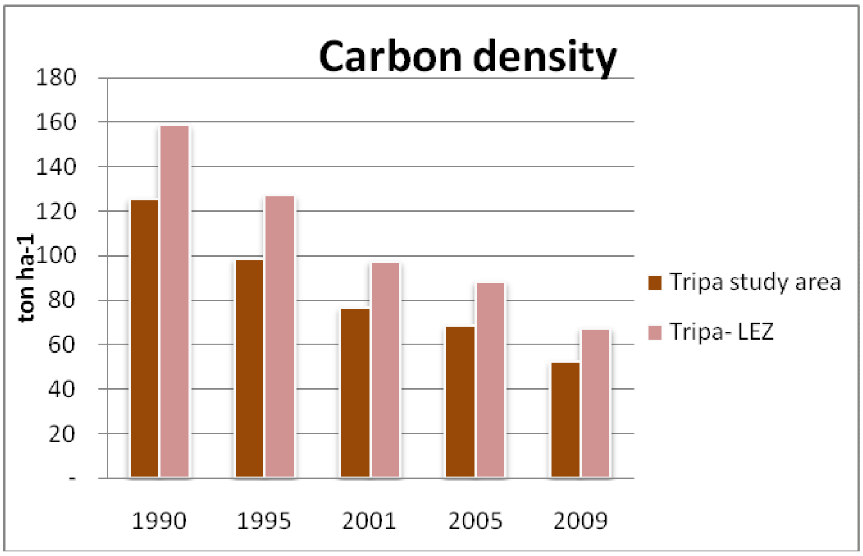
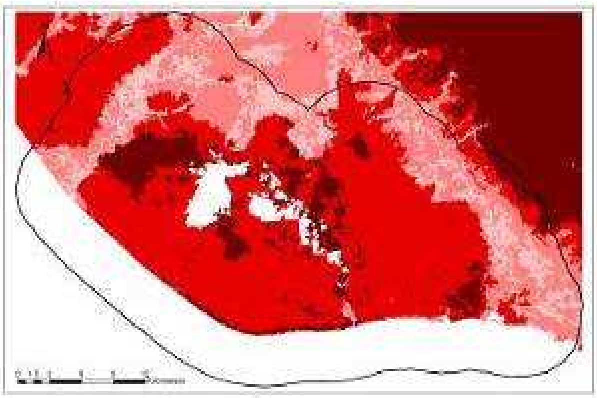
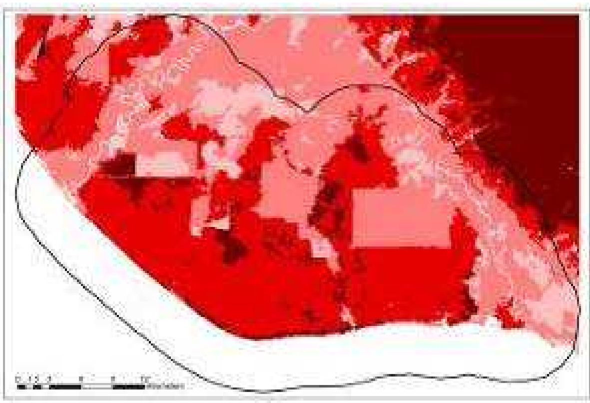


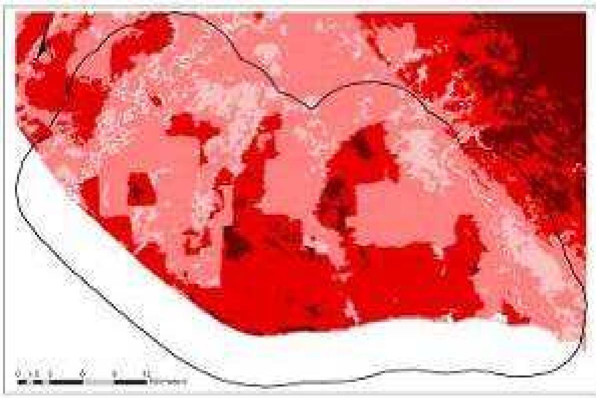
Figure 34. Carbon-stock density of Tripa study area and Tripa–KEL (written as 'Tripa-LEZ' in this figure)



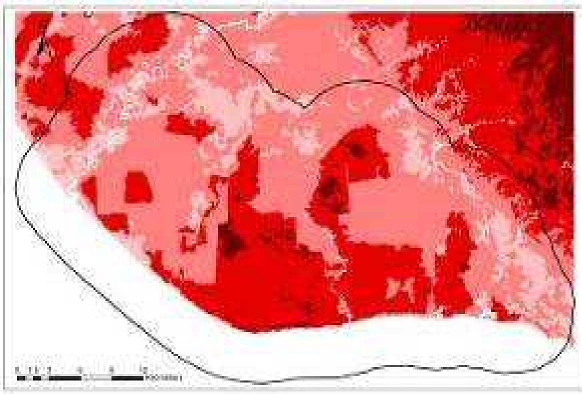
(a)



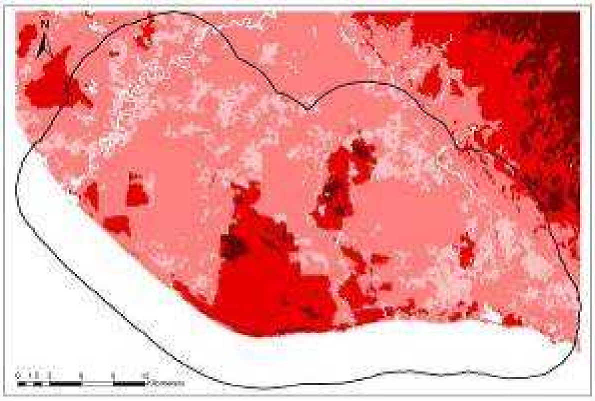
(b)



(c)



(d)



(e)

Figure 35. Maps of aboveground carbon-stock in Tripa study area: (a) 1990; (b) 1995; (c) 2001; (d) 2005; (e) 2009

Throughout the periods of observation, annual emission rates owing to land-use conversion in the study area ranged between 943 000 tCO_2e/yr and 2.2 $MtCO_2e$/yr, with the highest (2.2 $MtCO_2e$/yr) being in the period 1990–1995. By considering the aboveground carbon sequestration through land-use changes, the highest net emission rate was 2 $MtCO_2e$/yr, which occurred during 1990–1995.

For Tripa–KEL, the annual emission was highest in 1990–1995, 1.43 $MtCO_2e$/yr, and the lowest in 2001–2005 (588 000 tCO_2e/yr). And by taking into account the sequestration, the pattern is similar, in which annual net emission rate was highest in 1990–1995 (1.40 $MtCO_2e/yr$) and the lowest in 2001–2005 (502 000 tCO_2e/yr). The complete list showing the portfolio of aboveground carbon emissions and sequestrations in Tripa is shown in Table 33.

Table 33. Emission, sequestration and net emission from 1990 to 2009, based on aboveground carbon-stock changes in Tripa

	1990–1995	1995–2001	2001–2005	2005–2009
Tripa study area				
Emission: Study area				
Total emission (tCO_2e)	11 008 417	9 310 972	3 775 111	7 591 064
Annual emission (tCO_2e /yr)	2 201 683	1 551 829	943 778	1 897 766
Ave. ann. emission (tCO_2e/ha/yr)	21.58	15.21	9.25	18.60
Sequestration				
Total sequestration (tCO_2e)	929 925	1 057 174	740 446	1 652 640
Annual sequestration (tCO_2e /yr)	185 985	176 196	185 112	413 160
Ave. ann. sequestration (tCO_2e/ha/yr)	1.82	1.73	1.81	4.05
Net emission: Study area				
Total net emission (tCO_2e)	10 078 492	8 253 798	3 034 664	5 938 424
Annual net emission (tCO_2e/yr)	2 015 698	1 375 633	758 666	1 484 606
Ave. ann. net emission (tCO_2e/ha/yr)	19.75	13.48	7.43	14.55
Tripa–KEL				
Emission				
Total emission (tCO_2e)	7 169 491	7 177 397	2 353 612	5 252 623
Annual emission (tCO_2e/yr)	1 433 898	1 196 233	588 403	1 313 156
Ave. ann. emission (tCO_2e/ha/yr)	23.77	19.83	9.76	21.77
Sequestration				
Total sequestration (tCO_2e)	181 525	642 028	343 573	641 864
Annual sequestration (tCO_2e/yr)	36 305	107 005	85 893	160 466
Ave. ann. sequestration (tCO_2e/ha/yr)	0.60	1.77	1.42	2.66
Net emission				
Total net emission (tCO_2e)	6 987 965	6 535 369	2 010 039	4 610 759
Annual net emission (tCO_2e/yr)	1 397 593	1 089 228	502 510	1 152 690
Ave. ann. net emission (tCO_2e/ha/yr)	23.17	18.06	8.33	19.11

The emission factor from aboveground biomass obtained from the average annual emissions for Tripa study area ranged between 9.2 and 21.6 tCO_2e/ha/yr, while those for Tripa–KEL ranged between 9.8 and 23.8 tCO_2e/ha/yr. By taking into account the sequestration factor, the average annual net emissions, or net emission factor, for the entire study area were 7.4–19.7 tCO_2e/ha/yr, while for Tripa–KEL they were 8.3–23.2 tCO_2e/ha/yr (see Table 33 and Figure 36). Comparing average annual emissions and average annual net emissions for both levels or analyses, the trends show no major discrepancy, that is, the lowest in 2001–2005 (see Figure 36).

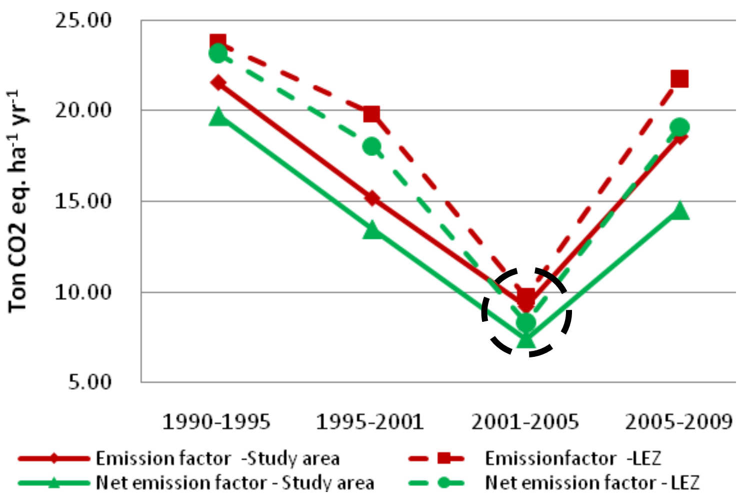


Figure 36. Emission factors and net emission factors for Tripa study area and Tripa–KEL (called LEZ in this figure) (For dashed-circle, see discussion in section 4.4.1)

4.4 Discussion and conclusions

Analyses of land-use and land-cover change in the vicinity of two habitats of Sumatran orangutan, Tripa and Batang Toru, showed dynamics of anthropogenic influences, albeit with different magnitudes and trends. Anthropogenic disturbances included massive forest land conversions in Tripa, while those in Batang Toru appeared to be mostly forest degradation, aside from the non-forest land-use dynamics in the surrounding areas. The sections below present summaries of the findings and associated discussions.

4.4.1 Batang Toru case study

Unlike in Tripa, where pressure of forest conversion was on the core part of the study area, at the Batang Toru study site anthropogenic pressure was on the forest edges and buffer area around the forest. When focusing only on the core habitat area, forest cover was stable and small patches of anthropogenic land use (rubber agroforest), which had already appeared on the 1994 map, did not show any significant increase throughout the period of observation. Within the habitat areas, forest degradation had occurred as a result of logging activities, forest encroachment and dwelling settlement by migrants (YEL/SOCP, 2010 ; Roshetko et al., 2007a; Roshetko et al., 2007b).

By including the 5-km-wide buffer area, as well as the 'strip' of land-use mosaics between the habitats, the dynamics of anthropogenic land uses were observed in more obvious patterns. Forest degradation was larger and disturbed forest covered approximately 2–11% of the total forest area. For other land uses, rubber agroforest areas decreased slightly from 2000 to 2009, while mixed gardens increased slightly. From the overall dynamics of tree-based agroforest and mixed systems in the buffer area, there were no significant changes during the period of observation.

When comparing emission factors for the two levels of analysis (entire study area and orangutan habitat), obvious differences appeared (Figure 30). For the study area, the sequestration factor was high in the last period of observation, resulting in a decreasing net emission factor. Such a trend did not occur for the orangutan habitats. With the low sequestration, the net emission is rather similar to emission. The sequestration trend was captured through the land-cover changes occurring in the buffer area, implying increased carbon density outside core habitat areas through increased plantations and mixed gardens/complex agroforest converted from patches of shrubs and/or low density agroforest.

The absence of a promising trend in the orangutan habitats, because of the low sequestration factor, should be carefully noted as being a limitation of the methodology applied. RaCSA applied 'stock difference' methods, which only takes into account differences owing to land-use and land-cover changes and does not take into account carbon sequestration or CO_2 removal through vegetation growth. The 'gain-loss' method as described in IPCC (2006) is the appropriate method for the latter subject.

Many mixed gardens, mostly identified as *kemenyan* gardens on the ground, owing to the very high canopy cover and the multi-strata vegetation, resembled forest cover canopy cover. Therefore, in some parts of the study area this land-cover type may be classified as forest. Such confusion could also occur between mixed gardens, rubber agroforest and plantations. A likelihood of mixed classification during image processing in the subset areas of mixed tree-based systems is quite high owing to the similarity in vegetation complexity and canopy covers (for example, Ekadinata et al*.,* 2004).

Even after including the more dynamic land cover in the buffer area, overall, the threat of forest conversion in Batang Toru area may be categorised as low. The stable carbon-stock density throughout the period of observation and the low emission factor from aboveground biomass confirm that conclusion. In comparison to the other orangutan habitat (Tripa), the aboveground carbon emission in Batang Toru was substantially lower. The stable agroforest and complex tree-based systems within the buffer area may suggest an effective buffer function which, together with the topography, prevents the core area being converted from forest into intensive land uses.

4.4.2 Tripa case study

For Tripa, the threat was clearly to the core of the study area where peat and peat swamp forests were threatened by, and converted to, oil palm plantations. Prior to the establishment of Leuser Ecosystem Zone *(*Kawasan Ekosistem Leuser or KEL*)* in 1998, the study area belonged to 'other land use' *(*Area Penggunaan Lain*)* forest status. Even after KEL was established, oil palm plantations continued to expand, based on concession rights. Between 2001 and 2005, activity slowed presumably due to conflicts as shown in Table 14, but during the period 2005 to 2009, large expansion of oil palm plantations once again took place. Rapid economic development, following both post-tsunami reconstruction and post-peace agreement, that lead to the reactivation of forest clearance may be the reasons (PanEco, 2010).

By observing land-cover changes in the entire Tripa study area and those in the core area (Tripa–KEL and HGU areas), the pressure in the core area suggests an alarming magnitude and trend, especially with regards to forest conversion. The inclusion of Tripa into KEL did not seem to slow down the rate of expansion. The forest cover in the Tripa study area (2009 observation) was 19 000 ha or 18% of the total area, 17 000 ha of which is located within the Tripa–KEL area. By applying the most recent rate of forest conversion to oil palm in Tripa–KEL (3300 ha/yr; see section 4.3.1.2) and assuming that oil palm expansion cannot be stopped through a 'protected area' approach, the 19 000 ha of forest left will likely be lost in the next 6–7 years, that is, by 2015/16. If this happens, upon the issuance of further oil palm concessions rights or HGU, it is likely that in approximately 26 years (1990–2016) peat and peat swamp forest in Tripa will have been completely wiped out.

The period when carbon emissions were highest was 1990–1995, while the lowest was during 2001–2005. The highest emission rate is attributed to the beginning of forest conversion to oil palm plantations. The lowest rate, during 2001–2005, confirms the slowing down of activities, as mentioned previously. Average annual net emission rate, or net emission factor, during 2005–2009 showed a slight reduction for the entire study area compared to the trend for Tripa–KEL (Figure 36). This rather positive trend for the Tripa study area as compared to Tripa–KEL might be attributed to the fact that in the northern part (residual area outside Tripa–KEL), oil palm expanded as non-forest conversion, mostly from other crops and low-density agroforestry systems. And owing to there being less carbon stored in those land uses, oil palm establishment implied a sequestration trend. This, nonetheles, inevitably means there was earlier forest conversion in that area prior to this project's observation.

A future scenario that will keep the existing forest cover intact (19 000 ha), if at all possible, will create a less bleak future for both carbon storage and orangutan habitat in Tripa. During the period of this project, anecdotal information revealed that approximately 6000 ha of peat forest in the south of the study area (see Figure 31) would be kept intact, as commited by the concession holder. However, in contrast to that, HGU concessions were still issued elsewhere during the past few years and land clearing for oil palm plantation was observed (YEL, pers.comm.; field observation, 2010).

The distinction between oil palm expansion from forest and that from lower density vegetation cover is important to note for understanding carbon-stock loss as well as the loss of orangutan habitat. From a carbon-stock perspective, conversion from forest results in a carbon debt committed by a plantation's establishment, while conversion from lower density vegetation implies a sequestration trend. Assessments of the trajectory of land-use change for oil palm establishment are crucial because there is room to avoid carbon debt (ICRAF Southeast Asia Program, 2009). Nevertheless, while the latter notion is time-bound, relevant only for aboveground carbon stock and for oil palm establishment on mineral soils, it is more complicated in the Tripa case owing to the belowground carbon content in Tripa's peat soil and peat swamp ecosystem.

Most of the land conversion in Tripa occurs on peat, which stores much higher carbon than what is stored in vegetation. Secondary sources show estimates of belowground carbon stock in Tripa peat to be as high as 2200 t/ha (Agus and Wahdini, 2008) and an average density of 1100 t/ha for Tripa–KEL and 800 t/ha for the Tripa study area (Atlas). Although this report does not calculate loss of belowground carbon during the period of observation, reported clearances, peat fires and drainage of peat swamp forests (PanEco, 2010; PanEco, 2008) inevitably emit carbon from belowground in a much higher amount than from aboveground. However, the magnitude of the loss is still unknown. For peat in a different area (Meulaboh, Aceh), Handayani (2009) concluded that when opened and drained, thicker peat tends to emit lower CO_2 owing to lower fertility resulting in lower decomposition rate.

5. Component D: Opportunity costs of emission reduction

Meine van Noordwijk, Hesti L. Tata, Andree Ekadinata, Atiek Widayati, Elok Mulyoutami

5.1 Introduction

Global concerns over the rate of climate change and the role of emissions from land-use change, in addition to those from the use of fossil fuels, have lead to international interest in, and support for, measures to reduce emissions from deforestation and degradation (REDD+). Being the country that over the past decade has the most emissions from land-use change, Indonesia is among the main targets for such policies. It has shown international leadership in articulating its national commitment to use local plus foreign investment to control and reduce emissions.

In 2010, Indonesia signed a letter of intent with Norway to reduce emissions from both forest and peat lands, and appropriate institutional arrangements are currently being discussed. In deciding on priorities for investment, considerations of efficiency suggest that priority should be given to cases where potential emission reduction is high relative to funds invested. Costs of emission reduction can be grouped into three categories: 1) transaction and negotiation costs; 2) opportunity costs for foregone economic benefits that would have been associated with a 'business as usual' pattern of land-use change; and 3) implementation costs. Of these cost categories, the opportunity costs are the most open to empirical analysis at this time; they are also likely to vary substantially between different types of land-use change.

Our current analysis is therefore focused on such opportunity costs, without claiming that they will always be the dominant cost category; in fact, where opportunity costs are low the other cost types probably dominate and should be subject to further analysis; situations where the opportunity costs are high, however, can generally be excluded from the list as they are out of reach of economic instruments. Opportunity costs of avoided emissions (or 'abatement costs') are estimated from the increase in profitability of land use that was achieved in a certain landscape over a certain time period, expressed per unit of emission of carbon dioxide (or its equivalent in the form of other greenhouse gasses). Every spatial unit ('pixel') of land that undergoes land-use change contributes to a change in profitability ($NPV_{after} - NPV_{before}$) which yields a cost (USD/ha) and a change in carbon stock ($Cstock_{after} - Cstock_{before}$) which, after appropriate unit conversion, can be expressed as an emission (tonnes of carbon-dioxide equivalent per hectare or tCO_2e/ha). The ratio of these two properties is expressed as US dollars per tonne of carbon-dioxide equivalent or USD/tCO_2e and is called the 'opportunity cost'. If we do this for many units of land-use change we can obtain a frequency distribution of opportunity costs, each with an associated contribution to the total emissions from a landscape over a period of time. A cumulative representation of these ratios then becomes an 'opportunity cost curve'. The method has been applied to analysis of land-use change in tropical forest margins in a number of countries (van Noordwijk et al., 2007a-d; Swallow and van Noordwijk, 2007; Swallow et al., 2007). There are several steps needed to do this analysis (Figure 37).

a) Establish an appropriate land-use classification system that balances the limitations of empirical data (that tend to be coarse) and the relevance of distinctions between categories, either because they differ in profitability or they differ in carbon stocks (Chapter 2 provides the basis for this).

b) Estimate typical carbon stocks for each land-use type (Chapter 3 provides the basis for this).

c) Estimate net present values for each land-use type (Chapter 4 provides the basis for this): the ratio of costs and carbon stocks provides the 'opportunity cost intensity' of every possible type of land-use change.

d) Create a land-use change matrix (Chapter 4 provides the basis for this) to determine how much emission associated with each different opportunity cost actually occurred.

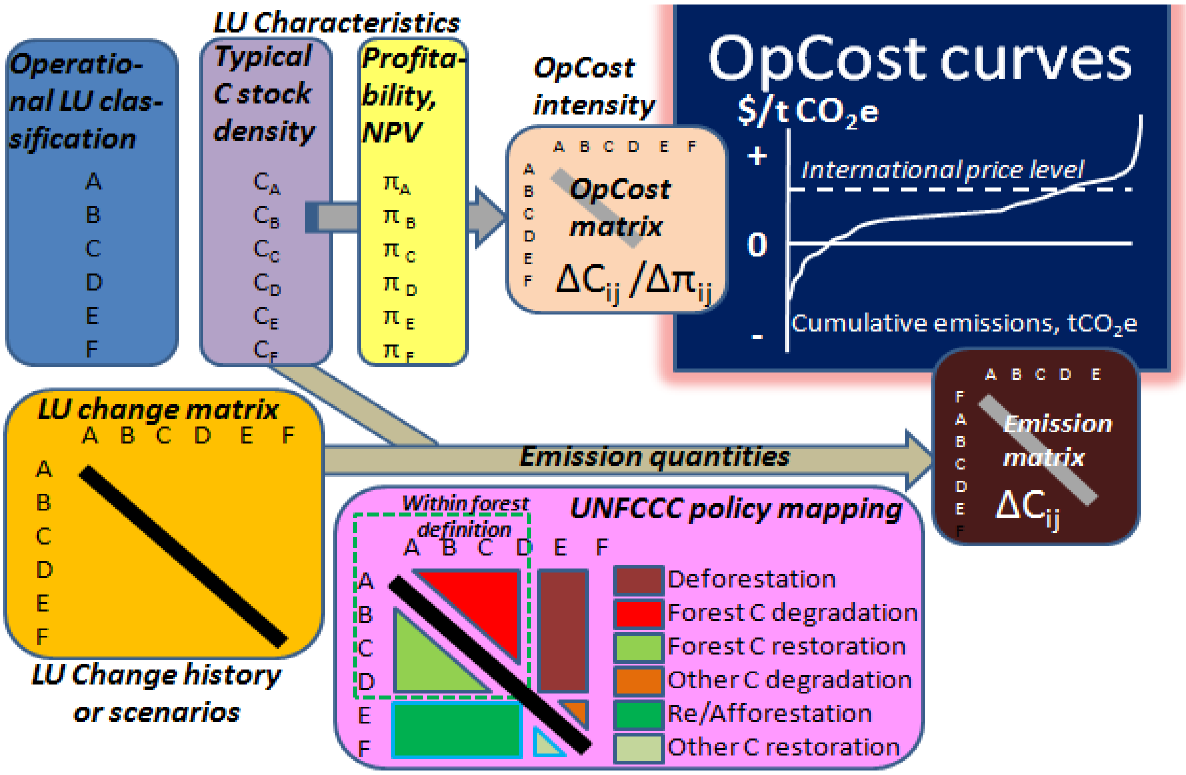


Figure 37. Steps in deriving an opportunity cost (OpCost) curve that relates the changes in economic profitability (net present value) and typical carbon stocks of land-use (LU) systems, to a land-use change matrix that describes the changes that have occurred (for a retrospective OpCost curve) or might occur (for a scenario OpCost curve)

A further step in the analysis provides a link to the current international policy debate on REDD+. The rules that have so far been negotiated for REDD+ (but at the time of writing there is no formal international agreement yet on the package as a whole) imply that only 'deforestation' and 'forest degradation' are to be included as emissions, with the plus (+) indicating potential carbon sequestration by increase of carbon stocks *within* the forest. To relate our landscapes of study to these emerging international rules and policies, we may need to know how much of the emissions refer to the various parts of the package, and how much would fall outside of the rules. A critical issue in this regard is the definition of 'forest': in international agreements, in Indonesian policies and institutions, and in common parlance and understanding. As analysed by van Noordwijk and Minang (2009), there are considerable differences between these various concepts of 'forest'. As well as 'forests with trees' and 'non-forests without trees, there is land that belongs to the classes 'forests without trees' and 'non-forests with trees'. Such lands include mixed and multi-strata agroforestry (intermediate land uses) which can store significant quantities of carbon, but are outside of the institutional mandate of Indonesian forest authorities. Significantly, they are, or can be, within the internationally agreed forest concept (Ekadinata et al., 2010). Emissions from peat land that has lost its forest status are likely to be outside of the scope of REDD+, but they can be included in the Indonesia–Norway bilateral agreements to reduce emissions from forest and peat. Internationally, there is discussion on the relevance and desirability of 'whole landscape carbon accounting' that would use existing AFOLU (agriculture, forestry and other land use) reporting rules.

In our current analysis we therefore start from all land-use change, without prejudice to the 'forest' concept or concepts used in policy analysis, with opportunities for later selection of a subset of the land-use changes (and their emissions) for specific policy applications.

The opportunity-cost analysis draws out several points.

- What volume of emission reduction could be possible at what cost (apart from transaction and implementation costs as discussed above).
- The 'easy wins' and threshold cases depending on investment in emission reduction; helping a country or local government to integrate its economic growth with land-use changes and other local, national and global needs.
- It can provide a basis for negotiating 'fair' compensation, that includes real benefits foregone and transaction costs.

As presented here, the opportunity costs are only one of the cost component of overall design of emission reduction programs (or projects), and may be complemented by low-cost shifts in tenurial security (Gregersen et al., 2010; Akiefnawati et al., 2010).

5.2 Methods

The opportunity-cost analysis was conducted in five steps (Figure 37).

1) Clarification and description of major land uses.
2) Calculation of time-averaged carbon stocks for the major land uses.
3) Calculation of the private and social profitability of the land uses in terms of discounted net present value.
4) Land-use characterization and land-use change analysis.
5) Processing the information into a two-dimensional graph charting the opportunity costs of avoiding deforesting land-use changes against volume of carbon-dioxide equivalent emissions.

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For each change in time-averaged carbon stock, economic value per unit emission (USD/tCO_2e) was calculated. First, the change in net present value was calculated, with positive numbers representing increases in net present value. Second, the units of carbon were translated into units of CO_2, hence CO_2e (CO_2 equivalent). Third, the change in the number of units of time-averaged CO_2e was calculated, with positive numbers representing emissions of CO_2e. Finally, the economic value per unit emission of CO_2e was calculated as the change in net present value divided by the reduction in carbon stock measured in CO_2e.

The curve that is generated by this analysis provides estimates of the average and marginal opportunity costs of emission reduction through avoided change. For comparison with sites of different sizes, the horizontal axis was transformed from cumulative CO_2e for the entire area to CO_2e per unit area by dividing the horizontal axis value by the size of the site. Software developed by World Agroforestry Centre (2009)[15], REDD–Abacus, was used to generate the abatement cost curve.

Some assumptions and limitations owing to lack of data were

- private net present value only;
- the establishment cost for land conversion was assumed to be similar for each pair; and
- the incentive for emission reduction/carbon price at farmgate was assumed to be USD 5/tCO_2e, leaving some space for transaction and implementation costs (Stern, 2007; Swallow et al., 2007).

Metadata used for abatement cost analysis of land-use change in Tripa and Batang Toru ecosystem is shown in Table 34.

[15] http://www.worldagroforestry.org/sea/projects/allreddi/softwares

Table 34. Land-use metadata, carbon stock and profitability

No	Land-cover/-use system	Carbon			Livelihood		
		Carbon-stock (t/ha)		Note	Private-NPV (USD/ha)		Assumption
		Min*	Peat		Min*	Peat	
1	Undisturbed forest	**243**	**246**	Batang Toru measurement (mineral=min) and Tripa (peat swamp forest)	**0**	**0**	Primary forest without any activity; private NPV is assumed to be 0
2	Logged-over forest	**152**	**121**	Batang Toru measurement (min) and Tripa (peat swamp forest)	**2760**	**2760**	Logging activity under sustainable yield regime: result from Berau study
3	Rubber agroforest	**114**		Measurement conducted in Jambi	**796**		Profitability analysis of rubber agroforest in Batang Toru
4	Mixed garden	**103**		Measurement conducted in *salak* agroforest in Batang Toru	**885**		Profitability analysis of *kemenyan* agroforest in Batang Toru
5	Industrial timber estate/ plantation	**93**		Measurement conducted in pine plots in Batang Toru	**1199**		Assumed to be the same as acacia plantation; value taken from Berau study
6	Oil palm (estate)	**40**		Measurement conducted in Riau and Central Kalimantan	**7832**		Assumed to be same as for smallholder systems
7	Oil palm (smallholder)	**40**			**7832**		Profitability analysis of smallholder oil palm in Tripa
8	Simple agroforestry (coffee, cacao)	**24**	**30**	Cacao and coconut agrofo-rest measurement in Tripa; coffee data from Lampung	**1012**	**2934**	Profitability analysis of cacao agroforest in Tripa; coffee agroforest in Batang Toru
9	Settlement	**27**	**27**	Averaged form measurements conducted in Lampung, Jambi and Kalimantan	**6087**	**6087**	Assumed to be the same as cost of developing transmigration settlement; value taken from Berau study
10	Paddy rice	**2**	**2**	Derived from measurement conducted in Lampung	**242**	**242**	Profitability analysis Batang Toru (Table 12)
11	Cleared land	**1.5**		Assumed to be equivalent with grass	**0**		Assumed as an intermediate system, future land use can be various
12	Shrubs and grass	**22**		Averaged form measurements conducted in Lampung, Jambi and Kalimantan	**0**		Assumed as an intermediate system, future land use is unclear
13	Secondary forest	**50**	**50**	Measurements in Tripa	**0**		Forest recovery stage after fallow abandonment

**: mineral soil*

Especially for Tripa, it was necessary to observe the magnitude of emission, hence opportunity cost incurred, if belowground emissions from peat areas were taken into account. For each of the land-use transitions, the peat emission was approximated from three major types of land-use conversion in peat soils (listed in Table 35) and deducted from the aboveground carbon-stock data.

Table 35. Estimates of peat emissions in Tripa

No	Conversion type	Peat emission estimate (tCO_2e/ ha/yr)
1	Opening into oil palm plantation	30
2	Conversion into seasonal and perennial crops	5
3	Natural degradation into less dense vegetation and/or shrubs	2

5.3 Results

5.3.1 Trade-off curves

The time-averaged carbon-stock data of the land-use systems can be compared with the profitability data as reflected in net present value. Figure 38 shows that there are broadly four clusters of points:

1) high carbon stock and low profitability;
2) medium carbon stock and medium profitability;
3) low carbon stock and high profitability; and
4) low carbon stock and low-to-medium profitability.

The first three groups together determine a classical trade-off curve, where increases in profitability are directly associated with decreases in carbon stock. The presence of the fourth group, however, shows that there are opportunities to enhance profitability without incurring further loss of carbon at landscape scale (by conversion from group 4 to groups 2 or 3).

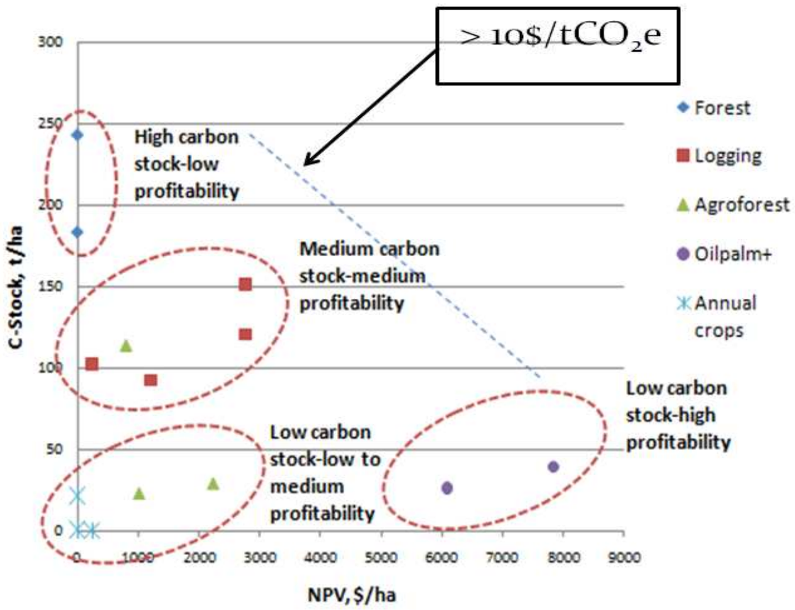


Figure 38. Trade-off between profitability (net present value = NPV) and typical carbon stock of the land-use systems encountered in Tripa and Batang Toru (details in Table 34)

The negatively sloping line in Figure 38 can be expressed as an opportunity cost (USD/tCO_2e). Between the natural forest (in group 1) and the oil palm (group 3) the slope of the line represents an opportunity cost of slightly over 10 USD/ tCO_2e. Only a few conversions (lines connecting points in the graph) will have a steeper slope, implying a higher opportunity cost.

The land-use change pattern expressed in these four groups differs strongly between the Batang Toru landscape and Tripa. Batang Toru is characterised by relatively slow change, a small but declining fraction in the medium carbon and medium profitability class and a small, but slowly increasing, fraction of high-profitability and low-carbon land uses. Tripa shows a rapid shift from high-carbon and low-profitability to low-carbon and high-profitability land use, with approximately steady fractions of the two intermediate categories (Figure 39).

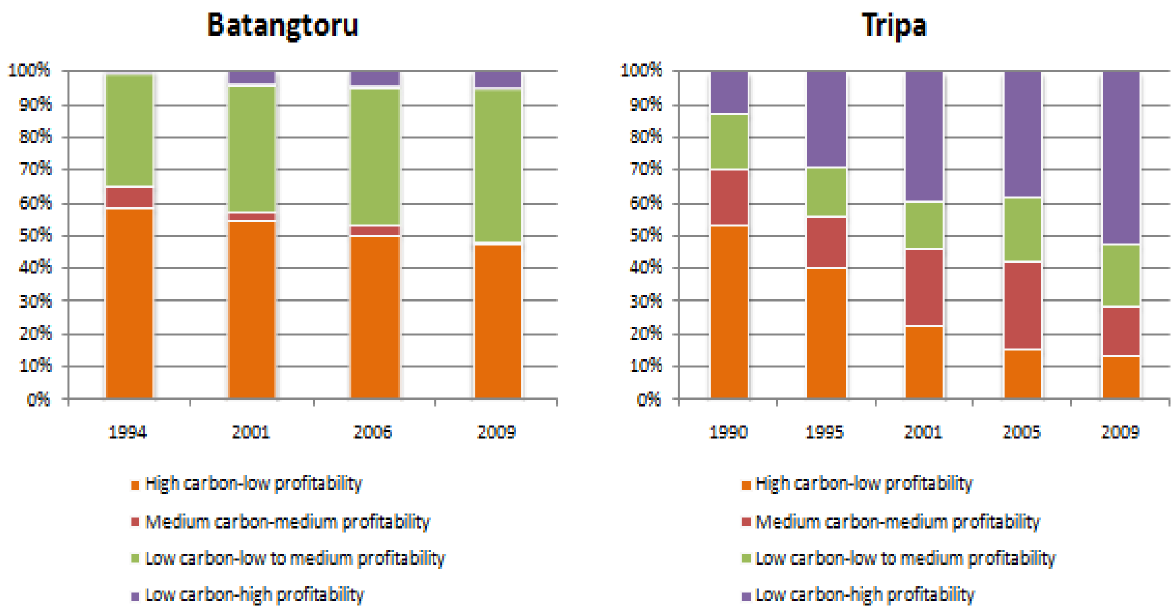


Figure 39. Land-use change patterns with time in Batang Toru and Tripa in the four groups of land uses, classified by carbon stock and profitability as in Figure 38

5.3.2 Land-use change matrices

The land-use change data of this section can now be summarised in a four-group format (Figure 40). The main diagonal represents the 'no-change' fractions of the land use, showing that in Batang Toru 47.6% stayed in the high carbon and low profitability state over the 1994–2009 period and 30.9% in low carbon and low-to-medium profitability.

For Tripa, these percentages are only 13.8 and 6.4, respectively. The cells above the main diagonal represent changes towards higher profitability and lower carbon stock: a total of 20.7% in Batang Toru and 65.4% in Tripa. Cells below the main diagonal represent the opposite trend, which is rare in both landscapes (0.5 and 2.6%, respectively, and potentially due to errors of classification).

Combining the opportunity cost intensity data and the emission totals for the two landscapes, we can now derive the OpCost curves.

Batangtoru

1994-2009	High carbon-low profitability	Medium carbon-medium profitability	Low carbon-low to medium profitability	Low carbon-high profitability
High carbon-low profitability	47.6%	0.1%	10.3%	0.4%
Medium carbon-medium profitability	0.0%	0.1%	5.5%	1.4%
Low carbon-low to medium profitability	0.1%	0.3%	30.9%	3.0%
Low carbon-high profitability	0.0%	0.0%	0.0%	0.3%

Tripa

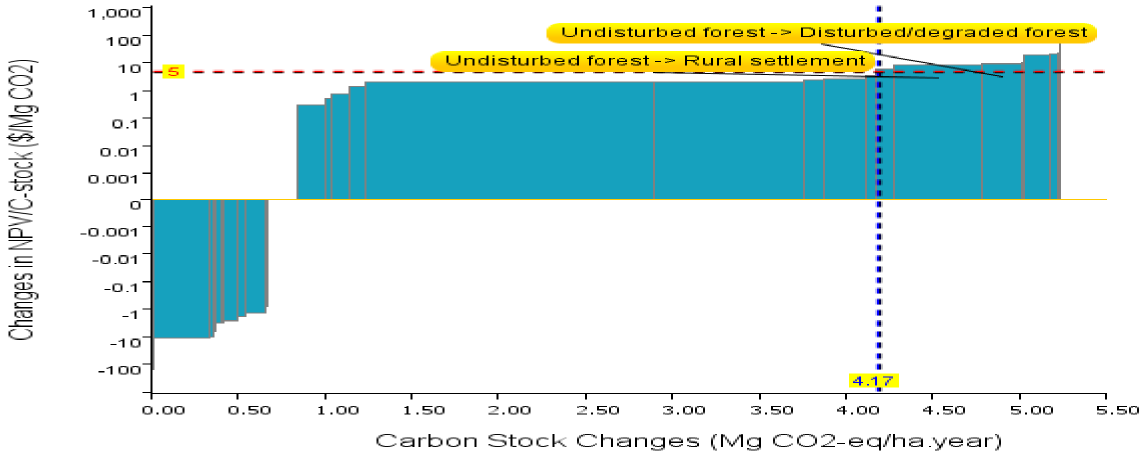
1990-2009	High carbon-low profitability	Medium carbon-medium profitability	Low carbon-low to medium profitability	Low carbon-high profitability
High carbon-low profitability	13.8%	13.8%	6.0%	20.2%
Medium carbon-medium profitability	0.0%	1.8%	3.3%	11.8%
Low carbon-low to medium profitability	0.0%	0.0%	6.4%	10.3%
Low carbon-high profitability	0.0%	0.0%	2.6%	9.9%

Figure 40. Land-use transition matrices from 1994 (row) to 2009 (column) for the four classes of land use in the Batang Toru and Tripa landscapes

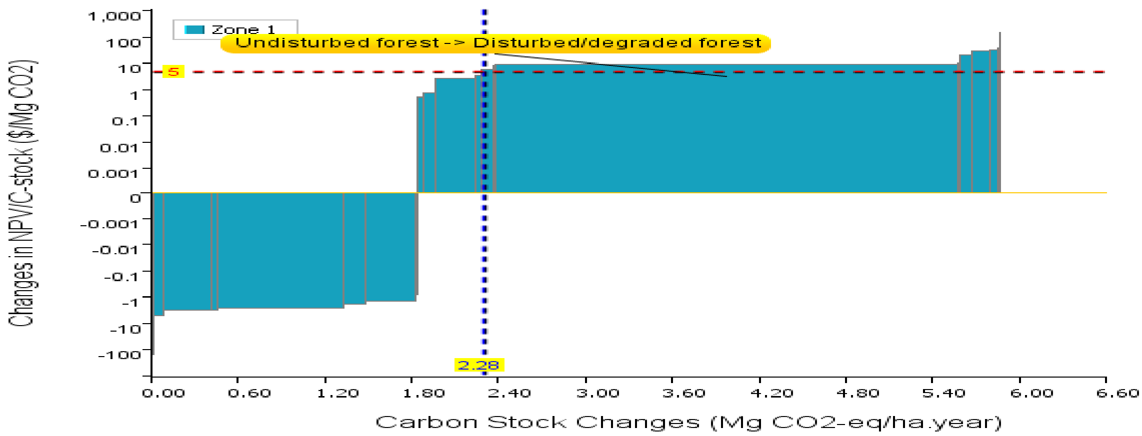
5.3.3 OpCost curves for Batang Toru

The total aboveground carbon emissions from the Batang Toru landscape were calculated to range from 5.2 tCO_2e/ha/yr during 1994–2001 (Figure 41(a)) and 7.4 tCO_2e/ha/yr during 2006–2009 period (Figure 41(c)). The dominant change, and the higest emission contributor, has been the change from undisturbed forest to disturbed forest, which reflects logging and other timber extraction activities in parts of the forest. Logging, however, is calculated to have an opportunity costs of 8.3 USD/tCO_2e, above the threshold price. On average, about half of the emissions in Batang Toru occurred at an opportunity cost below this threshold, with the highest proportion, 79.7%, in the 1994–2001 period.

(a)



(b)



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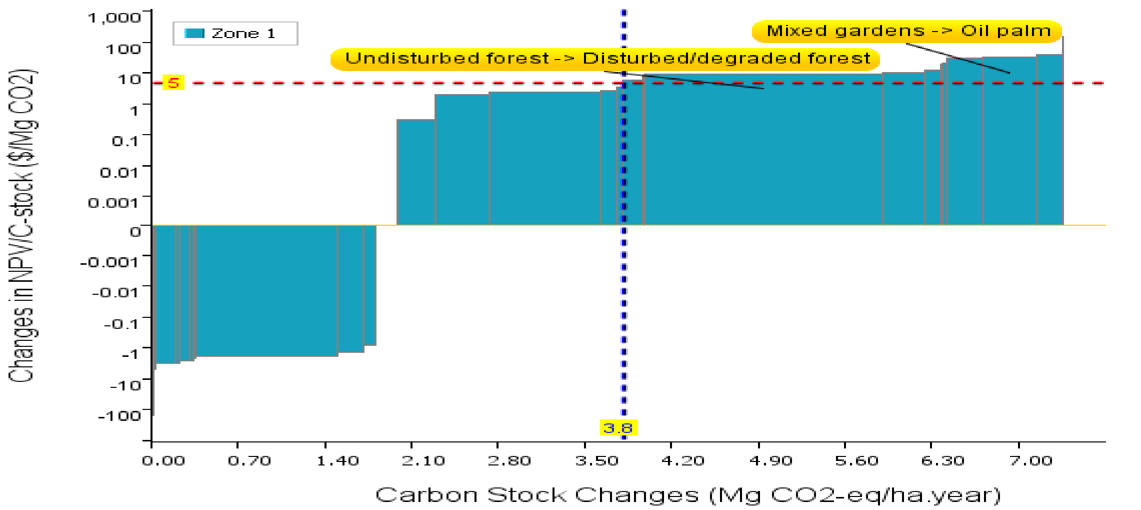


Figure 41. Abatement-cost curves for CO_2 emissions in Batang Toru: a) 1994–2001; b) 2001–2006; c) 2006–2009

5.3.4 OpCost curves for Tripa

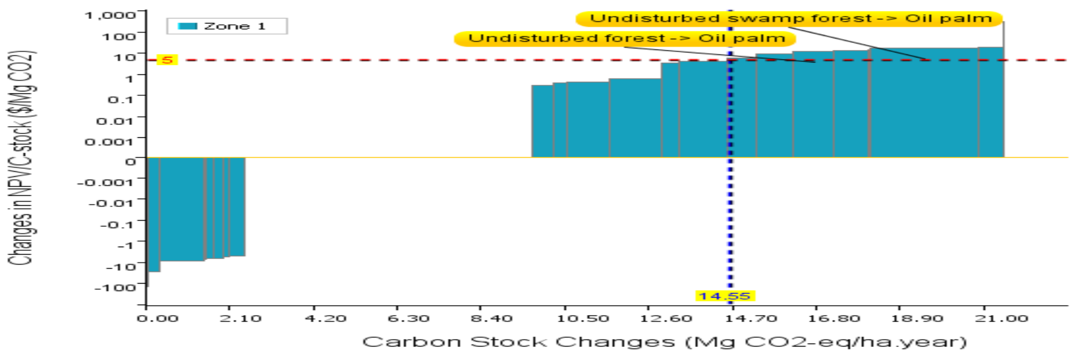
Total aboveground emissions in Tripa (Figure 42) were substantially higher than those in Batang Toru, ranging from 9.0 tCO_2e/ha/yr , in the period of 2001–2005 (Figure 42(c)), to 21.5 tCO_2e/ha/yr in the period 1990–1995 (Figure 42(a)). In all periods of analysis, forest conversion to oil palm plantation produces the largest component of emissions.

The pattern of land-use change in Tripa was dominated by conversion of undisturbed forest, including peat swamp forest, to oil palm plantations and smallholder oil palm. Forest opening and conversion for agricultural purposes and settlements were mostly associated with transmigration, which brought in the labour that allowed the concessions to operate.

The opportunity cost of conversion of natural forest and natural swamp forest conversion to oil palm plantations ranged from USD 10.5/tCO_2e to USD 17/tCO_2e. Using the threshold of 5 USD/tCO_2e, the emissions from land-use conversion that could have been avoided range between 6 tCO_2e to 14.6 tCO_2e in the periods of studied. The highest proportion of emissions that could have been avoided occurred in the 1990–1995 period (67.7%, totaling 14.6 tCO_2e), while the lowest was during 1995–2001 (40%, totaling 6.1 tCO_2e).

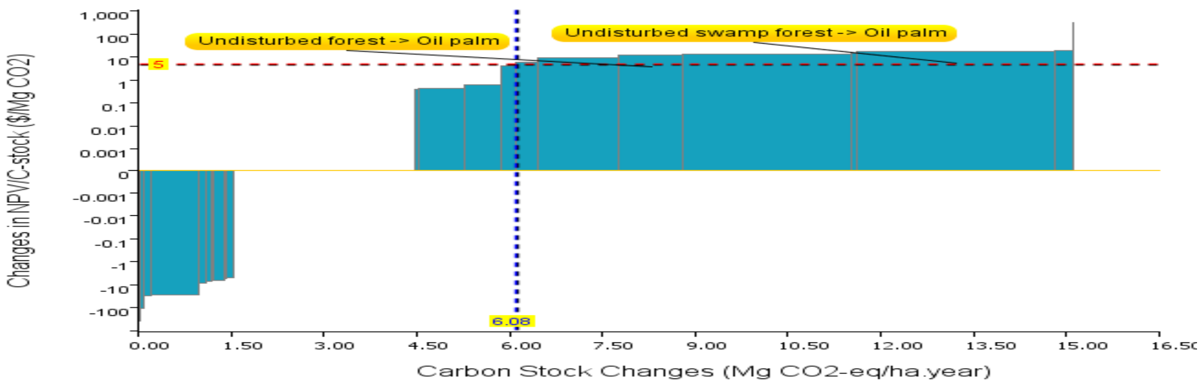
If data for belowground emissions were to be added, a much larger fraction of all emissions would fall below the USD 5/tCO_2e threshold, given the frequency of peat soils in this landscape.

(a)



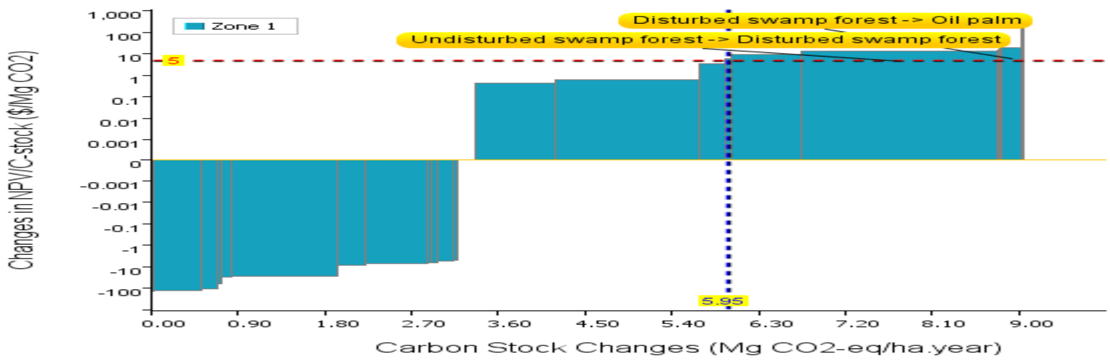
Zone 1
Undisturbed swamp forest -> Oil palm
Undisturbed forest -> Oil palm
5
14.55
Changes in NPV/C-stock ($/Mg CO2)
Carbon Stock Changes (Mg CO2-eq/ha.year)

(b)



Undisturbed forest -> Oil palm
Undisturbed swamp forest -> Oil palm
5
6.08
Changes in NPV/C-stock ($/Mg CO2)
Carbon Stock Changes (Mg CO2-eq/ha.year)

(c)



Zone 1
Disturbed swamp forest -> Oil palm
Undisturbed swamp forest -> Disturbed swamp forest
5
5.95
Changes in NPV/C-stock ($/Mg CO2)
Carbon Stock Changes (Mg CO2-eq/ha.year)

(d)

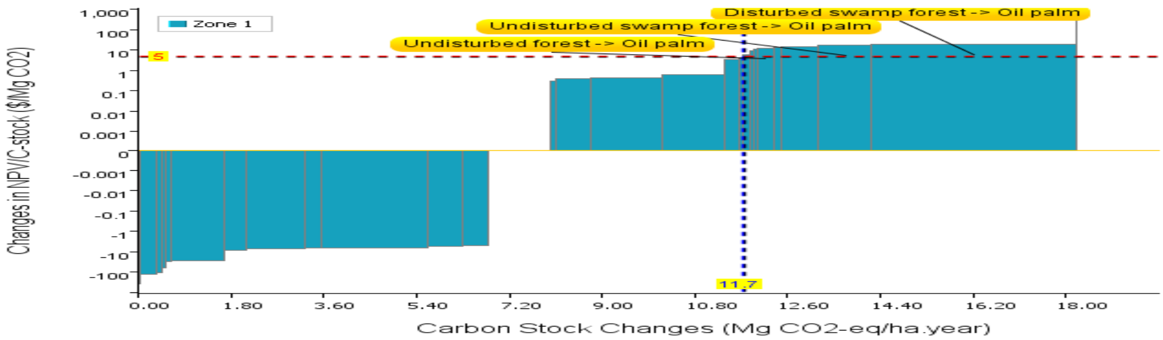


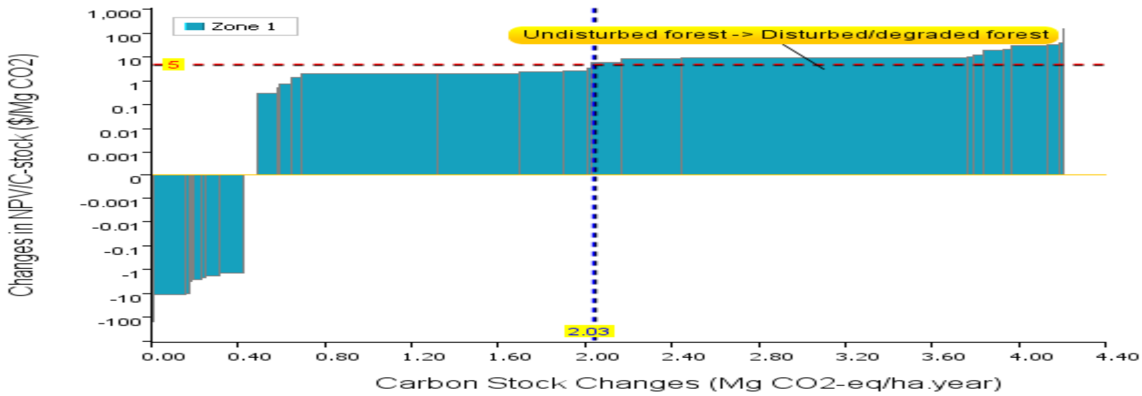
Figure 42. Abatement-cost curves for CO_2 emissions in Tripa: a) 1990–1995; b)1995–2001; c) 2001–2005; d) 2005–2009

5.4 Discussion

Comparing the cumulative emissions in Batang Toru and Tripa for all of the periods of observation (Figure 43), the average annual emission from Tripa (5.7 tCO_2e) was higher than that of Batang Toru (4.2 tCO_2e). Dominant conversion due to oil palm development in Tripa, while in Batang Toru with logging dominating carbon loss but also conversion to low-to-medium profitability land uses.

Venter et al. (2009) suggested that the cost of avoiding forest conversion is between USD 10–USD 33/tCO_2 based on oil palm plantation establishment cases in Kalimantan. Compared to that, the opportunity costs for similar conversions in Tripa and Batang Toru are considerably lower.

(a)



(b)

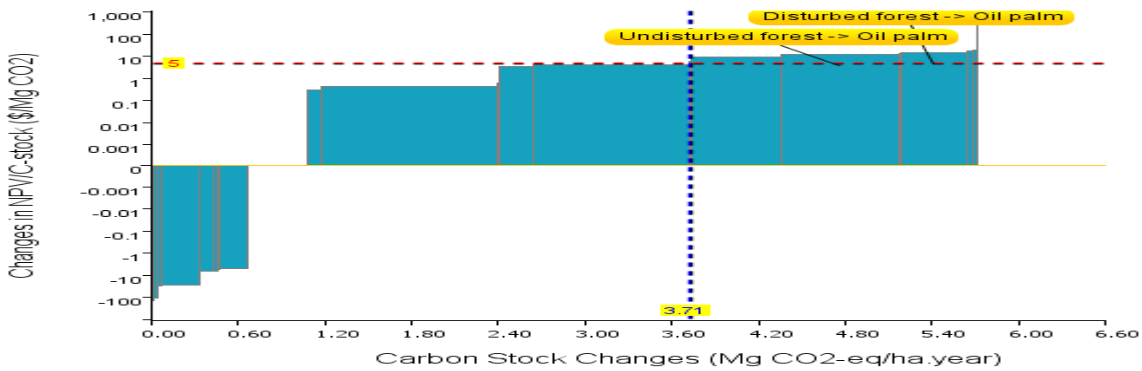


Figure 43. Abatement-cost curves for CO_2 emissions throughout the entire period of analysis (1994–2009): a) Batang Toru; and b) Tripa

For Tripa, the abatement-cost curve, with peat emission taken into account, for the entire observation period (1990–2009) is shown below (Figure 44).

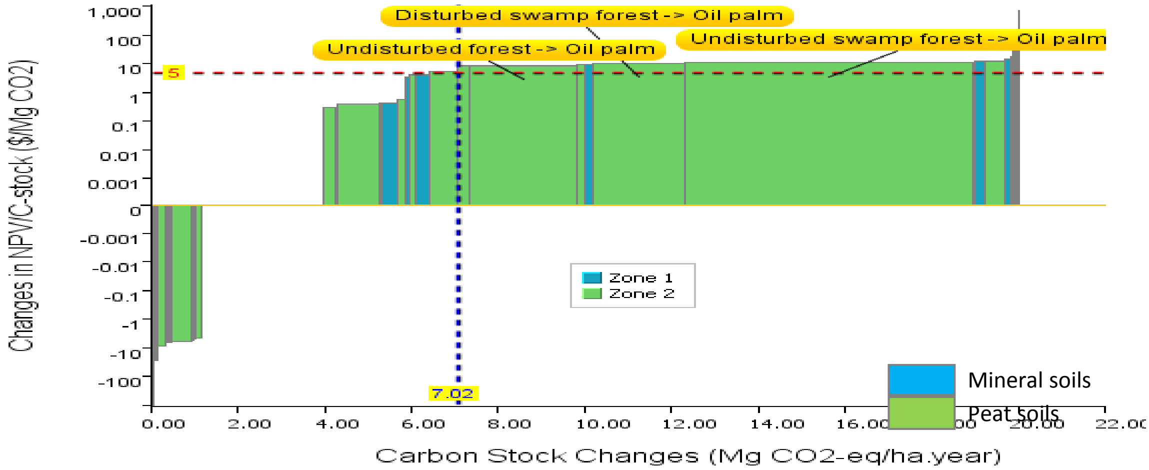


Figure 44. Abatement-cost curves for CO_2 emissions of peat and mineral soil throughout the entire period of analysis (1994–2009) in Tripa

Average emission was 20 tCO_2e/ha/yr, 28.5% higher than the figure when only aboveground emission was taken into account and five times higher than in Batang Toru. The amount of aboveground plus peat that could be compensated (7.02 tCO_2e/ha/yr) is higher compared to aboveground emission only (3.7 tCO_2e/ha/yr). As a fraction of the total emission, it is smaller (only 35% of 20 tCO_2/ha/yr) compared to aboveground only (65% of 5.7 tCO_2/ha/yr).

In conclusion, threats from forest conversion and degradation in two Sumatran orangutan habitats, Tripa and Batang Toru, show different magnitudes and patterns, which implies different levels of opportunity cost of avoiding forest conversion in the two landscapes. The opportunity cost for the dominant forest conversion/disturbance pattern in Tripa (oil palm establishment) is similar to that for logging as the major cause of carbon loss in Batang Toru, but in the Batang Toru landscape avoiding conversion of land use of relatively low profitability will incur a lower opportunity cost. When peat emission was taken into account for Tripa, in comparison with Batang Toru the pattern remained the same, although clearly the magnitude of emission was higher and the emission fraction that could have been avoided with the assumed carbon price was thus lower. It may appear, however, that transaction and implementation costs for avoiding logging or oil palm conversion, which are dependent on permits issued by local governments, may be lower than those for the smallholder-(and migrant-)lead conversions that have a lower opportunity cost. Differences in total REDD+ costs may be smaller than the current graphs show.

Conserving the habitat of orangutan where forest can be converted into profitable land uses such as oil palm plantation entails a relatively high opportunity cost. In a carbon market that is purely driven by ‘efficiency’, there may be other, lower cost opportunities. Orangutan conservation is unlikely to emerge as a ‘co-benefit’ from interventions that are primarily aimed at low-cost emission reduction. If, however, orangutan conservation is a primary rationale for external investment in the two landscapes under consideration, there will be emission reductions as a ‘co-benefit’.

6. Component E: Scenario analysis of land-use change: baselines and expected project impacts at landscape level

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6.1 Introduction

Land-use change is the end result of complex decision making at multiple scales. Land-use planning tries to influence these decisions to achieve landscape change that is aligned with some overall goals. However, successful land use planning can only occur if the decision makers of a 'business as usual' trajectory pay attention to the recommendations and subsequently adjust their decisions either spatially (redirecting investment to areas that better match overall goals) or sectorally (switching to other types of activities). A good understanding of how current decisions are made and the type of factors that will actually influence the behavior of decision makers is thus needed to make land-use planning more effective, beyond producing beautiful e colourfulpieces of paper on the walls of planners' offices.

One approach to achieve this is to make land-use planning more participatory, to encourage sense of ownership and responsibility among stakeholders involved in the planning during implementation phase. However, with the large number of stakeholders and possibility of conflicting interests among stakeholders, participatory land-use planning is not an easy process. Commitment to the final outcome may remain uncertain. Another, potentially complementary, approach is the use of 'multi-agent' models that apply and include the logic that decision makers use during the many small-step decisions that jointly cause land-use change. As reviewed by Villamor et al. (2010), most of the currently available 'multi-agent' models assume a basic economic logic of maximising expected utility at interaction level, within the agent-specific constraints of opportunity. The FALLOW model (van Noordwijk, 2002; Suyamto et al., 2009), as a 'hybrid' between system-dynamic and agent-based models, is explicitly considering 'knowledge' of agents as a constraint and as a dynamic property in learning landscapes. Among the various models available, it may be most suited for exploration of land-use change in complex landscape mosaics without requiring a huge investment in prior data collection and parameterization.

In large parts of Indonesia the drivers of land-use change often involve (a) smallholders linked to local communities (either with an historical link to the land or more recently initiated, as in transmigration projects); (b) spontaneous migrants originating in other landscapes but seeking opportunities to make a living, either by opportunistic extractive activities or by setting up new farms; (c) government-sanctioned large-scale plantations, often reliant on external labour sources that are brought to the landscape for the duration of a contract; d) forest authorities who legitimise extractive activities (logging) and/or impose conservation of watersheds and/or biodiversity; (e) development of physical infrastructure that influences access to markets and/or processing plants for products derived from forests, agriculture or intermediate forms of agroforestry. If left to its own course, the change brought by driver (a) alone will be gradual, but interaction with drivers (c) and (d) can accelerate change. Change can further accelerate if combined with opening up the area for (b) and (e) through erosion of traditional rights and community control.

For a complex system where many components and interactions between them influence the output, a simulation model is particularly useful to gather all information and knowledge related to the system, and provides outputs for the basis of prospection. Although all hypotheses can be tested by directly establishing experiments and making observations in the field, this certainly requires a lot of resources, time and energy. The world may have moved on before results are available.

At the very initial stage, an experiment should be based on a sound and sensible hypothesis that reflects current understanding of processes and local context. Statistical methods for testing hypothesis are widely available and a simulation model can help to shape sensible hypothesis by testing their quantitative outputs resulting from a prospective study. Based on the model's outputs, a new, more reasonable hypothesis might be formulated for implementation.

A dynamic land-use model must try to incorporate key features of all five agents mentioned above (local smallholders, spontaneous migrants, government-sanctioned large-scale plantations, forest authorities and development of physical and economic access to markets) and their basic interactions. The FALLOW model does allow a step-wise increase in complexity of the systems considered, building up from local land-use agents.

Large-scale plantations have permits that specify the agricultural products in which they invest and their decision frame is a long term one. Farmers who manage relatively small plots can change more dynamically, but will have individual variation in the way decisions are made. 'Conservative' farmers might be reluctant to change their farming system and products because they follow a tradition inherited within their family, but many farmers are sensitive to current profit information and may be inclined to shift their farming system. The experience provided by both large-scale plantations and farmer-innovators will lead to a knowledge base that influences the future landscape mosaic. The central or local government can surely influence the orientation of farmers' decisions through policy around prices, subsidies and/or extension availability. The final decision, however, is still in the farmers' hands related to which land-use option they would like to exert in current and subsequent years.

As part of a study of land-use change in two areas in northern Sumatra that serve both as orangutan habitat and as source of human livelihoods, the Tripa swamps along the western coast of Aceh and the Batang Toru watershed forests in North Sumatra, we developed two applications of the FALLOW model to 1) check our current understanding of land-use change in the areas; 2) extrapolate current trends to a 'business as usual' scenario; and 3) explore future change options based on various scenarios that include availability of knowledge, prices and price differentials, land-use rules that are enforced, changes in behavior of large-scale actors and constraints on immigration.

6.2 Materials and method

6.2.1 FALLOW model

The FALLOW (Forest, Agroforest, Low-value Lands Or Waste?) model was designed (van Noordwijk, 2001, 2002; Suyamto et al., 2009) to simulate land-cover change at landscape level driven by farmers' decisions on labour and land allocation. Initially constructed for simulation of a simple 10x10 cell landscape, the model can now handle input maps obtained from Landsat satellite images. The default plot size is 1 ha with possible modification depending on the objective of the study and adjustments to input parameters. The current model version (Figure 45, Figure 46) is integrated with the pc-raster simulation language and a visual basic model for a user-friendly interface. The model has been used for prospecting future landscape mosaic in different regions in Indonesia, for example, Lamandau (Central Kalimantan) and Arongan Lambalek (West Aceh).

Basically, FALLOW considers various external drivers that can influence farmers to make decisions related to their current and future livelihood options. These include both biophysical and social economic aspects for example: i) market mechanisms and relevant regulation interventions articulated through, for example, commodity prices, costs and harvesting labour productivities; ii) development programs, articulated through extension, subsidies, infrastructures (settlements, road, market, processing factories) and land-use productivities; and iii) conservation programs, articulated through forest reserves as prohibited zones for farmers. Farmers consider all these factors to make decisions on labour and land allocation and their impacts on both the economic and ecological prosperity of people living in the landscape area are measured. A detailed description of the model is given by van Noordwijk (2001, 2002) and Suyamto et al. (2009).

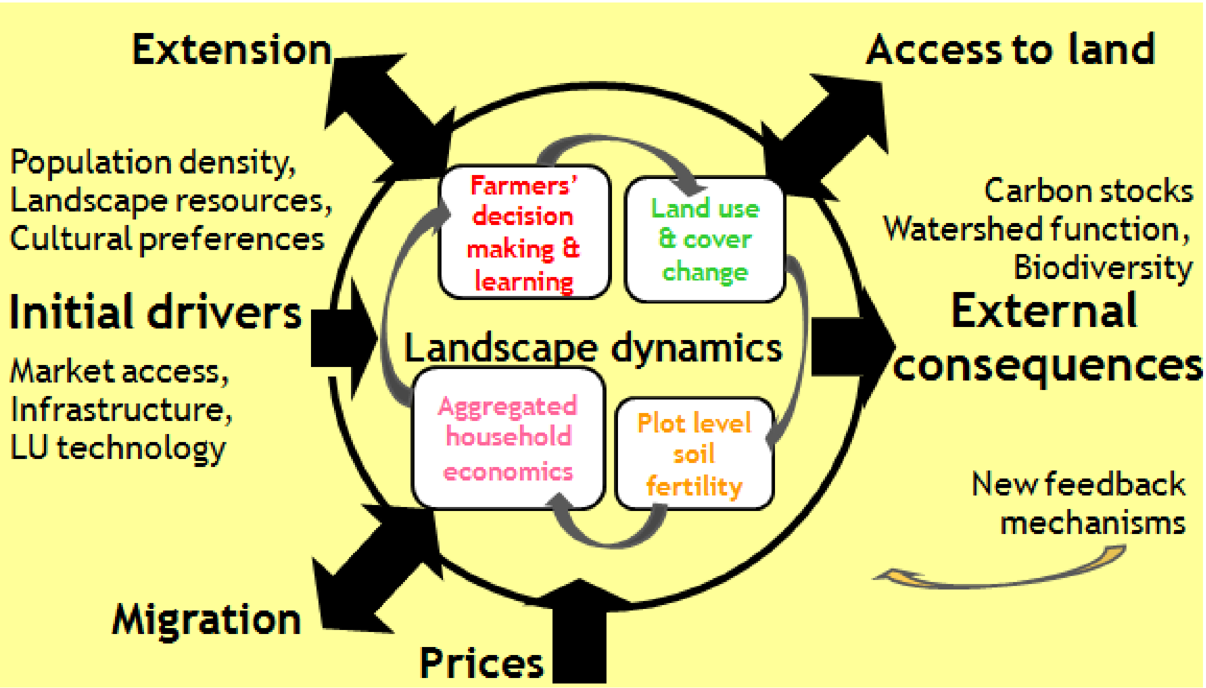

Figure 45. Design of the FALLOW model with an outer ring of external driving factors of local change and four core modules (see Figure 46) that relate farmers' decision-making to a spatial pattern of land-use change with consequences for productivity and households

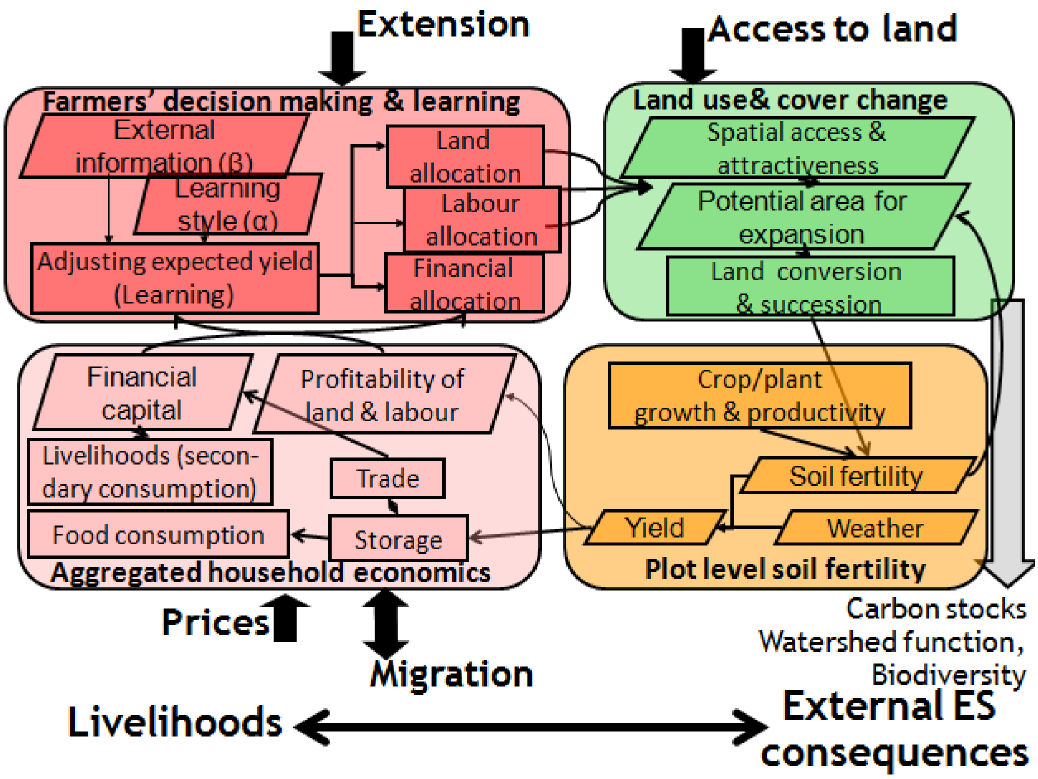

Figure 46. The four core modules that represent the primary interactions within FALLOW

Development strategies or decisions by farmers can be compared with current trend (Business As Usual condition or BAU) in terms of both economic and ecological performance (Figure 47): four possible directions can be tentatively labeled 'Conservation' and 'Red development' which bring improvement in only ecological and economical aspect, respectively, 'Green development' which achieves both and 'Collapse' which implies decline in both dimensions.

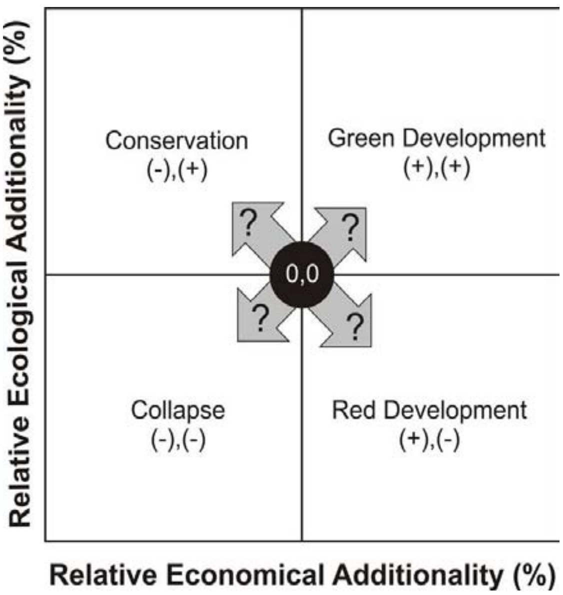

Figure 47. Prospective trade-off diagram depicting the impact of development strategies to economic (X axis) and ecological (Y axis) value relative to the initial condition before implementing the trategies (Business As Usual condition, central point of the diagram)

6.2.2 Simulated areas

Basic data on land use, carbon stocks and land-use change for Tripa and Batang Toru have been presented in the preceding chapters. The summarised description for each site that was used to construct the simulation model follows.

The Tripa coastal peat swamp forest is situated in three different districts: Kecamatan Darul Makmur, Babahrot and Kuala Batee. It has been a source of both economic and ecological prosperity for local people. In the early 1990s five large-scale oil palm estates were allocated land in the region and started operation. The estates were largely abandoned during the civil conflict in Aceh, but resumed activities after 2005 following the Aceh peace agreement and as part of the tsunami reconstruction process. Part of the Tripa swamp remained in a forest condition and still functions as orangutan habitat, on peat that in many locations exceeds 3 m depth and as such should not have been issued as concession.

A significant will exists from many stakeholders to stop further destruction of peat swamps such as Tripa and/or to restore ecosystems for the economic and ecological services they provide. Stakeholders are local and regional governments, local communities, private sector, local and international non-governmental organisations from human rights to environment, voluntary discussion fora such as the Roundtable on Sustainable Palm Oil (RSPO) and international actors such as the International Finance Corporation of the World Bank. Specific discussions to save and restore Tripa were initiated, and are still lead by, Yayasan Ekosistem Lestari (YEL) and PanEco. As a result, the local government plans to re-evaluate all oil palm plantation concession rights (Hak Guna Usaha or HGU) in 2012. Technically, oil palm plantations can be developed on available 'degraded lands' on mineral soils near to, but outside of, the Tripa peat swamp itself. Exploration of such scenarios in a spatial planning context is needed, including the requirements on labour and capital to make such a shift.

The Batang Toru orangutan habitat in North Sumatra is part of three different districts: North, Central and South Tapanuli. There is still a core of undisturbed forests, largely protected by terrain, surrounded by villages with various types of agroforest and tree-crop production systems as well as paddy rice fields. Rubber agroforest is the main local agricultural practice, but a wide range of other tree crop and mixed-garden systems provide livelihood options as well. Threats to the forest derive from logging and mining concessions, land clearing by local people and immigrants.

6.2.3 Scenarios for Batang Toru

As in the case of Tripa, some possibilities exist related to future landscape mosaic in Batang Toru and these will be simulated as different scenarios with the FALLOW model. The simulated area consisted of the habitat area and its surrounding 5 km buffer zone (compare Figure 1 in the Project Overview of this report; the red border indicates simulated area). The three districts covering the habitat area are indeed relatively different in terms of demography, main agricultural products and threats to forest existence (Mulyoutami et al., Component A of this report). These threats come from either expansion of mining and logging concession or land clearing by local people and new immigrants. A serious threat by new immigrants likely takes place in Central Tapanuli rather than in other two districts. They find places for settlement and clear nearby lands for cultivating crops such as *nilam* (*Pogostemon cablin*) for some years before establishing small-scale plantations. Local people clear forest lands either for timber or to cultivate various agricultural crops, for example, paddy, pineapple, *salak*, mangosteen and candlenut besides different types of plantation and agroforest. For the model simulations, we cannot make a distinction between new immigrants and established communities since we lack data of their exact locations and immigration rate. New immigrants usually stay in a remote place separated from local communities. We assume that longer-stay immigrants are already mixed within local communities over the three districts: they are simulated as a single community. There are four main plantation or agroforest types considered for the simulation (that is, oil palm plantation, rubber and coffee agroforest, and mixed gardens with *kemenyan* as the main product). Only one agricultural crop (paddy) was simulated, however, since biophysical and socio-economic data of other crop types as required by the model were not available. Data on non-timber and timber forest products were also not available. Expansion of logging and mining concessions seems to threaten the whole habitat. The current logging concession (Hak Penguasaan Hutan or HPH) is located in the western part of the habitat (see section below). Table 36 describes possible scenarios for Batang Toru and the model will assess their impacts over a 30-year period. The initial land-cover distribution derives from the 2009 land-cover map. The biophysical and socioeconomic parameter values used as input to the model are specified in Tables 36 and 37, respectively.

Table 36. Scenarios developed for Batang Toru

No	Scenario	Description	Remarks*
1	Business As Usual (BAU)	• No control over local people clearing forest lands in the whole habitat area including in the logging concession (HPH) area • Local people clear lands for different agricultural options: 1. Dry land paddy agriculture 2. Oil palm plantation 3. Rubber agroforest 4. Coffee agroforest 5. Mixed-garden (dominated by *kemenyan*) • The main off-farm job is animal husbandry. No jobs available for local people in the logging company	Weak control by the local government and the holder of the logging concession induces local people to clear forest lands wherever they wish within the habitat area. No clear activity inside concession area by the holder of HPH.
2	Concession A	• Logging company continues to operate inside the concession area • No control over local people clearing land outside HPH area • Other situations are the same as described in the BAU scenario	'Small' concession. Activity by logging company inside HPH area and forest clearing by local people outside HPH area to establish agricultural plots
3	Concession B	• Extension of the logging concession to include the whole habitat area • Agricultural activity by local people occurs within the 5 km buffer zone only • Other situations are the same as described in the BAU scenario	'Big' concession. Activity by logging company in the whole habitat area
4	Conservation A	• The holder of logging concession agrees to set the HPH area as forest conservation instead of logging • Other situations are the same as in BAU scenario	The concept of 'hutan harapan' with conservation inside (ex-) HPH area
5	Conservation B	• The local government and the holder of HPH agree to conserve remaining forests inside the habitat area including in the logging concession • Other situation is the same as in BAU scenario	Forest conservation in the whole habitat area to support orangutan preservation

*No change in road and settlement distribution and market price during 30-year simulation

[+] *Oil palm plantation is simulated here as it showed to appear into substantially larger areas in 2009 observation (component C of this report)*

Table 37. Observed aboveground biomass (AGB) and yield of each land use for FALLOW simulations in Batang Toru

Land cover	AGB (ton/ha)	Yield (ton/ha)
Pioneer forest	10	-*
Young secondary forest	75	-
Old secondary forest	184	-
Primary forest	243	-
Paddy	1	1.2
Oil palm pioneer	21+	0+
Oil palm early	49	17
Oil palm late	84	25
Oil palm post	121	12
Rubber pioneer	17.02	0
Rubber early	45.03	0.57
Rubber late	76.16	0.70
Rubber post	97.62	0.40
Coffee pioneer	15.65	0
Coffee early	16.92	0.22
Coffee late	24.72	0.28
Coffee post	26.82	0.28
Mixed garden pioneer	76.50#	0
Mixed garden early	142	0.24
Mixed garden late	173	0.24
Mixed garden post	180	0.24

*No data; +AGB and yield of oil palm for each stage are estimated with equation given by Dewi et al. (2009); #AGB of mixed garden for each stage are estimated by Antoko (2010).

Table 38. Socio-economic input parameters for the FALLOW simulations in Batang Toru

Land use	Harvesting product (ton/pd*)	Establish. cost+ (**MRp/ha)	Labour req. for establish+. (pd/ha)	Return to labour (Rp 000/pd)	Return to land (MRp/ha)	Price (MRp/ton)	Non-labour cost (MRp/ha)
Paddy	0.0124	2.065	10	15.43	2.78	3	0.786
Oil palm	0.00039	5.106	57	122	88.13	0.93	8.89, 16.1, 11.9, 17.9#
Rubber	0.00537	0.07	109	35	7.33	12	0.07, 1.3, 2.7, 1.99#
Coffee	0.038	0.32	66	38	9.31	13.5	0.32, 1.56, 5.44, 8.0#
Mixed-garden	0.00055	0.09	148	31	2.17	62	0.12, 1.14, 1.29, 0.84#

*pd =person day;**MRp=millions of rupiah; + this is the first year establishment cost, not establishment cost until positive cash flow. It excludes labour cost because we assume farmers exert their own lands. Labour requirement here is also for the first year only, not until positive cash flow; # for pioneer, early, late and post production stage respectively.

6.2.4 Scenarios for Tripa

Given the above, a number of scenarios were explored, but further ones may be formulated in support of local negotiations and debate. The simulation area is the Tripa area with its surrounding 5 km buffer zone (compare Figure 2.b, section Project Overview of this report; the red border indicates simulated area), where it falls within the boundaries of the Leuser Ecosystem. The initial land-cover distribution derives from the 2009 land-cover map. Economic impact is measured as the difference in the level of income between a particular condition/scenario and the Business As Usual scenario. Ecological impact is, at this stage, indicated by the difference in aboveground carbon stock (see next chapter for more specific considerations of orangutan habitat quality). Table 39 below describes some possible conditions and development strategies for Tripa to be modeled under the various scenarios to be run over 30 years, which is the length of time considered necessary to assess long-term impacts. The biophysical and socioeconomic parameter values used as input to the model are specified in Table 40 and Table 41, respectively.