Human livelihoods, ecosystem services and the habitat of the Sumatran orangutan

"Sumatran orangutan habitat ecosystem services assessment and opportunity cost analysis"

Project Report

World Agroforestry Centre

Human livelihoods, ecosystem services and the habitat of the Sumatran orangutan:

Rapid assessment in Batang Toru and Tripa

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"Sumatran orangutan habitat ecosystem services assessment and opportunity cost analysis"

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Sumatran orangutan in Tripa (Artist: Rahayu Oktaviani)

Summary

Outside of the national parks and formally protected areas in North Sumatra and Aceh, orangutan and people share landscapes that consist of remaining natural forest, forests that have been modified by human use, agroforests created by farmers, open farm land and settlements. The orangutan habitats are important for other rainforest fauna and flora that are under threat and the habitats store carbon and modulate water flows. In other words, these habitats provide environmental services that support human livelihoods inside and outside the landscape. Current global interest in reducing or avoiding carbon emissions provides an additional rationale for seeking alternative pathways for improvement of human livelihoods: pathways that are compatible with survival of orangutan populations and preservation of carbon stocks. Such alternative pathways will have to be fine-tuned to local conditions, expectations and perceptions of people living in the area, local and provincial governments and external stakeholders. In support of such a process of stakeholder negotiations, this report provides background data and makes a start on scenario analysis for two landscapes with habitat and remaining populations of the Sumatran orangutan: Tripa, Aceh and Batang Toru, North Sumatra.

The two landscapes have similar as well as contrasting characteristics. A comparison of the two highlights the concepts of 'segregation' and 'integration' of multiple functions in a landscape. The establishment, nearly a century ago, of the Gunung Leuser National Park in Aceh as a conservation area represented 'segregation' of functions, where people were excluded from the conservation area. Forests outside the protected area were transformed into open-field agriculture, intensive tree-crop production systems or plantations for the pulp and paper industry. These areas excluded orangutan. For conservationists, the primary way to achieve their goals was to try and increase the size and connectivity of 'protected areas', yet people continued to infringe on the existing areas and contested the legality of forest allocation to logging concessions and/or conservation agencies.

In the Batang Toru landscape, on the other hand, a more integrated and gradual transition from natural forest to human habitat has survived for a number of reasons. Here, the villages, generally located at lower elevations than the natural forest, maintained an active interest in the regularity of water flow and other ecosystem services that the forest provided. Maintaining a balance in such 'integrated' landscapes depended on appropriate incentives, rather than the 'command and control' approach of protected areas.

Renewed focus on forest preservation appeared to provide new opportunities for conserving the habitat of the 'red ape'. As part of global concerns over carbon emissions and climate change, international efforts to reduce emissions from deforestation and degradation (REDD) received a boost at the 13th Conference of Parties of the International Framework Convention on Climate Change (UNFCCC) in Bali in December 2007. Economic incentives provided in a REDD framework could be used to shift the balance towards protecting forests and reducing carbon emissions from deforestation. This could have substantial 'co-benefits' to local people as well as conservation. In such cases, a REDD scheme might provide co-benefits by providing upfront investment and performance-based rewards for local people not to convert forest to plantations and thereby protect the forest and the orangutan habitat. Other orangutan forest areas that are not so rich in carbon (because located on mineral soil) could also provide co-benefits. In particular, they could

be important watersheds, providing many services for downstream communities who could reward upstream residents for protecting forests and, hence, the watershed.

The World Agroforestry Centre (ICRAF), in collaboration with PanEco and Yayasan Ekosistem Lestari (YEL), conducted a rapid assessment of ecosystem services and human livelihood options provided by the remaining habitat of the Sumatran orangutan outside the Gunung Leuser National Park. We used a rapid analysis of carbon stock assessment (RaCSA) method to assess the carbon stock (above- and belowground) at plot level and calculated land cover for carbon stock at landscape level. We calculated the net present value of important crop and tree commodities in Tripa and Batang Toru and analysed the costs and benefits of each commodity. To find solutions for better management at the two study sites, applications of the FALLOW model were developed, which allowed comparison of several possible scenarios. An attempt was made to translate such scenarios into opportunities for human livelihoods, orangutan population size and carbon emissions and stocks.

Summary of findings

- A livelihood and economic study was conducted to assess current livelihoods and drivers of land-use change in both landscapes. Further analyses focused on economic incentives and alternative opportunities to produce multiple benefits from land uses. In the Batang Toru landscape, irrigated paddy rice was still the main land use that provided subsistence needs, with additional market orientation for some farmers. Mixed gardens with high economic value trees, such as rubber, *kemenyan* (benzoin) and various fruits, were important for cash income and additional subsistence needs. However, the *kemenyan* systems appeared to have become economically marginal. Improvement of production and/or marketing systems would be needed to avoid a destabilisation of the northern part of the Batang Toru forest block. Eco-certification of rubber, which is being researched elsewhere in Sumatra, that is produced in a sustainable and biodiversity-friendly way may in future allow farmers to get a better price for their rubber products. The 'integrated' landscape concept survived the analysis. Integration of functions is helped by the fact that the dominant commodities in the agroforests are not on the menu as normal food sources for orangutan and other wildlife. The three primary threats to orangutan conservation in this landscape are 'external' in their origin: the logging concession; the planned gold mining operations; and the continued immigration of people from Nias who open up forest for new farms and are reported to be opportunistic hunters of orangutan.

- In Tripa, expansion of oil palm companies was rapid, with land-use concessions (HGU) leading to the conversion of peat forest areas to oil palm. The Aceh Barat Daya government, one of the two regencies (*kabupaten*) with jurisdiction over parts of the Tripa swamp, had ruled that community members could establish oil palm plots of up to 2 ha per household. This regulation led to massive land conversion by smallholder farmers. The smallholder oil palm sector is now driving land-use change in Tripa and may be the greatest potential threat to the remnant peat swamp forest of Tripa and, thus, the orangutan.

- The aboveground carbon stock estimate for undisturbed forest in Tripa was similar to that in Batang Toru (averages of 246 and 243 t/ha, respectively). Most of the forest in Tripa, however, is disturbed, with an average aboveground carbon stock of 122 t/ha. Lowland peat swamps in Tripa have an average depth of 3.2 m, with average belowground carbon stock of 1350 t/ha and 4.19 t/ha/cm (root carbon stocks are not included in this estimate as yet). Soil-based carbon stock in Batang Toru ranged 32–58 t/ha for the top 15 cm, with lowest values measured in durian agroforest and highest in undisturbed forest.

- Undisturbed forest in Batang Toru contained many tree species supplying orangutan food. Ten dominant tree species found in Tripa (including *Eugenia jambos* as most common species) were identified as sources of orangutan food. Trees in Tripa were more diverse than those in primary forest in Batang Toru,with a Shannon-Wiener index of 3.5 and 2.9, respectively.

- In Batang Toru, by contrast, land-use was relatively stable for the whole period of observation. For the 1994–2009 period, loss of undisturbed forest was 1.17% per year; loss of disturbed and undisturbed forest was 0.5% per year (for a total loss of 5% of the landscape); and loss of disturbed, undisturbed and agroforest was 0.24% per year. Agroforests (with rubber, *kemenyan* or mixed fruit tree as main species) increased until 2001 (from 22 to 27.4% of the area), but had then declined to 23.6% in 2009. Other crops and monoculture plantations increased by 1.5% per year, from 11.9 to 15% of the area. The aboveground carbon stock 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 in 2009. Net emissions peaked during 2001-2006 (4.9 tCO_2e/yr). Emission factors from aboveground biomass changes in the orangutan habitat were highest during 2001–2006 (4.95 tCO_2e/ha/yr).

- At landscape level, the average aboveground carbon-stock density in the 1020 km^2 assessed in Tripa decreased from 148 t/ha in 1990 to 61 t/ha in 2009, while for the 480 km^2 subset of this that is conceded to oil palm plantations, carbon density decreased from 114 t/ha in 1990 to 48 t/ha in 2009. The annual emission rates owing to land-use conversion in the study area ranged between 0.94 MtCO_2e/yr and 2.2 MtCO_2e/yr, with the highest value in the period 1990–1995 when forest conversion to oil palm plantations peaked. The lowest rate, during 2001–2005, was because of a slowdown of activities during the conflict. Post-tsunami and after the peace agreement, emissions increased again.

- Analysis of opportunity costs of avoided emissions (or 'abatement costs') in Tripa and Batang Toru showed that the opportunity cost between natural forest and oil palm was slightly over 10 USD/tCO_2e. Carbon stock and profitability could be classified into four groups: 1) High carbon and low profitability (for example, forest); 2) Medium carbon and medium profitability (for example, logging and agroforest); 3) Low-carbon stock and low-to-medium profitability (for example, annual crops and agroforest); and 4) Low-carbon stock and high profitability (for example, oil palm). Based on these criteria, change of land use in Batang Toru was much slower compared to Tripa. In Batang Toru, the dominant change, and the higest emission contributor, was from undisturbed forest to disturbed forest, which reflected logging and other timber extraction activities taking place in parts of the forest. The opportunity cost for logging activity from natural forest was 8.27 USD/tCO_2e for all the periods of analysis.

- On the other hand, forest in Tripa decreased dramatically to more profitable but low-carbon stocks, that is, oil palm (both plantations and smallholder plots), while annual crops and agroforest remain constant. In Tripa, forest conversion to oil palm plantations produced high average annual emissions. Over the whole observation period, average annual emissions from Tripa (5.7 tCO_2e/ha/yr) were higher than those from Batang Toru (4.2 tCO_2e/ha/yr). The opportunity costs of natural forest and natural peat swamp forest conversion to oil palm plantations were the highest. By taking into account peat emission during land-use conversion, the average emission in Tripa was estimated to be 20 tCO_2e/ha/yr. Using the threshold of 5 USD/tCO_2e, the emissions from land-use conversion that could have been avoided ranged between 6 tCO_2e/ha/yr to 14.6 tCO_2e/ha/yr over different periods of observation. The proportion of high-opportunity-cost emission is also much higher in Tripa than in Batang Toru.

- FALLOW modelling scenarios in Batang Toru and Tripa highlighted the need to consider both livelihood and emission levels as dynamic baselines. While opportunity costs refer to current economic value, scenarios of land-use change indicate that income opportunities for local communities are key. A number of activities that enhance emissions also increase the number of people who can obtain income. When such effects are included at the landscape level, opportunity costs could increase to 15 USD/$tC_{O2}e$ for comprehensive emission reduction scenarios, while they could be 5 USD/$tC_{O2}e$ for limited activity, with lower relevance for biodiversity conservation. The FALLOW model also indicated that about 60% of the income opportunities that might be lost in Tripa if oil palm expansion was restricted could be absorbed by other land-use activities.

- Orangutan populations are likely slow to respond to ecological restoration owing to their low birth and dispersal rates. Further examination of the corridor scenarios explored how attractive such options could be from a conservation perspective, with a potential gain of 10–200 individuals in the area over 30 years.

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1. Project overview

Meine van Noordwijk and Hesti Lestari Tata (editors)

1.1 Orangutan conservation and human livelihoods

After many centuries of sharing the landscape of the northern half of Sumatra, human populations and orangutan (the red ape) appeared to become incompatible in the 20th century. The establishment of the Gunung Leuser National Park as conservation area excluded people while the transformation of forests outside of the protection area to open-field agriculture, intensive tree crop production systems or to the pulp and paper industry excluded orangutan. The 'segregation' of functions, however, was not complete and the boundaries remained contested. For the conservation stakeholders the primary way to achieve their goals was to increase the size and connectivity of 'protected areas', while people continued to infringe on the parks and contested the legality of forest allocation to logging concessions and/or conservation agencies. In part of the landscape a more integrated and gradual transition from natural forest to human habitat survived for a number of reasons. Here, the villages, generally located below the natural forest, maintained an active interest in regularity of water flow and other ecosystem services that the forest provided. However, hunting pressure remained an issue until the wildlife trade was effectively controlled (this goal has still not been fully achieved). Maintaining a balance in such 'integrated' landscapes depends on appropriate incentives, rather than the 'command and control' approach of protected areas. The Leuser Ecosystem, an area of 2.6 million hectare that includes the Gunung Leuser National Park, could offer such an alternative. Enacted by presidential decree in 1999, it stated that all activities in the Leuser Ecosystem must be compatible with sustainable management.

Renewed focus on forest preservation appeared to provide new opportunities for conserving the habitat of the red ape. As part of the global concerns over carbon emissions and climate change, international efforts to Reduce Emissions from Deforestation and Degradation (REDD) got a boost at the 13th Conference of Parties of the International Framework Convention on Climate Change (UNFCCC) in Bali in December 2007. Economic incentives provided in a REDD framework can be used to shift the balance towards protecting forests (aka carbon stock) and reducing carbon emissions from deforestation. This can have substantial 'co-benefits' to local people as well as conservation. For example, orangutan habitat sometimes coincides with peat lands (that have high carbon stock both above- as well as belowground). Local livelihoods depend on the peat lands for various food sources and materials. If there is pressure to convert forest to oil palm plantations, such work is usually implemented by, and provide benefits to, people migrating into the area, rather than local residents. In such cases, a REDD scheme might provide 'co-benefits' by providing rewards for local people not to convert forest to plantations and thereby protect the forest and the orangutan habitat. Other orangutan forest areas that are not so rich in carbon (because on mineral soil) could also provide co-benefits. In particular, they could be important watersheds, providing many services for downstream communities who can reward upstream residents for protecting forests and, hence, the watershed. As earlier research in Kalimantan (Suyanto et al., 2009a; Galudra et al., 2010) showed and as we will see in this report, however, such expectations are not yet easily translated into practice.

The institutional translation of the REDD concept has proved to be substantially more complex than initially thought and the way any REDD scheme will interact with land-use planning, the local economy and conservation outcomes still depends on multi-level negotiations (Van Noordwijk et al., 2008, 2009; Suyanto et al., 2009b).

Such negotiations require a common understanding among the parties of the various options, including analysis and exploration of scenarios that reflect various types of change. This study was set up to provide basic data and make a start with analysis of the options for supporting human livelihoods (and development agendas) as well as conservation of a highly endangered red ape. The study focuses on two specific and very complementary sites: the carbon rich coastal peat swamp forest of Tripa and the protected watershed forest of Batang Toru.

1.2 Agroforests in the landscape of Sumatra

Deforestation implies a shift from a 'forest' to a 'non-forest' status of land, and thus depends on the way forest is defined. Commonly used definitions of forest assume that 'forest' and 'agriculture' are not mutually compatible. Yet, a lot of agricultural systems critically depend on trees and when there are a lot of trees on a piece of land, it may start to look like a forest, act like a forest and be misclassified by foresters as being a forest, restricting access by farmers. In terms of actual vegetation, there is a class of tree-based land use that is called 'agroforest'. It easily meets the internationally accepted definition of forest based on tree cover and tree height, but it is managed by farmers rather than by forest management institutions. Or, it can be claimed by both and needs agreement by farmers (or rural communities) and forest authorities on the way the land can serve both local livelihoods and public ecosystem services. The institutional distinctions between 'forest' and 'non-forest' differ from the ecological ones, with the latter referring to a gradient of types of land use, rather than a dichotomy. With the current international attention on the rate of deforestation, its consequences and drivers, the nuance of 'agroforests' as a type of land use must be put on the map[1]. Agroforests must be understood on the basis of their history, management style and current function for watershed protection and biodiversity conservation, and such appreciation can help to reduce the conflict between local communities and forest authorities, leading to forms of joint management. In North Sumatra and Aceh, the opportunities for survival of a 'flagship' species—the *forest person* or orangutan—is of special interest. Current efforts to stem the tide of deforestation, loss of habitat for forest fauna and flora, and loss of buffering of water flows, are linked to emissions of greenhouse gasses and reduction in the amount of carbon stored in trees and soil. We need to understand how 'agroforests' relate to these functions and how the interest in maintaining 'forest functions' can be reconciled with the livelihoods of the human relatives of the orangutan.

A typical village in Sumatra has rice fields along a stream and may have developed local structures to control the amount of water that flows through them; it may also have more technical forms of irrigation and superficial drainage to allow rice production beyond the rainy season. Around the houses one finds fruit trees of many types, many of which are in early stages of domestication with wild relatives still found in the natural forest. Some of these trees still depend on pollinators and

[1] According to the first maps of Indonesia that include agroforests as a category, the area has declined from about 20 Mha in 1990 (roughly 10% of Indonesia's land area) to 16 Mha in 2005 (about 8% of Indonesia), while oil palm plantations cover less than 5% of the total area (http://www.worldagroforestrycentre.org/sea/ALLREDDI).

seed dispersal agents from the natural forest but when forest animals claim their share of the fruits, they are unwelcome guests, or 'pests'. Conflicts arise when sun-bears or orangutan feed on the durian, *petai*, mangosteen and other fruit trees that are common in home gardens as well as natural forest. Beyond the home garden, we may find a zone of agroforest with tree crops that provide regular income. This may consist of trees that provide 'non-timber forest products', as well as firewood and timber for local use. Some of the trees will have been planted, others grew spontaneously but are selectively retained by farmers according to their usefulness. Some of the trees that are planted come from forests far away: nutmeg was brought to Aceh when the colonial traders sought to reduce their dependence on production in the Moluccas of a tree that was worth shipping around the world. Later, commercially important trees were brought in from Africa (various coffee species, oil palm) and Latin America (including cacao, para rubber, quinine). The agroforest blended local and foreign, old and new, 'agro' and 'forest'.

Figure 1. Artist's impression of the village–forest gradient in Batang Toru as discussed with villagers during the ICRAF/Winrock support for orangutan-compatible livelihood enhancement (artist: Wiyono)

Moving further from the village, the agroforest grades into modified natural forest without specific tree management. Here, land may still have a history of being partially cleared for a swidden (*ladang*) at some time in the past as the human population has fluctuated over time, through diseases and wars, and people have roamed across the landscape. Charcoal in the soil and the presence of patches of fruit trees, may indicate such history. Beyond the modified forest may be natural forest that has been, and still is, used for hunting, collection of honey, fishing in the rivers and harvesting of resins and agar-wood from trees that are not yet, or only partially, domesticated in the agroforest. Where the terrain becomes hard to access, nature prevails; or prevailed, until logging companies found reason to create access to the valuable timber species that Sumatran forests are renowned for. Government-sanctioned logging concessions became widespread in and after the 1960s and opened up forest areas to further human settlement and use.

The gradient that we here describe around a single village in fact forms a mosaic with multiple claims on the forests that can be reached from different villages as starting points. It is a mosaic of land cover, of functions and of institutions, where it is hard to draw clear boundaries.

Yet, boundaries rather than gradients have been the basis for policy, land-use planning and institutions to reduce conflict and manage land for multiple functions. Now that the conservation of critically endangered species such as the Sumatran orangutan is a global priority, the opportunities for co-habitation with humans have become a critical issue. Our analysis aims to contribute basic facts about *what* is *where* (the types of agroforest and other tree-based land use that complements natural forest and rice fields in the landscape), *who* uses it, *how* this has changed over the recent decades and with *what consequences* for carbon emissions and survival of forest flora and fauna. Only if such basic facts are understood in their spatial context can we hope to find new ways to reconcile human development ambitions and the ecosystem functions on which our species, as well as so many others, depend.

1.3 The Sumatran orangutan

The Sumatran orangutan (*Pongo abelii*) is a red great ape only found on Sumatra in Indonesia. It mainly occurs in two provinces, Aceh and North Sumatra, but in the past it occurred further south as well and has in the past decades been reintroduced by release of formerly captive individuals on the border of Jambi and Riau where the local language retained traces of former orangutan presence (*hantu*). The Sumatran orangutan almost exclusively lives in trees, has red short and smooth hairs compared to its Bornean relative (*Pongo pygmaeus*) who is more frequently on the ground on an island that has no tigers. The Sumatran orangutan have more fruits in their diet than the Borneans, as the soils in Sumatra are geologically younger and consequently richer in nutrients, supporting a richer forest. One of the fruit trees in Sumatra, *Neesia,* a relative of the durian, is part of the orangutan diet because they have learned (and culturally transmit the know-how) to use sticks as tools to open the fruits and avoid the sharp, needle-like hairs that protect the unripe seeds (van Schaik and van Duijnhoven, 2006). *Neesia*, most common in the peat swamp forests, is not part of the human diet, but durian is sought after by both humans and orangutan.

The population of Sumatran orangutan in Aceh and North Sumatra province was estimated at 6642 individuals (Wich et al., 2008), with the three biggest populations in West Leuser (2508 individuals), East Leuser (1052 individuals) and in Rawa Singkil (1 500 individuals). The Sumatran orangutan possess greater diversity compare to the Bornean orangutan (Locke et al., 2011). The Batang Toru area south of Lake Toba is habitat to a population that has been isolated from those to the north when the Toba volcano exploded 70 000 years ago, creating Lake Toba. Recent analysis of DNA patterns (Nater et al., 2011) has indicated that the Batang Toru populations genetically distinct from that north of Toba and that their mitochondrial DNA, that is inherited purely matrilineally, may in fact be more similar to the Bornean species. This finding, to be corroborated, suggests an even higher conservation value for the Batang Toru populations.

The Sumatran orangutan occurs in relatively high densities in peat swamp forest (in the few places where that is left) and in lowland forest. Where these forests grade into sub-montane forest at around 1000 MASL, orangutan become scarce. The Leuser ecosystem contains the full gradient of forest type (Wich et al., 2003; 2008). The swamp forests have an abundance of fruits that support orangutan in periods when fruits are scarce in other areas and the higher densities in this habitat are linked to different social behaviour (Wich et al., 2006, van Schaik and van Duijnhoven, 2006). The Tripa swamp represents this habitat and may well offer the last chance to add to the peat swamp forest area that is effectively protected (especially since the lowland swamps south of Sibolga were converted in the 1990s).

Sumatran orangutan are a flagship species, listed as critically endangered in the IUCN Red List (IUCN, 2010). They were first protected in Indonesia with the prohibition of hunting and killing certain species by ordinances of 1931 *(Dierenbeschermingsordonantie* and *Dierenbeschermings verordening* 1931*)* and 1932, which made it illegal to catch alive, to disturb, to trade alive or dead, or to hold certain species of primate in captivity. Under Indonesian law, orangutan are protected by Law No. 5 year 1990, regarding conservation of natural resources and their ecosystems (*Undang-undang No. 5 tahun 1990 tentang Konservasi Sumber Daya Alam Hayati dan Ekosistemnya*) and Government Regulation No. 7 year 1999 regarding preserving the diversity of plants and animals. Several regulations relate to orangutan conservation. A regulation—P.83/Menhut-IV/2007 on Strategy and Action Planning for the Indonesian Orangutan 2007–2017—was promulgated by the Ministry of Forestry in 2007 (Soehartono et al., 2007). The regulation consists of five strategies and action planning: (i) strategy and program on orangutan conservation management; (ii) strategy and program on regulation and policy; (iii) strategy and program on partnership and cooperation to support Indonesian orangutan conservation; (iv) strategy and program on communication; and (v) extension for Indonesian orangutan conservation. The regulation also lays down the rules for monitoring and evaluation of national action planning for Indonesian orangutan conservation for 2007–2017.

Orangutan habitats, such as peat swamp, lowland and sub-montane forests, in North Sumatra and Aceh are currently under pressure owing to extensive logging and conversion to oil palm plantations. The two greatest threats to orangutan survival are habitat loss and illegal trade in the animals. The number of Sumatran orangutan decreased rapidly (by 45%) from approximately 12 000 in early 1993 to 2000–01 (van Schaik et al., 2001). Departemen Kehutanan (2007), in the strategy and program for orangutan conservation management, listed a number of threats to the orangutan and ranked them either high or medium. Land-use change, forest fires, illegal logging and illegal trading were ranked as high, while others, such as weak law enforcement, mining and population pressure, were ranked as medium. Nantha and Tisdell (2009) reported land-use conflict between orangutan and oil palm because orangutan need forest cover but oil palm needs cleared land. Many oil palm plantations used forest instead of existing crop land (Koh and Wilcove, 2007).

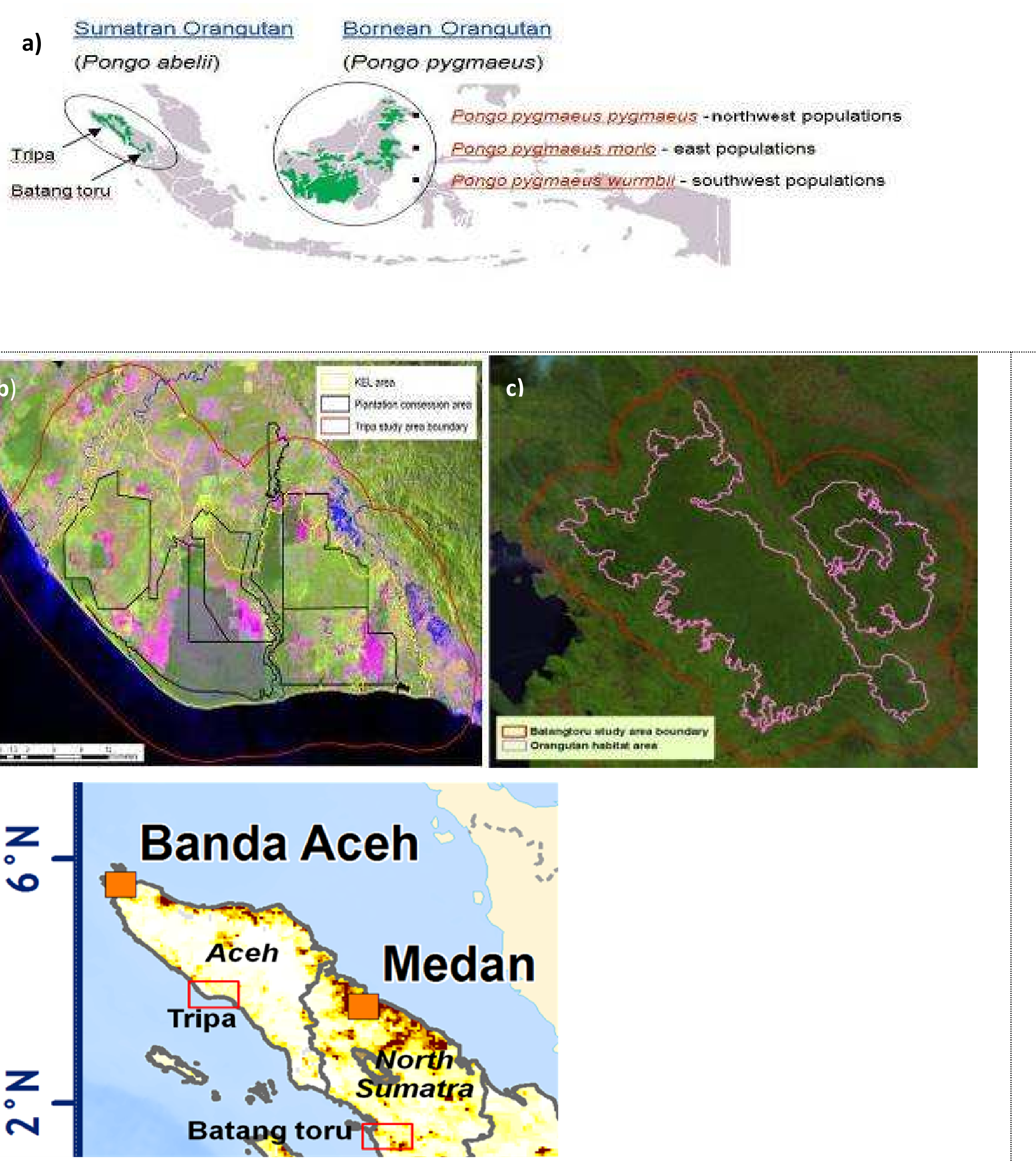
In attempt to reduce the conflict between orangutan and humans, the Ministry of Forestry (2008) promulgated regulation number P.48/Menhut-II/2008 regarding regulation of conflict management between humans and wildlife. Procedures on handling conflict between orangutan and human needs were described in detail. Another approach to avoid conflict is using the status of High Conservation Values Forest (HCVF). The forest as orangutan habitat is considered to have HCV 1, that is, globally, regionally or nationally significant concentrations of biodiversity values; and HCV 3, that is, rare, threatened or endangered ecosystems (Jennings et al., 2003). However, conservation scenarios still need ways to offset the legal opportunity cost of companies that already obtained rights to convert forest to oil palm (Koh and Wilcove, 2007; Wilcove and Koh, 2010).

Sumatran orangutan are still found in the Tripa peat swamp ecosystem. The estimated number in Tripa was 280 individuals (Wich et al., 2008). Tripa is experiencing land-use conflict over orangutan habitat and oil palm plantations. There are five oil palm plantations in the Tripa area (Ruysschaert et al., 2009). Notwithstanding, Tripa was designated as Kawasan Ekosistem Leuser (Leuser Ecosystem Zone or KEL) by Presidential Decree number 33 in 1998 regarding management of the Leuser Ecosystem. The decree appointed the Leuser International Foundation to manage the ecosystem.

Outside the Leuser Ecosystem, Sumatran orangutan are found in the Batang Toru area south of Lake Toba. The estimated number of individuals in the west block of Batang Toru was 400 (Wich et al., 2008). The Batang Toru is an important habitat of Sumatran orangutan, consisting of low land to low montane forest. The Batang Toru forest is well known for its high biodiversity of flora and fauna (Fredriksson and Indra, 2007). These two sites were selected as the study area of the research.

Sumatran orangutan occur in Aceh province in peat swamp forest. This is a unique ecosystem which consists of high organic matter, low pH (3-4), low nutrient levels, spongy and high water content. The forest floor is flooded during the wet season and sometimes even in the dry season. The ecosystems are very fragile and susceptible to forest fire owing to high levels of organic matter. When the forests are cleared and drained, large amounts of CO_2 are released (Yule, 2010; Jauhiainen et al., 2005), making the preservation of peat swamp forest nationally and globally important. The major role of tropical peat swamp forest in carbon sequestration is now well established (Page et al., 2002; Jauhiainen et al., 2005; Sorensen, 1993).

It is well known that tropical forest has a high carbon stock compared to any other vegetation ecosystem. Tropical forest also has high flora and fauna diversity. The lowland and montane forests have more diverse vegetation compared to peat swamp forest but the latter has a distinctive character compared to other forest typologies. Peat swamp forests are located in areas with high rainfall and poor drainage with the surface always waterlogged. They are covered by different vegetation types, which indicate the depth of the peat (Page et al., 1999). However, the net rate of deforestation of this kind of forest remains high: approximately 1 million ha per year.



d)

Figure 2. a) Approximate orangutan distribution in Indonesia (source: Wikipedia); b) Study site in Tripa, Aceh province; c) Study site in Batang Toru, North Sumatra province; d) Position of the two landscapes on a map indicating relative human population density

Deforestation, peat fires and drainage contribute to carbon stock loss and CO_2 emission, increased flooding, subsidence that threatens entrance of salty water from the sea, and flora and fauna loss.

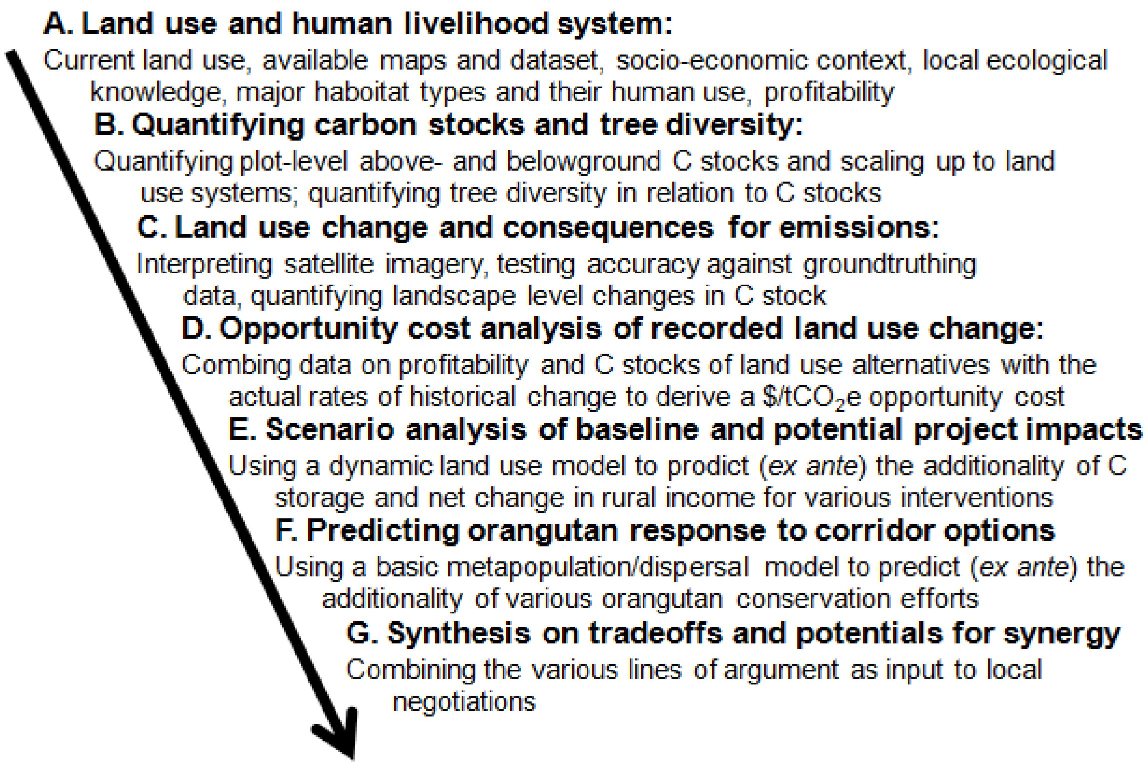
1.4 Study sites

The study was conducted in Tripa, Aceh province, and Batang Toru, North Sumatra province, Indonesia (Figure 2.d). The size of the Tripa study site is approximately 102 040 ha, or 1020 km^2, covering the area of Kawasan Ekosistem Leuser (60 000 ha) and the 5 km buffer area, as shown in Figure 2(b). The size of orangutan habitat in Batang Toru is approximately 110 000 ha (based on two maps (Wich et al. 2008 with update by Fredriksson, Usher and Wich) and the 5 km buffer area, covering an area of 247 000 ha or 2470 km^2.

1.5 Framework of the study

The World Agroforestry Centre (ICRAF), in collaboration with PanEco and Yayasan Ekosistem Lestari (YEL) conducted a rapid assessment of carbon stock and carried out spatial, livelihoods and costs-benefits analyses for orangutan habitat the two sites. We used Rapid Analysis of Carbon Stock Assessment (RaCSA) to assess the carbon stock (above and below ground) at plot level and calculated land cover for carbon stock at landscape level. We calculated net present value (NPV) of important crop/tree commodities in Tripa and Batang Toru and analysed the costs and benefits of each commodity. To find solutions for better management at the two study sites, a FALLOW model was used, which generated several possible scenarios.

The assessment was conducted via several stages, as illustrated below.



2. Component A: Land use and human livelihoods

Elok Mulyoutami, Endri Martini, Yuliana C Wulan, Katrina Riswandi, Amri Nasution, Panggalih J Susetyo and Pinda Sianturi

2.1 Socio-economic aspects of current land use as a basis for change

The western block of Batang Toru forest in North Sumatra and the Tripa swamp in Aceh are both unique and have globally important biodiversity and conservation values. Human pressures owing to economic and population expansion drives the conversion of forests into unsustainable land uses. Suitable livelihood systems that will support economic and environment values for local communities have to be identified and developed. Therefore, a study of livelihood options and socio-economic value forms an important baseline for discussing any conservation scheme.

A livelihood and economic study was conducted to assess the current condition of livelihoods and drivers of land-use change in both landscapes. Further analysis was focused on economic incentives and alternative opportunities to produce multiple benefits from the land use. Under this study, there are four main activities. First, to identify current and previous livelihoods, strategies and priorities of the people living in the Batang Toru and Tripa landscapes. Second, to identify problems, opportunities and risks related to their livelihoods. Third, to collect specific data on profitability of the main land-use system. Fourth, to start a dialogue on scenarios for future change.

2.2 Methods

2.2.1 Study design

The study started with a broad characterization to understand current and previous livelihoods context, strategies, and priorities of people living in the Batang Toru and Tripa landscapes. This initial phase was used to stratify the landscapes and select four to five villages for a more in-depth second stage of interviews and focus groups to identify problems, opportunities and risks related to current livelihoods. As a third step, specific data on the input/output relations, market prices and profitability of the main land-use system were collected through household interviews (12 per village). As the dominant land uses involved perennials, costs and benefits needed to be considered at the 'life-cycle' scale of a land use, while comparing the discounted cost and benefit flows of the establishment, early, mature and late production stages. Results can be expressed as net present value per unit of land, when standard labour costs are used, or as 'returns to labour' when the returns to land are restricted to any potential change in land value as such (see Tomich et al., 1998). Based on our increased understanding of constraints and options, dialogues were started on scenarios for future change as the fourth phase. Stages in this study are listed in Table 1.

Table 1. Project stages

Step 1: Identify land use and land-use change and the relationship with livelihood patterns	
Land cover	• *Analysis of land-use change map, ecological and other physical maps*
Demography	• *Literature study*
Economic	• *Desktop study of available statistical data* • *Historical analysis: local consultations* • *Direct observation*
Stratification and selection of villages for in-depth study	• *Overview of each district: socio-economic indicators, history of livelihood strategies and priorities* • *Analysis of secondary information and related documents* • *Consultations with relevant local stakeholders*
Step 2: Identify current community livelihoods and dependency on forest and swamp ecosystems	• *In-depth interviews* • *Analysis of secondary information and related documents* • *Consultations with relevant local stakeholders*
Step 3: Assess income and expenses pattern	• *In-depth interviews* • *Household survey (70 households)* • *Analysis of secondary data and information* • *Income and expenses analysis* • *Consultations with relevant local stakeholders* • *Semi-structured interviews*

The primary field activity in the Tripa ecosystem took place 4–14 April, 2010, in Batang Toru 12–21 May 2010.

2.2.2 General characterization, village selection and demography of Batang Toru

The study area surrounded the western block of Batang Toru forest, which covers three districts: North, South and Central Tapanuli. Within the three, agriculture was the basis of the local economy, with primary production approximately half of the total economy. In North Tapanuli, contribution from agricultural sectors was more than fifty percent (55.6%), while in Central and South Tapanuli it was 44.5% and 48.2% respectively.

Table 2. Characteristics of three districts that include part of the Batang Toru landscape

Districts	South Tapanuli	Central Tapanuli	North Tapanuli
Area	1 235 620.28 ha	219 498 ha	379 371 ha
GRDP at current market price	Rp 4 064 279.92 (in 2006)	Rp 1 610 426.30 (in 2007)	Rp 3 126 116.99 (in 2008)
GRDP at 2000 constant market price	Rp 2 705 250.03 (in 2006)	Rp 1 002 818.90 (in 2007)	Rp 1 456 881.25 (in 2008)
Main plantation commodities	Rubber, oil palm, *salak* (snakefruit), tobacco, cinnamon, coffee, clove	Main: Rubber, coconut, oil palm and cocoa Other: clove and coffee	Rubber, coconut, traditional *kemenyan* resin, coffee, clove
Main crops	Paddy, maize, soybeans	Paddy and maize Animal husbandry	Paddy, peanut, maize Animal husbandry
Main commodities in mixed gardens	Mixed garden: rubber, *salak*, cocoa, betel nut, sugar palm	Mixed garden: Rubber, coconut, cocoa	Coffee, rubber, *kemenyan* resin

Villages close to the forest (pop.)	**Marancar** sub-district → Aek Nabara (514), Janji Manaon (262), Bonan Dolok (75), **Batang Toru** sub-district → Batu Horing (2018), Aek Pining (2636), Batu Hula (857), Sitinjak (258), Garoga (784), Huta Godang (1623), **Sipirok** sub-district → Hutaimbaru (307), Bulu Payung (538), Gunung Hasahatan (116), Dano Lombang (306), Paske (263), Sitandiang (195), Bulu Mario (1398), Huraba (124) **Arse** sub-district → Sipogu (596), Lancat Jae (536), Gunung Tua Arse (148) Selected village: Tanjung Rompa (Marancar)	**Sibabangun** sub-district → Sibiobio (1167), Masundung (1927), Hutagurgur (1018), Muara Sibuntuon (1762) Selected village: Hutagurgur	**Adian Koting** Sub-district → Pagaran Lambung II (611), Pagaran Lambung III (708), Adian Koting (1501), Dolok Nauli (1195), Banuaji I (764), Banuaji II (976), Pansur Batu (1255), Pardomuan Nauli (688), Siantar Naipospos (860) **Pahae Julu** Sub-district → Simataniari (570) **Pahae Jae** Sub-district → Suka Maju (855), Siopat Bahal (1585), **Simangumban** Sub-district → Dolok Sanggul (685), Aek Nabara (1025), Lobu Sihim (233), Dolok Saut (977) **Purba Tua** Sub-district → Bonan Dolok (617), Selamat (913), Purba Tua (491), Pardomuan Janji Angkola (583), Parsaoran Janji Angkola (701), Janji Nauli (755), Sitolu Bahal (672), Huta Nagodang (560), Sidua Bahal (220), Sibulan-bulan(463) Selected village: Banuaji Ampat (Adiankoting) and Simardangiang (Pahae Julu)

Source: Tapanuli Tengah Dalam Angka 2008; Tapanuli Utara Dalam Angka 2009; Tapanuli Selatan Dalam Angka 2007.

Our selection of which villages to study used land-use change history as the first criteria. Based on an analysis of land-use change from 1990 to 2005, the Batang Toru area was classified into two groups.

1. Group 1 represented areas that had a longer land conversion history. Some conversion spots were seen in land-cover data from the year 2000.
2. Group 2 represented areas with a nimble conversion rate within five years (as seen from land-cover data for the year 2005).

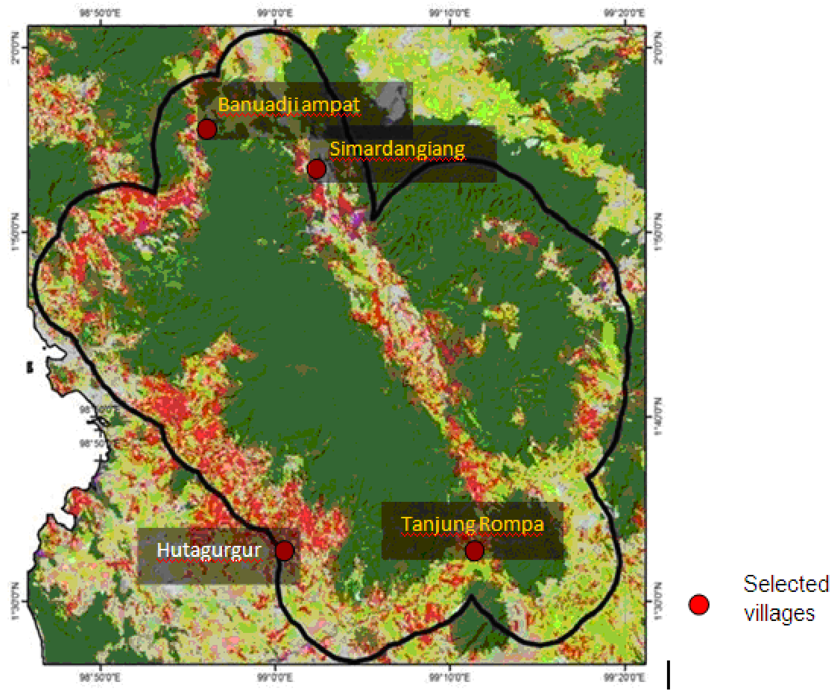


Figure 3. The villages of Banuaji Ampat and Simardangiang in North Tapanuli district represented Group 1; Hutagurgur (Central Tapanuli district) and Tanjung Rompa (South Tapanuli district) represented Group 2

Representative villages were sampled in each block. Additional criteria were applied to select the village, such as closeness to the forest and the dominant livelihood from tree-based farming systems. We had earlier defined the dominant commodities in each district. Tapanuli Utara featured *kemenyan* (benzoin = *Styrax benzoin*) agroforests; Tapanuli Selatan was dominated by *salak* (snakefruit = *Salacca zalacca*) and rubber agroforests; and Tapanuli Tengah had mainly rubber agroforests (Budidarsono et al., 2006). Four villages from three districts were selected Figure 3.

The presence of migrants from Nias, who pursued their livelihoods within local Batak culture, was an additional reason for selecting Hutagurgur village. Tanjung Rompa village was of interest because of its historic establishment of the 'Tanjung Rompa declaration', which protected the forest as a water catchment[2].

Table 3. Characteristics of the four districts in the Batang Toru area

District	North Tapanuli	North Tapanuli	Central Tapanuli	South Tapanuli
Sub-district	Pahae Julu	Adiankoting	Sibabangun	Marancar
Village	Simardangiang	Banuaji Ampat	Hutagurgur	Tanjung Rompa
Grouping	Group 1	Group 1	Group 2	Group 2
Main land use (percent of households)	• Paddy (20%) • Cover crops and perennial crops in **agroforestry**: rubber (10%), *kemenyan* (50%), durian, mangosteen and candlenut (30%)	• Paddy (17%) • **Agroforestry:** coffee (22%), rubber (25%), cocoa (11%), *kemenyan* (31%) • Pines (4%)	• Steep land **agroforestry:** rubber (39%), cocoa (39%) • Flat land in the mountains: *nilam* (patchouli) (11%) • Paddy (13%)	• Paddy (38%) • Irrigated non-technically • **Agroforestry**: *salak* (21%), cocoa (25%), coffee (8%), rubber (17%)
Land holding per household (percent of households)	• **Agroforestry** 1–2 ha • Paddy rice 0.5 ha (peanut and chilli intercropped)	• ***Kemenyan* agroforest** 1–2 ha • Paddy rice 0.5 ha (peanut and chilli intercropped)	• **Agroforestry** 1–4 ha • Paddy 0.5 ha • *Nilam* in steep areas 0.5 ha	• **Agroforestry**: cocoa, coffee and rubber 0.5–2 ha • Paddy 0.5 ha, harvested once per year, with chilli intercropped
Ethnicity	Batak Toba	Toba	Batak Toba and Nias	Batak Toba, Angkola
Religion	Christian	Christian	Christian	Muslim and Christian equally

Of the study villages, the population density was highest in Simardangiang village and Pahae Julu sub-district. In the migrant village, Hutagurgur, households were large (7–8 persons per household) compared with other villages (average 4–5 persons per household). Annual population growth in Hutagurgur village was relatively high, at 1.8% per year, and expansion of the village was rapid.

[2] See http://dongants.wordpress.com/2009/03/25/turun-temurun-menjaga-kemilau-batang-toru-2/
http://orangutanumatra.files.wordpress.com/2009/04/090313-mb-laskar-konservasi-aek-batang-toru.pdf

For the area as a whole, population density was in the range 26–78 persons per km^2, which was around the average for Sumatra[3]. High annual population growth, in particular in Central Tapanuli (3–4% per year), posed a threat to forest use.

Table 4. Demography of several villages in Batang Toru

Desa	Population	Household	Male	Female	Persons per household (average)	Population density (persons per km^2)
Hutagurgur village	1 018	135	505	515	7.54	28.5
Sibabangun sub-district	27 308	5 543	13 586	13 722	4.93	62.1
Simardangiang village	671	156	336	335	4.30	78.1
Pahae Julu sub-district	12 411	2 991	6 042	6 369	4.15	74.8
Banuaji Ampat village	968	225	468	500	4.30	54.2
Adiankoting sub-district	13 306	4 044	6 669	6 637	3.29	26.5
Haun Atas	615	126	297	318	4.88	60.7
Tanjung Rompa	476	92	243	233	5.17	38.2
Marancar sub-district	10 267	2 258	5 116	5 151	4.55	40.3

2.2.3 General characterization, village selection and demography in Tripa

Agriculture was also the most significant driver of the local economy in the bigger part of Nagan Raya and Aceh Barat Daya districts, as seen in Table 5. In Nagan Raya, the agriculture sector accounted for 63.4% of economic activity. Within the sector, plantations were the dominant activity (24.69%) followed by horticulture (19.8%) and animal husbandry (8.85%)[4]. Plantation crops were dominated by oil palm, which has been present in the landscape for many years. In Aceh Barat Daya, agricultural production was dominated by rice cultivation and horticulture such as corn, soybean and peanut. Cocoa production from Aceh Barat Daya was also high, at about 1758 t/yr.

Table 5. Economic structure (in million rupiah)

District	Fisheries	Agriculture	Non-timber forest products (NFTP)
Aceh Barat Daya	147 853	844 625	10 235
Nagan Raya	35 638	1 494 337	9595

Note: NTFP includes rattan production etc. Source: BPS (2007)

[3] A tentative classification of districts in Indonesia was made according to the following categories: Low: <10 persons km/^{2}, Lower medium: 10–100 persons/km^2, Upper medium: 101–300 persons/km^2, High: >300 persons/km^2.
[4] BAPEDA Kabupaten Nagan Raya and BPS Kabupaten Nagan Raya. 2008. *Produk Domestik Regional Bruto Kabupaten Nagan Raya (Menurut Lapangan Usaha) Tahun 2002–2007*.

Politically, the two districts showed differences in land-use approaches. In Nagan Raya, expansion of oil palm companies was fast, with land-use concessions leading to the conversion of peat forest into oil palm plantations. At the smallholder level, cocoa was still the number two commodity, while oil palm had become number one and was mostly planted by smallholders with higher incomes. Most farmers (about 65%) within surveyed villages had oil palm plots of at least 1–2 ha each, with different ages of oil palm planted. Many of the oil palm plantations were already producing.

The Government of Aceh Barat Daya had ruled that community members could establish oil palm plots of up to 2 ha per household. The Government provided planting materials and fertilizer. This regulation led to massive land conversion by smallholder farmers. Travelling to the sea along the Seumayam River, which separates the two districts, land clearance by smallholders on the Aceh Barat Daya side can easily be seen.

Village selection was based on villages' location, some within the Tripa swamp, others on the edge. The history of the village, transmigration, and other factors (such as being a relocated or 'displaced' village after the tsunami) were also taken into account.

Household surveys were focused on Babah Lueng and Ladang Baru in Nagan Raya and Ie Mameh in Aceh Barat Daya. In-depth studies were carried out in five selected villages while market surveys were conducted in two areas: Kuala Batee and Alue Bilie (Figure 4).

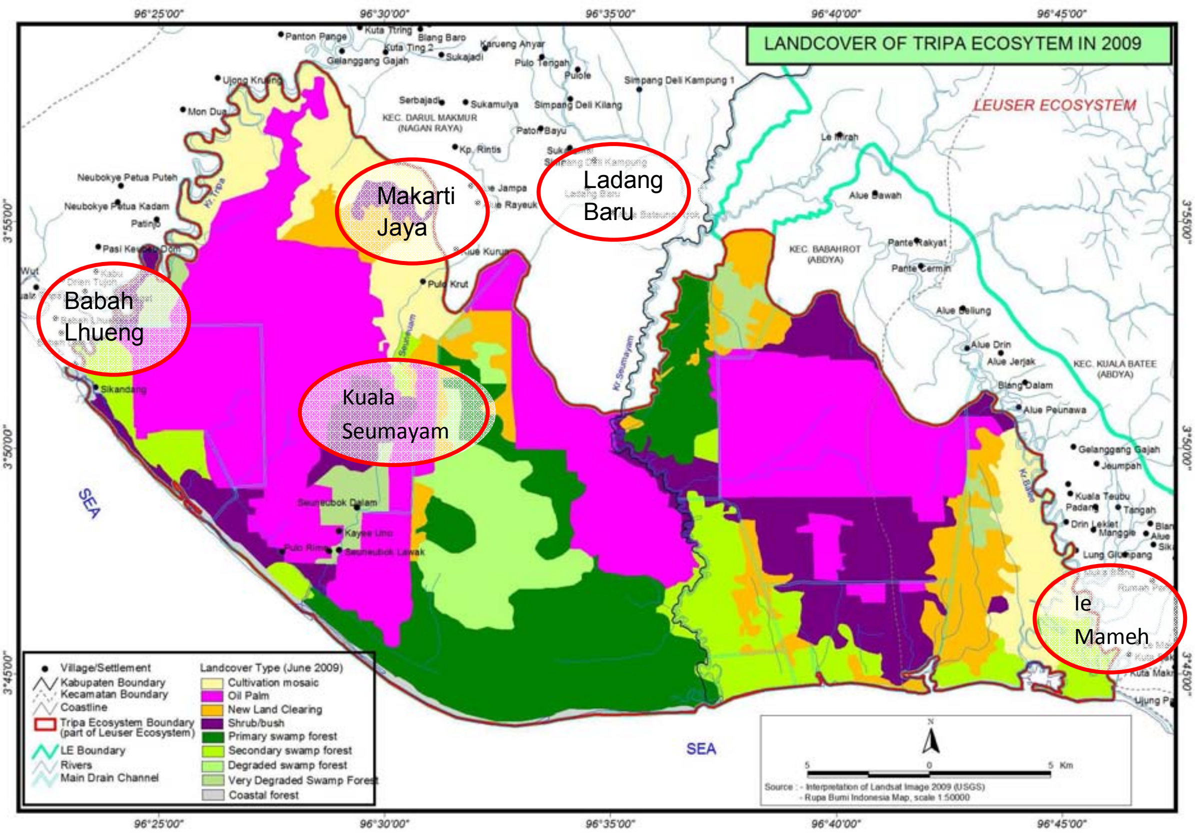


Figure 4. Location of livelihood and economy study in Tripa (PanEco, 2010)

Table 6. Selected villages for livelihood study

Village	Sub-district	District	Description
Babah Lhueng	Darul Makmur	Nagan Raya	Coastal village
Kuala Seumayam	Darul Makmur	Nagan Raya	Displaced village, from the coast to inland, shifting the livelihood source from farming and fishery at the coast to farming inland. Some residents still depend on fishing
Ladang Baru	Darul Makmur	Nagan Raya	Farming and plantations
Ie Mameh	Kuala Batee	Aceh Barat Daya	
Markati Jaya	Darul Makmur	Nagan Raya	Transmigration area, people not only depend on oil palm plantations but also orange (*Citrus sinensis*) production.

Among the villages surveyed, Markati Jaya (a transmigration village) was the most populous village, while Ladang Baru (dominated by Acehnese) was the lowest (Table 7). The larger population density in Markati Jaya was caused by transmigrants selling their land, thereby attracting more residents from surrounding areas. This phenomenon occurred in almost all migration areas (Table 8).

The agricultural density in Markati Jaya was also very high because migrants, who came via the transmigration program in 1957, dominated the village. Transmigrants could have 2 ha of land per household allocated for crop farming and tree-based farming, but Ladang Baru village was low in agricultural density owing to large areas being included in one oil palm company's plantations. There was some continuing conflict over land used by the company that the village claims was wrongfully taken[5]. Similar conflict has been reported in Kuala Seumayam[6].

Table 7. Village hamlet population and household numbers

Hamlet	Number of households	Population			Density (Persons per km^2)	Agricultural density (Persons per km^2)
		Men	Women	Total		
Babah Lhueng	206	403	311	714	44.6	27.69
Kuala Seumayam	84	195	230	425	26.56	14.88
Ladang Baru	76	168	180	348	17.4	11.68
Markati Jaya	158	303	288	591	89.83	77.74
Ie Mameh	168	336	283	619	17.2	30.21

Source: BPS Kabupaten Nagan Raya, 2008

Table 8. Migration patterns in the surveyed villages

Migration	Settlements			
	Farming community, migrants	Fishing community	Displaced fishing community	Farming community (gardening)
Out-migration	Medium	Low	High	Low
In-migration	High	Low	Low	Low

Source: interviews and discussions with key informants

[5] http://www.serambinews.com/news/view/6757/warga-ambil-alih-ribuan-hektare-lahan-kallista-alam
[6] http://buntomijanto.wordpress.com/2009/01/16/antara-lele-kalkulator-dan-sawit-2

2.3 Land use in Batang Toru

2.3.1 Land holding in Batang Toru

In Tanjung Rompa and Simardangiang, irrigated paddy rice was the main land use providing subsistence needs and additional market produce, while in Hutagurgur and Banuaji Ampat, upland rice was common. In Hutagurgur, 29.6% of households had irrigated paddy fields. People originally from the island of Nias lived in the hilly areas (26% of total households) in this village, with 1–3 ha of land, producing rubber and upland paddy as their major tree and crop products. In Banuaji Ampat, 62% of households had paddy rice fields and 81% had upland fields.

In Simardangiang, paddy rice field households were about 65% of the total, while upland field households were about 25%. In Tanjung Rompa, upland rice was only grown when establishing new rubber or cocoa gardens. Nearly 90% of households in this village used the irrigated paddy system; they had clean water from the forest that they had been maintaining well for many years.

Table 9. Landholding types in selected villages

District	**Central Tapanuli**	**South Tapanuli**	**North Tapanuli**	
Sub-district	Sibabangun	Marancar	Pahae Julu	Adiankoting
Village	**Hutagurgur**	**Tanjung Rompa**	**Simardangiang**	**Banuaji Ampat**
Land holding per household (HH)	• Paddy 0.5 ha • Upland rice field 0.5 ha • Mixed garden (rubber, sugar palm, etc) 1–4 ha • Rubber **agroforest** 1–2 ha	• Paddy 0.5 ha, harvested once per year, and chilli intercropped • Mixed garden (rubber, sugar palm) 1–4 ha • Snakefruit (semi-monoculture) 0.5–2 ha	• *Kemenyan* **agroforest** with rubber 1–2 ha • Coffee 0.5–1 ha • Cocoa 0.5–1 ha • Paddy 0.5–1 ha (harvested once per year; peanut and chilli intercropped)	• *Kemenyan* **agroforest** 1–2 ha • Paddy 0.5–2 ha (harvested once per year, and peanut intercropped) • Other crops (chilli) • Mixed garden: coffee dominant

Mixed gardens with high economic value trees were also important, particularly for their cash income. Almost all surveyed villages had mixed garden ownership varying from 0.5 to 4 ha, with an average 1 ha per household. However, the main commodity in each mixed garden system varied depending on the land-use history, soil and climate suitability, and land steepness.

2.3.2 Community typology and their resources in Batang Toru

Two types of communities with tree-based livelihood systems were identified within and surrounding the western block of Batang Toru forest.

1. **Migrant, forest-dependent community**: Hutagurgur village, Central Tapanuli. Migrants, particularly from Nias, made up more than 70% of the population. Some of them came to the village driven by the migration tradition (*merantau*) in search of better livelihoods, while the rest came as refugees from the tsunami disaster. The migrant community usually occupied the hilly areas of Batang Toru. The distance between one household and another was quite far, about 1–1.5 km. Some of the migrants (about 20%) were cultivating *nilam*

(patchouli = *Pogostemon cablin)* on sloping land. Most of them planted rubber trees (*Hevea brasiliensis*; 90% of households) as a mixed garden system with other useful trees, such as sugar palm (*Arenga pinnata*; 30–50% of households), cocoa (*Theobroma cacao*; 50%), coffee (*Coffea robusta* and *Coffea arabica*; 20%) and fruit trees (30%). These commodities were the main livelihood sources. The migrant community who lived in flat areas cultivated irrigated paddy systems (60% of households) occasionally. They were, however, still practising 'slash and burn' and 'slash without burn' to open land.

2. **Farming, mixed garden community:** Tanjung Rompa village in South Tapanuli and Banuaji Ampat and Simardangiang villages in North Tapanuli. Irrigated paddy fields, employing both technical and non-technical[7], were the main sources of livelihoods (nearly 92% of households). In Tanjung Rompa, the community cultivated rice twice a year using 'locally improved' planting materials. Rice was planted to meet subsistence needs, however, some rice was sold from time to time to meet specific financial needs. In Simardangiang and Banuaji Ampat villages, rice was only cultivated once per year. After the harvest, farmers planted perennial crops, such as peanut or chilli. Other sources of cash income came from simple and more complex traditional agroforestry systems. Communities in Tanjung Rompa cultivated several commodities in traditional agroforestry systems, such as rubber (50% of households), cocoa (20%), sugar palm (20–60%), coffee (20%) and *salak* (50–70%) as important sources. In Simardangiang and Banuaji Ampat, high economic value tree species planted were rubber (50–60% of households), *kemenyan* (60–80%), cocoa (30–60%), and coffee (20%). Most of the communities were Batak people who migrated to the area almost one hundred years ago.

2.3.3 Livelihood sources in Batang Toru

Sources of livelihood were mainly from the agricultural sector. Land uses to generate income were rice cultivation, mixed tree-based gardens (agroforestry) and forest extraction.

Initial surveys identified rubber, durian, cocoa, sugar palm and *kemenyan* resin as important sources of income in the four focal villages. In most of the surveyed villages, these five tree crops contributed most to household farm incomes. Batang Toru coffee, betel nut (*pinang*), coconut and cinnamon were also economically important smallholder crops, but were only minor crops in the four surveyed villages. Oil palm was also an important agricultural crop in the area but not for smallholder farmers. Subsequent activities and surveys also identified the following smallholder products as currently or potentially important: agar-wood (*Aquillaria* sp.), *petai* ('stinky bean' = *Parkia speciosa*), *nilam* (patchouli = *Pogostemon cablin*), flowers (*Nepenthes* spp., *Amorphophallus* spp., orchids), high-quality rubber seedlings, medicinal plants, mushrooms, vegetables, goats and pigs.

In general, each household would receive weekly income from rubber and sugar palm in their mixed tree-based gardens. Monthly, they received income from cocoa, coffee, *kemenyan* and *salak*. Annually, income came from their fruit gardens: durian, *jengkol* (*Archidendron jiringa*), *petai*, mangosteen etc.

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[7] Technical irrigation uses permanent buildings, complete with water regulators and measurement tools, and usually is built with full support from the public works agency. Non-technical irrigation is characterised by non-permanent buildings and usually is developed and maintained by farmers.

1. Rice cultivation

In general, farmers cultivated rice for their own consumption. Farmers had two harvests a year. In North Tapanuli, occasionally farmers harvested once a year and cultivated peanut and chilli afterwards. A semi-technical irrigation system was applied to most of the paddy rice field cultivation. Fertilizers were applied, such as N, N-P-K and TSP.

2. Mixed tree-based gardens

The local communities had a long history of sustainable forest resource management through a gradient of land-use intensities ranging from mixed tree gardens—where species composition was largely controlled by farmers and intermediately managed—to natural forests where human intervention was low and produced smaller amounts. In between were various types of agroforests in which farmers planted valuable tree and other plant species and managed them extensively. Mixed tree gardens and agroforestry systems are collectively referred to as upland agroforestry systems.

Key products of these systems included upland rice (*Oryza sativa*) during the establishment period, rubber, cacao, coffee, *kemenyan*, sugar palm, durian, *petai*, candlenut (*Aleurites moluccana*), *salak* and banana (*Musa* sp.). Other fruits, medicinal crops and timber were also produced. Rice, medicinal crops and timbers were primarily produced for home use, while rubber, cacao and *kemenyan* were exclusively market crops. Other crops could be marketed or consumed at home. None of the agroforestry systems were intensively managed because farmers lacked access to high quality germplasm, technical support, infrastructure and market information.

3. Cacao-based systems

Cocoa (*Theobroma cocoa*) was introduced in the 1980s. It became of particular importance to smallholders in North and Central Tapanuli. Commonly, cocoa was planted in a monoculture system in a 0.5–1 ha of land near the village to make monitoring pests easier. Some other farmers planted cocoa as fence trees in paddy rice fields or mixed them with rubber and fruit trees in an agroforestry system. Cocoa-based gardens were managed less intensively, that is, irregular weeding and pruning and less fertilizers and pesticides.

4. Coffee-based systems

Coffee production under *C. robusta* agroforestry systems were dominant in this region, growing continuously grew for the three years preceding this study. Arabica coffee was common only in North Tapanuli (Table 10). The intensity of garden management was low–medium, with fertilizer application only in the first year and weeding when necessary. Most households had land under coffee systems of around 0.5 ha (85.5%), though nearly 15% of households had more than 0.5 ha to less than 2 ha.

Table 10. Arabica and robusta coffee area and production in Batang Toru

	North Tapanuli		**Central Tapanuli**		**South Tapanuli**	
	Area (ha)	Production (ton)	Area (ha)	Production (ton)	Area (ha)	Production (ton)
Robusta coffee	1311.50	698.18	160.00	88.01	1751.50	929.30
Arabica coffee	8554.25	9057.07				
Total	9865.75	9755.25	110.00	88.01	1751.50	929.30

Source: Sumatera Utara Dalam Angka, 2008

According to farmers, coffee bean productivity was about 1–1.5 t/ha per year. The price of arabica was about Rp 10 000–14 000 per kg and robusta was Rp 10 000–15 000. Agricultural statistics give 0.6 t/ha yields for arabica and 1.1 t/ha yields for robusta coffee (Table 10).

5. Kemenyan (benzoin)-based systems

Benzoin or *kemenyan* was introduced more than 100 years ago. *Kemenyan* is locally known as *kemenyan durame* (*Styrax benzoin)* and *kemenyan toba* (*Styrax sumatrana*). The resin was exported to the Middle East as a preservative ingredient and also as incense for cosmetics, perfumes and cigarettes. The *kemenyan* system is commonly practised in North Tapanuli, Toba Samosir and Dairi; it is the most important livelihood source as nearly 65% poor farmers rely on it. In North Sumatra in 2007, North Tapanuli had the largest area of *kemenyan*-based systems (16 395 ha), followed by Humbang Hasundutan, Pakpak, Simalungun, Toba Samosir and Dairi districts with 5593 ha, 1501.20 ha, 370.75 ha, and 213 ha respectively. Nearly half of the total *kemenyan* resin production in North Sumatra came from North Tapanuli (3634.12 t). Central Tapanuli contributed 0.02% of the total production provincially, from 5 ha of *kemenyan*-based systems. Data in 2000 showed the productivity rate for *kemenyan* resin was 2000–3000 t/yr, which was lower than previous (around 1990) production of 4000–5000 t/yr.

Kemenyan agroforests are usually located near forests and most of the gardens were neglected, because farmers considered the benzoin resin price was too low. The price was set by middlemen. The *kemenyan* agroforest garden was extensively managed, without fertilizers or pesticides. *Kemenyan* trees regenerated naturally, therefore farmers were keen to find high quality seedlings then transplant them to their plot, without maintaining any regular planting distances. This created a multi-strata canopy.

There were two different types of *kemenyan* agroforests in the surveyed villages. In Banuaji Ampat, gardens were dominated by *kemenyan* trees (80%) mixed with rubber and some fruit trees, such as durian, *petai* and *habo* (*Archidendron bubalinum*). In Simardangiang, *kemenyan* trees only represented 45% of the total in the plots, with some tapped rubber trees, light wood trees and a few fruit trees. This is similar to Fernandez' (2001) description of *kemenyan* gardens, that is, the *kemenyan* garden can be found not only as almost a monoculture with more diverse understorey but also as a complex agroforest.

Farmers did not invest much effort in tapping *kemenyan*, however, within the surveyed villages, benzoin resin production contributed 30–55% of family incomes, ranging from Rp 960 000 to Rp 3 990 300 (±USD 107–445) per year. Owing to less intensive management, the input cost of *kemenyan* was very low. Farmers only need to have secure land to cultivate *kemenyan* trees. The trees were also important to indicate ownership of land (Siregar 2001, Sitompul 2002 and Sinaga 2010).

People planted *kemenyan* trees after the second harvest of paddy rice. They carried out maintenance work on the land once a year, as a minimum, to ensure that there were no weeds or pests. Eight to ten years after planting, *kemenyan* resin was produced and farmers started to tap the resin.

Within the surveyed villages, *kemenyan toba* was more commonly found than *S. benzoin*. The resin had a clear chain of distribution: local/sub-district traders collected and channelled it to manufacturers outside Sumatra (the majority in Java). Selling price was Rp 90 000 to 120 000 (±USD 10–13) per kg for the best quality resin, locally known as *kemenyan mata*; and Rp 55 000 to 80 000 (±USD 6.15–8.90) per kg for secondary quality, locally known as *tahir*. Farmers usually produced 10 to 20 kg of *mata* quality per year and the same amount of *tahir*.

Figure 5. *Kemenyan* agroforest in Banuaji Ampat village. Upper right: *Kemenyan* tree and resin. Below right: resin

6. Salak-based systems

Salak (snakefruit = *Salacca zalacca*) is a palm tree harvested for its fruit. *Salak*-based systems were common in South Tapanuli district, particularly in West Angkola sub-district, West Padang, Sidempuan sub-district and Marancar sub-district. In general, *salak* was usually planted as a monoculture system, however, in some areas such as Marancar sub-district, *salak* was also planted with other trees like rubber, durian and *petai*. Similar to other tree-based agroforestry systems in the region, *salak* agroforestry garden management was extensive, without fertilizers or pesticides. Seedlings were usually bought from seedling suppliers and farmers' nurseries.

7. Rubber-based systems

Rubber trees were introduced in the area in the 1930s. The rubber agroforestry systems in Batang Toru were mostly found in South and Central Tapanuli, which have lower elevations than North

Tapanuli. Rubber trees usually grow at elevations up to 1000 MASL. When planted above 1000 MASL, rubber production is low.

Within the Batang Toru landscape, most of the farmers' rubber gardens were inherited from their parents, who had practised rubber-based agroforestry for many decades. Rubber trees were mixed with fruit trees such as durian, *petai* and *duku* (*Lansium domesticum*). The rubber gardens were managed extensively, without fertilizer and pesticide applied, and used seedlings. However, farmers who lived in and near the Batang Toru sub-district usually planted rubber trees in a monoculture system because they had learned from the Perusahaan Terbatas Perkebunan Negara[8] III, which is located in this sub-district.

8. Fruit tree-based systems

Most farmers in the landscape practised mixed fruit tree garden systems. Durian had become the main commodity and contributed to local livelihoods more regularly compared to other fruits in the landscape. Durian was marketed locally and also to Riau (a nearby province).

9. Oil palm cultivation

Smallholder oil palm was found in some areas, such as Sibabangun sub-district, Angkola and Siais sub-district (which has now become Angkola Selatan sub-district), Muara Batang Toru and Batang Toru sub-districts. Large-scale oil palm plantations were found in Marancar and Muara Batang Toru (PTPN Afdeling III Marancar with 273.9 ha) and Angkola-Siais (PT ANJ Agri Siais).

2.3.4 Land inheritance system and land availability issues in Batang Toru

Community-owned land involves three types of system: (i) through inheritance; (ii) via converting forested areas; and (iii) land sales. Based on consultations with local farmers in each village, we observed that local people in the surveyed villages were highly dependent on mixed tree gardens and that about 75% of people obtained their land through inheritance (Figure 6). By contrast, the migrants, particularly in Hutagurgur village, were usually dependent on the forest. About 55% of people in Hutagurgur opened forested areas or cultivated bare land as a form of land acquisition. This information concurred with the overall condition in South Tapanuli as described by Ritonga (2008) and the information gathered from a previous survey carried out by Yayasan Ekosistem Lestari (YEL). Most land was recognised by local customary institutions based on customary territory. Only a small amount of land (less than 5%) had land certificates as issued by the state land agency (Ritonga, 2008).

The land inheritance system in the area was based on Batak tradition. Research conducted by Simbolon (1998) showed that in Batak communities a patrilineal land inheritance system and collateral inheritance still continued owing to land scarcity, however, the tradition of giving land to the younger female generation (as a wedding gift, locally known as *pauseang*) was very rare. The youngest daughter in a family usually stayed in the village to take care of her parents, however,

[8] PTPN *(*Perseroan Terbatas Perkebunan Nusantara*)* is a state-owned enterprise in the plantation sector in Indonesia with a scope that includes cultivating plants, processing and selling plantation major commodities such as tea, rubber and oil palm, as well as quinine and cocoa.

she would not receive land from her parents although she had married. She and her husband might receive land through other reciprocal land transactions, such as selling (*dondon pate*), pawning (*dondon*), profit sharing (*bola pinang*), rent or borrowing (*silehonlehon*) (Simbolon, 1998). In landscapes where no there was no available farmland, a new family or newcomer to the area might rent land from a landholder who had large farmlands. The land tenure system also allowed land selling, which was usually approved by the head of the village and the head of the sub-district.

Based on government regulation (Ministry of Forestry, 1982) *Penunjukkan Kawasan Hutan berdasarkan Tata Guna Hutan Kesepakatan* (TGHK), most of the area in the Batang Toru was designated as limited production forest and protected area. This designation restricts the community from opening new land for production inside forests. The government encouraged the community to intensify their current land-use systems to improve their livelihoods. However, with the increasing population in the area, people cleared forest to establish new gardens. In discussions with farmers in Tanjung Rompa village, one farmer asked,

> Jadi apa jaminannya bagi kami, [yang] telah menjaga hutan kami untuk [tetap] mendapatkan air? Tapi karena lahan semakin sempit, serta penduduk yang semakin bertambah, pasti masyarakat akan mulai kembali membuka hutan demi mendapatkan lahan… Jadi apa yang harus kami lakukan?
>
> (So what guarantee is there for us for preserving the forest to keep the water flowing? [Currently], land is getting scarcer while the population is increasing; then people will start to clear the forest to get land… So what should we do?)

The question is indicative of the people's commitment in Tanjung Rompa to protecting the forest. However, they feel uncertain about the future and finding ways to simply survive. Thus, encroachments will continue in some forested areas, which may have negative effects on the areas' integrity.

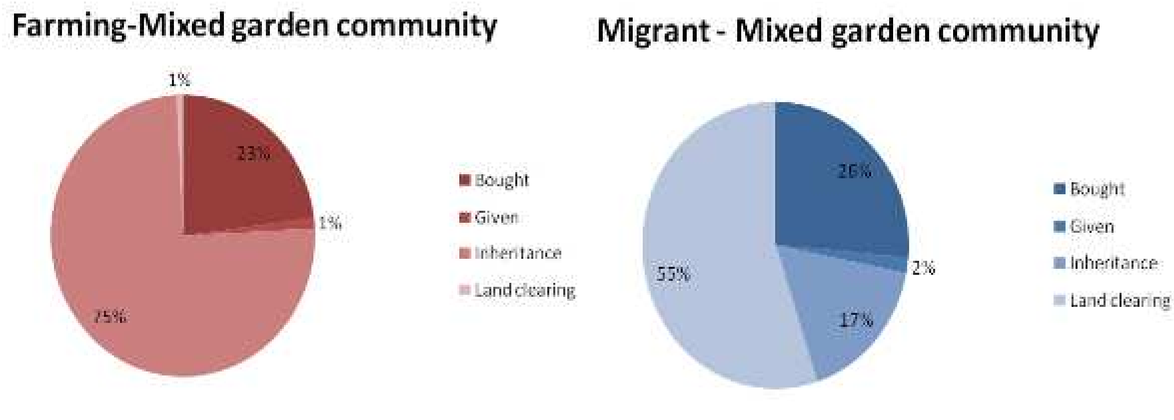

Figure 6. Land ownership (source: focus groups)

2.3.5 Household economy and profitability assessment in Batang Toru

Annual total income per household in the surveyed area was Rp 2 789 000–56 132 000 (±USD 311–6265). Income per capita per household was Rp 475 000–14 827 000 (±USD 53–1655). Common off-farm income sources included operating small shops, government service, trade in agricultural crops, and remittances. Off-farm income ranged from Rp 130 000 to Rp 1 800 000 (±USD 14.50–201). Livestock production and non-timber forest products (NTFP), which maybe be collected from natural forests or cultivated in tree gardens or agroforests, provided secondary sources of income.

The profitability analysis of the systems that were common within the surveyed villages took into account the majority of land-use systems as determined by the spatial analysis (Component C), which was then used for scenario development. The profitability assessment of land-use systems in Batang Toru employed a detailed farm budget calculation. However, owing to time constraints and technical difficulties, not all of the land-use systems are covered and the calculations only represent private analysis[9]. The prices used in the calculation are based on nominal local market prices valued at private price. The study uses single price data from 2010 that is linked to the time when data when was collected.

The calculation uses macroeconomic parameters of 2010 as presented in Table 11. The exchange rate was approximately Rp 9199.12 to USD 1, based on the average (January to May 2010) of the Central Bank of Indonesia's mid-market rate. Nominal interest rate is the discount factor used to value future cash flows in current terms. A private discount rate of 6.5% is based on rupiah credit interest rate by state banks for working capital. For agricultural wage rate, we used a calculation of Rp 30 000 per day.

Table 11. Macroeconomic parameter used in the study

Parameters	**July 2009**
Exchange rate	Rp 9199.12/USD 1
Wage rate in Sumatra	Rp 30 000 per person per day
Nominal interest rate	6.5% per year

Return to land and return to labour were evaluated competing long-term projects in capital budgeting. While return to land was supposed to be defined as gross revenue minus the actual and attributed current inputs and labour, return to labour or income also included family labour.

Table 12. Return to labour and land per land-use system in Batang Toru

Land-use system	**Return to labour (Rp/person)**	**Return to land (Rp 000/ha)**	**Labour requirement (pd*/ha/yr)**
Coffee agroforest	38 067	9 309	87
Mixed garden *kemenyan*	29 555	4 586	146
Rubber agroforest	34 889	7 327	121

[9] 'Private analysis' is the economic profitability accounting base for prices actually experienced by households or farmers ('private prices'). In contrast to private prices, 'social prices' are the actual price with some adjustment to eliminate policy distortion and market failures. The cause of distortions could be input and output price subsidies, tariffs and quotas.

Irrigated rice paddies	32 433	2 229	73

Note: Prices based on 2010 prices and expressed in June 2010 Indonesian rupiah (Rp 9199 = USD 1). *pd = person day

Coffee-based agroforest (60% coffee trees) and rubber agroforest (50% rubber) yielded almost similar results in terms of return to land. However, coffee agroforest performed higher since coffee-based systems have a shorter immature period. Additionally, coffee agroforest systems also have the highest return to labour which indicates that these systems would be more attractive to farmers.

Kemenyan agroforest performed lower return to land compared to rubber agroforest, however, in terms of return to labour it was slightly lower than the average wage rate. However, many *kemenyan* gardens that had been planted in the Batak region since 1907 have become culturally important for the Batak people (Katz et al., 2002). Despite the price of *kemenyan* resin having progressively dropped, farmers still keep the trees, which are commonly managed under an agroforestry system that has them mixed with rubber and fruit trees such as durian and *petai*.

The profitability of agriculture (paddy) was also relatively low because of low productivity, but return to labour was still higher than the agricultural wage rate. Additionally, farmers also considered this system important for food security. Coffee-based systems were the lowest employer at 87 person-days per hectare per year, since these systems were not managed intensively. The systems could be improved with greater labour intensity, which could result in more productivity and profitability as well as expanding job opportunities in the region. Mixed-garden *kemenyan* was more labour intensive (151 person-days per hectare per year) than other systems, but it had lower return to labour since most of the outputs had relatively low productivity as well as low prices.

2.4 Land use in Tripa

2.4.1 Community typology and their resources in Tripa

The preliminary result of the study shows there are four main groups of communities living within Tripa ecosystems (Figure 4). The remaining forest in this ecosystem is no longer enough to fulfil local livelihoods. At the time of study, smallholder oil palm, cocoa production and betel nut were the main livelihood sources from land-based systems. Off-farm activity was becoming an increasingly attractive alternative livelihood in some villages owing to land shortages (Table 13).

Table 13. Typology of communities in Tripa

Village type	Group	Current livelihoods	Ethnic background	Village	Population
Farming community, migrants	1	Paddy farming, horticulture , poultry, swiftlet culture, citrus (*Citrus* aurantium), oil palm plantations, cocoa, outsource labour (oil palm)	Javanese, Sundanese	Markati Jaya	High migration
Fishing community	2	Fishing (sea, river, peat swamp), cows, goats, young oil palm plantations, temporary outsource labour (oil palm), coconut, betel nut	Acehnese	Babah Lueng	Low migration
Displaced fishing community	3	Fishing (sea, river, peat swamp), cows, goats temporary outsource labour (oil palm), coconut, betel nut	Acehnese	Kuala Seumayam	High migration
Farming community (gardening)	4	Poultry, swiftlet culture, betel nut, cocoa, coconut, oil palm plantation, outsource labour (oil palm), logging, trading, transportation services	Acehnese	Le Mameh, Ladang Baru	Low migration

2.4.2 Land use history and the relations with local livelihood in Tripa

The history of land-use change was collected through semi-structured interviews with some key informants. We focused on interviews in Nagan Raya district and some in Aceh Barat Daya (Table 14).

Table 14. History of land use in Tripa ecosystem

Period		Description	Livelihood changes
1930s	Plantations established by Dutch colonial government (rubber and oil palm)	Introduction of plantation crops such as oil palm (in Sukaraja), cocoa (in Seunaam, Seumayam settlement area), or rubber (Babah Leung and Ladang Baru area) outside the peat swamp.	From swidden agriculture, people became more involved in plantation oil palm cultivation
1991–8	Transmigration program	SP 1, 2, and 3 in Seunaam, along with oil palm expansion Five oil palm concessions established on peat land	Oil palm expansion Citrus (*Citrus sinensis*) production in some transmigration areas (in particular Seunaam 4)
1998–2004	Conflict era	Farming activity decreases significantly	Farming activity decreases: frequency of farmers accessing forest and farm areas decreases owing to safety issues
2005	Tsunami rebuilding program, peace resolution	Natural forest opening movement: wood extraction	People involved in logging to get raw material for tsunami rebuilding program
2008	End of rebuilding period, oil palm plantation becomes popular	Land conversion to plantations (oil palm) increases	People return to farming; some move to off-farm activity such as oil palm harvesting
2008–09	'Thousand hectare of oil palm' program in Nagan Raya and Aceh Barat Daya	Land conversion to plantations (oil palm) increases	

2.4.3 Land holding in Tripa

Our survey shows that the average landholding in the study area was 1.1 ha per household. The average landholding in villages within Nagan Raya was 1.3 ha per household and in Aceh Barat Daya 0.4 ha. Landholding with oil palm in Darul Makmur was the highest (Figure 7). Smallholder oil palm expansion within this area was beginning along with tsunami rebuilding programs.

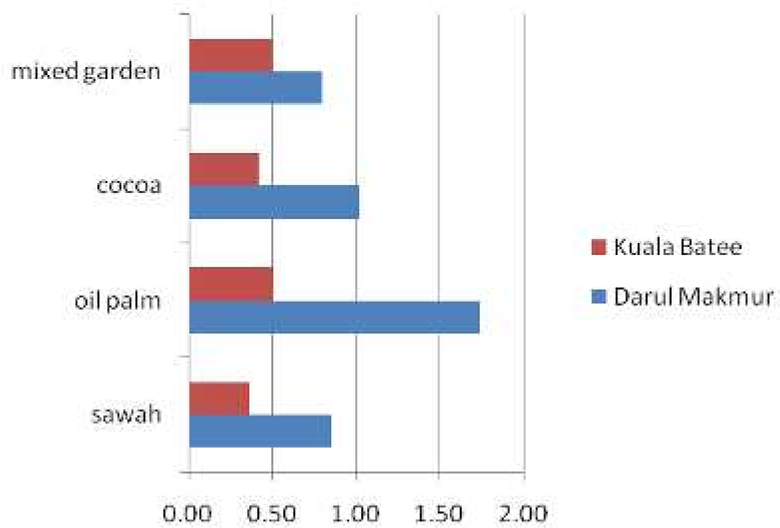

Figure 7. Comparison of land holdings in two sub-districts in Tripa

According to Table 15, irrigated paddy system was dominant in Babah Lhueng, while in Kuala Semayam there were no such systems. The main livelihood in Kuala Seumayam, a displaced coastal village, was fishing. At their previous village site on the estuary, Kuala Seumayam had some paddy farming that was, however, washed away by the tsunami. At the time of this study, some of the farmers were still cultivating the area for dry field farming.

Table 15. Total area of farm land and non-farm land in five hamlets

Hamlet	Farm Land (ha)		Non-farm area (ha)	Total (ha)
	Irrigated paddy	Dry field		
Babah Lueng	1180	405	15	1600
Kuala Seumayam	-	1599	1	1600
Ladang Baru	50	1800	150	2000
Markati Jaya	50	480	70	600
Ie Mameh	95	3464	41	3600

Source: BPS Kabupaten Nagan Raya, 2008

2.4.4 Livelihood and profitability in Tripa

2.4.4.1 Rice cultivation

Rice cultivation was very important for subsistence needs (household food security). After fulfilling basic need, any surplus was sold. Historically, within the Tripa ecosystem, in particular on peat, rice cultivation was mostly in swamp areas. However, since the expansion of oil palm plantations, swamps are no longer being used for paddy owing to water shortages.

Within the surveyed villages, rainfed paddy system intercropped with some annual crops, such as soybeans, maize and mung beans was dominant in some areas (Table 16). Dry field paddy systems occurred when farmers opened land for cocoa and oil palm plantations. When they established plantations they usually planted local varieties of dry paddy for one or two years.

Table 16. The presence of rice cultivation in five villages of Tripa

Desa	Rainfed paddy	Semi-technically irrigated	Irrigated field	Dry field paddy
Babah Lhueng	***			*
Kuala Seumayam				
Ladang Baru	*			
Markati Jaya	**	*		**
Ie Mameh			**	*

Rice varieties commonly used were improved varieties such as Fatmawati, IR 66 and Ciherang. Many farmers still used high quality local varieties (6–7 months growth period) such as Kuneng, Simuelue, Sigupai, Sangko and Simeuria. Sigupai is a high quality local paddy variety that was highly esteemed for its fragrance and flavour and fetched a high price in local markets in Aceh Barat Daya. Sigupai was usually cultivated under rainfed paddy or within semi-irrigated paddy systems. As well as introducing many improved paddy varieties, local people were not interested in planting Sigupai[10]. In the Darul Makmur area, farmers usually used Sigupai varieties in dry field paddy systems[11].

2.4.4.2 Homegarden (pekarangan)

Mixed garden systems were found in home gardens as well as in gardens far from settlements. Usually, farmers had at least one plot of mixed garden located 0.5–2 km from their home as well as home gardens surrounding their house, consisting of some fruit trees such as durian (*Durio zibethinus*), *kweni* (*Mangifera odorata*), nutmeg (*Myristica* sp.), mango (*Mangifera* sp.), rambutan (*Nephelium* sp.), *sawo* (*Acrhras zapota*), *nangka* or jackfruit (*Artocarpus heterophyllus*), *pinang* or betel nut (*Areca catechu*), papaya, banana, *tangkil* (*Gnetum gnemon*), *jambu bol* (*Syzygium malaccensis*), *sirsak* (*Annona muricata*), cocoa (*Theobroma cacao*), *salam* (*Eugenia polyantha*) and breadfruit (*Artocarpus altilis*). Home garden size was 0.2–0.8 ha, while mixed garden systems were usually larger: 0.5–2 ha.

Fruit trees were not only used for commercial purposes but for 'social self interest', playing an important role in the socio-cultural system. Fruits were important in hospitality with neighbours and family.

2.4.4.3 Cacao-based systems

Cocoa cultivation was less developed and relatively new (first introduced 5–6 years ago). Most farmers cultivate cocoa in mixed garden systems with other economic trees such as coconut, *areca* nut and some fruit trees, with different ages. Farmers were practicing less intensive management of cocoa: no pruning and low fertilizer application. Farmers applied fertilizer (urea, TSP and KCl) at least once every one or two years, but no regular pruning was conducted. Cocoa farmers lacked knowledge and extension service assistance.

Cocoa plots usually consisted of 50–100 trees per hectare. The majority of cocoa farmers were using seedlings sourced locally from previous cocoa plantations. The origin of the seedlings used by previous farmers was Medan.

Cocoa prices at farmer level were fluctuating. The lowest price mentioned by farmers was Rp 12 000 per kg and the highest was Rp 25 000.

2.4.4.4 Rubber-based systems

Only a few smallholder rubber plots were found within the surveyed villages. However, historically, rubber was common in some areas in particular in Aloe Bateung Brook and Ladang Baru. Traditional rubber systems using local seedlings, commonly known as *bibit belanda* (seedlings from the Dutch colonial era), covered a lot of area in the two villages and now is converted to oil palm.

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[10] http://www.serambinews.com/news/view/22872/tamatnya-riwayat-padi-sigupai-di-abdya
[11] http://andhen09.blogspot.com/2010_04_11_archive.html

Rubber is mainly cultivated for commercial purposes. Rubber is managed within mixed garden systems, together with *kapuk*, *kweni*, rambutan, jackfruit, *kedondong*, *langsat* and *rambe* (*Lansium* sp.), durian, coffee and mangosteen. Usually farmers had 0.5–2 ha of rubber garden, with low intensity of management, low fertilizer use and dense spacing.

2.4.4.5 Smallholder oil palm

In Nagan Raya district, land-use systems are dominated by oil palm plantations (about 36 525 ha), while at the smallholder level, oil palm plots cover about 13 022 ha. Most farmers have at least one plot of 1–4 ha with multi-aged oil palm. Different conditions were seen in Aceh Barat Daya (in Ie Mameh area) with many smallholder oil palms still at the early stages of production as they were planted only in 2004. It is important to note that in Aceh Barat Daya the establishment of smallholder oil palm plots was encouraged by the local government. Research carried out by Eye on Aceh showed that in Aceh Barat Daya, oil palm plantations covered 4969 ha and smallholder oil palm about 1258 ha in Nagan Raya (Eye on Aceh, 2007).

In both districts, within every smallholder plot there were 120–150 oil palms per hectare, with gross production valued at Rp 600 000–1 500 000 (±USD 67–168) per month per hectare. In 2010, fresh fruit bunch prices fluctuated from Rp 700 000 to 1 050 000 (±USD 80–110) per tonne.

2.4.4.6 Fishing

Fishing was a very important livelihood source both for cash income and local consumption. In some coastal parts such as Babah Lueng and Ie Mameh villages, people pursued mixed livelihood strategies, having farm or off-farm activity during the day and fishing at night.

In the river

Fishing was common in Seumayam and Tripa rivers and their branches. The catch included *kerling* or *jurung* (genus: Tor), *bawal* (*Colossoma macropomu*), *lokan* (*Polymesoda* sp.), shrimp and crab, which were sold locally.

Figure 8. *Lokan* (*Polymesoda* sp.)

Lokan collectors could gather a 20 kg sack, selling for Rp 110 000 (±USD 12.30), per day. Usually *lokan* was collected at least once per week in the dry season when the river water receded. Fishers could catch 2–8 kg of *bawal* per week and sell to the local market for Rp 30 000 (±USD 3.35) per kg.

Figure 9. A farmer with a *lele* or *limbat* (*Clarias nieuhofii*) trap

Local informants mentioned that the catch had decreased by up to 60% owing to massive land conversion after the peace agreement in 2005. Waste from oil palm factories was discharged into the rivers through canals, causing a decrease of fish and *lokan* populations.

Table 17. Frequency of fisher activity per month per commodity

Month	1	2	3	4	5	6	7	8	9	10	11	12
Lele	**	*	**	***	**	**	**	**	**	***	**	**
Lokan	**	***	**	-	**	*	*	**	**	-	*	*
Nila	**	**	**	**	**	**	**	**	**	**	**	**

In the peat

The main products from peat in the Tripa ecosystem were *lele* (*Clarias nieuhofii*), known locally as *limbat*. Farmers caught *limbat* using a fish trap or *bubu* made from rattan. They used oil palm fruit or coconut as bait. People who were catching *lele* in the Seumayam area came from several villages in Nagan Raya and some from Aceh Barat Daya, particularly from coastal communities.

Lele catchers usually worked in groups (2–3 people) because peat swamps, which were the *lele* habitat, were getting rarer and usually located deep within forested areas. They spent 3–4 days per week catching *lele*, keeping the fish alive in water containers, which they then took home for consumption.

Figure 10. *Clarias gariepinus* or African catfish, formerly common in Tripa (Photo: Ian Singleton)

Before the massive land conversion in 2005, *lele* production was relatively high, as much as 80% higher than at the time of this study. Each fisher could get 30–50 kg of *lele* per day per person. *Lele* catchers could sell their products not only in the local market but also at the provincial level, for example, to Medan. Now, they exclusively sell in the local market because they can only catch 100–150 kg of *lele* per week per group (price per kilogram of Rp 9000–16 000 (±USD 1–1.78)). Roughly, *lele* catchers earned net incomes of Rp 900 000–2 400 000 (±USD 100–268) per week per group.

Villagers from Kuala Seumayam mentioned that in the past they might occasionally catch a big catfish they called *lele Dumbo* or *lele Jumbo* (*Clarias gariepinus*), which was known as an exotic species from Africa but was commonly found in Tripa peat swamps (Singleton, pers. comm.). However, the villagers added that the *lele Dumbo* was rarely found in Kuala Seumayam area since the forested areas decreased.

2.4.4.7 Oil palm labour

Working for an oil palm company is another alternative livelihood that was very important within the surveyed areas. There were two types of work that we identified.

Contract labourers[12], usually called *buruh syarat kerja umum* (SKU), were permanent workers of oil palm companies on a daily basis. Their main responsibilities were garden maintenance and harvesting. Wages of contract labourers should be above or at least equal with provincial minimum labour payments (*Upah buruh Minimum Provinsi* or UMP), which, in 2008 in Aceh province was Rp 1 000 000 per person per month. They worked six-day weeks, seven hours per day. Within the surveyed villages, the contract labour force was dominated by Javanese and Sundanese. Contract labour from outer areas were provided with a small house inside the plantation. Some of the labourers came directly from Java or were descendants of previous contract labourers who came to the region when the company was first established many years ago. The rest are transmigrants or their descendants who were not successful enough at farming.

Daily wage labourers usually work on specific tasks such as fertilizer application, weeding, pesticide or herbicide spraying and collecting bunches. This work was dominated by women. Men usually built or fixed roads, drainage systems and bridges. Most such workers were not equipped with safety equipment. Daily wage labourers worked five-hour days, starting at 6 AM, for a wage of Rp 25 000–40 000 (±USD 2.80–4.45) per day. Daily labourers usually came from the surrounding villages. Interviews with some native Acehnese showed that they were not interested in working for an oil palm company as contract labour because they mostly had farms. Working as daily wage labourers was not part of their culture or habit because the oil palm concessions took away their land. However, to get quick cash, they would agree to work as daily wage labourers in their spare time.

Extra labour was usually deployed for harvesting. They either already worked for the oil palm company or on smallholder oil palm plots. Some were paid a daily wage, others through a profit-share system.

2.4.5 Household economy

Household income was defined as gross revenue and income per capita was defined as gross revenue divided by total population. The main sources of household income of people in the study area included farming, fishery and oil palm production.

Table 18 shows estimates of annual income of the household samples. People in Ladang Baru had higher incomes than in other settlements. On average their income per year was nearly Rp 19 000 000 (±USD 2120) per household whereas in other places it was Rp 8 000 000–17 000 000 (±USD 893–1898).

[12] Locally known as JAKON or *Jawa kontrak* or *kuli kontrak*. These systems have been used since the first plantation came to this area during Dutch colonial times. Then, the majority of labour came from Java, forming the initial period of in-migration to Aceh.

Table 18. Income of sample households

	Babah Lueng (n=23)	Ladang Baru (n=23)	Ie Mameh (n=23)	Total (n=69)
Household income (Rp 000)				
Minimum	1800	2880	600	600
Maximum	84 000	78 000	38 960	84 000
Average*)	17 323	18 954	8326	15 426
Standard Deviation	20 780	21 284	8063	18 393
Income per capita (Rp 000)				
Minimum	600	390	241	3,887
Maximum	28 000	17 140	9740	42 300
Average*)	4808	4574	2128	6742
Standard Deviation	5837	4480	2009	4532

The income data indicated a higher income among people engaged in smallholder oil palm plots (Rp 1 200 000 per month, in particular, farmers in Ladang Baru). This was consistent with the income of people based on their main occupation, which showed the highest income from smallholder oil palm. In Ladang Baru and Babah Lueng villages, there were a lot of smallholder oil palm plots. Income from off-farm activity dominated by oil palm work showed a high range, with the distribution of oil palm labour working in the concession nearly half of the household sample (Table 19).

Table 19. Monthly household income by occupation

Occupation	Household sample		Range of income per month (Rp 000)	Median (Rp 000/month)	Standard Deviation
	n	%			
Fishing	10	14.29	115–750	199	111
Agriculture	32	45.71	108–486	167	126
Mixed garden	32	45.71	30–3000	125	526
Smallholder oil palm	12	17.14	160–5500	1,233	2045
Non-farm: oil palm workers	31	44.29	120–2800	450	585

The household income from smallholder oil palm was relatively high, however, two farmers from Ladang Baru village and a farmer from Markati Jaya village mentioned that farmers who had less than 2 ha of oil palm would get little profit compared with farmers with more than 2 ha.

> Kalau lahannya cuman satu hingga dua hektar saja gak akan nutupin… untuk biaya sekolah, paling hanya untuk biaya makan sehari-hari… kalau lahannya lebih dari dua hektar baru lah cukup untuk kebutuhan lain…
>
> (If we have only one or two hectare, that won't be enough for [paying] school fees, only daily food [consumption]. However, if we have more than two hectare, we can fulfil other needs.)

Table 20 shows gross income from oil palm plots bigger than 2 ha varied with a high range of values. This confirmed the farmer's statement above, that oil palm productivity depended on the land holding, level of effort and efficiency of land management (labour and input).

Table 20. Monthly household income from smallholder oil palm plots based on land holding

Land holdings of smallholder oil palm plots	Household sample		Range of income monthly (Rp 000)	Median (Rp 000/month)	Standard Deviation
	N	%			
< 2 hectares	9	75.00	160–1466	367	392
> 2 hectares	3	25.00	1000–5500	4000	2291

2.4.5.1 Profitability assessment in Tripa

Profitability assessment was based on the same principles and subject to the same constraints as for Batang Toru.

Table 21. Return to labour and land per land-use system in Tripa

Land-use system	Return to labour (Rp/pd*)	Return to land (Rp 000/ha)	Labour requirement (pd/ha/yr)
Cocoa agroforestry	48 855	26 993	87
Smallholder oil palm	139 881	88 134	57
Home garden	56 804	5972	77
Irrigated rice paddies	32 433	2229	73

Note: Prices based on 2010 prices and expressed in June 2010 rupiah (Rp 9199 = USD 1). *pd = person day

Most land-use systems in Tripa were profitable and yielded higher return to labour compared to the daily agricultural wage rate in the region, as shown in Table 21. However, oil palm plantations were the most profitable systems in Tripa. The return to land at private prices (25 years production scenario at 6.5% discount rate) was about Rp 88 000 000 (±USD 9824) per hectare. Oil palm plantations are the most profitable land-use systems not only in the Tripa region but also in Indonesia because Indonesia's oil palm producers have the lowest unit costs in the world (Ekadinata et al., 2010).

Regarding return to labour, oil palm plantations also gave the highest return of Rp 139 881 per person-day or ±USD 15.65, which was far above the daily agricultural wage rate in the region. Cocoa mixed coconut systems gave relatively high return to labour and return to land, however, the single year prices that were used in the calculation could not accommodate the price fluctuations of the outputs. In terms of labour, cocoa mixed coconut agroforests required the highest amount of labour, which should be attractive to policy makers for expanding job opportunities. Home garden profitability was performing low, however, owing to low labour investment; but return to labour was still higher than the daily agricultural wage rate. The profit generated from home gardens was considered as additional income, hence, many farmers still maintained this system.

2.5 Conclusions

The two study landscapes were both in transition, with a combination of gradual changes in local livelihood patterns in relatively stable village–forest gradients interacting with more rapid change brought by outside agents: migrant families settling of their own accord on the western side of Batang Toru and government-sponsored transmigrants and government-sanctioned concessions establishing oil palm in Tripa.

The villages around the western block of Batang Toru largely relied on traditional agroforestry systems that lay between their settlements and the remaining core forest. Rubber was the economically most important tree, with the locally domesticated *kemenyan* (benzoin) trees important in the northern part of the area and coffee locally important in both the south and the north. *Kemenyan* production is on the edge of economic viability, with problems owing to price fluctuations and perceived fairness in the marketing system. Efforts to revitalise *kemenyan* production and marketing may help farmers improve their income while contributing to conservation efforts in the region, as the *kemenyan* agroforest forms an important buffer around the core forest.

Forest encroachment continued, mostly on the western side, where migrants started new mixed garden systems. Population growth and migration are a threat to the stability of the village–forest gradient.

Livelihoods of local communities within and surrounding the Tripa ecosystem have increasingly come to rely on oil palm as the main income source, with cocoa production in home garden systems as an alternative. In Nagan Raya district, local people still have unresolved tenurial claims with the oil palm companies. The wage rate offered by these companies was not interesting to local people as a form of 'off-farm' labour and the companies largely relied on migrants as a labour force. However, most communities relied on smallholder oil palm cultivation as a way to improve their livelihoods. Almost all farmers we interviewed expected such systems to be profitable, even though the high input costs (mostly for fertilizer), intensive labour demands in the establishment period and limited land availability were constraints. They expected that at least 2 ha of oil palm per household was needed to provide income at desirable levels. The dual pattern of oil palm expansion, one part under control of concession companies, the other based on local smallholders, has consequences for conservation efforts. The large-scale actors derive their legitimacy from higher levels of government but are also open to external pressure that affects their expected profitability. The smallholder pattern, once established, has a more gradual dynamic but is less easily influenced as long as local processing capacity for oil palm remains in place.

The expansion of oil palm in Aceh Barat Daya follows the 'smallholder' pattern, where the local community is supported to open oil palm smallholder plots (each household may open 2 ha of land within working groups consisting of 10–20 people). Farmers obtain technical assistance on land management and oil palm cultivation from the local government. Further expansion will require opening remaining peat forests when farmers have no other option.

3. Component B: carbon stocks and tree diversity

Subekti Rahayu, Rahayu Oktaviani and Hesti L. Tata

3.1 Background

The land-use systems described in Component A have different levels of carbon stock. As part of the appraisal of the feasibility of carbon-based incentives for land-use change, data is needed to compare the various types of human land use and habitat for the Sumatran orangutan (*Pongo abelii*). Conserving habitat through payment for reduced emissions from deforestation and degradation is now becoming attractive (Gaveau et al., 2009) but needs quantification. Measuring carbon stock at plot and landscape level is one method that can be used to estimate carbon emissions (Lusiana et al., 2002). Alongside the plot assessment of carbon stocks, relevant data on tree diversity can be collected to assess which species are likely to complete their life cycle in various habitat types.

3.2 Method

Five carbon pools are to be assessed according to the Intergovernmental Panel on Climate Change (IPCC): aboveground biomass (tree and understorey), dead wood, surface litter (necromass) and belowground biomass (roots) and necromass (soil organic carbon and peat). The sampling method used in this survey refers to the ASB protocol (Hairiah et al., 2001), although aboveground biomass (and its associated roots) was the prime interest (Murdiyarso et al., 2008).

A total of 23 plots were measured in undisturbed peat forest, disturbed peat forest and secondary peat forest of Tripa (Figure 11.A) and 10 plots in undisturbed forest, disturbed forest, durian agroforest, *salak* agroforest and monoculture pines of Batang Toru (Figure 11.B) (Table 22). Forest cover in Tripa had been classified based on visual observation and information from local informants. It is classified as undisturbed peat forest or virgin peat forest; disturbed peat forest, when timber logging had occurred; and as secondary forest if the forest was a result of clearing or fire regrowth. Similar to Tripa, undisturbed forest of Batang Toru was located around the YEL research station; the disturbed forest was forest which was logged about 10 years ago. Durian agroforest and *salak* agroforest was classified as mixed garden, since durian was planted with cacao, *arenga*, rubber, mahogany, *petai*, *jengkol*, jackfruit and candlenut, and *salak* was also planted with rubber, *aren* and candlenut. The condition of disturbed peat forest in Tripa and other land uses in Batang Toru is shown in Figure 12 and Figure 13.

Three nested sub-plots were established in each sample plot depending on vegetation: 40 m x 5 m sub-plot for counting trees and dead wood between 5 to 30 cm diameter; 100 m x 20 m plots for measuring trees and dead wood of more than 30 cm diameter; quadrant of 2 x 0.5 m x 0.5 m set up inside the sub-plot used to count understorey, litter and soil. Bulk density and carbon content in mineral soil of Batang Toru were estimated from soil samples taken using a metal box 20 cm x 20 cm x 5 cm for 0 to 5 cm soil depth and a metal box 20 cm x 20 cm x 10 cm for 5 to 15 cm soil depth in each land use.

Peat depth, classification, bulk density and carbon content were estimated from a previous study which was conducted by YEL, PanEco and ICRAF (Agus and Wahdini, 2008).

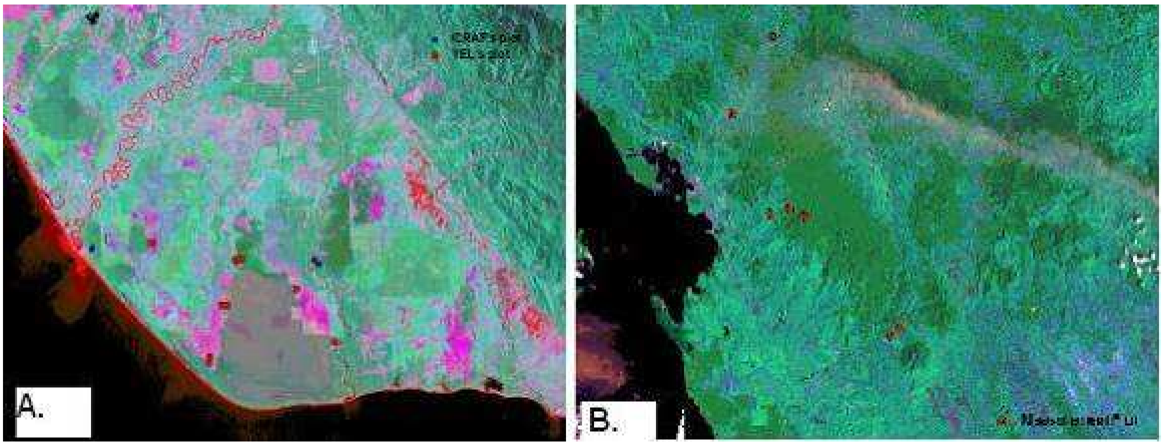


Figure 11. Plot samples of carbon-stock measurement: A. Tripa study area; B. Batang Toru study area

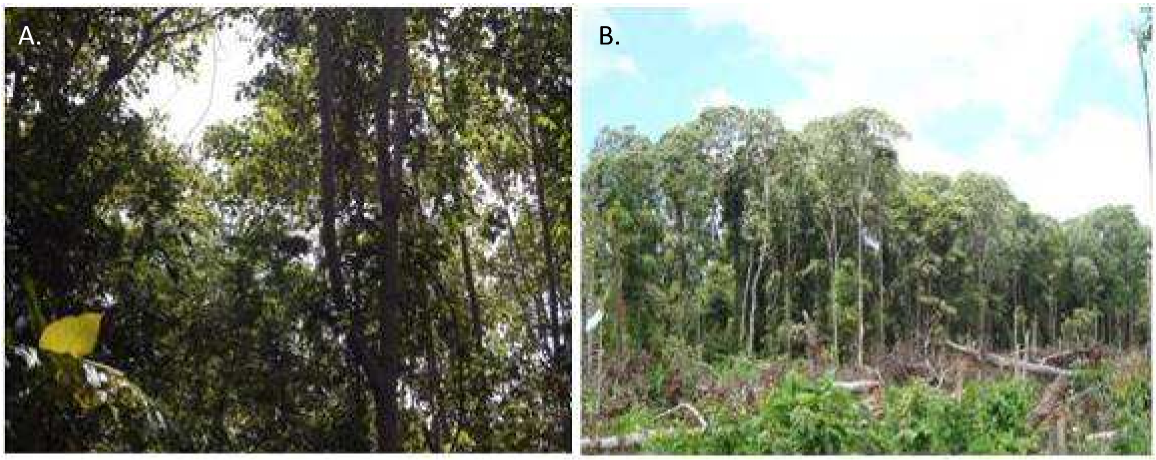


Figure 12. Cover condition of disturbed forest in Kuala Tripa: (A) and Kuala Seumayam (B) (Photo: Rahayu Oktaviani)

Figure 13. Cover condition in Batang Toru of (A) primary forest; (B) secondary forest; (C) monoculture pines; (D) durian agroforest; and (E) *salak* agroforest (photo: Rahayu Oktaviani)

Table 22. Number of sample plots for carbon-stock assessment in Tripa and Batang Toru

No	Land uses	Number of plot
	Tripa	
1	Undisturbed peat forest of ICRAF 2010	3
2	Undisturbed peat forest of YEL/PanEco/ICRAF 2007	6
3	Disturbed peat forest of YEL/PanEco/ICRAF 2007	6
4	Disturbed peat forest of ICRAF 2010	6
5	Agroforest of YEL/PanEco/ICRAF 2007	2
	Batang Toru	
1	Undisturbed forest	2
2	Disturbed forest	2
3	Durian agroforest (mixed with cacao, *arenga*, rubber, etc.)	2
4	*Salak* agroforest (mixed with candlenut and rubber)	2
5	Monoculture pines 30 years old	2

3.3 Results

3.3.1 Batang Toru Ecosystem

3.3.1.1 Carbon stock

The primary forest of Batang Toru, especially at lower elevations, is an important habitat for orangutan and other wild life. Carbon stock assessment of five land uses (primary forest, logged-over forest, *salak* agroforest, durian agroforest and monoculture pine) indicated that primary forest contained the highest carbon stock: 243 t/ha (Figure 14). Other land uses in Batang Toru, such as durian and *salak* agroforest, monoculture pines and logged-over forest, contained 90–100 tC/ha.

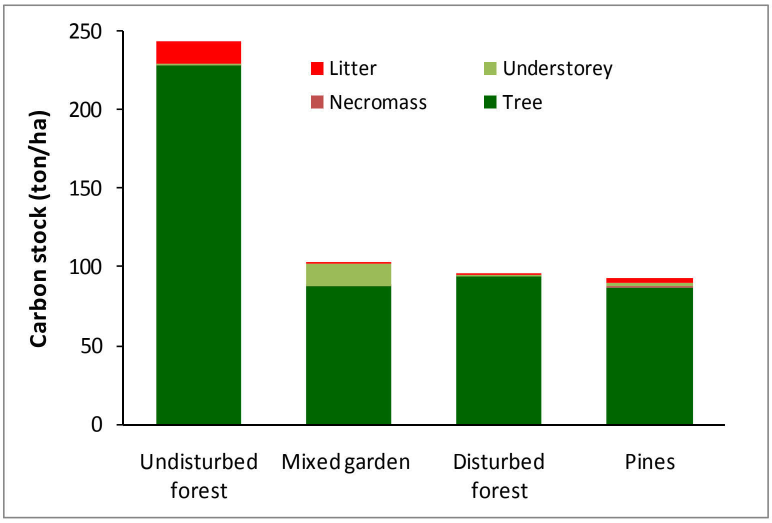


Figure 14. Carbon stock of tree and necromass in Batang Toru

Rubber agroforest was a common land use surrounding primary forest in Batang Toru. Rubber agroforest patterns in this area were similar with rubber agroforest in Jambi: fruit trees such as durian, *petai*, *jengkol*, candlenut and some timber trees like mahogany and albizia or *sengon* (*Paraserianthes falcataria*). Based on a survey of rubber agroforests in Jambi, the growth rate of carbon stock in rubber agroforest was about 2.1 t/ha/yr (Figure 15) (Jambi data from ICRAF's database). If the life time of rubber agroforest is up to 40 years, maximum carbon stock in rubber agroforest reach 84 t/ha.

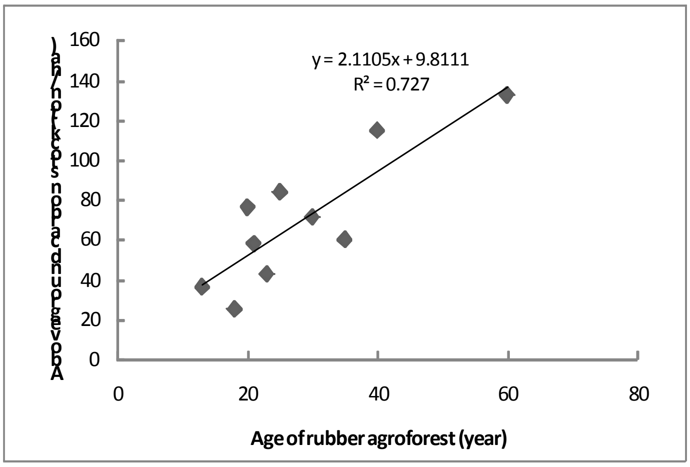


Figure 15. Relationship between aboveground carbon-stock and age of establishment in rubber agroforestry systems in Jambi (source: ICRAF database)

Rubber agroforest can be classified into two types: (i) simple rubber agroforest, which consists of rubber with some fruit trees and (ii) complex rubber agroforest with fruits and timber trees. In term of carbon stock, complex rubber agroforest contains higher carbon stock, on average 114 t/ha, compared to simple rubber agroforest at only 56 t/ha.

Soil carbon content in the top 5 cm of primary forest in Batang Toru was more than 40%, indicating peat-like conditions. Fine litter and dead fine roots were found in this layer. Linked to this accumulation of litter and roots, the stream in the primary forest has a reddish-brown colour like water in peat lands (Figure 16).

Figure 16. Water colour in a stream in primary forest (photo: Subekti Rahayu)

Total carbon in the soil at 0-15 cm depth ranged from 25 t/ha in durian agroforest to 58 t/ha in primary forest, as shown in Figure 17.

Soil carbon in undisturbed forest was probably highest owing to high levels of organic input such as litter and dead roots. Loss of soil organic matter owing to conversion can be attributed to both increases in the decomposition rate of litter and a decrease of litter input (Yanai et al., 2003).

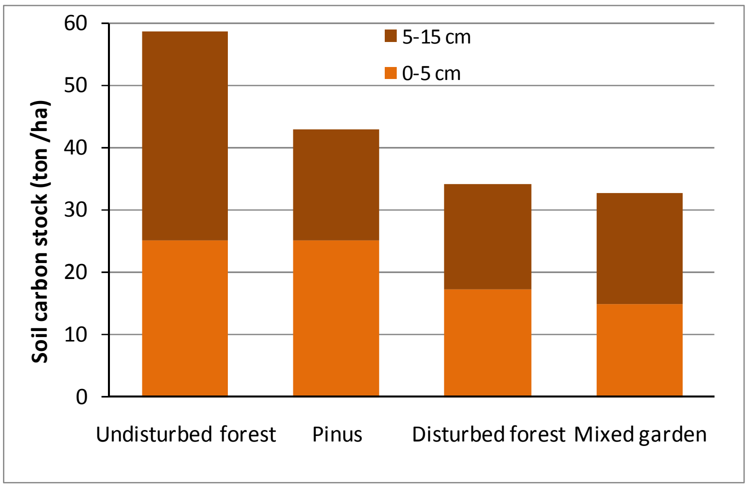


Figure 17. Soil carbon-stock in various land uses in Batang Toru

3.3.1.2 Tree diversity

A total of 45 tree species, with diameter above 5 cm, were found in the 0.4 ha sample plot in the primary forest of Batang Toru. Most of them were late succession species, such as Dipterocarpaceae, Lauraceae, Fagaceae, Meliaceae, Sapotaceae and Myrtaceae. The fifth most dominant species in the primary forest were *Syzygium* sp., *Madhuca laurifolia, Palaquium* sp., *Syzygium napiformis, Campnosperma auriculatum, Lithocarpus* sp., *Palaquium hexandrum, Palaquium rostratum, Swintonia floribunda* and *Agathis borneensis*. In logged-over forest, there were only 12 species, dominated by *Palaquium hexandrum, Syzygium* sp., *Lithocarpus* sp., *Cinnamomum* sp., *Styrax* sp., *Parkia* sp. and *Koompasia malaccensis*. Tree diversity in logged-over forest and agroforest decreased dramatically.

Within this comparison between land use types, carbon stock is positively correlated with tree diversity as indicated by the Shannon-Wiener index (Figure 18); the correlation with the number of tree species recorded per plot is weaker. The species richness was highest in the durian agroforest plots, while the primary forest had the highest carbon stock. Earlier research in Batang Toru showed old agroforests rich in fruit trees to have the highest numbers and diversity of bats as well (Joshi et al., pers. comm.)

In regards to orangutan habitat, the logged-over forest still had many species that could serve as orangutan food.

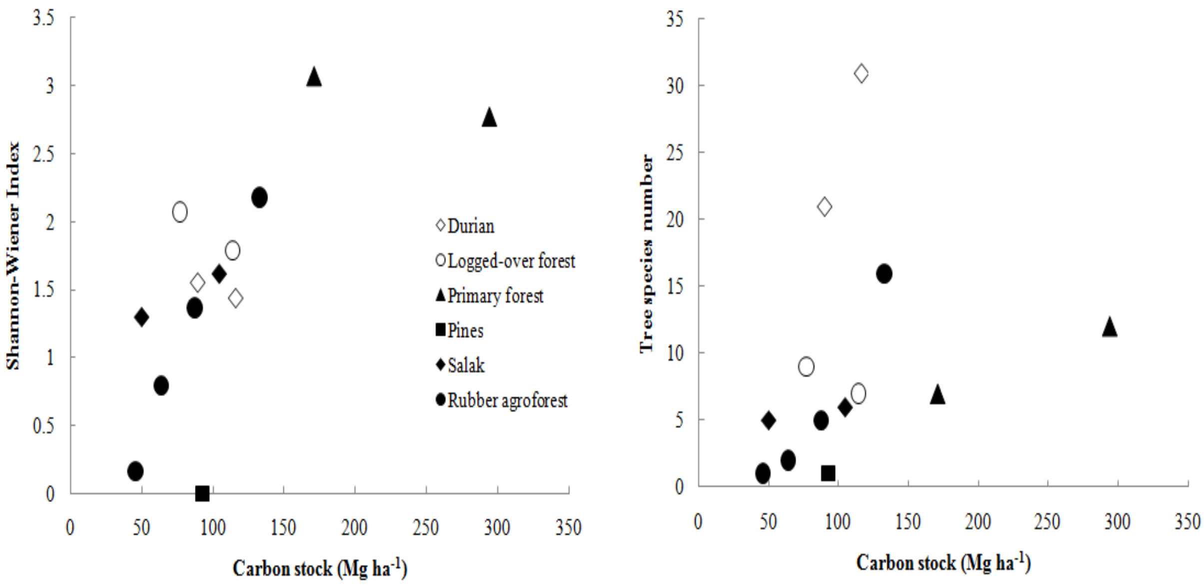


Figure 18. Shannon-Wiener diversity index (left, A) and number of tree species (right, B) recorded per plot in relation to total aboveground carbon stock for various land uses in Batang Toru (RAF = rubber agroforest)

3.1.1 Tripa Ecosystem

3.1.1.1 Carbon stock

Land use in Tripa was dominated by oil palm, even though there were still patches of degraded and secondary forest, as well as undisturbed forest in the oil palm concessions of PT AAL and PT KA. Carbon-stock measurement had been done in secondary forest, primary forest low and high density at 2007 (YEL data) and 2010 (this study).

During the assessment in April 2010, a mature male orangutan was observed in the remnant forest of Kuala Tripa. Otherwise, potential threats to orangutan habitat appeared in Kuala Seumayam, because the remnant degraded forest in this area was being opened by the local community.

Three types of forests, that is, primary forest high density, primary forest low density and secondary forest, which consisted of regenerated vegetation and forest burnt in 1996, were used in this study to differentiate carbon stock density. Average density in each type of forest was 193 ton ha^{-1} from undisturbed peat forest of YEL/PanEco/ICRAF 2007 and ICRAF 2010 survey, 84 ton ha^{-1} from disturbed peat forest YEL/PanEco/ICRAF 2007 and ICRAF 2010 survey, 112 ton ha^{-1} from disturbed forest of ICRAF 2010 survey and 28.5 ton ha^{-1} from agroforest in peat of YEL/PanEco/ICRAF 2007 survey, respectively (Figure 19).

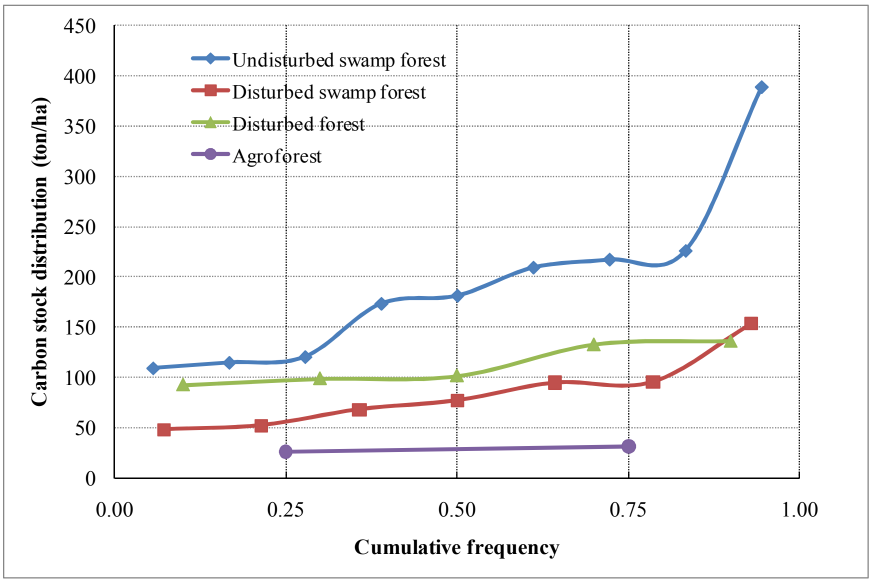


Figure 19. Cumulative frequency of aboveground carbon stock based on land cover classification in Tripa area

Data collected in 2007 (Van Belle and Hennin, 2008) were compared with the 2010 data set. These authors classified Plot-1, Plot-2, Plot-2, Plot-4, Plot-5, Plot-6, Plot-7, Plot-13 and Plot-14 as primary forest. In the data set, high-density primary forest (Plot-5, Plot-6, Plot-7, Plot-13) was differentiated from low-density forest (Plot-1, Plot-2, Plot-3, Plot-4, Plot-14). Plot-8, Plot-9 and Plot-10 were classified as burnt forest, while Plot-11 and Plot-12 as regenerated forest. Plot-7 had the highest carbon density: 388 t/ha. Other plots in their survey were in the same range as the 2010 data collected in undisturbed forest.

Carbon tree contributed high component of carbon stock (Table 23). In undisturbed peat forest, tree contributed high percentage of carbon stock that is 95%, while in disturbed peat forest and secondary peat forest decreased to 87% and 79%, respectively. Understorey contributed about 10% of carbon in disturbed peat forest (or degraded forest) where pandanus, small palm and other woody shrub grow in Kuala Tripa area. Compared to other forest type, carbon of necromass in secondary forest is higher due to some standing dead and felt down tree after burning.

Table 23. Carbon stock of tree, understorey, litter and necromass in each plot sample

Plot code	Forest type	Tree (tC/ha)	Understorey (tC/ha)	Litter (tC/ha)	Necromass (tC/ha)	Total (tC/ha)
Plot-1*	Disturbed swamp forest	87.77	7.75	0	0	95.51
Plot-2*	Disturbed swamp forest	91.03	3.68	0	0	94.71
Plot-3*	Undisturbed swamp forest	115.15	5.15	0	0	120.3
Plot-4*	Undisturbed swamp forest	104.06	10.56	0	0	114.62
Plot-5*	Disturbed swamp forest	139.91	13.52	0	0	153.43
Plot-6*	Undisturbed swamp forest	204.76	5.61	6.72	0	217.09
Plot-7*	Undisturbed swamp forest	378.54	5.7	4.18	0	388.42
Plot-8*	Disturbed swamp forest	23.58	4.42	1.1	22.91	52.02
Plot-9*	Disturbed swamp forest	56.08	0.55	5.52	5.81	67.96
Plot-10*	Disturbed swamp forest	65.41	2.58	1.84	7.14	76.96
Plot-11*	Agroforest	25.65	0	0	0	25.65
Plot-12*	Agroforest	30.93	0	0	0.36	31.29
Plot-13*	Undisturbed swamp forest	214.19	7.36	4.23	0	225.78
Plot-14*	Undisturbed swamp forest	173.21	0	0	0	173.21
KT1	Disturbed swamp forest	45.07	2.76	0	0.06	47.9
KT2	Undisturbed swamp forest	105.95	1.5	1.64	0	109.08
KT3	Undisturbed swamp forest	68.23	137.37	2.45	1.07	209.13
KT4	Disturbed forest	129.42	0.62	5.65	0	135.69
KT5	Disturbed forest	92.42	0.82	8.1	0	101.34
KT6	Undisturbed swamp forest	165.85	2.57	10.99	1.78	181.19
KT7	Disturbed forest	93.96	2.18	2.42	0	98.57
KT8	Disturbed forest	128.84	2.45	0.99	0	132.28
KT9	Disturbed forest	90.81	1.31	0.36	0	92.47

*YEL data (2007) reprocessed

For belowground carbon-stock, Agus and Wahdini (2008) reported that peat depth in the Tripa area (see plot samples in Figure 11.A) ranged from 130–505 cm, categorised as moderate (100–200 cm), deep (200–400 cm) to very deep peat (>400 cm) (Figure 20). Average carbon-stock in peat at moderate depth was 382 t/ha, deep was 1368 t/ha and very deep was 1621 t/ha.

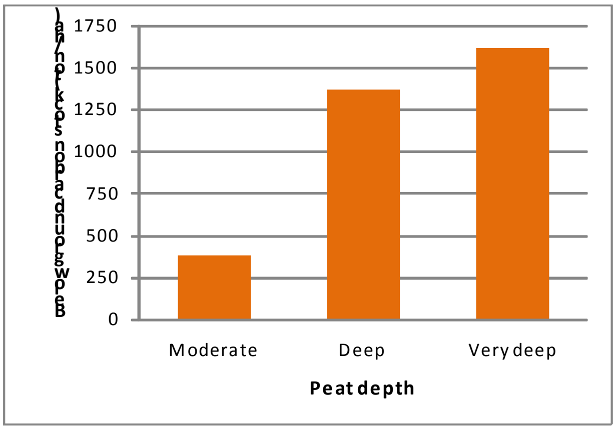


Figure 20. Belowground carbon-stock in moderate, deep and very deep peat (source: Agus and Wahdini, 2009)

Peat density in Tripa was low and in the range 0.01–0.03 g/cm and carbon content was 12–63%, resulting in an average of 4.19 tC/ha/cm and a carbon stock that ranged from 382 t/ha for a 130 cm depth profile to 2240 t/ha for a location with a depth of 390 cm.

Table 24. Peat thickness and carbon stock in each plot sample

Land use	Peat depth (cm)	carbon stock, t/ha	t/ha/cm
Oil palm	237	1071	4.52
Oil palm	350	1852	5.29
Oil palm	390	2240	5.74
Secondary forest	130	382	2.94
Secondary forest	220	945	4.30
Secondary forest	238	1032	4.34
Secondary forest	250	1523	6.09
Secondary forest	325	1345	4.14
Secondary forest	400	1274	3.19
Secondary forest	445	1430	3.21
Secondary forest	505	1554	3.08
Shrub	240	1034	4.31
Shrub	460	1879	4.08

Source: Agus and Wahdini, 2008

3.1.1.2 Tree diversity

A total of 92 tree species were identified in 23 plots (4.6 ha) in the Tripa area. In undisturbed peat forest (4 plots), a total of 20 species were encountered, with average species numbers in each plot at 8. Secondary peat forest had less species, with 11 species found in 5 plots with an average of 5 species per plot. Species numbers in disturbed forest on mineral soils was higher: 79 species in 14 plots with an average of 12 species per plot. *Eugenia jambos, Eugenia curtisii, Litsea cubeba and*

Laurus nobilis were the most common species in the Tripa area, dominating all types of forest (Table 25).

Table 25. List of ten dominant tree species in three forest types in Tripa

Low density		High density		Secondary forest	
Species name	**Important Value Index**	**Species name**	**Important Value Index**	**Species name**	**Important Value Index**
Campnosperma sp.	15.48	*Eugenia jambos*	41.67	*Eugenia jambos*	58.28
Litsea cubeba	10.25	*Laurus nobilis*	36.98	*Eugenia curtisii*	29.27
Eugenia curtisii	9.84	*Areca* sp.	30.73	*Macaranga triloba*	19.46
Eugenia jambos	7.70	*Litsea cubeba*	11.46	*Litsea cubeba*	14.64
Laurus nobilis	6.95	*Myristica* sp.	7.29	*Ficus fistulosa*	17.14
Shorea sp.	7.96	*Litsea* sp.	6.25	*Quercus lutea*	17.14
Quercus lutea	6.29	*Eugenia curtisii*	5.73	*Knema laurina*	12.23
Hopea sp.	3.90	*Cinnamomun iners*	5.21	*Laurus nobilis*	11.02
Mezzettia parviflora	5.80	*Cryptocarya griffithiana*	5.21	*Camnosperma coriaceum*	9.82
Syzygium chloranthum	5.21	*Camnosperma coriaceum*	7.81	*Syzigium commune*	6.11

Based on a list of trees used by orangutan (Russon, 2007), all of the dominant tree species in Tripa were sources of orangutan food. Analysis of tree diversity using the Shannon-Wiener Index showed that tree species diversity in Tripa was 3.61 (with a 95% bootstrap confidence interval of 3.48–3.64 and a bootstrap standard error of 0.04). High tree species diversity particularly occurred in Kuala Seumayam (KT4, KT5, KT6, KT7, KT8, KT9), ranging 2.2–2.76, even though this area was categorised as low density primary forest. Unfortunately, this habitat is under threat of forest clearing.

For only eight species all growth stages (sapling (5–10 cm diameter), pole (10–20 cm diameter) and tree (> 20 cm diameter)) were observed in each plot, indicating local regeneration: *Campnosperma auriculatum, Hopea* sp.*, Laurus nobilis, Litsea* sp.*, Macaranga triloba, Myristica* sp.*, Phylanthus emblica and Shorea* sp. In contrast, 30 tree species (79%) in undisturbed peat forest were only found at the tree stage. This indicated that these species did not regenerate well and they may disappear with time. Most of these are categorised as major timbers from the families Dipterocarpaceae, Lauraceae, Ebenaceae, Anacardiaceae, Annonaceae and Leguminosae.

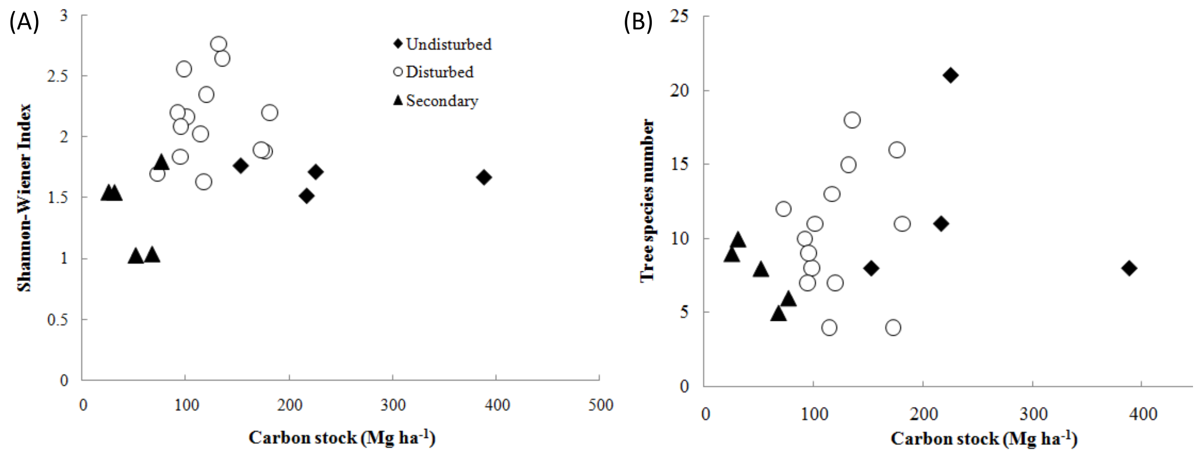


Figure 21. Tripa. (A) Shanon-Wiener diversity index; (B) number of tree species encountered per plot

The Shanon-Wiener diversity index has only a weak relationship with aboveground carbon stock and is on average higher for the 'disturbed' than for 'undisturbed' forest; is it, however, relatively low for the 'secondary' forest plots (Figure 21.A). The relationship between the number of tree species per plot and aboveground carbon stock is more pronounced (Figure 21.B), but still weak. The plot with the highest carbon stock has less than half of the maximum tree diversity.

3.4 Conclusion

In terms of carbon stock, the agroforests are a glass half empty (when compared to natural forest) or half full (when compared to open-field agriculture). The carbon-stock data will be used for landscape scale analysis of emissions in the next chapter.

Carbon stocks are correlated with indicators of tree diversity, but the relationship varies between the landcapes and is not very strong. The relationship will vary with the taxonomic or ecological group under consideration, which is consistent with the challenge of any flora or fauna to be an 'indicator' of any other. Rather than the broad concept of biodiversity the focus may have to be on the aspect that is of the highest public value.

The tree-diversity data provides some indication of consequences of human forest use for orangutan. The swamp forest of Tripa is rich in species that can be a food source for orangutan, while the logged-over forest of Batang Toru still contained many such species as well. Direct human disturbance rather than shortage of food trees may be the primary constraint to orangutan in both landscapes. The large trees that orangutan need to construct nests are associated with high carbon stock. Core areas with large trees surrounded by areas that provide edible fruits or leaves at low levels of human disturbance are needed for orangutan survival at landscape scale. Current forest conversion in both landscapes is already testing the limits.

4. Component C: Consequences of land-use change for carbon emissions

Atiek Widayati, Andree Ekadinata, Feri Johana and Zuraidah Said

4.1 Introduction

Two important habitats of the Sumatran orangutan—the Tripa swamp and Batang Toru landscape—face threats owing to changes to, and degradation of, forest cover. After a broad description of land-use patterns and quantification of carbon stocks for the major forest types and land-use systems in preceding sections, this component provides a technical background to assessments of the changes in land use and land cover at the two sites.

The analyses of changes and trajectories for this study have three objectives.

1. Observation of the various land-use changes.
2. Examination of the trajectory of changes.
3. Assessment of the patterns as well as magnitudes of the changes relevant to the context and issues in the respective study sites, specifically carbon emissions.

Forest clearing and conversion to lower-density vegetation such as crops or monoculture plantation carry direct consequences in the decrease or loss of the carbon stored. Therefore, following our analyses of changes to land use and land cover, we conducted subsequent analyses of the aboveground carbon-stock changes, emissions and sequestrations at the two study sites.

4.2 Materials and methods

4.2.1 Materials

Remotely sensed data have been widely applied in the analyses of the dynamics of land use and land cover. Two of the most common sources of remotely sensed data are Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) (NASA, 2005).

A series of Landsat TM/ETM imageries were used in this study and the complete list is presented in Table 26.

Table 26. List of satellite images for this study

Scene-ID	Satellite/Sensor	Acquisition dates
	Tripa	
P130-R057	Landsat 5 Thematic Mapper	January 6, 1990
P130-R057	Landsat Composit (3,4,5)	1995 (*)
P130-R057	Landsat 7 Enhanced Thematic Mapper	August 24, 2001
P130-R057	Landsat 7 Enhanced Thematic Mapper	February 08, 2005
P130-R057	Landsat 7 Enhanced Thematic Mapper	April 24, 2009
	Batang Toru	
P128-R059	Landsat 5 Thematic Mapper	July 14, 1994
P128-R059	Landsat 7 Enhanced Thematic Mapper	July 9, 2001
P128-R059	Landsat 7 Enhanced Thematic Mapper	January 28, 2006
P128-R059	Landsat 7 Enhanced Thematic Mapper	June 29, 2009

(*) Raw satellite imagery was obtained from secondary source (YEL, pers.comm.) which had been resampled into 50 m composite imagery

4.2.2 Methods

4.2.2.1 Study site and area coverage

The Batang Toru study area was determined based on two orangutan habitat maps (Wich et al., 2008 with update by Fredriksson, Usher and Wich) and the 5 km buffer area, covering an area of 247 000 ha, or 2470 km^2 (Figure 22(a)).

The Tripa study site was approximately 102 040 ha, or 1 020 km^2, covering the area of Leuser Ecosystem Zone (Kawasan Ekosistem Leuser or KEL) (60 000 ha) and the 5 km buffer area, as shown in Figure 22(b).

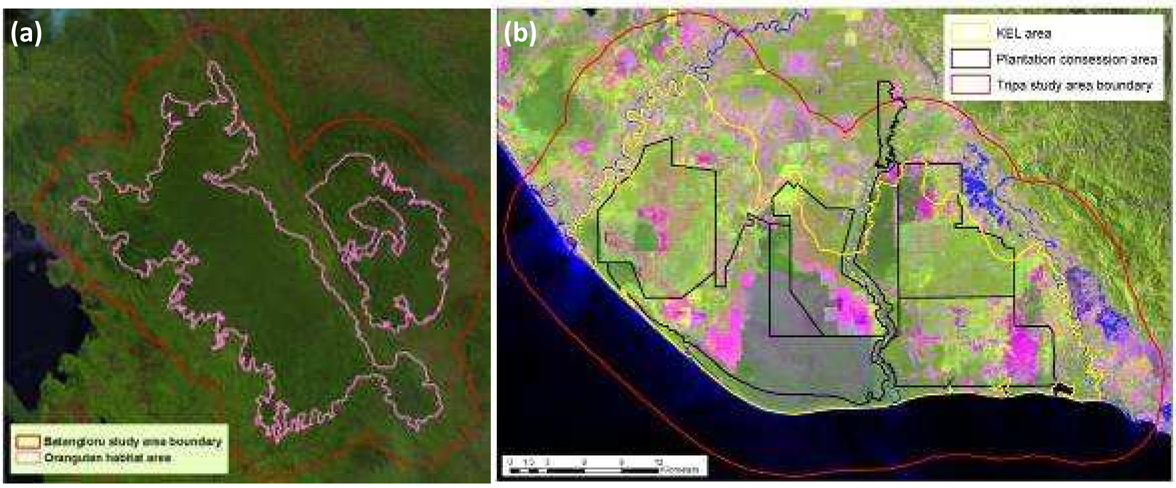


Figure 22. Batang Toru study area (a) and Tripa study area (b) overlaid on 2009 Landsat TM (bands 5-4-3)

Analysis of Land-Use/-Cover Trajectories (ALUCT)

Analyses of land-cover changes and the trajectories in this study are presented as a standardised framework developed at ICRAF called 'Analysis of Land-Use/-Cover Trajectories' (ALUCT) and is based on interpreted and classified satellite images. The entire procedures applied in ALUCT are presented in Figure 23 and are explained briefly below.

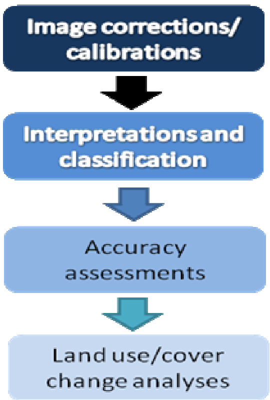


Figure 23. Overall workflow in ALUCT

Image corrections

Image corrections normally consist of radiometric calibration and geometric correction. Radiometric calibration fixes the image from the distortions caused by atmospheric factors, viewing angles, scene illumination, and instrument response characteristics (Lillesand and Kiefer, 1994; Chavez, 1996), while geometric correction fixes the image into the geo-reference coordinates of the earth surface. For this study, the provision of Landsat images was based on the geometrically corrected images, coded as L1-G (NASA, 2005), consequently, only radiometric corrections were conducted, applying ATCOR2 algorithm within PCI Geomatica software (Richter, 1991).

Image interpretation and classification

Image interpretation and classification in ALUCT applies an 'object-based hierarchical classification' approach. This classification system is built in several levels or hierarchies, each of which consists of two stages: image segmentations; and image classifications (Blumberg and Zhu, 2007). Image segmentation was conducted to obtain 'image objects', which are a set of pixels having homogeneous spectral and spatial characteristics (see Figure 24). The hierarchical image classification processes are implemented by applying different sets of rules, depending on the types of land cover classes and the levels in the hierarchies, and are guided by 'groundtruth' (verification at selected sites) samples, auxiliary information and/or expert judgments. The hierarchical nature of this classification approach can be seen in Figure 25.

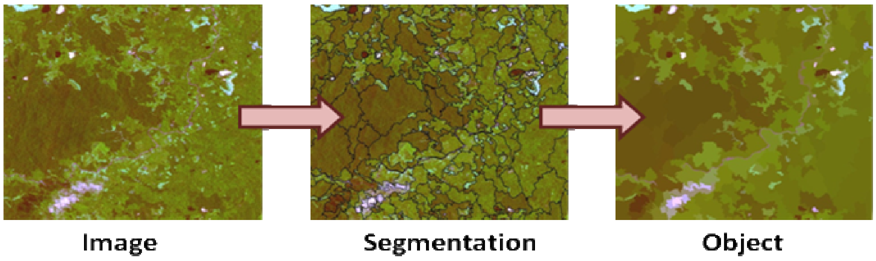


Figure 24. Segmentation process in object-based classification

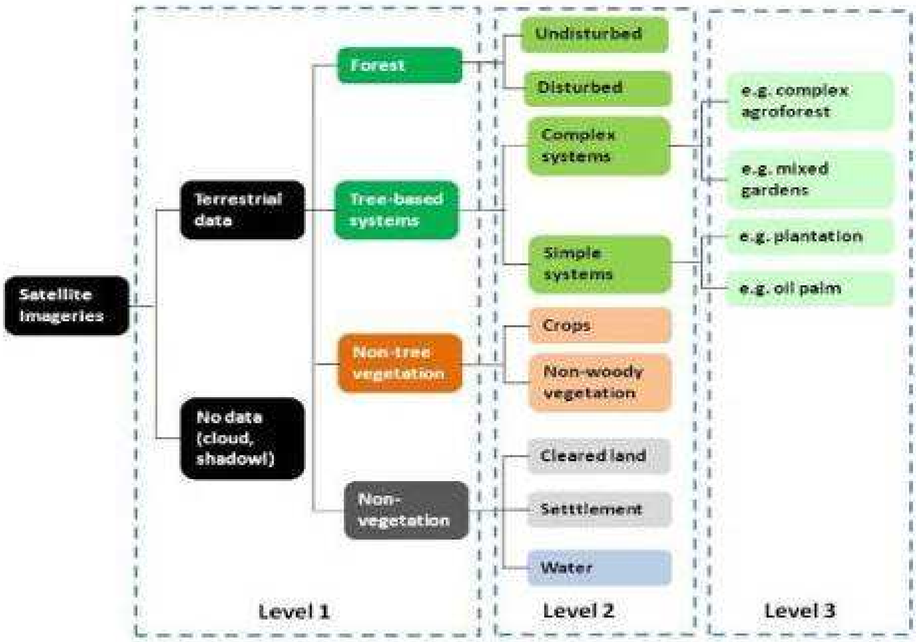


Figure 25. General framework of object-based hierarchical classification

Land-cover types to be classified are determined and defined prior to the classification processes. This stage is important to guide the sampling and the classification. For the two study sites, the land-cover categories and the respective definitions are presented in Table 27 below.

Table 27. Land-cover types and definitions

No.	Land-use/-cover types	Description
1	Undisturbed forest	Undisturbed forest is natural forest cover with dense canopy, highly diverse species and basal areas. It has no logging roads, indicating that it has never been logged, at least not on a large scale, and is usually located in areas with rough topography. Canopy cover of undisturbed forest is usually >80%. In satellite images it is indicated by high value of vegetation index and infrared spectrum channels and lower value in visible spectrum channels.
2	Undisturbed swamp forest	Similar to #1, but located in swamp environment and normally with lower vegetation and canopy density compared to lowland and mountainous forest.
3	Disturbed/degraded forest	Natural forest area having been disturbed by logging or other timber extraction or fire but still has relatively dense tree cover and dense canopy. Canopy cover is around 20–60%. Large trees with diameter >30 cm can be found.
4	Disturbed swamp forest	Similar to #3, located in swamp environment.
5	Rubber agroforest	Rubber agroforest is characterised by the presence of rubber trees mixed with other tree species, which form a stand structure similar to secondary forest. Rubber trees typically account for less than 70% of the population of trees above 10 cm dbh (diameter at breast height). When the presence of non-rubber trees is dominant and the plot is old enough, the area will be very hard to differentiate from natural forest.
6	Mixed garden	Mixed garden is a tree-based system with more than 30% of the area consisting of various species of trees. Mixed gardens are usually located relatively close to settlements or roads.
7	Agroforest	Agroforest is defined as a tree-based system mixed with crops and other vegetation with a range of density and diversity lower than but similar to mixed gardens; usually also includes natural understorey vegetation. The location is not limited by distance to any other land use.
8	Estate/plantation	Monoculture plantation of tree crops and/or timber. Tree canopy cover is around 30–50%.
9	Oil palm	Monoculture plantation of oil palm planted by private companies and local people.
10	Coffee agroforest	Mixed cultivation system of coffee and shade trees, mostly managed by local people; normally located close to settlements.
11	Cleared land	Area where trees have been cleared, which includes ex-logging areas or slashed-and-burned areas prepared for agriculture; vegetation cover is usually herbaceous vegetation and/or grass.
12	Cropland	Cropland is intensively cultivated land and is mostly planted with annual crops such as staple food, vegetables, fruit.
13	Shrubs, grass	Area dominated by non-woody vegetation, which is usually an ex-forest clearing area that undergoes natural secondary regrowth. For old shrubs, there is a low cover of trees, around 5% cover; but no trees with diameter >20 cm.
14	Settlement	Settlement refers to built area (city or village), which includes road, main road and/or logging road; for rural settlement this includes home gardens immediately located near the houses.
15	Water body	Water body refers to an area covered with water, for example, stream, lake, pond.
16	No data	No data refers to unclassified area, clouds, and shadow area.

The Tripa swamp is dominated by peat soils (Wahyunto et al., 2003). The peat-land map was utilised to distinguish between swamp forest and lowland forest, as the aboveground carbon-stock differs between these vegetation types.

Accuracy assessments

After producing the final land-cover maps and prior to applying further analyses, the quality and accuracy of the maps need to be assessed. Accuracy assessment is applied by evaluating the maps using an independent set of groundtruth data and, for time-series maps, such as were produced in this study, commonly conducted to the most-recent-year map. 'Overall accuracy' is the proportion of correctly classified pixels over the total number of references (Lillesand and Kiefer, 1994). To reduce the effect of random errors and chance agreement in the accuracy assessment, the overall accuracy figure is usually accompanied by the Khat (sometimes called Kappa) statistics, which is a measure between the actual agreement between reference data and the classifier and the chance agreement between the reference data and random classifier (Lillesand and Kiefer, 1994).

Land-cover change and trajectory analyses

There were three specific objectives for the land-use/-cover change analyses. For the Batang Toru site, the analyses focused on 1) orangutan habitat; and 2) the larger area incorporating the 5-km-wide buffer around the boundaries. These two levels of analyses would give an idea of the similarity/differences of the pressure of human activities both in the core habitat areas and in the surrounding areas.

For Tripa, the issues of forest conversion have been more alarming and more specific owing to the rapid and widespread establishment of oil palm plantations in the core part of the study area. This core area was where oil palm plantation concession rights (Hak Guna Usaha or HGU) were given to companies, mostly in the mid–1990s and a few recently. In 1998, Kawasan Ekosistem Leuser (Leuser Ecosystem Zone or KEL) was established based on Presidential Decree no. 33, 1998, which included the Tripa peat swamp ecosystem. The Tripa–KEL and HGU areas are overlapping with only small residual non-HGU areas within Tripa–KEL (see Figure 22(a)). The next level of land-cover change assessments were emphasised in the Tripa–KEL area by focusing on oil palm expansions based on HGU concession rights.

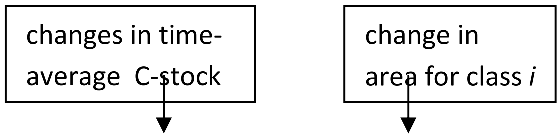
Problematic issues that normally appear in land-cover change analyses are 1) illogical change; and 2) no data in one or more of the time-series maps. To address problem 1, adjustments need to be made by providing expert judgments and/or refining the classified images. For problem 2, the common solution is to accumulate all no-data patches throughout the period of analysis and apply them to all the time-series maps. As a result, the no-data areas are constant throughout. The water body class also, when relevant, follows the same treatment as no-data areas.

4.2.1.1 Rapid Carbon-Stock Appraisal (RaCSA)

The IPCC refers to two types of approaches in calculating emissions from land-use changes (IPCC, 2006): 1) gain-loss method, which accounts for the detail of fluxes owing to both human activities and natural processes at a relatively short time scale; and 2) stock-difference method, which accounts for changes in stock at a coarser time scale.

Rapid Carbon Stock Appraisal (RaCSA) is an adoption of the second IPCC approach, that is, a stock difference and overall methodology for landscape-level carbon dynamics estimation developed by ICRAF (Hairiah et al., in preparation). Two types of data are required in RaCSA: 1) area of changes and trajectories of land-use systems; and 2) time-averaged carbon-stock for each land-use system.

Data on area of changes of land-use systems is produced by ALUCT (see above), while time-averaged carbon stock is normally obtained from measurements. The basis for area-based carbon-stock accounting is an equation for changes in carbon stock: within and between land-use systems, each characterised as a fraction (a_i) of total area (A) (the stratum weighting) and with time-dependent carbon stock density $C_{i,t}$ (the stratum mean).



$$\Delta C_{t->t+1} = A_t\left(\sum_{i=1}^{n}(a_{i,t}(C_{i,t+1}-C_{i,t})+(a_{i,t+1}-a_{i,t})C_{i,t})\right)$$

ΔC = annual change in carbon stocks in the landscape, Mg per yr or tonne per yr

Within RaCSA, emission and sequestration factors for a pair of land-use systems within a time period are defined as the stock differences between initial and subsequent land-use systems per unit area; 'Emission' is defined as a decrease of the aboveground carbon-stocks, while 'sequestration' is an increase. Total emissions/sequestration in a landscape owing to land-use changes are emission/sequestration factors multiplied by the total area of each pair of land-use systems (Hairiah et al., in preparation). Net emission/net sequestration is an estimate obtained by deducting sequestration from the emission in a given area and period of time. For emission and sequestration, equivalence to CO_2 is applied, hence multiplication with 3.67[13] , and is expressed as CO_2-equivalent (CO_2e) (see IPCC, 2006). 'Emission/sequestration factor' is alternately used with 'average annual emission/sequestration rate' to refer to the emission/sequestration density per unit area and per unit time, keeping in mind that it is based on aboveground biomass changes and does not include other emission sources such as fire and peat-land decomposition.

Aboveground carbon-stock reference

For both Tripa and Batang Toru study areas, land-cover classes and the respective carbon density reference for each type is presented in Table 28 below (Rahayu et al., this report).

[13] Based on the ratio of atomic weight of CO_2 (44) and that of C (carbon) (12)

Table 28. Aboveground carbon-stock (Rahayu et al., this report)

No	Land-cover system	Carbon stock (t/ha) Batang Toru	Tripa	Remarks
1.	Undisturbed forest	243		Equivalent to primary forest in component B (Rahayu et al., this report)
2.	Disturbed forest	152		
3.	Undisturbed swamp forest		184	Average of high density and low density peat swamp forest, to avoid overestimation (Rahayu et al., this report)
4.	Disturbed swamp forest		121	Equivalent to the low density peat swamp forest in component B (Rahayu et al., this report)
5.	Estate/plantation (pines)	93		
6.	Mixed gardens	103		Tree-based system planted with durian, *kemenyan* and *salak*
7.	Agroforest/vegetation mosaics		30	Tree-based system planted with cacao and coconut and including other vegetation mosaics
8.	Rubber agroforest	114		Complex rubber agroforest system
9.	Coffee agroforest	24		
10.	Oil palm		40	
11.	Crops		1	Assumed to be equivalent with paddy rice
12.	Shrubs and grass		22	
13.	Rural settlements		27	
14.	Cleared land		1.5	Assumed to be equivalent with herbaceous vegetation and grass

4.3 Results

4.3.1 Batang Toru

The size of orangutan habitat in Batang Toru was approximately 110 000 ha, while the total area of the study site, that is, orangutan habitat and 5-km-wide buffer area, was approximately 247 000 ha. The land cover maps in Batang Toru site were categorised into the following classes: 1) Undisturbed forest; 2) disturbed forest; 3) rubber agroforest; 4) coffee agroforest; 5) mixed gardens; 6) plantation/estate; 7) crops; 8) shrubs and herbs; 9) cleared land; 10) rural settlement; and 11) water body. The pictures of land-cover types observed in the field can be seen in Annex 1.