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Conflicts between rubber plantations and nature reserves

A case study in Naban River Nature Reserve, China

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Contents

Abbreviations

ALOS	Advanced land observing satellite
a.s.l	Above sea level
BCI	Biodiversity conservation corridor initiative
CONNECT	Connection index
CONTAG	Contagion index
DEM	Digital elevation model
ESS	Ecosystem services
ESV	Estimated ecosystem service value
ETM+	Enhanced thematic mapper plus
GMS	Greater Mekong subregion
IJI	Interspersion and juxtaposition index
LCM	Land change modeler
LPI	Largest patch index
LSI	Landscape shape index
LU/LC	Land use/land cover
MA	Millennium ecosystem assessment
MAB	Man and biosphere
Mfl	Monsoon forest over limestone
Mfrb	Monsoon forest on river banks
MLP	Multi-layer perceptron
MPS	Mean patch size
MSS	Multispectral scanner
NDVI	Normalized difference vegetation index
NFPP	National forest protection plan
NIR	Near infrared
NTFP	Non timber forest products

PM	Pattern metrics
REDD	Reducing emissions from deforestation and forest degradation
RMS	Root mean squared error
Sebf	South-subtropical evergreen broad-leaved forest
SLCP	Slope land conversion program
TE	Total edge
TCA	Total core area
TM	Thematic mapper
Tmr	Tropical montane rainforest
Tsr	Tropical seasonal rainforest
SHDI	Shannon's diversity index
SHEI	Shannon's evenness index
UN	United Nations

Summary

The demand for, and therefore also the price of natural rubber, is increasing strongly the last decades. As a consequence, rubber is becoming an important cash crop in tropical regions of China, Laos and Myanmar. Farmers are turning large areas of agricultural land or forest into rubber plantations. This causes deforestation, fragmentation, problems with erosion, changes of the hydrological regime, and the expansion of infrastructure in areas that often used to be dominated by tropical forest.

A study area of 278 ha in the south of China, Naban River Nature Reserve, was surveyed in terms of the past, present and future land use and land cover (LU/LC) based on spaceborne remote sensing. First a LU/LC map of 2011 was made using satellite images and field data. This was done in correspondence with the maps of the previous years that were available (1975, 1988, 1995, 2003 and 2004). Based on this time series, the change between 1975 and 2011 was modeled in terms of NDVI, area in each LU/LC class and spatial properties of the changes. Special attention was given to the changes in rubber plantations. Also pattern metrics (PM) describing the fragmentation in the study area were calculated over the time series. The driving forces steering these changes were defined and a prediction for the LU/LC in 2016 and 2018 with and without driving variables was made. Results show that the area in rubber increases during each time period studied, and mostly in the periods when rubber prices increase. The increase will keep going during the following years, according to the predictions. Forest fragmentation occurs in the periods of strongest rubber expansion.

Because changes in LU/LC cause changes in ecosystems, also the ecosystem services (ESS) of the area were investigated. The evolution of the value of ESS in Naban River Nature Reserve over the time series was calculated following a method used in previous studies and shows a strong increase between 2004 and 2011, but a slow decrease during the other periods. The valuation of ESS can be used in future research about nature reserves to quantify the changes directly influencing people.

Samenvatting

De vraag naar, en daarmee ook de prijs van natuurlijke rubber is de laatste decennia sterk aan het stijgen. Als een antwoord hierop is rubber een belangrijke cash crop aan het worden in regio's in China, Laos en Myanmar. Landbouwers zetten grote oppervlakten landbouwgebied of bos om in rubberplantages. Dit zorgt voor ontbossing, fragmentatie, problemen met erosie, veranderingen in waterhuishouding en uitbreiding van infrastructuur in de gebieden, die dikwijls voordien grotendeels bestonden uit tropisch bos.

Een studiegebied van 278 ha in Zuid-China, Naban river Nature Reserve, werd onderzocht wat betreft vroeger, huidig en toekomstig landgebruik en landbedekking (land use and land cover, LU/LC) met behulp van satellietteledetectie. Een LU/LC kaart werd gemaakt voor het jaar 2011 met behulp van satellietbeelden en velddata. Dit werd gedaan in overeenkomst met de beschikbare kaarten van de vroegere jaren (1975, 1988, 1995, 2003 en 2004). Gebaseerd op deze tijdsserie werden de veranderingen tussen 1975 en 2011 gemodelleerd met NDVI, oppervlakte in elke LU/LC klasse en ruimtelijke eigenschappen van de veranderingen. Speciale aandacht ging naar de veranderingen in rubberplantages. Ook landschapsmetrieken (pattern metrics, PM), die de fragmentatie in het studiegebied beschrijven, werden berekend doorheen de tijdsserie. De drijvende krachten achter deze veranderingen werden gedefinieerd, en een voorspelling werd gemaakt voor het LU/LC in 2016 en 2018, zowel zonder als met het gebruik van de drijvende krachten. Resultaten tonen aan dat de oppervlakte rubber stijgt gedurende elke tijdsperiode die werd bestudeerd, waarbij de grootste stijging worden waargenomen in de perioden waarin rubberprijzen stijgen. Deze stijging zal, volgens de voorspellingen, blijven doorgaan in de komende jaren. Fragmentatie komt vooral voor in de perioden waarin rubber het sterkst uitbreidt.

Omdat veranderingen in LU/LC ook veranderingen in ecosystemen met zich meebrengen, werden ook de ecosysteemdiensten (ecosystem services, ESS) in het gebied onderzocht. De evolutie van de waarde van de ESS in Naban River Nature Reserve doorheen de tijdsserie werd berekend volgens een methode die in eerdere studies al gebruikt werd en vertoont een sterke stijging tussen 2004 en 2011, maar een trage afname gedurende de andere perioden. De evaluatie van de waarde van ESS kan in toekomstig onderzoek in natuurreservaten nog gebruikt worden om de veranderingen te kwantificeren die directe invloed hebben op mensen.

1. Introduction

1.1 Problem statement and objectives

The demand for natural rubber has increased substantially during the last decades. With demand, also prices are increasing. Rubber (*Hevea brasiliensis*) plantations have become a major source of income for farmers in Xishuangbanna (Fu *et al*., 2008). Next to the introduction of cash crops, also the population is growing, which creates a need for more food and thus more land needs to be brought in cultivation. Competition for this land often makes the farmers choose for the most profitable activity, often being the cultivation of cash crops. In regions of Laos, Myanmar and China, rubber is selected (Sturgeon, 2010).

One of these regions in China is Xishuangbanna prefecture. It borders Laos and Myanmar and the climatic conditions are a transition between tropical and subtropical areas (Xi, 2009), rendering it the boundary of the area where rubber can grow. The area of primary forest is decreasing, making room for rubber plantations and other cash crops, other agricultural activities and transition forest. More issues related to the introduction of rubber in the area include forest fragmentation, soil erosion, changes in hydrology and infrastructure expansion (Zhang, 2011).

To address the spatial land use problems in this region, mapping of LU/LC is an essential tool. A part of Xishuangbanna, namely Naban River Nature Reserve, was chosen as study area. Following research objectives were put forward:

1. Make a map of the LU/LC in Naban River Nature Reserve based on satellite images of 2011

2. Quantify the change in LU/LC in Naban River Nature Reserve between 1975 and 2011

3. Predict LU/LC in Naban River Nature Reserve in 2016 and 2018

4. Assess the ecosystem services (ESS) in Naban River Nature Reserve and the changes herein due to LU/LC changes

1.2 Study area

Naban river nature reserve is located in the Dai Autonomous Prefecture of Xishuangbanna in the province Yunnan, in southwest China. It is bordered by the Lancang river in the east. The Lancang river is the upper part of the Mekong river, which flows from China to Laos, Cambodia and Vietnam, where it flows in the South China Sea (Figure 1.1). The river is an important feature in the nature reserve, as well for the population as for the ecosystem. Xishuangbanna is located in the southwestern tip of Yunnan province, between 21°10' and 22°24'N; 100°16' and 101°55'E, and it borders Laos and Myanmar (Figure 1.1). The altitude varies from 475 m to 2429 m above sea level (a.s.l.) (www.unesco.org). There is a monsoon climate, with an annual average temperature of 21.7°C in Jinghong. 85% of the annual rainfall (1221 mm) occurs in the rainy season, from May to October (Zhang and Cao, 1995).

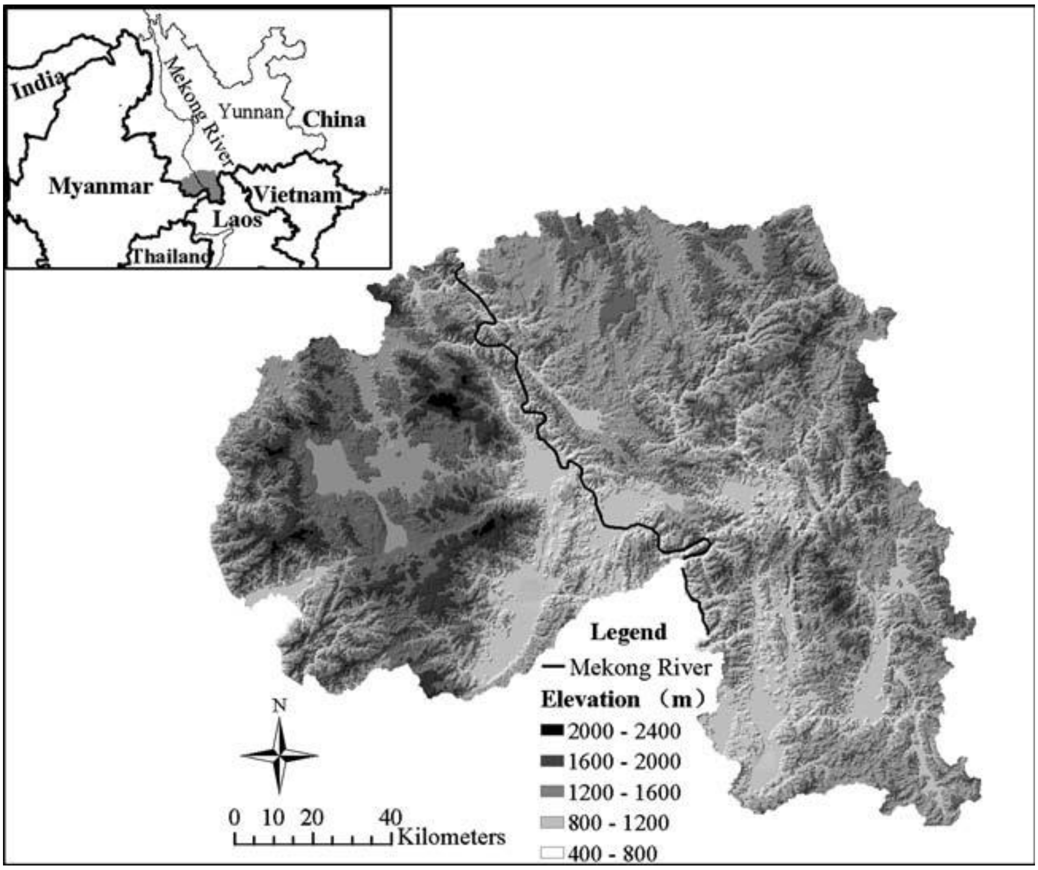

Figure 1.1: Mekong river watershed and the location of Xishuangbanna (Li *et al.,* 2007)

Naban river nature reserve, the study site, is located northwest of Jinghong city, the capital of Xishuangbanna Autonomous region (Figure 1.2). The nature reserve covers an area of 268 km². As is shown in the digital elevation model (DEM) in Figure 1.3, the eastern, lower part of the nature reserve is close to the Lancang river. It is therefore wetter and the agriculture feature paddy rice fields, tea plantations, rubber plantations and on a smaller scale banana plantations and corn. In the western, more mountainous part, less water is available and the slopes are steeper. Here, shifting cultivation is more common.

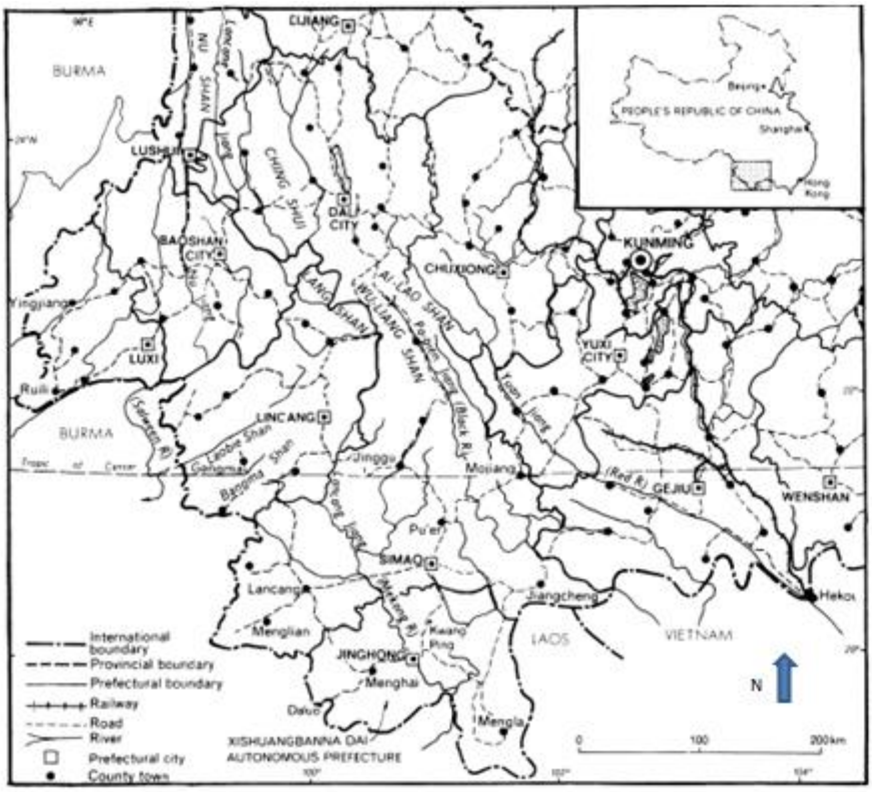

Figure 1.2: Xishuangbanna Autonomous Prefecture (Chapman, 1991)

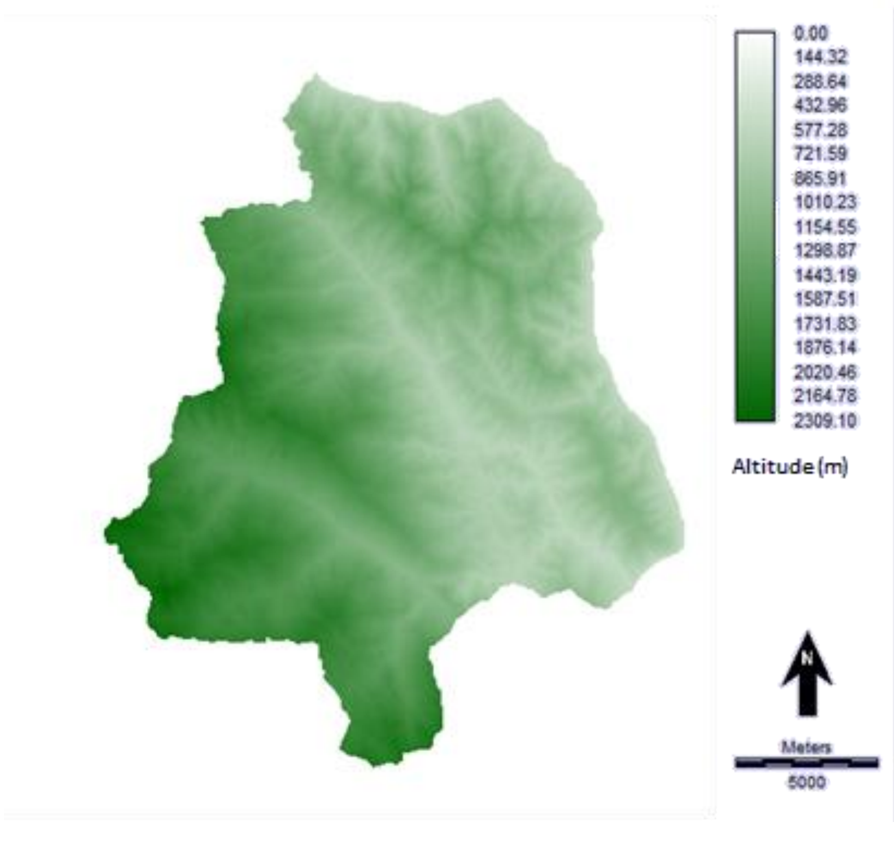

Figure 1.3: DEM of Naban river nature reserve

1.3 Primary vegetation

Xishuangbanna is situated in the transit zone between the tropical and the subtropical region. Therefore there is a wide variety of forest types. The primary forests in Xishuangbanna can be classified in 4 types: tropical rainforest, monsoon forest, monsoon forests on limestone and south-subtropical evergreen broad-leaved forest (Zhang *et al.*, 1995).

Tropical rainforest can be divided in two subtypes: tropical seasonal rainforest and tropical montane rainforest. Tropical seasonal rainforest (Tsr) is called seasonal because, apart from the mainly evergreen formation, a few deciduous trees are present. It is the forest naturally occurring below 900 m. The most common species in this type of forest are: *Terminalia myriocarpa*, *Pometia tomentosa*, *Baccaurea ramiflora, Garcinia cowa, Alphonsea mollis, Pseudouvaria indochinensis, Horsfieldia pandurifolia*, *Acrocarpus fraxinifolius*, *Litsea dillenifolia* and *Garuga floribunda* var. *gamlei* (Zhang *et al.*, 1995). 16 plots in Naban river nature reserve were analysed in terms of tree (and shrubs) species by the Forestry Bureau of Jinghong City, Xishuangbanna Prefecture. Table 1.1 gives an overview of the forest types found in these plots. Plot 1, 2 and 16 are of the tropical seasonal rainforest type. Above 900 m, tropical montane rainforest (Tmr) is more common. However, since it is tropical, it only occurs in places where the humidity is sufficiently high (Zhang *et al.*, 1995). Plot 10 and 13 in Table 1.1 belong to this type of primary forest. The most common species are: *Alstonia scholaris*, *Dysoxylum spicatum*, *Actinodaphne henryi*, *Paramichelia baillonii* and *Castanopsis hystrix*. Monsoon forests on riverbanks (Mfrb) mainly occur along the Lancang riverside. They are partly deciduous, and shed their leaves in the dry season. The monsoon forests on limestone (Mfl) are small patches on limestone formations below 800 m. South-subtropical evergreen broad-leaved forest (Sebf), also called montane evergreen broad-leaved forest, is common in mountains, in altitude ranges above 1000 m. This is the most common forest in Xishuangbanna. In Figure 1.4, the types of primary forests in Xishuangbanna are schematically depicted. In Figure 1.5, the region of Xishuangbanna is depicted along with the different forest types present. In this picture, it is clear that in Naban river nature reserve, tropical seasonal rainforest is the predominant vegetation.

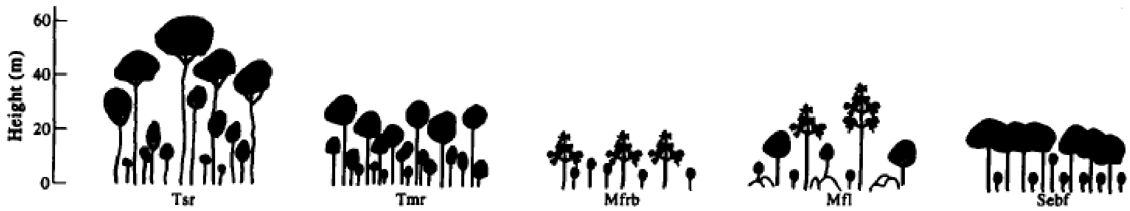

Figure 1.4: Forest types in Xishuangbanna (Zhang *et al.*, 1995) Tsr= Tropical seasonal rainforest; Tmr= Tropical montane rainforest; Mfrb= Monsoon forest on river banks; Mfl= Monsoon forest on limestone; Sebf= South-subtropical evergreen broad-leaved forest

Table 1.1: Plots and forest types

Plot code	Latitude	Longitude	Forest type
1	2468207	689821	Tropical seasonal rainforest
2	2465875	687789	Tropical seasonal rainforest
3	2486197	676306	Tropical semi-evergreen (monsoon) forest
4	2466651	688352	Secondary bamboo
5	2474106	678791	South-subtropical evergreen broad-leaved forest
6	2490017	682036	South-subtropical evergreen broad-leaved forest
7	2471365	678536	Mixed forest (bamboo and evergreen)
8	2465973	693227	Tropical semi-evergreen (monsoon) forest
9	2459663	674690	Deciduous forest
10	2449295	666037	Tropical montane rainforest
11	2452346	685745	South-subtropical evergreen broad-leaved forest
12	2472898	685987	Deciduous forest
13	2446460	674092	Tropical montane rainforest
14	2453777	670359	Tropical semi-evergreen (monsoon) forest
15	2452572	672111	Tropical semi-evergreen (monsoon) forest
16	2450834	672273	Tropical seasonal rainforest

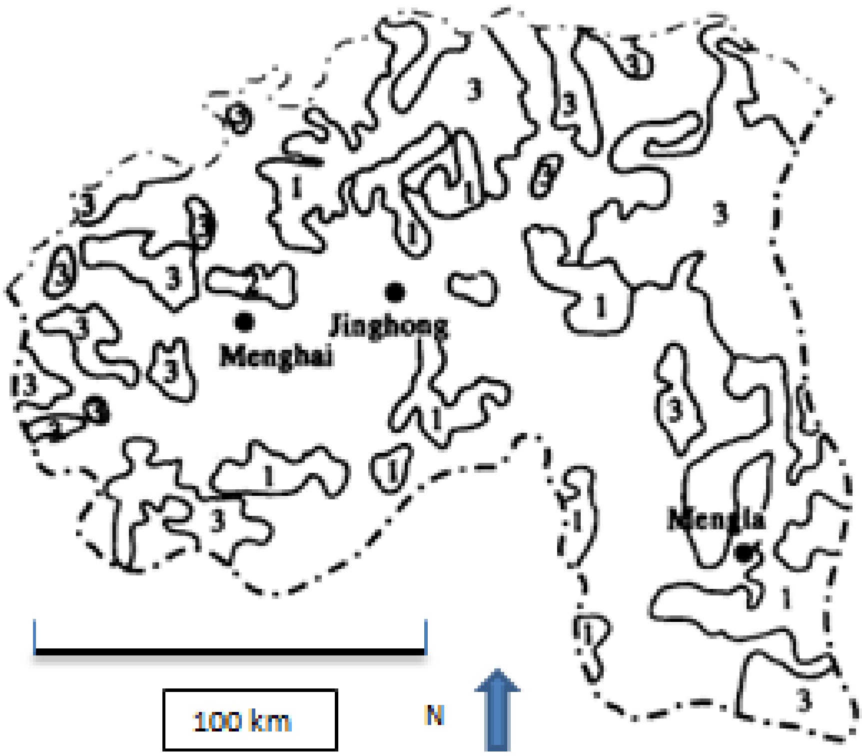

Figure 1.5: Forest types in Xishuangbanna (Zhang *et al.*, 1995) 1= Tropical seasonal rainforest; 2= Tropical montane rainforest; 3= South-subtropical evergreen broad-leaved forest

1.4 Secondary vegetation

Due to clearing of primary forests and abandonment of these areas, secondary vegetation has the opportunity to develop. Depending on the water supply, soil and previous treatment of the soil, different types of secondary vegetation will take over the land. In Xishuangbanna, 5 types of secondary vegetation are distinguished (Zhang *et al.,* 1995). Secondary deciduous monsoon forest is a low density forest mostly without shrubs. Where primary forest was cut but not burnt, secondary savanna woodland often develops. This vegetation consists of sparse trees and shrubs. Bamboo forests (*Dendrocalamus membranaceus*), with a bamboo coverage of 70 to 80 %, occur along the west side of the Lancang river, below 1000 m. Due to burning, secondary grassland often appears on abandoned shifting cultivation areas. *Chromolaena odoratum* communities of tall grasses exist at low altitudes and will gradually be taken over by woody plants (Zhang *et al.*, 1995).

In Naban river nature reserve, the bamboo forests occur next to the Lancang and Naban river. In the western part, where shifting cultivation is practiced, savanna woodland and secondary grassland are common.

1.5 Economic and political drivers

In China, the predominant ethnic group are the Han Chinese, but many people who live in the region of Xishuangbanna belong to ethnic minorities. These are mostly hill tribes, like Dai, Hani and Bulang. Dai people are Buddhist, but also worship nature. The holy hills (Manyangguang) in their villages covered by primary forests can easily be recognized in the field. The Hani people have cemetery forests, and they practice shifting cultivation on the hillslopes. Bulang also have a culture of shifting cultivation (Xu *et al.,* 2005).

In the 1950's, ethnic minorities were officially classified. Most minorities still worked with agricultural systems which were used by Han Chinese in earlier times. Therefore, it was believed that the minorities were of less 'quality' than Han Chinese, and were economically of less value (Sturgeon, 2010). The shifting systems they were practicing were, according to the socialist, Maoist model, destructive, backward and low in productivity (Xu, 2006). To modernize these systems and increase the economic value, shifting cultivation systems were replaced by paddy rice and rubber plantations (Xu, 2006). During the last decades, China has known an impressive economic growth. In Xishuangbanna, this growth is represented by rubber production. The first rubber plantations in the area were established in 1956 by Han Chinese farmers from Hunan Province who came to Xishuangbanna. This rubber was needed mostly for national defense (Li *et al*., 2007) and land use decisions were based on national quota. The best areas (in low altitudes) were occupied by these plantations. In 1979, the agricultural policy in China was changed to the household responsibility system (Xu *et al.*, 2005). From then on, many farmlands were given to households. In the mid 1980's, the Chinese government, following the ideology of Mao to replace traditional farming systems, tried to decrease the amount of shifting cultivation by teaching minorities to plant rubber trees. Therefore, rubber trees were also introduced in areas with more extreme temperatures and at more extreme altitudes (Sturgeon, 2010).

Rubber plantations are however included as 'economic forests' in the Chinese law, and hence are excluded from the law of farmland (Li *et al.,* 2007, china.org.cn). As to forest, the first reforms occurred in the mid 1980's. From then on, community forest could be, under contract, allocated to households (Xu *et al.,* 2010). A lot of the earlier established state rubber farms were transferred to communities and some of these were contracted to households (Chapman, 1991). Also, new small scale farms were established, by the conversion of shifting cultivation areas into rubber plantations which were of higher economic value (Xu, 2006). By 1988, 40 percent of the rubber planted areas in Xishuangbanna were privately owned (Chapman, 1991). The fact that smallholders can sell their rubber at the private market provides them (next to a higher vulnerability) with an economic advantage over the state farms, which have to abide by the nationally established prices. In 1998 China implemented the Natural Forest Protection Plan. The aim of this policy was to control deforestation and increase forest cover. Due to this law, many nature reserves have been established. In 1999, the logging ban was a subsequent attempt to protect China's forests (Li *et al*., 2007).

While rubber production is still growing, consumption increases even more quickly (Figure 1.6). With the growing demand, also the prices of rubber increase. In 2011, the price for one kg of rubber was 33 Yuan or 4.2 Euro (1 Chinese Yuan is equal to 0.126 Euro). In Figure 1.7, the monthly income from the production of rubber in Daka, a village in Xishuangbanna to the southeast of Naban river nature reserve, is shown. It is clear that, from 2001 on, the rubber prices increased drastically (Fu *et al.,* 2008). Moreover, the construction of a hydropower dam on the Lancang river upstream of Naban river nature reserve in 2004, has improved the water availability in the lower parts of the reserve.

In section 2.1.3.2, the driving forces behind LU/LC changes will be addressed in more detail. This knowledge should enable to characterize the different changes and predict future changes in LU/LC.

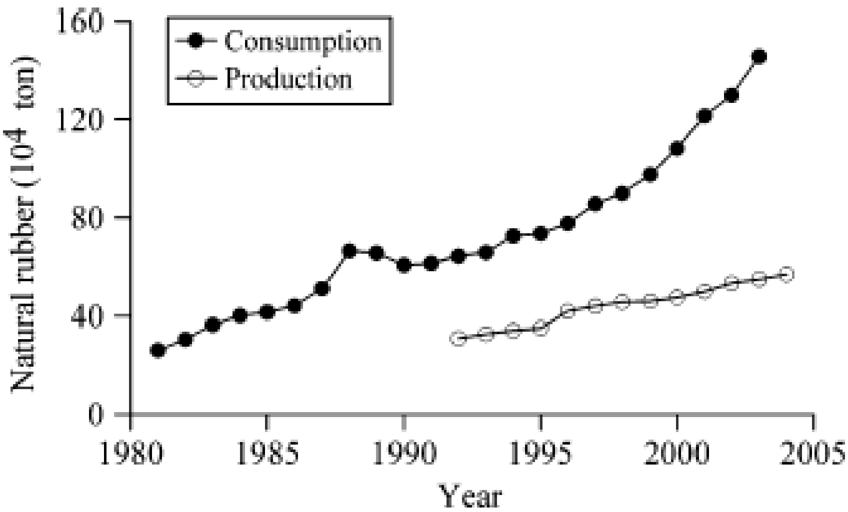

Figure1.6: Rubber consumption and production (Li *et al*., 2007)

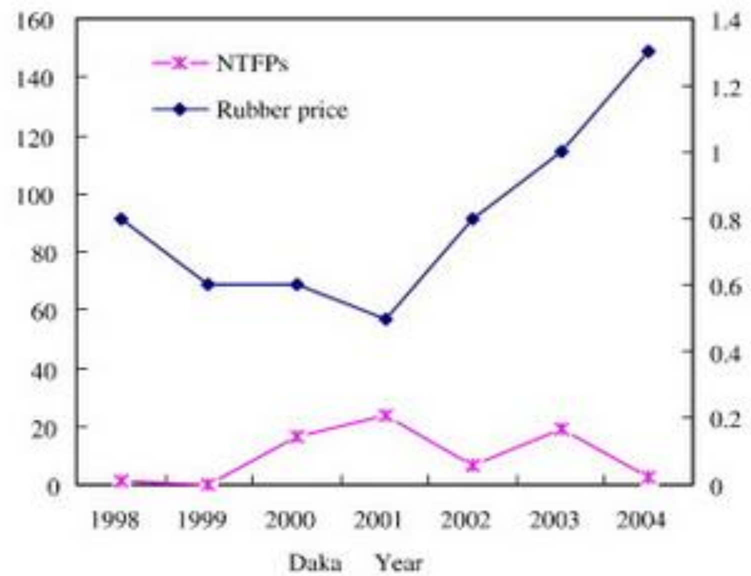

Figure 1.7: Evolution of income by rubber plantations (Fu *et al.*, 2008)

1.6 Ecological issues

The ecological impact of the political and economic drivers described above is diverse. The major ecological problems in Xishuangbanna originate from deforestation, rubber plantations, erosion, road construction and the construction of hydropower plants (Zhang, 2011).

As will be shown in the land change modeling, deforestation, combined with forest fragmentation, is a serious problem in Xishuangbanna in the last decades. The most important causes of fragmentation in Xishuangbanna are described by Li *et al.* (2009) as: population increase and the subsequent expansion of arable land, shifting cultivation in the period between 1976 and 1988, and rubber plantations between 1988 and 2003. They observed a decrease in total forest cover and in the mean size of a patch, and an increase in number of patches. The consequences include the collapse of primary productivity, a decline in species diversity, together with an alteration in species composition, and a further decrease in forest area by tree mortality caused by edge effects (Li *et al*., 2009). Zhu *et al.* (2004) also observed an altered microclimate (temperature and humidity) and a deteriorated soil (organic matter, extractable N, extractable K) in fragmented forest areas. In terms of species composition, they could specify that in fragmented areas, more pioneer species and less shade tolerant species were present (Zhu *et al*., 2004). The primary forests are also of high importance to many endangered animal species living in Xishuangbanna. Amongst others, the chevrotain (*Tragulus javanicus*), Indian ox (*Bos gaurus*) and the Asian elephant (*Elephas maximus*) have Xishuangbanna as one of their most important habitats (Zhang, 2011). Moreover, 90 % percent of the wild elephant population in China lives here (www.unesco.org). According to Li *et al.* (2009), the elephants live in habitats below 1000 m. This is the area that is most affected by the fragmentation. The small forest fragments are not large enough for the elephant's migration and survival. The extent of fragmentation in Naban river nature reserve and the consequences hereof will further be investigated in more detail.

Fragmentation and forest loss is also strongly influenced by infrastructure. In the research of Li *et al.* (2009), the edge effects experienced in fragmented forests are strongest in a 12.5 km buffer around the roads. Also Liu *et al.* (2011) could link fragmentation to the road network in Xishuangbanna. Especially minor roads have a great impact on forest fragmentation. Road construction, necessary for rubber planting and export, has increased since the increasing rubber production (Zhang, 2011). Roads, bridges and electricity were brought in Xishuangbanna by state rubber farms (Sturgeon, 2010).

Deforestation is also strongly related to other issues. The more indirect ecological issues concerning soil and hydrology are erosion, reduction in soil fertility, runoff, water availability and changes in infiltration capacity. On hillsides, erosion is a problem when forest is converted to agricultural land. In comparison to shifting cultivation areas, rubber plantations protect the slopes better from erosion (Chapman, 1991 and Xu, 2006), because the trees require a terraced slope. However, since rubber plantations are regarded as 'forests' in China, they can contribute to the Slope Land Conversion Program (SLCP), which was put in practice in 2000 and aims to return agricultural land on slopes steeper than 25° back to forest (Zhang, 2011). However, the law aims at reducing shifting cultivation by converting these areas to forests or to cash crops. By planting rubber trees, both the income of the farmers can be raised and the tree cover is increased (Liu *et al*., 2006). The SLCP also has serious consequences for the hill tribes with farms on sloping land, who can lose their income. Often, the best agricultural land, at lower elevations, is converted into rubber plantations, and therefore forests at higher elevations (and more vulnerable to erosion) are converted into agricultural land (Li *et al.,* 2007). Furthermore, since the understory of rubber is open, erosion is increased. Li *et al.* (2007) suggest the planting of tea shrubs under rubber trees. This reduces erosion, but can also diversify farmer's production and thus increase income security (Li *et al.,* 2008). Another option is to encourage secondary regeneration under rubber trees (Li *et al.,* 2007). The consequence of severe erosion is a reduction in soil fertility (Nguyen, 2013). Satisha *et al.* (2000), as cited in Nguyen (2013) have reported a reduction in N, P and extractable Zn and an increase in Fe and Cu in soils planted with rubber, and they could link this observation with altitude. Next to changes in soil properties, changes in the hydrological conditions of the area are also observed. There is the depletion of neighbouring forests in terms of water, which might induce change of local climatic conditions. According to Gong and Ling (1996) (as cited in Li *et al.,* 2007) the number of foggy days (1 mm precipitation per foggy day was recorded in Mengla County, Xishuangbanna) (Zhu, 1997) in Jinghong has decreased from 166 in the 1950's to less than 60 in the 1990's. These foggy days compensate for the insufficient precipitation in the dry period. If this change continues, this can mean a decline in the amount of species, and a gradual change of the vegetation type.

Carbon dynamics are also affected by the conversion of land. Since they have a global effect, they are an important factor to take into account when studying deforestation problems. According to Houghton (2002), LU/LC change provided for a release of 43 000 Tg (Teragram, 1 000 000 ton) for tropical Asia and 23 000 Tg for China in the period from 1850 to 2000.
Li *et al.* (2008) performed a study on the carbon dynamics in Xishuangbanna, resulting from the recent LU/LC changes. They report annual carbon emissions of 0.37 +/- 0.03 Tg between 1976 and 1988 and 0.13 +/- 0.04 between 1988 and 2003 in Xishuangbanna. These emissions mainly result from the conversion of forest to agricultural land and rubber plantations. Two scenarios for the future were investigated: the 'rubber expansion' and the 'forest recovery' scenario. In the rubber expansion scenario, a decrease of 4.13 +/- 1.14 Tg carbon would be the case between 2003 and 2023. In the forest recovery scenario, there would be an increase of 12.07 +/- 1.17 Tg carbon. However, rubber plantations also store carbon (more than for example shifting cultivation) (Li *et al*., 2008).

In Part 3, the ecological issues and the associated changes in ESS will be addressed.

1.7 Actions taken

Different measures are already taken to improve the situation in Xishuangbanna. The Man and the Biosphere (MAB) programme of UNESCO aims to improve the relationship between people and the environment. In this programme, research is performed and attention is paid to ecological, social and economic consequences of biodiversity loss. This knowledge should provide the basis for measures to reduce biodiversity loss. (www.unesco.org). The MAB programme is thus closely related to the ESS concept (see chapter 3). Xishuangbanna is part of the MAB programme since 1993. Pilot villages are selected to implement sustainable development models. In this way settlement of conflicts, promotion of economic development in the region, and wise use of the available resources is promoted (www.unesco.org).

The SLCP aims at reducing erosion and is therefore also a measure addressing the problems related to rubber plantations in Xishuangbanna. In 2005 the Biodiversity Conservation Corridor Initiative (BCI) was implemented in Xishuangbanna (Xi, 2009). The scope of this initiative is to counteract fragmentation by establishing corridors. An (semi-)natural ecological network is to be created to conserve biodiversity. By 2015, the countries of the Greater Mekong Subregion (GMS) (Laos, Cambodia, Vietnam, Myanmar, Thailand and Yunnan province) should have established corridors for the maintenance of ecosystems (Xi, 2009). In Xishuangbanna, 3 pilot corridors were established, of which one is neighbouring Naban River Nature Reserve.

2. Change modeling

Chapter 2.1: Materials and methods

2.1.1 LU/LC map of 2011

2.1.1.1 Objectives

To be able to model the change in LU/LC, a LU/LC map of the vegetation in Naban River nature reserve was created to quantify the current land cover. Because some classes in this map are not strictly representing a land cover but also carry a land use function, the map will be labeled a LU/LC map. The most recently available satellite images, ALOS images of 2011, were used to perform this classification. The satellite images were classified in IDRISI Selva (Eastman, 2012a). First, an unsupervised classification was performed in order to assess if there are clusters which are easily distinguishable as a particular LU/LC class. These could then be used in a supervised classification procedure. Next, training sites were delineated using field data. Special attention was given to the accuracy of the map and to the resolution requirements. The satellite images were resampled to the resolution of a panchromatic image (2.5 m). The resulting map will later be used in combination with the existing LU/LC maps of 1975, 1988, 1995, 2003 en 2004, in order to assess the land changes which occurred over time in the nature reserve. Therefore, it is important the LU/LC map has a resolution that matches the previous maps.

2.1.1.2 Available data

The image classification was performed using the multi-spectral Advanced Land Observing Satellite (ALOS 2) satellite image of 2011. This image is available from the Pegasus data search system of ALOS (pegasus.alos-pasco.com). It consists of 4 spectral bands (blue, green, red and near infra-red (NIR)) with a spatial resolution of 10 m. The wavelengths of the radiance measured in the different bands are given in Table 2.1.1. A panchromatic image with a spatial resolution of 2.5 m was also obtained from Pegasus.

Table 2.1.1: Bands of the ALOS 2 AVNIR sensor.

Band	Wavelength (microns)	Corresponding waveband
1	0.42-0.50	Blue visible light
2	0.52-0.60	Green visible light
3	0.61-0.69	Red visible light
4	0.76-0.89	Near infra-red

Next to these images, ancillary data were available from the China State Bureau of Surveying and Mapping (www.sbsm.gov.cn), namely the DEM of the area with a spatial resolution of 25 m. In order to solve the resolution problem and have equal resolutions for all used images, both the ALOS images and the DEM were resampled to a resolution of 2.5 m with the help of the panchromatic image. For the classification, 6 bands are thus used.

2.1.1.3 Unsupervised classification

Unsupervised classification was executed in different ways. In broad unsupervised classification, a peak must contain a frequency higher than all of its non-diagonal neighbours. Using this method, peaks next to a higher peak are missed because there is no dip between the peaks. In fine unsupervised classification one of the non-diagonal neighbours can have a higher frequency, which enables peaks localized next to higher peaks to be detected (Eastman, 2012b). This last method leads logically to more clusters. It is possible to drop the least significant clusters or to set a maximum amount of clusters. In some cases, it is possible to detect clearly delineated clusters in the result, which can be used in the supervised classification.

2.1.1.4 Training sites

To perform the supervised classification, extra information was needed. Field work was performed to collect reference data. A list of the used GPS-coordinates is included in attachment 1. These coordinates originate from three different sources. Interesting sites, areas where a change in the satellite images compared to the images of 2004 is visible, or where special structures are present, were delineated. It is made sure that sites where physical properties changed, for example a river with a different course or a new agricultural area, were visited. In these sites, GPS coordinates were recorded, and pictures of the surrounding vegetation were taken. Because of limited field information, also reference data from 2004 were used next to the newly collected coordinates in 2012. This was only possible in the sites where no change is observed. The used training sites from 2004 were thoroughly examined, visually as well as spectrally, and if no change was found, the training site could be used for the image classification of 2011. Thirdly, plots of forest sampled earlier by the forest rangers of the Forestry Bureau of Jinghong City, Xishuangbanna Prefecture, were used. Based on the GPS-coordinates in attachment 1, training sites could be delineated for the supervised classification.

In order to perform the change analysis accurately, the LU/LC map of 2011 must (as much as possible) be generated according to the same methodological framework as the maps of the previous years. This means that the same LU/LC groups were used and the same classification method was applied. 15 subclasses were used to delineate the training sites (Table 2.1.2). These subclasses will later (post-classification) be merged into LU/LC classes, but need to be considered separately during classification, because they differ in spectral response. The classes of rubber and evergreen forest in the sun or in the shadow show a different spectral response because the area is mountainous. Therefore, different classes were used to classify the images. The class of 'bamboo' was considered because near water, forests consisting of only bamboo (*Dendrocalamus* *membranaceus*) (secondary vegetation) were observed. These bamboo forests show a spectral pattern which is different from the mixed deciduous forests but the classes were merged later. 'Young rubber' (3 to 4 years) was classified separately because the spectral response pattern is different from older rubber and because of the importance of this class for this research. Because often grasses or weeds are growing between the young rubber trees (Figure 2.1.1), the risk exists that the spectral response pattern of this class is confounded with the class 'low shrubs and grassland'. The biggest difference between these classes is the elevation in which they occur, as is also clear from the signature comparison chart (Figure 2.2.4). This problem is thus reduced by using the DEM for the classification.

Table 2.1.2: Subclasses considered for supervised classification

Value	Class
1	Water
2	Rubber trees (sunlit)
3	Rubber trees (shadow)
4	Bamboo forest
5	Burnt land
6	Evergreen forest (sunlit)
7	Evergreen forest (shadow)
8	Urban land
9	Banana plantation
10	Grassland and low shrubs
11	Agricultural land
12	Low density forest and tall shrubs
13	Deciduous forest
14	Clouds and shadow
15	Young rubber trees

Figure 2.1.1: Young rubber

2.1.1.5 Supervised classification

A multilayer neural network (MLP) was used to perform the classification. This classifier was selected as it had been used to generate the previous LU/LC maps. Moreover, MLP's are often more efficient and require less training data than other parametric classifiers (Eastman, 2012c). A classifier usually also performing well is the maximum likelihood classifier, but in this case description of the data distribution (Gaussian) is a prerequisite.

The training sites were randomly divided in 3 equal parts: 2 parts serve as the input for the multi-layer perceptron (MLP) analysis, and 1 part is used for the independent post-classification validation. It was ensured that for each LU/LC class the amount of pixels used in the MLP was more than 10 times the amount of input bands (6) (Eastman, 2012c).

The MLP is an iterative method that searches for a minimum on an error surface (a minimum value in the RMS, root mean squared error). A three-layer structure was used, with in the input layer 6 nodes (the number of input bands), in the output layer 15 nodes (the number of subclasses) and in the hidden layer there were 10 nodes. The amount of hidden nodes is the result of trial and error. In models with one hidden layer, the amount of nodes in this layer is often empirically chosen as (with n the amount of nodes in the input layer, here 6): 2n+1, 2n, n or n/2 (Zhang *et al.*, 1998). Models with an amount of nodes in the hidden layer ranging between these values were tested, and the model with 10 hidden nodes performed slightly better than the other models. The sigmoid constant was kept at 1, but for the momentum and learning rate factor different values were tested to find the best fitting parameters. By trial and error it was found that the best results were reached for a momentum factor of 0.02 and a dynamic learning rate starting at 0.005 and decreasing to 0.001 through the iterations.

The spectral response patterns of the LU/LC classes in the different bands were compared, resulting in a signature comparison chart. While the 15 classes were chosen in function of difference in spectral response pattern, the reclassified classes are the result of merging the subclasses which are similar in land cover or land use. This was done after the classification step. The subclass ‘urban land’ is included in the class of agricultural land because this was done likewise in the map of 2004, and because urban land and agricultural land tend to overlap considerably as to spectral characteristics. A value of zero was assigned to pixels where clouds or shadow made the spectral data unsuitable for classification. In Table 2.1.3, the final classes are presented.

Table 2.1.3: Classes in LU/LC map

Value	New class	Old classes included
0	No data	Clouds and shadow
1	Rubber trees	Rubber trees (sunlit), rubber trees (shadow), young rubber trees
2	Evergreen forest	Evergreen forest (sunlit), evergreen forest (shadow)
3	Low density forest	Low density forest and tall shrubs
4	Deciduous forest	Deciduous forest, bamboo
5	Water	Water
6	Agricultural land	Agricultural land, banana trees, urban land
7	Shrubs and grassland	Grassland and low shrubs
8	Burnt land	Burnt land

2.1.2 Change analysis

2.1.2.1 Objectives

The change in LU/LC was quantified using two methods. First, the change in NDVI was assessed through time series analysis. Second, the created LU/LC map of 2011 was compared with the previous LU/LC maps in the Land Change Modeler (LCM) of IDRISI. The NDVI is calculated before the images are classified and thus possible classification errors will not influence the result. The change analysis on the other hand, is performed after classification. The changes between different LU/LC classes are here evaluated. Through this set of tools, it is possible to rapidly assess the changes in amount of pixels in each class as well as the spatial properties of these changes (Eastman, 2012c). Special attention was paid to the link with the elevation, because elevation is an important factor for the occurrence of rubber plantations. By visual inspection it was observed that changes in the class of rubber trees were closely linked to elevation. In addition the link with forest ownership was examined, because the tenure factor could be an important driver for changes (see chapter 2.1.3). Maps of these changes were created to facilitate the interpretation of the results. To assess the consequences of these changes, fragmentation was measured. Apart from losses in size of forest, fragmentation is also important because it can entail a loss in quality of forest and a subsequent loss in ESS (see part 3). Landscape indices (pattern metrics, PM), which can quantify fragmentation, were calculated through FRAGSTATS (McGarigal *et al.*, 2012). Special attention was given to the class of evergreen forest, because for this LU/LC class, fragmentation entails the most severe consequences.

2.1.2.2 Time series data set

Satellite images of 6 different years are available (Table 2.1.4). Since these images originate from different satellites, they have different properties. The earliest images (1975) are Landsat Multispectral Scanner (MSS) images. They have a resolution of 68m*83m resampled to 57m. The spectral properties of the MSS bands are listed in Table 2.1.5. The next images, from 1988, 1995 and 2004, are Landsat Thematic Mapper (TM) and consist of 7 bands. Band 6 (thermal infra-red) has a resolution of 120m, while the other bands have a resolution of 30m (Table 2.1.6). In Table 2.1.7, the properties of the 8 bands of Landsat Enhanced Thematic Mapper+ (ETM+) are shown. The image used for 2003 is an ETM+ image. It has a resolution of 15 m for band 8, 120 m for band 6, and again 30 m for the other bands. The image of 2011, used to create the LU/LC map of 2011, is an ALOS image with a resolution of 10 m. The properties are listed in section 2.1.1.2. The DEM (with a resolution of 25 m) and forest ownership map (with a resolution of 2.5 m) were also used. In Naban, three types of ownership rights are in use: national forest (owned by the Chinese government) community forest (owned by a village or a few villages) and household forest (owned by an individual household or a few households) (Figure 2.1.2).

Table 2.1.4: Image data

Date	Sensor
1975-04-25	MSS
1988-02-02	TM
1995-03-09	TM
2003-03-07	ETM+
2004-03-01	TM
2011-02-11	ALOS

Table 2.1.5: MSS bands

Band	Wavelength (µm)	Corresponding wave
1	0.50-0.60	Green visible light
2	0.60-0.70	Red visible light
3	0.70-0.80	Near infra-red
4	0.80-1.10	Near infra-red

Table 2.1.6: Landsat TM bands

Band	Wavelength (µm)	Corresponding wave
1	0.45-0.52	Blue visible light
2	0.52-0.60	Green visible light
3	0.63-0.69	Red visible light
4	0.76-0.90	Near infra-red
5	1.55-1.75	Mid infra-red
6	10.4-12.5	Thermal infra-red
7	2.08-2.35	Mid infra-red

Table 2.1.7: Landsat ETM+ bands

Band	Wavelength (µm)	Corresponding wave
1	0.45-0.515	Blue visible light
2	0.525-0.605	Green visible light
3	0.63-0.69	Red visible light
4	0.75-0.90	Near infra-red
5	1.55-1.75	Mid infra-red
6	10.4-12.5	Thermal infra-red
7	2.09-2.35	Mid infra-red
8	0.52-0.9	Panchromatic

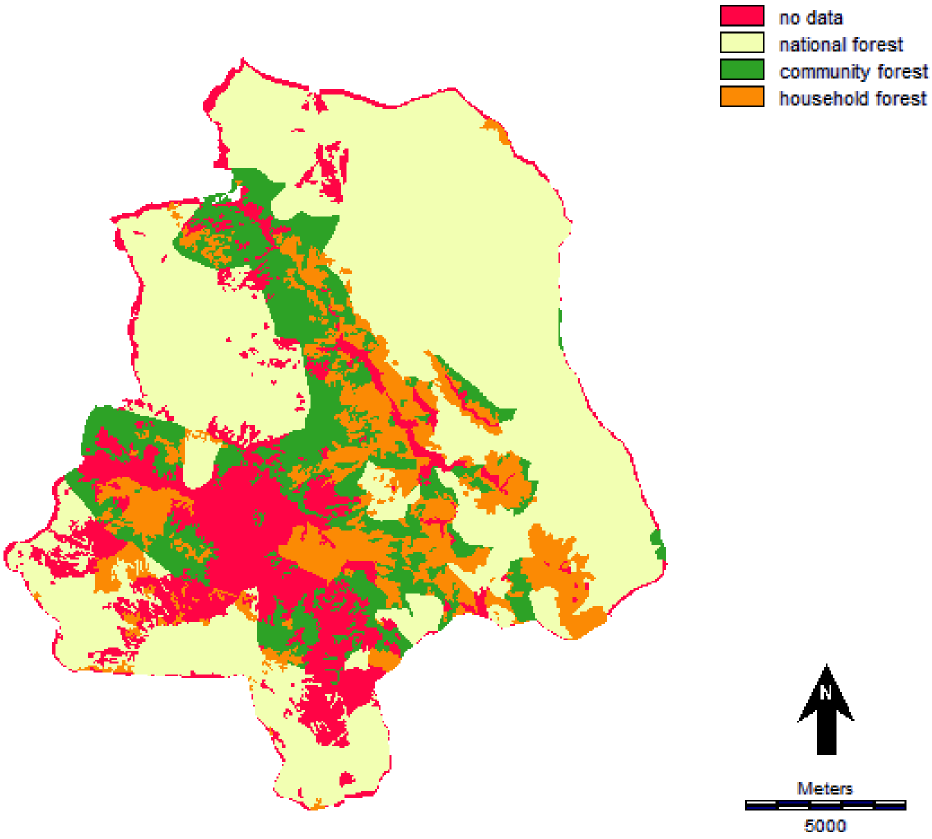

Figure 2.1.2: Forest ownership map of 2008 (Source: Forestry Bureau Jinghong City, Xishuangbanna Prefecture)

2.1.2.3 Change analysis of NDVI

The normalized difference vegetation index (NDVI) was calculated by means of the red and NIR bands. The NDVI is calculated as follows (formula 2.1.1):

$$NDVI = \frac{NIR - VIS}{NIR + VIS} \qquad \text{(formula 2.1.1)}$$

With

NIR the radiance value of the near-infrared band

VIS the radiance value in the red band

It is a number between -1 and 1, in which a higher value refers to denser vegetation. The NDVI value can be compared over the different years, but attention must be paid because the bands used are not completely the same in the different multispectral images. Especially in the red band, small changes in the wavelength measured can cause big changes. Despite of this shortage, the NDVI is considered as a suitable good variable to describe LU/LC changes. Brown *et al*. (2006), comparing NDVI calculations through different satellite images, showed that the calculated NDVI anomalies have similar variances. Moreover, composited NDVI images seemed to be quite robust. The changes in mean NDVI of the total study area were examined. The changes in mean NDVI value of all pixels classified as rubber in a particular year were compared to these in the whole study area.

To examine the spatial component of the change in NDVI, the Kendall slope over the whole period was calculated and mapped. The Kendall slope is calculated for each pixel separately, and the calculation is based on the Theil-Sen estimator. This estimator calculates the slope of each pair of observations (two points in time) and the final slope is the median of all the pair-wise slopes. A positive slope means an increase in NDVI, while a negative slope stands for an increase. This measure is insensitive to outliers.

2.1.2.4 Change analysis of LU/LC maps

The LU/LC maps were resampled using the panchromatic image, in order to obtain an equal resolution of 2.5 m in all maps. Subsequently, the time series was examined in the LCM of IDRISI. Proportions in the different LU/LC classes through the periods were calculated. From the NDVI-analysis, different periods were distinguished. Following periods were used (in accordance with the periods used by Zhang (2011)):

1975-1988
1988-1995
1995-2004
2004-2011

In these periods, the changes in LU/LC were mapped, ignoring changes of less than 268 hectares (this is 1% of the total study area, arbitrarily chosen). Special attention was given to the class of rubber trees and the contributors to the change in this class were listed. Gains and losses in each category were examined and the spatial trend of the third order of the change from EF to RT was mapped in view of the objectives of this research. For calculating the spatial trend, the areas are treated as if they are quantitative, and get a value between 0 (no change) and 1 (change). The spatial trend is then the polynomial trend surface that fits best to the pattern of change.

The proportions of rubber trees in different elevation classes (<800 m, 800-1000m, 1000-1200 m, >1200 m) and the trend in these proportions over the years was assessed. Li *et al*., 2009 observed that the expansion of rubber shifts to higher elevations. According to Priyadarshan *et al.* (2003), an elevation exceeding 700 m can cause extreme conditions for rubber trees. The Bureau of State Farm Management decided in the mid 1970's to restrict state rubber farms to an elevation below 1000 m (Chapman, 1991).

The class 'young rubber' in 2011 and the class 'rubber' in 2011 were compared in terms of elevation and forest ownership. The system of household forest only exists since the mid 1980's, when community forest could be allocated to households (Xu *et al.,* 2010). Also state farms have been broken down and given to individual workers (Xu, 2006). According to Xu *et al.* (2010), the rights to access and use the forest (this includes conversion to another type) become stronger when the forest is more individually owned. In 1998 and 1999, respectively the National forest protection (NFPP) plan and the logging ban were amended. This logging ban was at first focused on nationally owned forests, but by 2003 also covered almost 27 million hectares of community and household forest (Xu *et al.,* 2010).

2.1.2.5 Landscape metrics

Next to deforestation, also fragmentation of forest is important to assess. Forest fragmentation is by the Society of American Foresters defined as "the process of dividing large tracts of contiguous forest into smaller isolated tracts surrounded by human modified environments" (clear.uconn.edu).

Fragmentation is a worldwide problem, causing biodiversity losses and decreases of primary production in tropical rainforests (Li *et al.,* 2009). Habitat properties can be altered in such a way the organisms once living in their ideal environment, are forced to live in their marginal area in extreme conditions. This can have an effect on their reproduction and can induce species loss (Li *et al*., 2009). Moreover, the edges become more important, and the edge effects can increase in such a way the ESS provided by the forest are lost. The decline in patch area is a particular problem for large mammals, like the Asian elephant in Xishuangbanna.

Isolation of forest patches is a risk when the connections between different patches disappear. Forest fragmentation is expressed in an increase in edge length and a subsequent reduction in interior habitat, and an increase in isolation of patches (Li *et al.*, 2009).

To assess the fragmentation in Naban river nature reserve, a selection of PM were calculated through FRAGSTATS. De Clercq *et al*. (2006) described the use of PM in 2 regions of Flanders, Belgium. Following conditions were proposed:

- no correlation with other PM in the study
- be capable to capture changes in landscape pattern over space and time
- be insensitive towards the spatial resolution of remote sensing data
- be insensitive towards the number of classes used in the study

In this research, the resolution of the LU/LC maps used differs greatly, namely the resolution of the map of 1975 is 58 m, the next 4 years have a resolution of 30 m and the map of 2011 has a resolution of 10 m. It is important to take into account the fact that the spatial resolution increases. Therefore, indices should be used which are independent from the resolution of the categorical map. The sensitivity of different PM to the spatial resolution is calculated through the ζ -value. This value is calculated as in formula 2.1.2 (De Clercq *et al.*, 2006). Indices with small ζ-values and thus small sensitivity should be selected.

$$\zeta = \frac{max\ (x_5, x_{10}, x_{20}, x_{30}) - min\ (x_5, x_{10}, x_{20}, x_{30})}{max\ (x_5, x_{10}, x_{20}, x_{30})} \qquad \text{(formula 2.1.2)}$$

with

x_i the value of the PM of the map which was degraded to a resolution i

The largest patch index (LPI) was calculated because it provides useful information about fragmentation of forest. LPI was calculated through formula 2.1.3 (McGarigal *et al.*, 2012).

$$LPI = \frac{\max\ (a_{ij})}{A} * 100 \qquad \text{(formula 2.1.3)}$$

with

a_{ij} the area of a patch (m²)

A the total area of the landscape (m²)

A number between 0 and 100 is obtained, in which 100 means that the landscape consists of only one patch.

Mean patch size (MPS), total edge (TE) and landscape shape index (LSI) were calculated because these indices can help to assess forest fragmentation. They have an intermediate ζ -value, but it was noticed that the effect of resolution in this research was too large. The fact the value of these indices differs significantly between 1975 and 1988 and between 2004 and 2011, and much less in the other periods (where the resolution stays the same), is an indication they are not appropriate for use. In the case of the MPS (mean area of one patch within the study area or within on LU/LC class), the comparison of the MPS of the total area and the MPS within the evergreen forest class was made to eliminate the resolution effects.

The core area is important for forest fragmentation and habitat loss, especially for large mammals such as elephants.

According to De Clercq *et al.* (2006), the total core area (TCA) (formula 2.1.4) has an average ζ-value.

$$TCA = \sum_{j=1}^{n} a_{ij}^2 * (\frac{1}{10000}) \qquad \text{(formula 2.1.4)}$$

With

a_{ij} the area of a patch (m²)

The formula is based on a fixed specific edge depth. This is a buffer width which is supposed to feature edge effects influencing organisms living there. The radius of influence differs for each organism, but no specific information is available for this research. Because Xishuangbanna is an important habitat for the Asian elephant as well as the Indian fox, it can be assumed the edge depth can be taken rather large. Therefore, the edge depth is here arbitrarily chosen to be 100 m. Li *et al.* (2009) also argue that the most important edge effects occur within 100 m of the forest edge. TCA becomes 0 when no core area is found and increases with more core area. For this research, it is useful to divide the TCA by the total area of respectively the study area and evergreen forest. This was done because the area of forest differs over time and in this way, the percentage of core area is calculated.

The other metrics that were calculated pertain to the texture of the study area. They describe how “aggregated” the landscape is. The aggregation is important in many ecological processes and a quality feature of habitat for many species (Dunning *et al.,* 1992). Contagion (CONTAG) and connection (CONNECT) were calculated because they are a good first measure for the aggregation. CONTAG varies from 0 to 1 where 0 means that the area is maximally disaggregated (every pixel is a different class) and maximally interspersed (adjacencies between different classes are highly unequal). However, it was observed that CONTAG is much influenced by resolution, because the biggest changes in value were noticed between 1975 and 1988 and between 2004 and 2011, the periods in which the resolution of the maps changes. CONNECT is calculated using formula 2.1.5.

$$CONNECT = 100 * \frac{\sum_{i=1}^{m}\sum_{j=k}^{n} c_{ijk}}{\sum_{i=1}^{m}(n_i * \frac{n_i - 1}{2})} \quad \text{(formula 2.1.5)}$$

Where

c_{ijk} is 0 when patches i and j are unjoined and 1 when they are joined

n_i is the number of patches in the LU/LC class.

The threshold distance is again arbitrarily chosen as 100 m. CONNECT ranges from 0 to 100 and increases when the landscape is more “connected”.

In terms of diversity, the interspersion and juxtaposition index (IJI) and the Shannon’s evenness index were used. IJI is calculated as follows (formula 2.1.6):

$$IJI = -100 * \frac{\sum_{i}^{m'}\sum_{k}^{m'}\left(\left(\frac{e_{ik}}{E}\right) - \ln\left(\frac{e_{ik}}{E}\right)\right)}{\ln(0.5*(m'(m'-1)))} \quad \text{(formula 2.1.6)}$$

With

e_{ik} the total length (m) of edge between patch types i and k

E the total length of edges (m)

m’ the number of LU/LC classes

IJI ranges from 0 to 100, with 100 meaning that all patches are equally adjacent to all other patch types. To assess dominance of LU/LC classes, the Shannon’s evenness index (SHEI) is calculated through the Shannon’s diversity index (SHDI) (formula 2.1.7 and 2.1.8). SHEI ranges from 0 to 1, where 1 means that the area is distributed evenly over the LU/LC classes. Approaching 0, it indicates dominance of certain LU/LC classes.

$$SHDI = -\sum_{i}^{m'} P_i * \ln P_i \quad \text{(formula 2.1.7)}$$

$$SHEI = \frac{SHDI}{\ln m'} \quad \text{(formula 2.1.8)}$$

With

P_i the proportion of the landscape of LU/LC class i

m’ the number of LU/LC classes

2.1.3 Change prediction

2.1.3.1 Objectives

Based on the changes observed in a past period, a prediction can be formulated for the following period. First, the possible driving forces were listed and examined for their relevance in the prediction model. From these driving forces, the drivers which are useful for the change prediction (driving variables) were selected.

Next, two kinds of predictions were made, based on two different procedures. A prediction without as well as with the implementation of driving variables was made. With the help of the latter, it was possible to incorporate the different processes of change. Transition potentials (the spatial properties of the driving variables) were therefore composed. Then it was possible to make a prediction of the future LU/LC, taking into account the driving forces behind the changes. Both procedures were used to predict the LU/LC in 2016 and 2018. Because only 7 years were between the vegetation maps on which the prediction is based (2004 and 2011), it was decided not to predict the LU/LC for later years because the extrapolation could be imprecise.

2.1.3.2 Driving forces

The main drivers can be divided in bio-physical and socio-economic factors. The bio-physical drivers examined are climate (temperature and rainfall), altitude and water availability. The actual situation in Xishuangbanna was described, together with the changes in these factors observed. The important socio-economic drivers are the forest ownership rights, the population growth, and the rubber price together with the farmer's income.

2.1.3.2.1 Climate

The ideal climate for *Hevea brasiliensis* trees has been described by Priyadarshan *et al.* (2003):

a) 2000–4000 mm rain fall distributed over 100–150 rainy days/ annum
b) mean annual temperature around 28 °C with a diurnal variation of about 7 °C
c) sunshine hours of about 2000 h/ year at the rate of 6 h per day in all months.

These conditions correspond to tropical moist forest regions. Since Xishuangbanna is situated at the margin of a tropical moist region, it is not a very suitable area for rubber growth. The climate in Jinghong features monthly temperatures between 16 and 26 degrees Celsius and a total rainfall of 1194 mm, divided over the year as shown in Figure 2.1.3 and Figure 2.1.4 (Chapman, 1991). According to Zhang and Cao (1995), Xishuangbanna is cooler and has lower rainfall than other typical rainforest zones. The region is actually too northern to be tropical, but the climate exists thanks to the geomorphological barrier of the Himalayas, blocking the northwestern wind coming from the steppe.

Figure 2.1.3: Mean monthly rainfall in Jinghong (in mm) (Chapman, 1991)

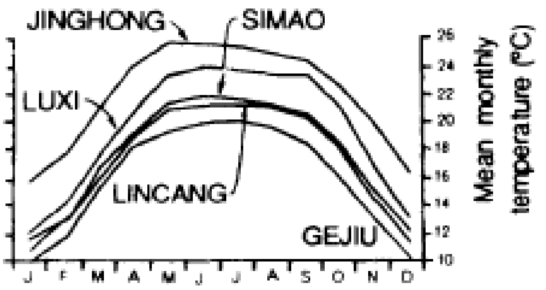

Figure 2.1.4: Mean monthly temperature in a few locations in Xishuangbanna (in °C) (Chapman, 1991)

It is clear that the temperature is lower than the best suited temperature for *Hevea brasiliensis* trees. However, it is mostly the extremes instead of the mean temperatures that cause damage to the trees (Chapman, 1991). Cold temperatures have caused considerable damage to the latex vessels of the trees and death of trees in Xishuangbanna. The region is however shielded from cold northwestern winds by the Himalayan mountains, which alters the climate.

Fan *et al.* (2011) have researched the trends in temperature on the Yunnan plateau from 1961 till 2004. They found a statistically significant average increase of 0.3 °C of the annual temperature during the period 1961–2004. They furthermore state that the regions which have known a significant deforestation (such as Xishuangbanna), carbon emissions have accelerated climate change. According to Gong and Ling (1996), as cited in Li *et al*. (2007), the number of foggy days in Xishuangbanna has decreased from 166 per year in the 1950s to less than 60 in the 1990s. This change has been attributed to the difference in water relations between rubber plantations and natural forest (Huang *et al.* 2000; Liu *et al*. 2003, cited in Li *et al*., 2007).

2.1.3.2.2 Altitude

Maybe even more than climate, the altitude is a limiting factor. Priyadarshan *et al.* (2003) indicate an elevation level of 200 meters above sea level as the boundary. Naban River Nature reserve lies entirely above this elevation level. From Figure 2.1.5, the effect of elevation on temperature is clear.

Nguyen (2013) performed a study in Vietnam, which is a region comparable to Xishuangbanna. He found that with increasing elevation, latex productivity, tapping density and yield per tree decreased in an S-shaped way.

Rubber plantations were historically established as low as possible, but are shifting to higher elevations in time, as the lower areas are already in use. Recently, rubber plantations are observed as high as 1600 m a.s.l.. The Bureau of State Farm Management restricted rubber planting of state farms to an elevation below 900-1000 m above sea level in the mid 1970's (Chapman, 1991). However, with the increasing amount of small-holder farms, the amount of rubber trees above this altitude is again increasing.

Hybrids of *Hevea brasiliensis* are searched for, which are suitable for cultivating in higher areas. The risks of cultivating rubber in extreme elevations (above 700 m), where periodic cold temperatures can generate an unstable income generation and subsequently farmer vulnerability has to be stressed (Feng, 1982, as cited in Xu *et al.,* 2005).

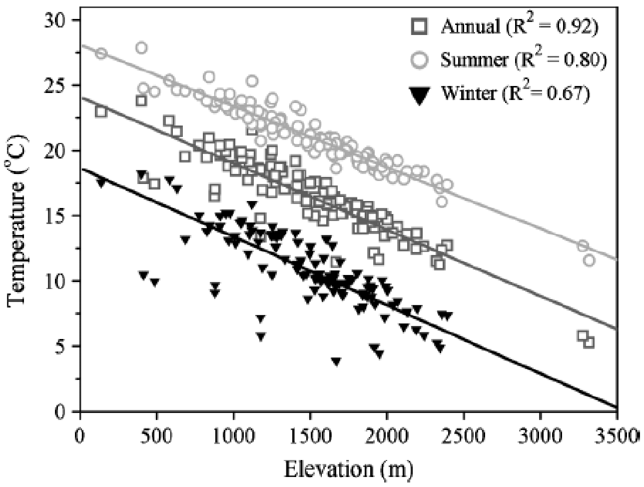

Figure 2.1.5: The relationship between elevation and temperature in Yunnan Province (Fan *et al*., 2011)

2.1.3.2.3 Water

The availability of water can be linked to the elevation and to the climate (rainfall). Yet water availability can also be anthropogenically altered. The establishment of the Jinghong dam in 2004 is such an example. Also the rubber trees themselves are changing the hydrological conditions in the region. The decrease of foggy days (Huang *et al.* 2000; Liu *et al.* 2003, cited in Li *et al.,* 2007) has been attributed to the difference in water relations between rainforest and rubber trees.

2.1.3.2.4 Forest ownership rights

The forest ownership rights determine who can decide what will happen to a certain piece of forest land. It will thus also determine where and how many changes will take place. In Xishuangbanna, three types of ownership are found: household, community and national forest.

2.1.3.2.5 Population density

In 1935, around 188 000 people were living in Xishuangbanna, of whom 73% was from the Dai minority (Chapman, 1991). In 1949, only 0.3 % of the people were reported as being Han Chinese (Xu, 2006). However, from the 1950's on, large amounts of Han Chinese people migrated to Xishuangbanna to work in the state rubber farms. This, in combination with the cultural revolution, which was started by Mao Zedong in 1966 and caused a lot of people to migrate from the cities to the countryside, caused the proportion of Han Chinese in Xishuangbanna to grow to 28.8 % of the total population in 1982 (Xu, 2006). By 1988, the total population had increased to 700 000, from which one third was Han Chinese, one third Dai and one third belonged to one of the other 12 minorities present in Xishuangbanna (Chapman, 1991). Jiang *et al.* (2011) reported a total population of 1 070 000 in 2008.

In Jiang *et al.* (2011), population density was indicated as the most important driving force for change of area in plantations. A growing population, in addition to an increasing demand for economic development and better living, causes a higher demand for food and thus crop land. However, people also take advantage of water and energy resources and establish highly economic plantations (rubber and tea) (Jiang *et al.,* 2011). On the other side, population density also causes forested land to decrease because of the need for economically more profitable land. As a result hereof, population density can also be seen as a driving force in change in forest area, and even in area of shrubs and grassland, because the degraded forest land results in a higher amount of shrub land (Jiang *et al.,* 2011).

2.1.3.2.6 Price of rubber

The varying price of rubber (Figure 2.3.1) also has an important share in the timing of expansion of rubber plantations. The moment prices go up, more trees are planted and plantations shift to less suitable areas (higher elevations, less water, further from urban land), even though it takes 7 years for the rubber trees to produce rubber. According to Xu *et al. (*2005), a farmer's income in the year 2000 was highly correlated with the amount of land on which he planted rubber. From a study (Fu *et al.*, 2009) in Daka, a village in Xishuangbanna, price fluctuations cause quick shifts in crops cultivated. Moreover, they noticed that when rubber prices increased, there was a decrease in the number of varieties of rice that were cultivated in the village. This implicates that, together with the increasing income from rubber cultivation also increasing risks are taken, related with the decrease in varieties. Moreover, farmers are prepared to take extra risks when the prices of rubber are high compared to other crops, for example by planting rubber in higher elevations. This can be a liability for farmers if the rubber price decreases. In Daka, some farmers are taking precautions by intercropping tea with rubber (Fu *et al.*, 2009).

2.1.3.3 Spatial analysis of change without driving variables

Through a Markov chain analysis, a prediction of the future LU/LC was made. As a result of this analysis, a transition probability matrix, containing the probability that each land cover category will change to every other category, is obtained. These transition probabilities are based on the assumption that the amount of pixels undergoing a certain change in a certain period will be the same as the amount of pixels undergoing that change in an equal amount of time. The transitions will however reach an equilibrium state, causing the transition potentials to change over time. Therefore, the Markov chain analysis is not a really linear extrapolation (Manandhar *et al*., 2009). The transition probabilities are converted to the areas that will undergo these transitions, given the year of prediction. A prediction was made for 2016, using 5 cellular automata. This means that one time step equals one year. Also for 2018 a prediction was made with one time step a year. The analysis is based on the difference in LU/LC between the year 2004 and 2011. A mode filter was used to reduce the 'salt-and-pepper effect' created by the prediction.

2.1.3.4 Spatial analysis of change with driving variables

2.1.3.4.1 Driving variables

From the factors described in section 2.1.3.2, the ones which were considered interesting for the analysis were selected. The driving variables which can be included are the ones which vary over the study area or over time. Variables that feature a lack of information (climate change, change in population density) cannot be included.

Of the bio-physical factors, only the altitude (the DEM) can be included in the change prediction. The climate can (apart from differences related to the elevation) be considered the same throughout the small area of the nature reserve, and thus will not influence the spatial configuration of rubber plantations. Moreover, it is (more or less) constant in time. The availability of water changed drastically between 2004 and 2011, but it is quite constant in time since (according to the LU/LC maps) and is therefore not likely to influence the evolution of future rubber plantations in the future.

The forest ownership rights are also included in the model because the conversion of forest to plantations becomes easier when the land is individually owned (Xu *et al*. 2010). The evidence likelihood of this driving variable is calculated and incorporated. This procedure calculates the relative frequency of pixels belonging to the different categories (Eastman, 2012c). The pixels in a certain category then get as a new value this relative frequency, representing the likelihood that a changing pixel would change to this category. The other socio-economic factors (population density, rubber prices) are also uniform throughout the study area. They only determine when changes will take place, but are not spatial.

Next to these drivers, also other factors determining the places where most change will occur are included in the analysis. The distance from villages and roads is important in the case of smallholder rubber farms. The plantations have to be visited twice a day by the farmer. Also for other anthropogenic LU/LC changes, distance from urban land is an important factor. Li *et al.* (2009) found that roads induce landscape modification in Xishuangbanna and that forest fragmentation was most severe in the area around roads in the past decades. The distance from roads and villages was taken as the distance from the LU/LC class of urban land.

The importance of distance from rubber processing factories was also determined. However, throughout Xishuangbanna, many rubber processing factories exist. These factories arrange to pick up the rubber every day, so the distance to these factories does not really matter to the farmers and can therefore not be considered as an important driving force.

Changes in the period from 2004 to 2011 are also included in the model. Changes during this period, that have the same driving variables (they belong to the same submodel), were grouped. The Euclidian distance to these changes were calculated and a map was produced. The maps with the distance functions were added to the respective models. For changes to rubber, also the distance to the class of 'young rubber' in 2011 was calculated, because these new rubber trees often indicate where rubber plantations will expand.

2.1.3.4.2 Submodels

The changes from 2004 till 2011 which were larger than 268 hectares (arbitrarily chosen) were divided in 5 submodels according to their nature. Within these submodels, the transitions are steered by the same driving variables. An overview of the different submodels and the transitions included is given in Table 2.1.8.

Table 2.1.8: Submodels used for the transition potentials, and transitions included

Submodel	**Transitions included**
Forest to rubber	Evergreen forest to rubber trees
Deforestation	Evergreen forest to low density forest Evergreen forest to deciduous forest
Reforestation	Rubber trees to evergreen forest Burnt land to evergreen forest Agricultural land to evergreen forest Low density forest to evergreen forest Rubber trees to deciduous forest
Plantations	Low density forest to rubber trees Deciduous forest to rubber trees Agricultural land to rubber trees
Shifting cultivation	Agricultural land to low density forest Burnt land to low density forest Shrubs and grassland to low density forest Agricultural land to shrubs and grassland

The submodel of *shifting cultivation* could not be included in the analysis because it has a relatively fixed cycle of 7 to 8 years. There are no real driving variables for the transitions in this submodel. Since this area (the western valley of the study area) has been under shifting cultivation since the recording of the LU/LC (1975) and was never used for something else, it can be assumed this will stay under shifting cultivation in the next period. Therefore, no transition potential map is created for these transitions.

For each subclass, the corresponding driving variables were selected. The explanatory power of the different variables was tested. With the help of the explanatory power, it was decided which driving variables were used for which subclasses.

The Cramer's V is calculated as follows:

$$Cramer's\ V = \sqrt{\frac{\chi^2}{N(k-1)}} \qquad \text{(formula 2.1.9)}$$

With

χ^2= Pearson's Chi-squared test statistic

N= number of observations

k= number of rows/columns

The general rule used to decide whether a factor is included in the model or not, is that if the Cramer's V value is higher than 0.15, the variable is useful to the model. A variable with a Cramer's V of 0.4 or higher is good (Eastman, 2012c).

For each of the submodels, a MLP procedure was used to model the transitions. Each of the submodels was subjected to a MLP separately. The modeling parameters of the submodels are listed in Table 2.1.9 and were found by trial and error. The MLP searches for a minimum value on an error surface (a minimum in the RMS). A dynamic learning rate was used for all the submodels, in order to let the model look for the best solution with a decreasing step. The automatic training mode reduces the start and end learning rate by half if significant oscillations are detected within the first 100 iterations of modeling (Eastman, 2012c). When the momentum factor is small, there is a smaller chance for oscillations (resulting from missing the minimum in the error surface). The number of nodes in the input layer is equal to the amount of driving variables used in the submodel. The number of output nodes is the number of transitions that is modeled by the submodel. The number of hidden layer nodes is empirically chosen in function of the number of input nodes (n). Zhang *et al*. (1998) argues that this parameter is often chosen as 2n+1, 2n, n or n/2. However, the optimal number of hidden nodes was found by trial and error. The sigmoid constant determines the gradient of the sigmoidal function in passing on the information from one layer to the next one. When it is smaller than 1, the sigmoid function is steeper. As such, 11 transition potential maps were obtained, one for each transition.

Table 2.1.9: Parameters used in the different submodels

	Kind of training	Start learning rate	End learning rate	Momentum factor	Number of hidden layer nodes	Sigmoid constant
Forest to rubber	Dynamic learning rate	0.001	0.0001	0.02	3	1
Deforestation	Automatic training	0.00005	0.00002	0.05	7	0.9
Reforestation	Dynamic learning rate	0.0005	0.00005	0.02	7	0.9
Plantations	Dynamic learning rate	0.001	0.0001	0.02	4	1

2.1.3.4.3 Change prediction

After the transition potential maps were obtained, a prediction based on these maps was made. The prediction is again based on the Markov chain procedure, but the difference with the conventional Markov procedure (section 2.1.3.3) is that the driving variables are included in the analysis. The processes' start however is the same as the conventional Markov method, where also the transition probabilities remain the same. Then, from all transitions, a list of host classes and a list of claimant classes for each host (classes that will lose land and classes that will claim land) is produced. Through multi-objective allocation, the land is then divided over the claimant classes of each host class (Eastman, 2012c). After overlaying the results for all host classes, a prediction map is obtained. A prediction was made for 2016 and 2018 to allow comparison it with the prediction without the use of driving variables.

Chapter 2.2: Results

2.2.1 LU/LC map of 2011

2.2.1.1 Unsupervised classification

The broad and fine unsupervised classification results are presented in Figure 2.2.1 and Figure 2.2.2. Broad unsupervised classification resulted in 7 clusters. In the broad classification, many of the clusters included pixels from different classes, rendering this procedure unsuitable for detecting LU/LC classes. Fine unsupervised classification, retaining all clusters, produced 33 clusters. Classifications with an intermediate amount of clusters (fine classification where the least significant clusters were dropped) were also performed but were found less usable because the clusters included different classes. In the fine classification retaining all clusters, both the class of water and the class of evergreen forest could be distinguished easily (resulting from a combination of different clusters). The result was less appropriate to distinguish rubber plantations from agricultural land. In certain clusters, pixels from different classes were included, making it impossible to assign the cluster to one LU/LC class. Since the distinction between rubber plantations and agricultural land is essential for the research, the unsupervised classification results were not used to assess the subsequent supervised classification procedure.

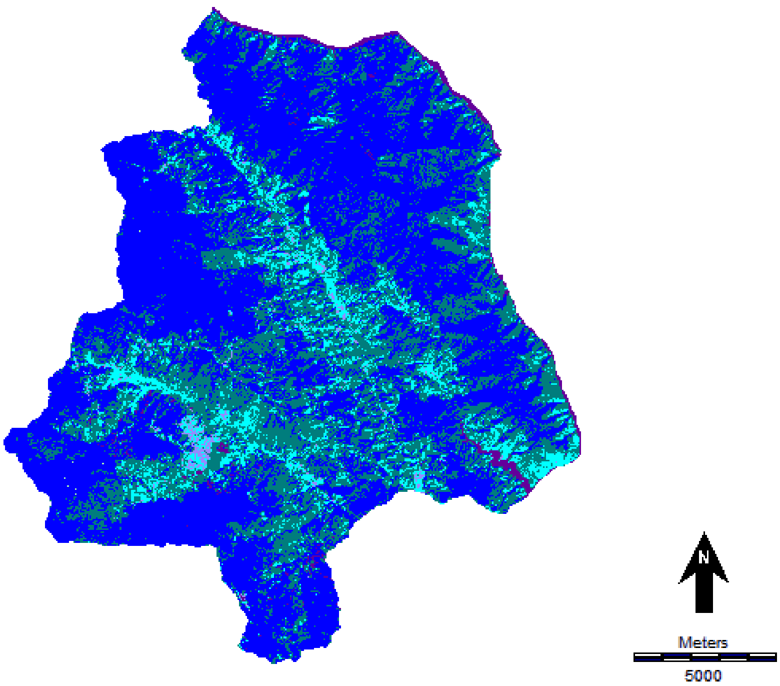

Figure 2.2.1: The 7 clusters of the broad unsupervised classification, retaining all clusters (using 6 grey levels, saturation percentage 1%)

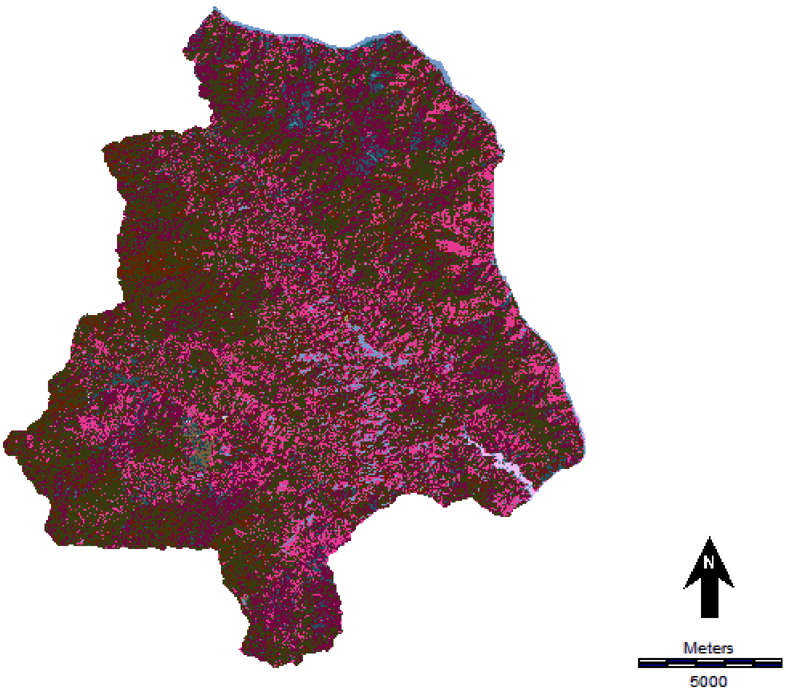

Figure 2.2.2: The 33 clusters of the fine unsupervised classification retaining all clusters (using 6 grey levels, saturation percentage 1%)

2.2.1.2 Training sites

In Figure 2.2.3, the training sites used for the classification are displayed. Figure 2.2.4 shows the spectral response patterns of these classes in the used bands. The most difficult classes to distinguish from each other are rubber (sunlit) and deciduous forest, but the infrared band allows to distinguish between the two. Also the DEM appears to be a useful band to distinguish the LU/LC classes from each other.

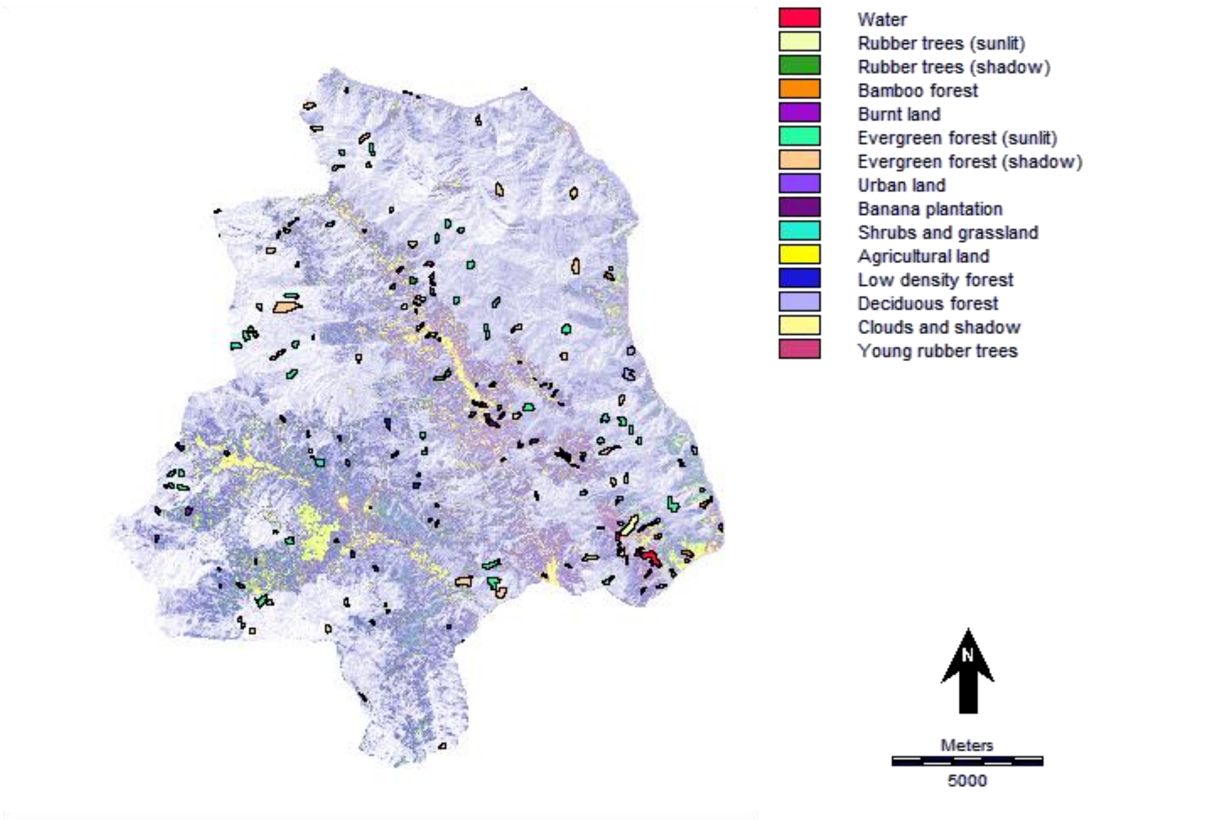

Figure 2.2.3: Training sites

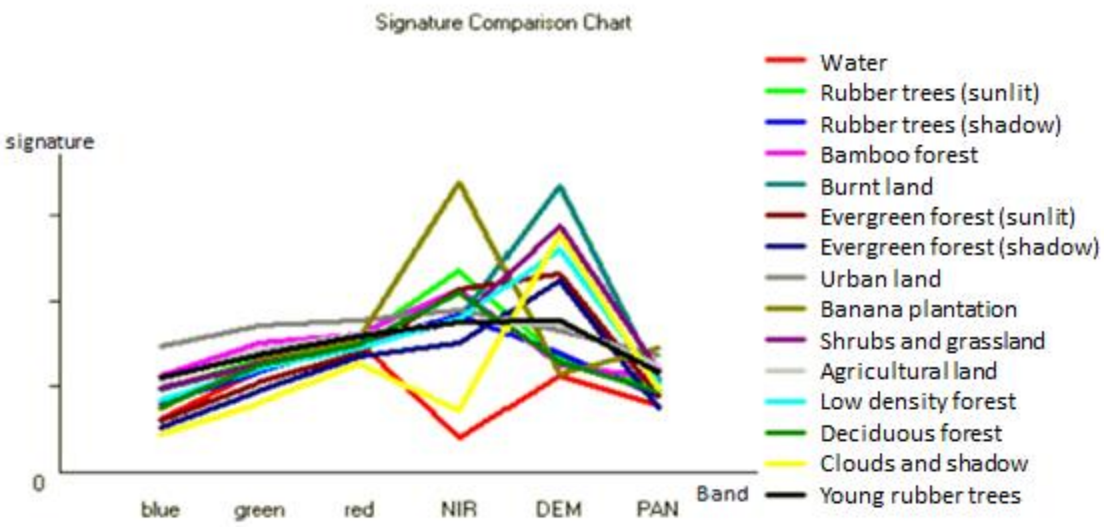

Figure 2.2.4: Signature comparison chart (blue= blue visible light, green =green visible light, red =red visible light, NIR= Near infra-red, DEM= Digital elevation model, PAN= Panchromatic)

2.2.1.3 Supervised classification

The obtained RMS in the MLP was 0.15 for the testing pixels and 0.14 for the training pixels. In this way, in the independent validation, an overall kappa of 0.72 was reached. The resulting LU/LC map of 2011 and the reclassified map are shown in Figure 2.2.5 and 2.2.6. After reclassification the overall kappa was equal to 0.85. For rubber, the class of most interest for the purpose of this research, the omission and commission errors were 0.0722 and 0.14 respectively. This means that 7.22 % of the pixels that are actually rubber were classified as something else. On the other hand, 14 % of the pixels that were classified as rubber actually belong to another LU/LC class. These values are lower than the ones for most other classes, indicating the class of rubber is classified satisfactorily. On the resulting map, a 3X3 mode filter was used to eliminate small groups of pixels corresponding with the procedures used to produce the previous LU/LC maps.

The structure of the study area is clearly distinguishable on the map. The highest parts are covered with evergreen (primary) forest. In the east, deciduous forest and bamboo cover the area next to the river. The two large valleys crossing the area are in cultivation. In the western valley mainly agricultural land, low deciduous forest, burnt land and shrubs and grassland are present. This part is higher in altitude and is used for shifting cultivation by hill tribes. In the lowest parts of this valley, also young rubber trees are cultivated. This was not the case in the LU rom visual comparison with the LU/LC map of 2004 (Figure 2.2.7), in the western valley (w/LC maps of 2004 and before, where no rubber was found in the western valley. The eastern part of the area is characterized by lower altitudes and more water. Because the suitable elevation range for rubber is below 700 m a.s.l., and the altitude of this valley is between 500 m and 1000 m (see Figure 1.3), and rubber trees require a large amount of water, this valley is more suitable for the cultivation of rubber. Also in the LU/LC maps of preceding years, rubber was present in this valley. This shift to higher areas is also translated in the fact that in the western valley, which is higher than the eastern valley, the first rubber is present in 2011, while it was not in 2004. Other differences (shifts between low density forest, agricultural land, shrubs and grassland and burnt land) in the western valley can be related to shifting cultivation. The cycle of shifting cultivation in this area is about 7 years. However, the frequency of measurements does not allow to see this cycle return in the LU/LC maps. In the eastern valley, rubber plantations shifted to higher elevations, while the lowest parts of the valleys are occupied by agriculture (mainly paddy rice fields and tea plantations). In the next part, the differences in LU/LC will be compared in a quantitative way.

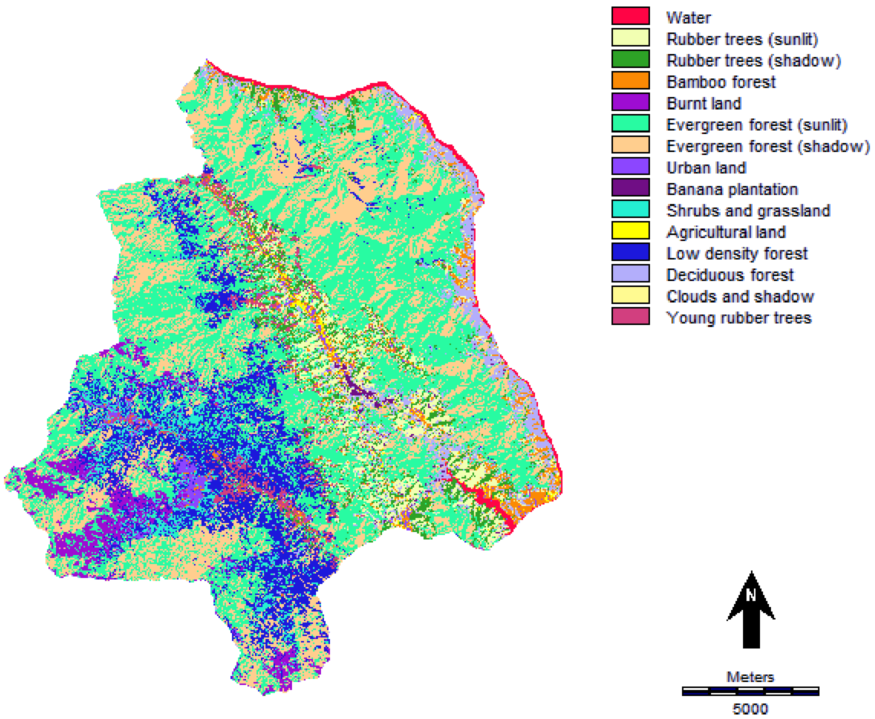

Figure 2.2.5: LU/LC map of 2011

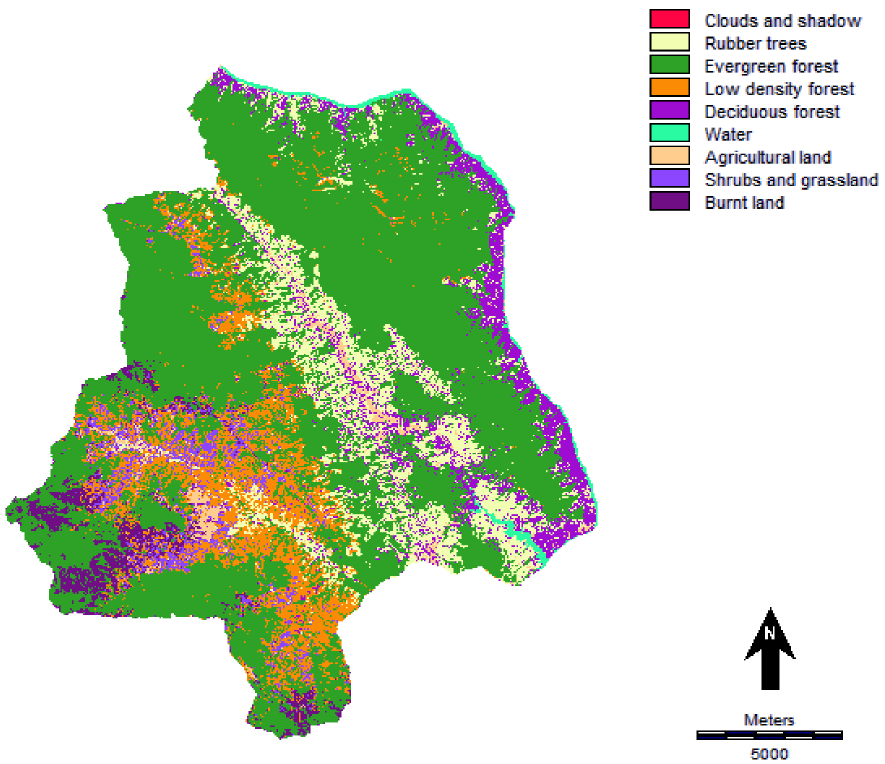

Figure 2.2.6: Reclassified LU/LC map of 2011

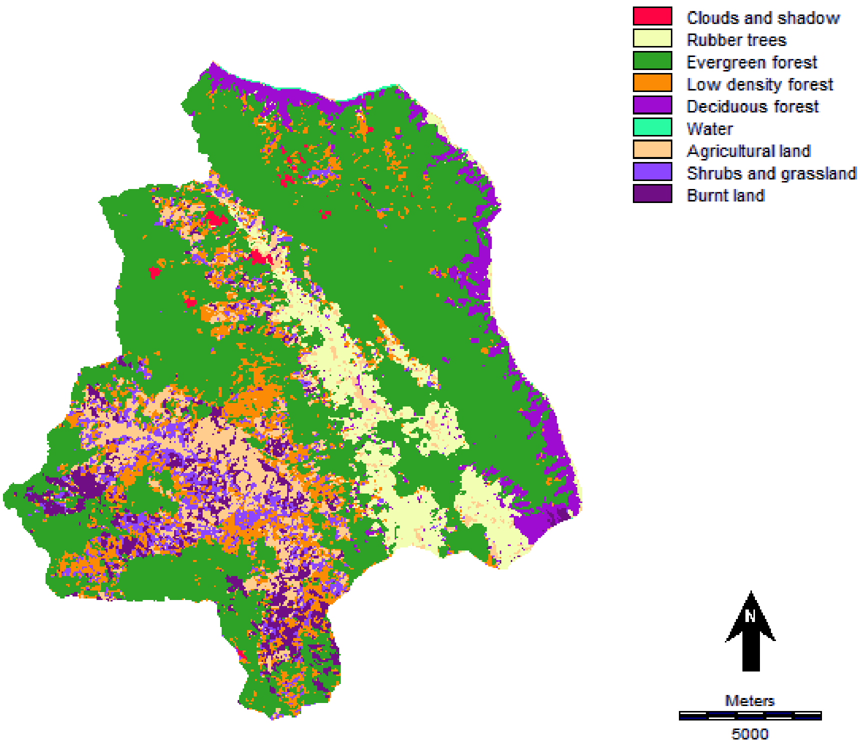

Figure 2.2.7: LU/LC map of 2004

2.2.2 Change analysis

2.2.2.1 Change analysis of NDVI

The profile of the mean NDVI in the study area and in the class of rubber is presented in Figure 2.2.8. Attention must be paid to the fact that the wavelengths measured in the different years (the different image types) are not exactly the same. The red band in 1975 (MSS) and in 2011 (ALOS) is broader, so the VIS values in formula 2.1.1 can be higher, causing the NDVI values to be lower. However, since the NDVI is a normalized measure, the differences are restricted and the values can be compared.

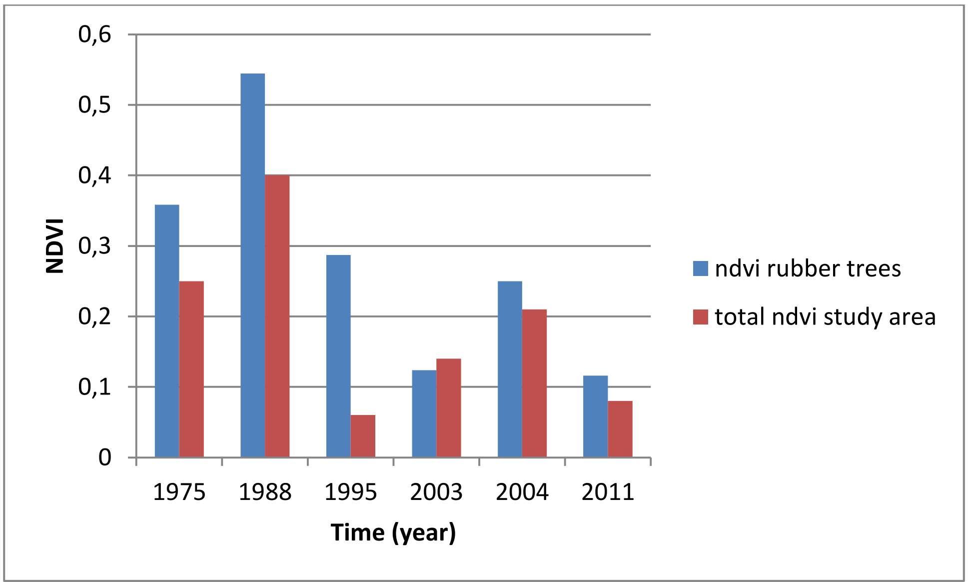

Figure 2.2.8: Mean NDVI in the total study area and in the class 'rubber'

In Figure 2.2.9, the change in the amount of hectares of rubber is depicted. Two large increases in rubber trees are observed in this figure, namely between 1995 and 2003 and between 2004 and 2011. In Figure 2.2.8, the NDVI of the total study area can be compared to the NDVI within the class of rubber trees. With the help of the LU/LC changes, it can be examined whether the increase is likely to be due to a real increase in NDVI, thus an increase in vegetation density, or due to the difference in bandwidth measured. In the period between 1975 and 1988, the total NDVI and the NDVI within the class of rubber run parallel. Between 1988 and 1995, the total NDVI decreases more quickly than the NDVI of rubber. This can be an indication that little new rubber is planted and that the already existing rubber trees are growing. The vegetation in the rubber plantation is thus getting denser, causing the NDVI to decrease less than the average NDVI. Between 1995 and 2003, an opposite trend is observed: the NDVI of rubber decreases, while the total NDVI increases. A possible explanation is that a lot of new rubber is planted in this period. The small rubber trees do not entirely cover the soil, and the soil is kept free of vegetation which can impede the growth of the trees, causing the NDVI to decrease. Between 1995 and 2003 indeed a large change in area of rubber is observed in Figure 2.2.9. The following period, both the NDVI of the total area and the NDVI of the rubber increases. Little new rubber is planted (Figure 2.2.9), and the already existing rubber trees continue to grow. Between 2004 and 2011, a large increase in rubber is observed in Figure 2.2.9. In Figure 2.2.8 however, the patterns of NDVI run parallel. A possible explanation is that the rubber trees planted between 2004 and 2011 were planted right after 2004 (after the building of the Jinghong dam, bringing more water in the area and thus being a driving force for rubber planting). In this case, the rubber trees are already 7 years (and thus quite dense) in 2011, and the NDVI of the rubber class has already increased again.

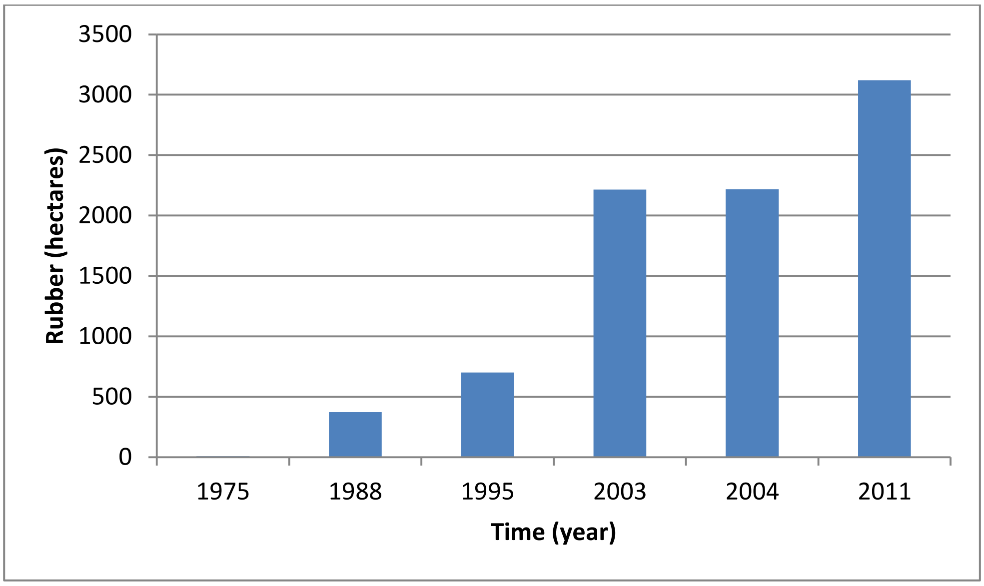

Figure 2.2.9: Number of hectares classified as rubber

The Kendall slope is presented in Figure 2.2.10. This is the overall slope over the entire time series. A more negative slope means a steeper decrease in NDVI between 1975 and 2011. In Figure 2.2.10, it is obvious that in most places, the slope is less than zero. Over the total period, the NDVI thus decreased in most places. In areas where evergreen forest was the main vegetation through the whole period, the Kendall slope is small (around -0.12). In the eastern valley, where rubber trees are the current vegetation, the slope is about -0.03. In the western part, where shifting cultivation is practiced, the slope is varying from negative to positive values.

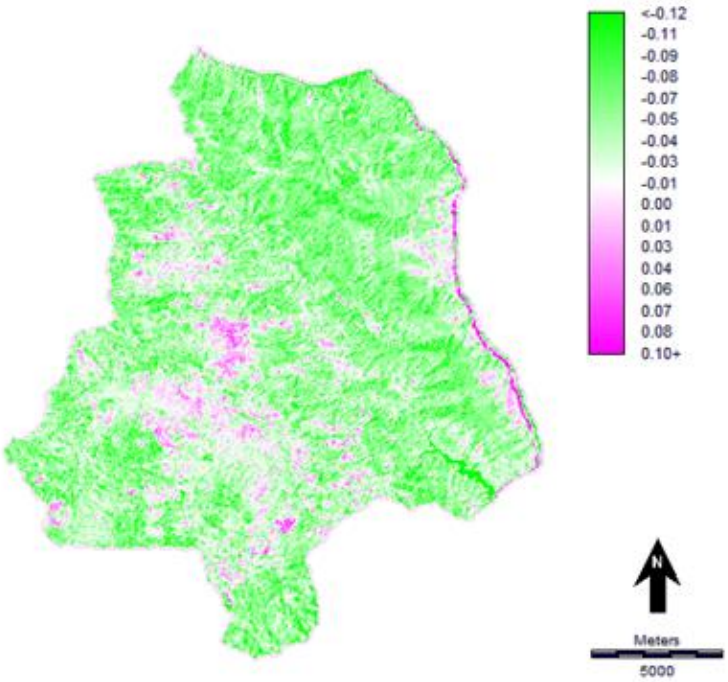

Figure 2.2.10: Kendall slope of the NDVI between 1975 and 2011

2.2.2.2 Change analysis of LU/LC maps

2.2.2.2.1 Change in areas within LU/LC classes

In Figure 2.2.11 and 2.2.12, the trends in area of each LU/LC class are presented. The change in rubber is the most apparent and unidirectional. The class of water displays a strong increase after 2004. The changes in the other LU/LC classes can all be attributed to shifting cultivation. Because the land use in shifting cultivation is changing quickly, the measurements each few years are insufficient to discern a clear pattern of change. The spatial properties of the changes are discussed in chapter 2.2.2.2.2.

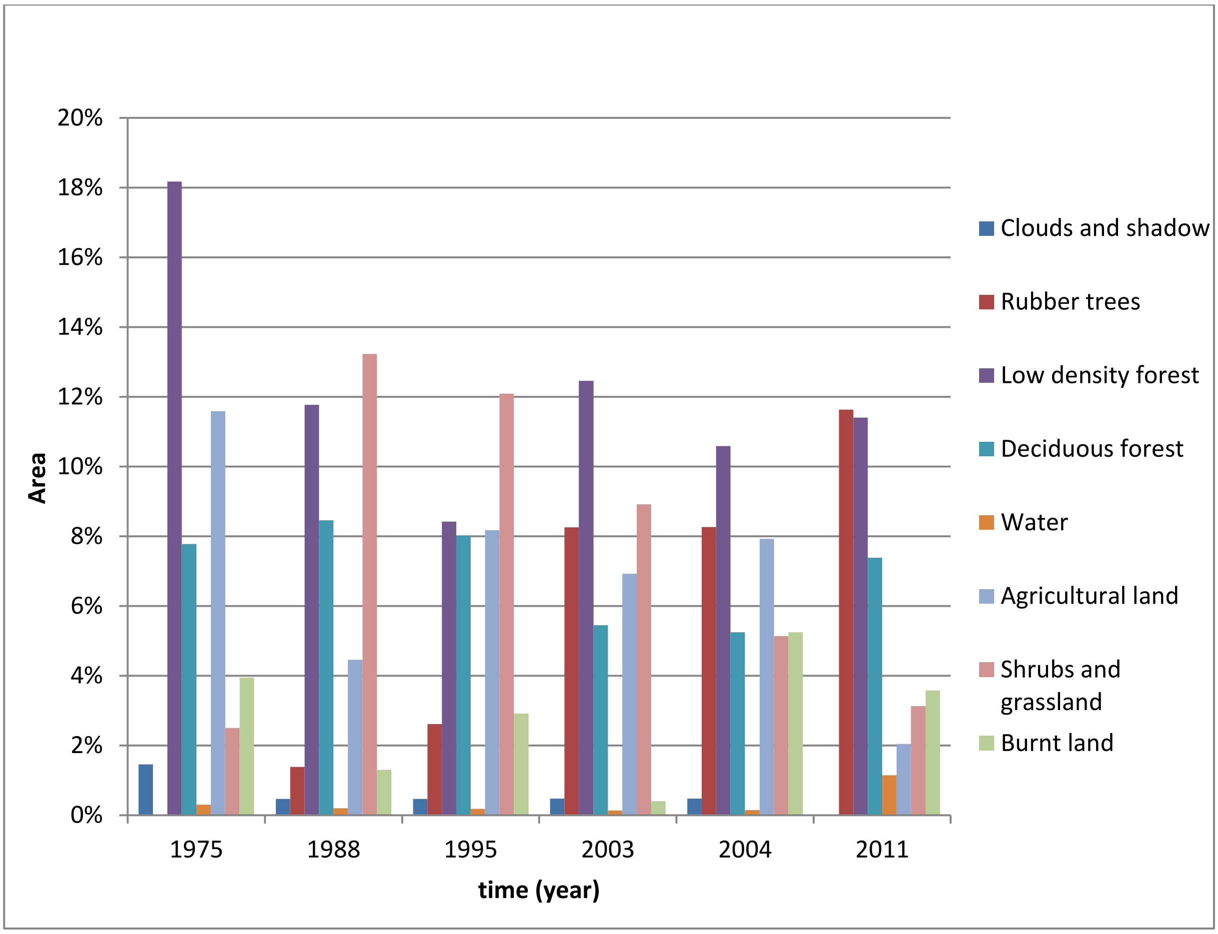

Figure 2.2.11: Proportions different LU/LC classes in the study area.

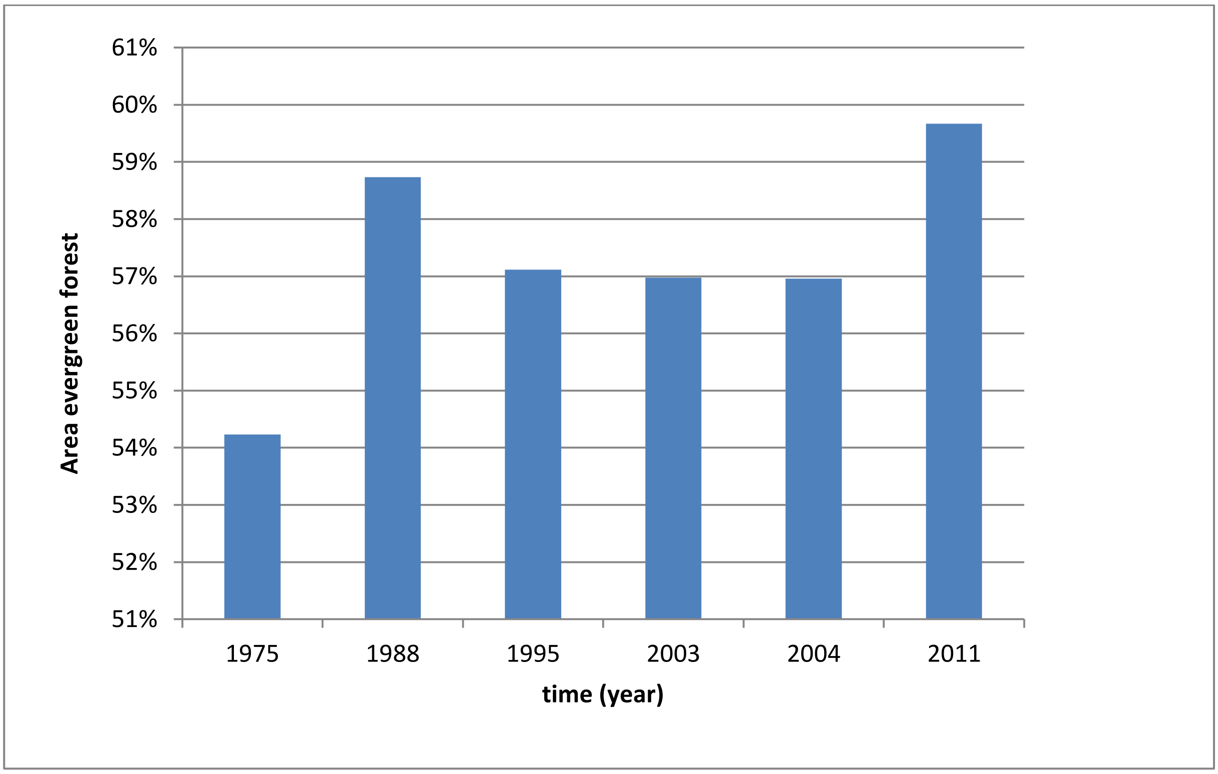

Figure 2.2.12: Proportion LU/LC class of evergreen forest in the study area

2.2.2.2.2 Spatial properties of the changes in LU/LC

Figures 2.2.13 to 2.2.16 show all changes larger than 268 hectares (1% of the area) in the four periods. This threshold was arbitrarily chosen to only include the important changes. The first observation is that there are larger areas that are subject to changes in LU/LC in the more recent periods. Between 1975 and 1988 and between 1988 and 1995, most changes occur in the western part of the study area, where shifting cultivation is practiced (changes between agricultural land, low density forest, shrubs and grassland and burnt land). Changes in the eastern part of the study area in these two periods are mainly changes between different types of forest.

In the subsequent periods, important changes are also observed in the eastern valley. The changes in the eastern part are more unidirectional: mostly changes to rubber trees, evergreen forest and low density forest. Until 2004, the western part of the study area did not feature rubber. However, in 2011, young rubber also appears in the valleys of the western part.

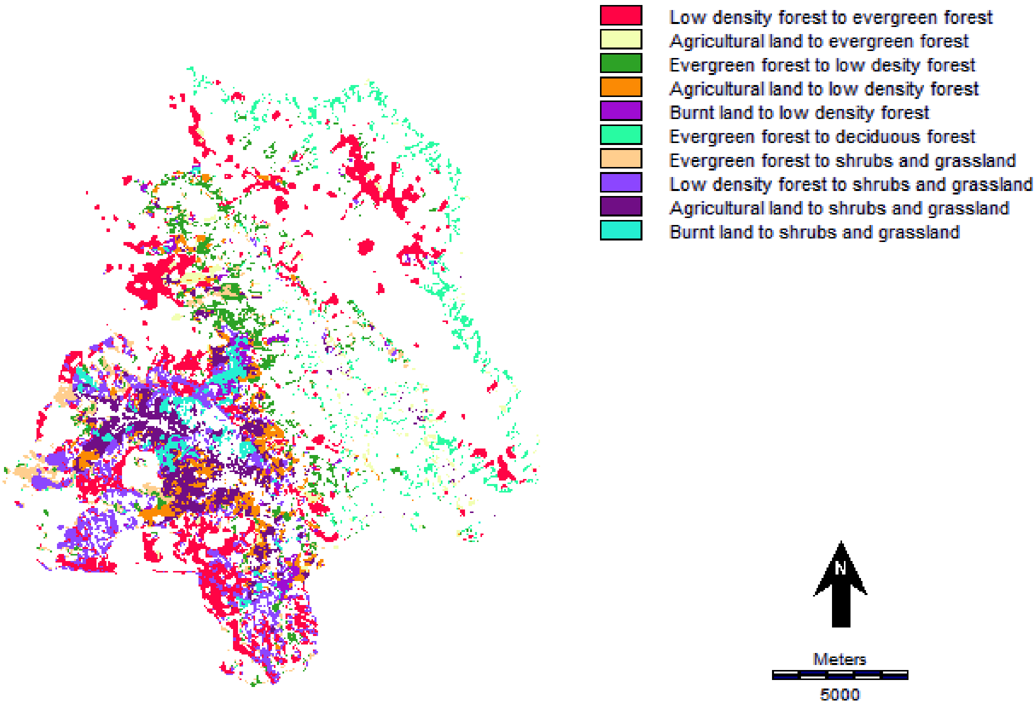

Figure 2.2.13: Overall changes (>268 ha) from 1975 till 1988

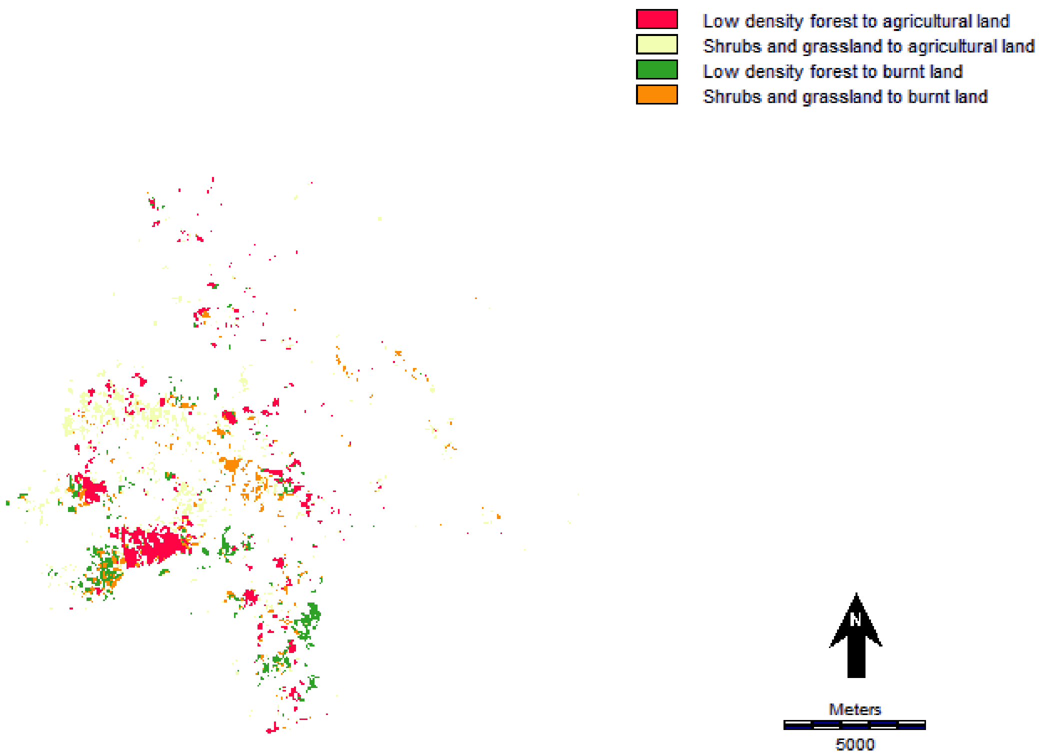

Figure 2.2.14: Overall changes (>268 ha) from 1988 till 1995

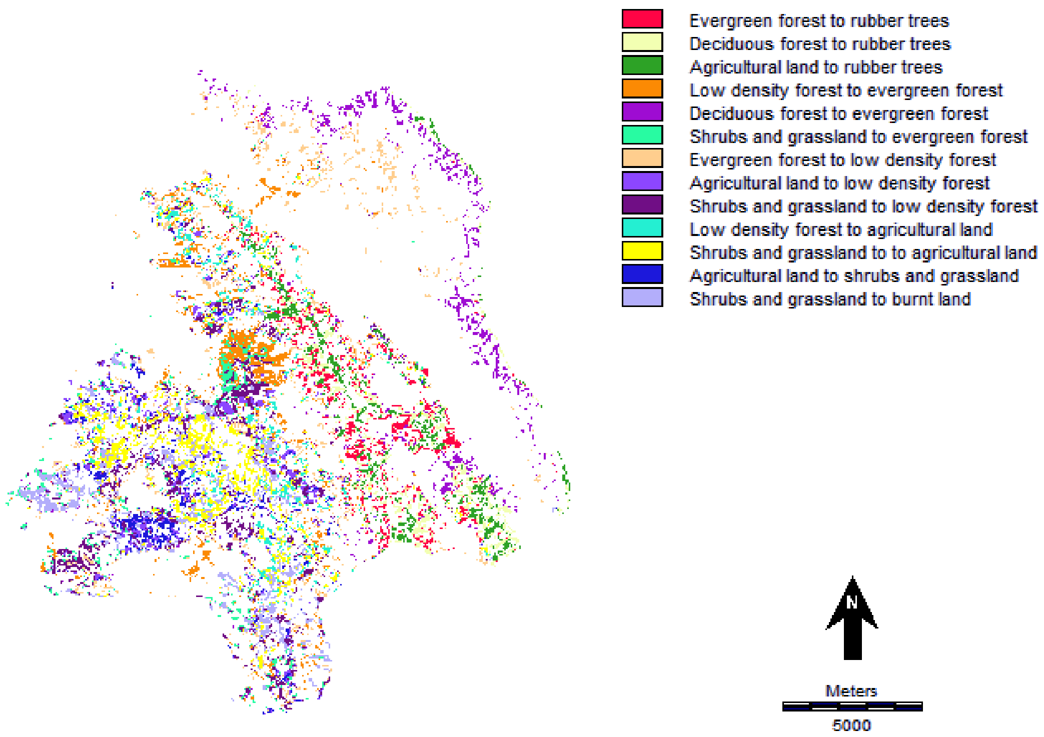

Figure 2.2.15: Overall changes (>268 ha) from 1995 till 2004

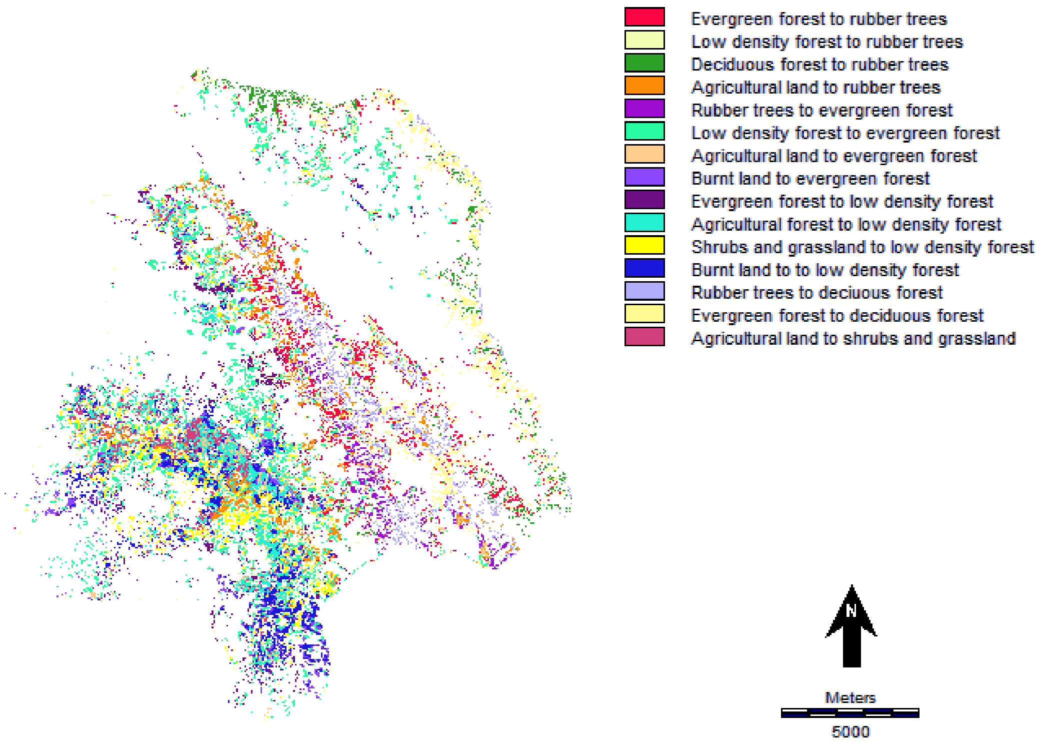

Figure 2.2.16: Overall changes (>268 ha) from 2004 till 2011

2.2.2.2.3 Factors explaining changes in rubber tree areas

In Figures 2.2.17 to 2.2.20, the classes which contributed to the changes in rubber trees are displayed. A positive number reflects a loss of area in the shown class at the advantage of an area gain in the class of rubber trees. It is clear that, between 1975 and 2004, mainly agricultural land, deciduous forest and evergreen forest were lost in favor of rubber trees. Between 2004 and 2011, the situation is slightly different. This can be explained by the effects of the Jinghong dam, built in 2004. This dam has brought considerable amounts of water into the eastern valley. The negative values in Figure 3.20 for the class of water and deciduous forest are the result of this change. The water has taken over the lowest parts of the eastern valley, causing a loss in rubber there. On the other side, more rubber was planted in the higher areas of the valley, which receives a higher supply of water. Parts of the valley and the parts next to the river in the most eastern part of the study area, formerly planted with low density forest or evergreen forest, are converted to rubber plantations.

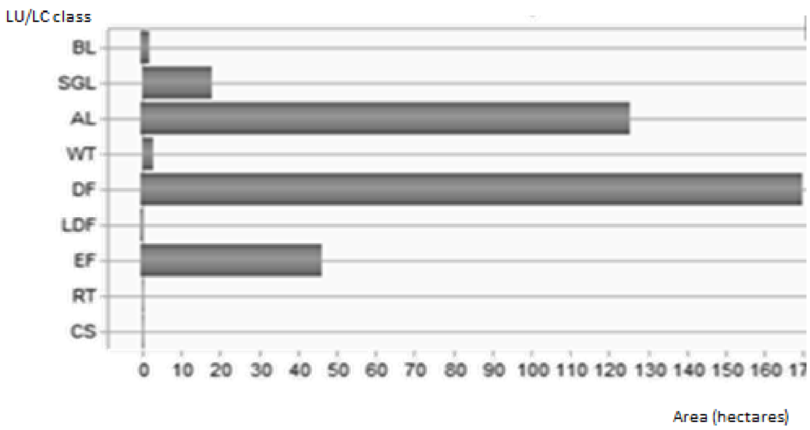

Figure 2.2.17: Contributors to changes in rubber from 1975 to 1988

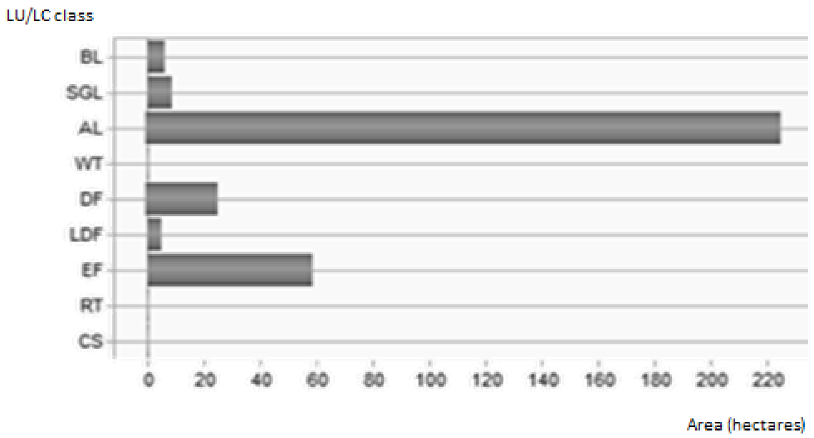

Figure 2.2.18: Contributors to changes in rubber from 1988 to 1995

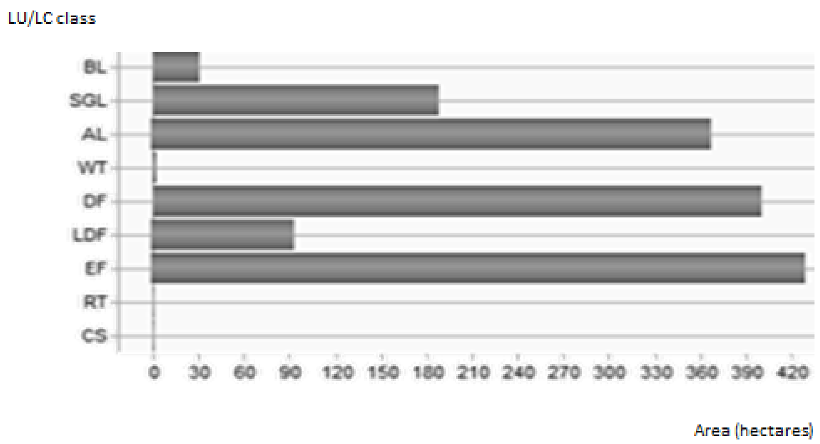

Figure 2.2.19: Contributors to changes in rubber from 1995 to 2004

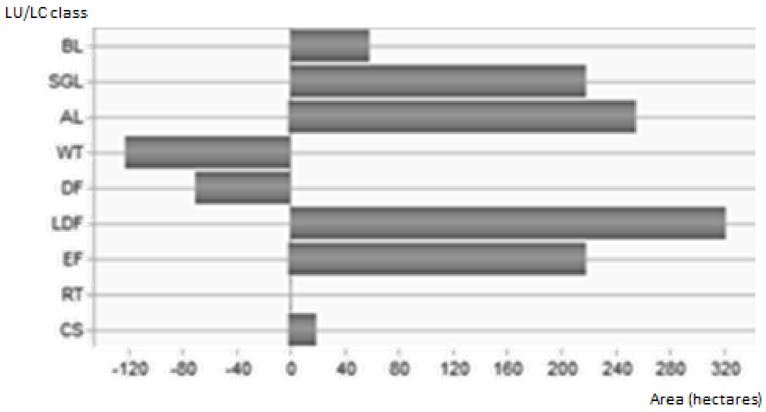

Figure 2.2.20: Contributors to RT changes from 2004 to 2011

2.2.2.2.4 Gains and losses in rubber tree areas

The locations where rubber trees are lost and gained are shown in Figures 2.2.21 to 2.2.24. From these figures, the area where a change in the class of rubber trees is observed spreads out during the different periods. This is because each period new, less suitable areas are planted with rubber. The hotspot (the area where the change is the most intense) remains on the same location. Remarkably, between 2004 and 2011, the area in which the changes in rubber trees occur becomes larger, but also higher losses are observed at the riverside and in the valley, in favour of water and deciduous forest.

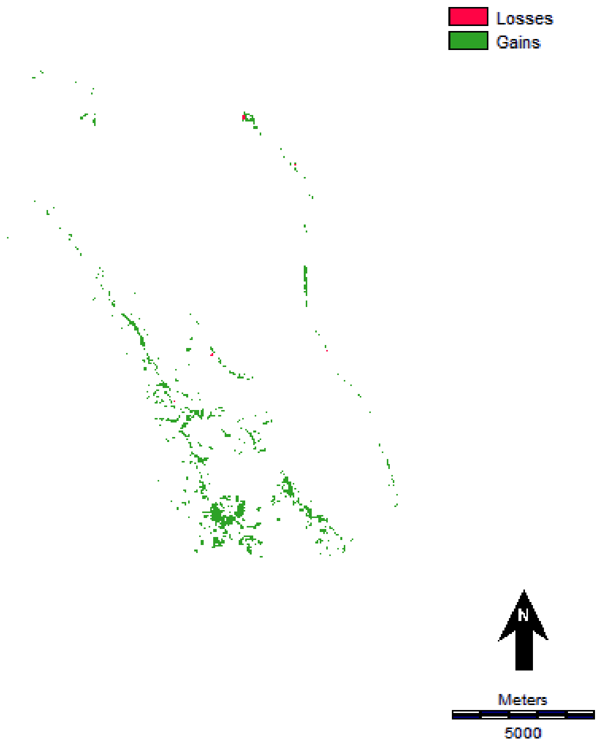

Figure 2.2.21: Gains and losses in rubber trees from 1975 to 1988

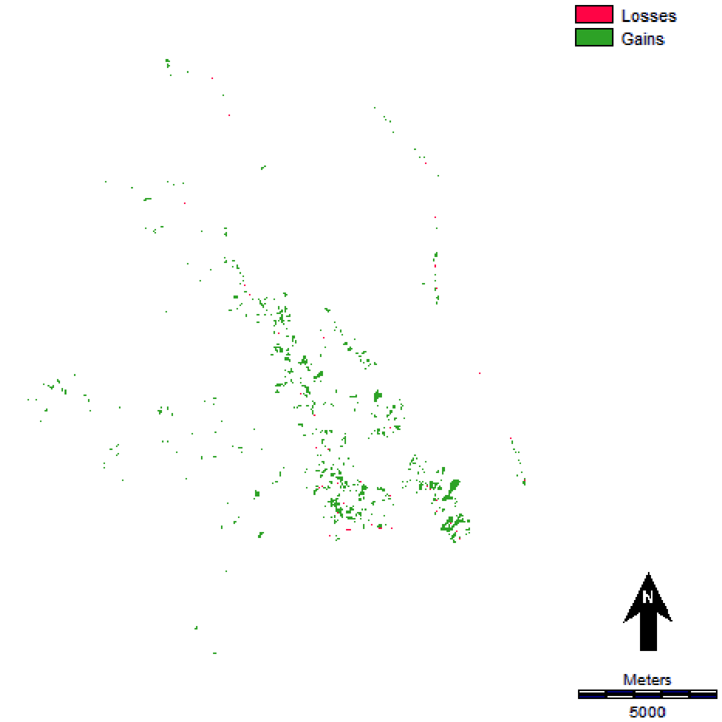

Figure 2.2.22: Gains and losses in rubber trees from 1988 to 1995

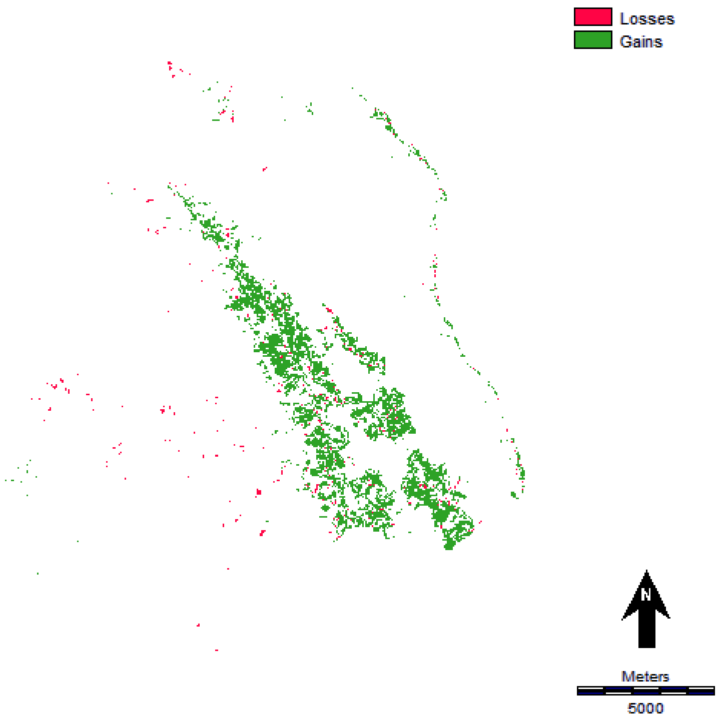

Figure 2.2.23: Gains and losses in rubber trees from 1995 to 2004

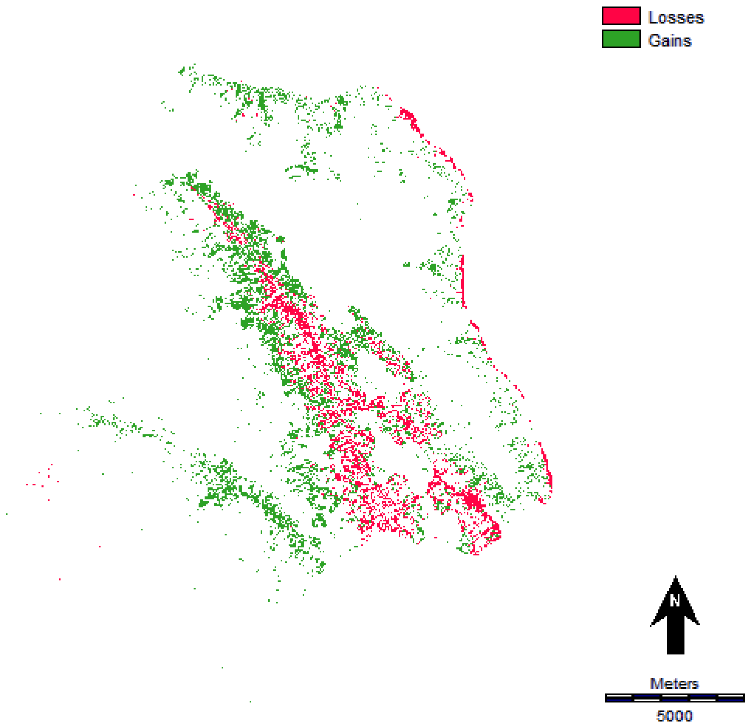

Figure 2.2.24: Gains and losses in rubber trees from 2004 to 2011

2.2.2.2.5 Relation of rubber tree occurrence with elevation

In Figure 2.2.25, the proportions of rubber in different elevation categories are shown. The proportion of rubber in the lowest elevation class (below 800 m), is decreasing from 1988 on. Yet, at the same time, the proportion between 800 and 1000 m started to increase. The increase in the subsequent elevation class (1200-1600 m) starts in 2004. These trends were already visually observed from the vegetation maps. The fact that farmers take more risks to grow rubber in higher elevations is related to the increasing rubber prices.

If the class 'young rubber' in 2011 is compared with the complete class of 'rubber' in 2011 in terms of elevation, it is clear that the young rubber trees in 2011 appear mainly at higher elevations. Figures 2.2.26 and 2.2.27 compare the DEM values of young rubber and rubber. The mean elevation for young rubber is 1131.82 m, while for rubber in general it is 874.85 m.

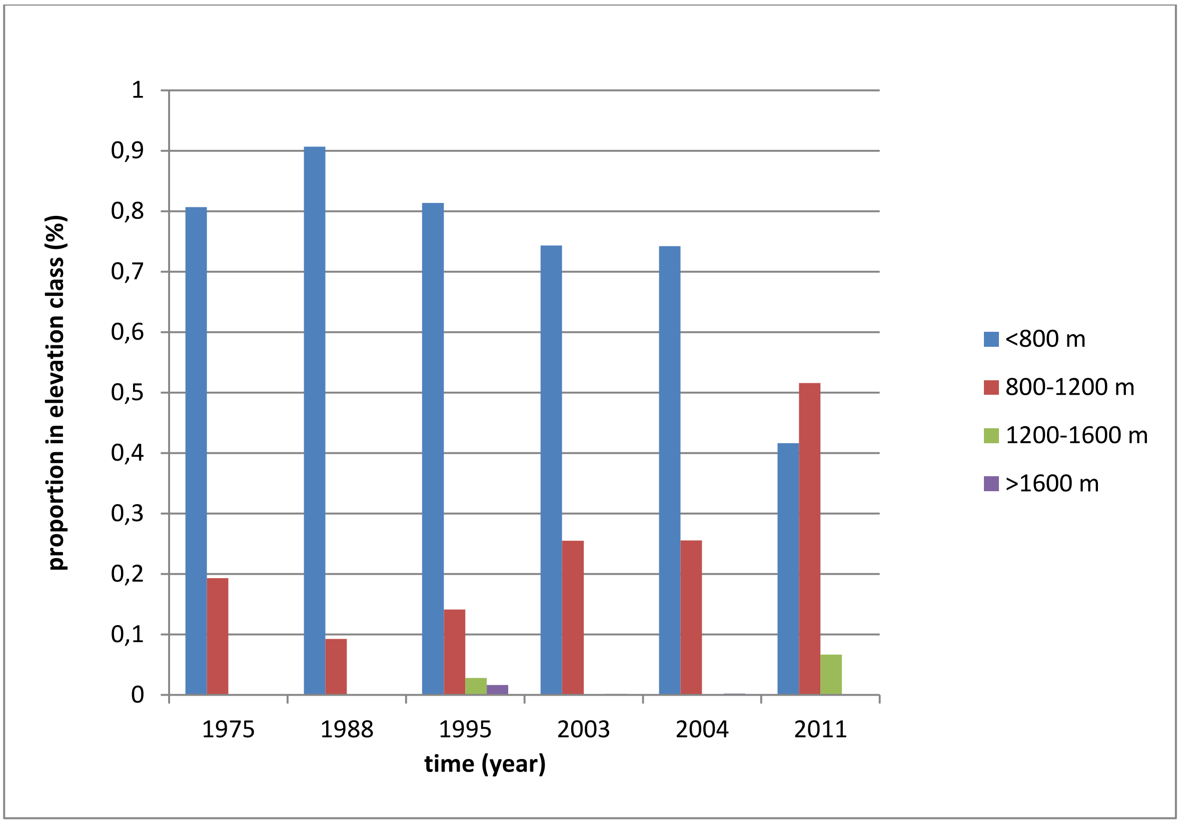

Figure 2.2.25: Proportions of rubber in elevation classes

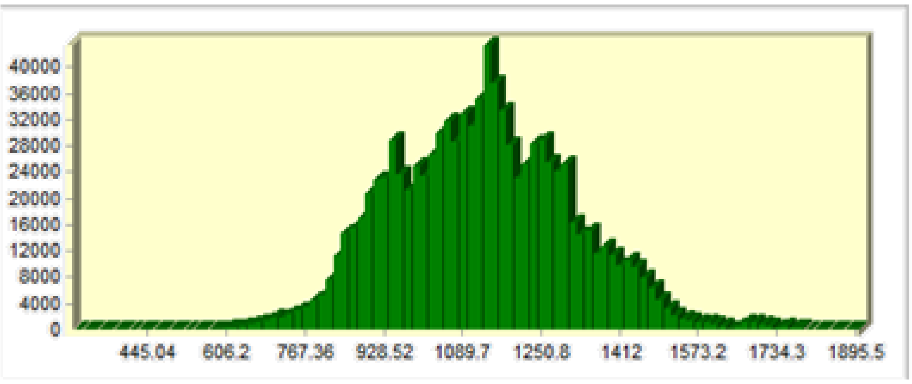

Figure 2.2.26: Histogram of the DEM-values of young rubber in 2011

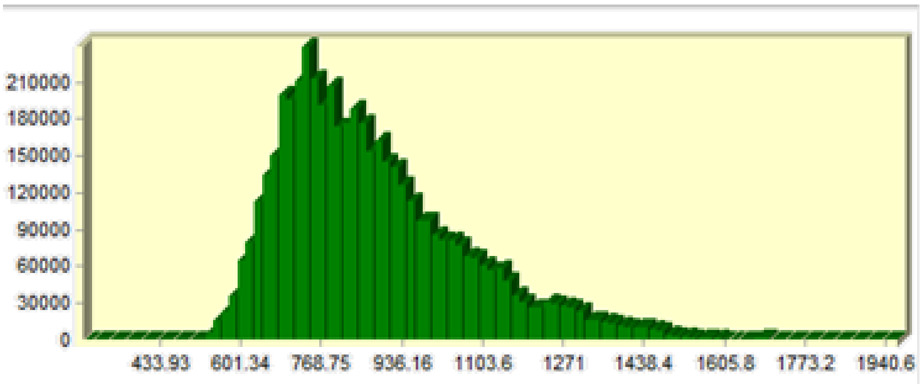

Figure 2.2.27: Histogram of the DEM-values of rubber in 2011

2.2.2.2.6 Relation of rubber tree occurrence with forest ownership

The evolution of rubber plantations can also be compared in terms of the ownership. In Figure 2.2.28, the proportions of rubber in the different ownership classes are presented. The portion in national forest is declining, while in community forest rubber plantations become more abundant. More smallholder rubber farms are established, while the proportion of state rubber farms declines. From 2004 on, the proportion in household forest declines. This land is more often used for agricultural use (see Figure 2.2.6). This is also noticed in Table 2.2.1, where less new rubber appears in household forest. New rubber in 2011 is appearing especially in community forest (Table 2.2.1). In nationally managed forests, less new rubber appears in 2011.

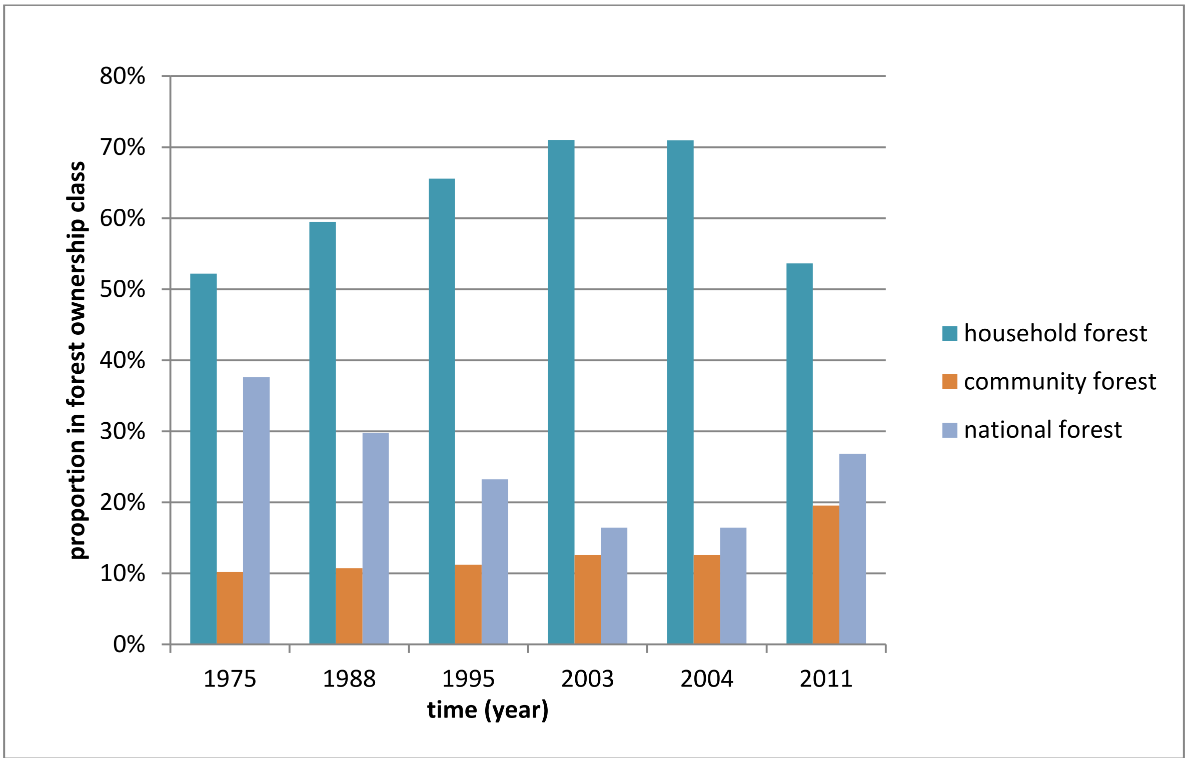

Figure 2.2.28: Proportion of rubber in ownership classes

	Young rubber 2011 (%)	Rubber 2011 (%)
No data	36.8	12.8
National	10.7	23.4
Community	22.4	17.0
Household	30.2	46.8

Table 2.2.1: Comparison of the property rights for young rubber and rubber

2.2.2.2.7 Spatial trend of change from evergreen forest to rubber trees

The third order spatial change from evergreen forest to rubber trees from 1975 to 1988 is presented in Figure 2.2.29. Because the study area is relatively small, a higher order is not relevant to calculate. The highest change is observed in the southeast of the study area, as was already apparent from examining gains and losses of rubber trees. This is the lowest and most wet place, and is thus the most suitable for rubber plantations. In the other periods, the change is similar, only the values are more widespread and higher in the hotspot of change from 1995 to 2004 and from 2004 to 2011.

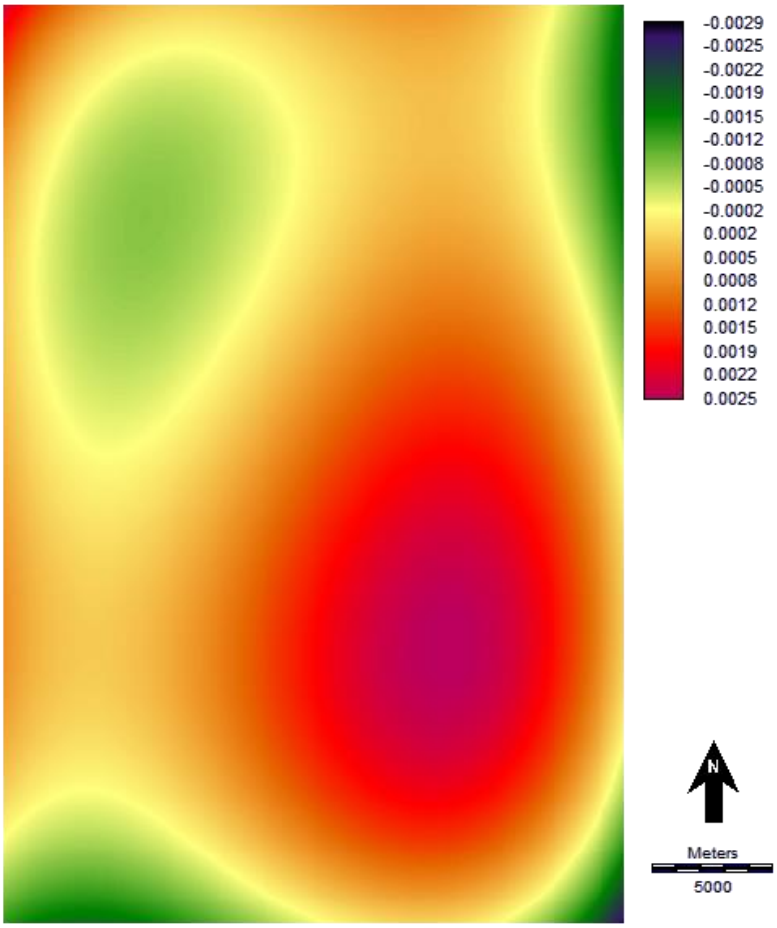

Figure 2.2.29: Spatial change from EF to RT from 1975 to 1988

2.2.2.3 Landscape metrics

The trends in the different landscape metrics are given in Figures 2.2.30 to 2.2.35.

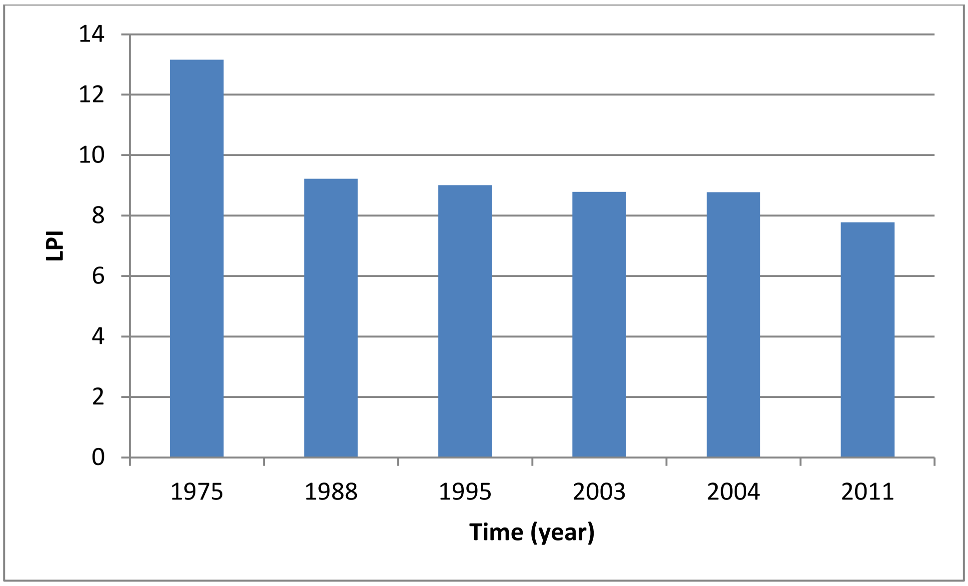

Figure 2.2.30: Largest patch index values in the study area.

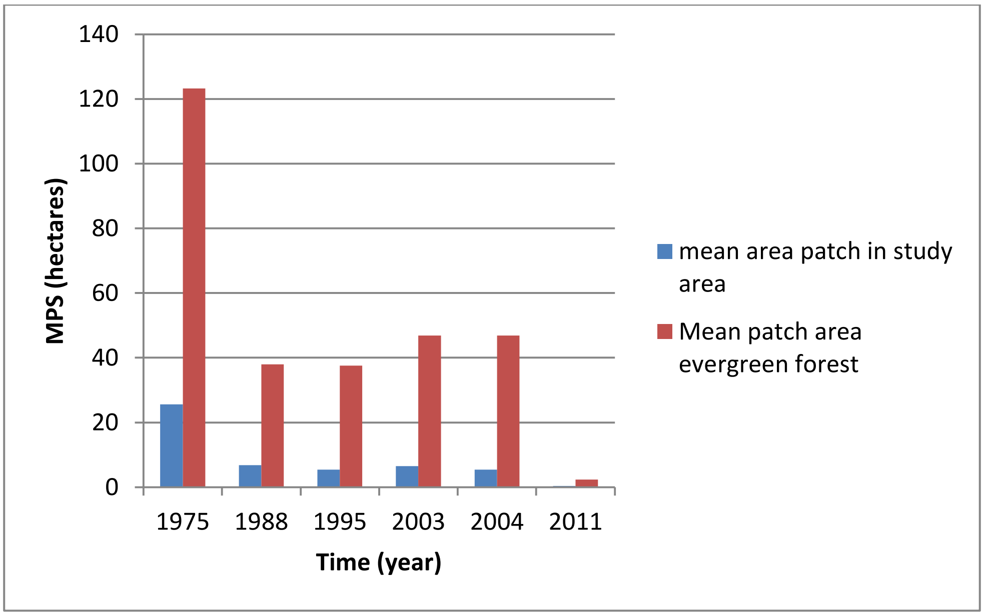

Figure 2.2.31: Mean Patch Size in study area and within the class of evergreen forest

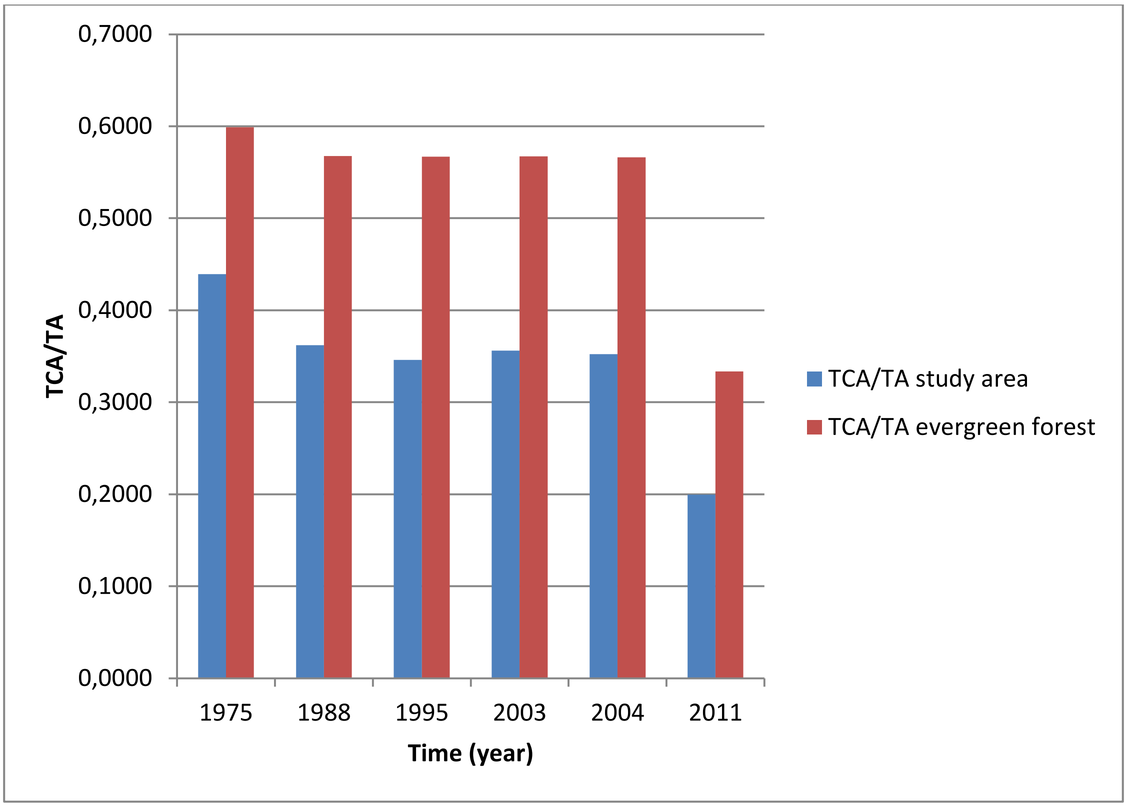

Figure 2.2.32: Total core area divided by total area for Naban reserve.

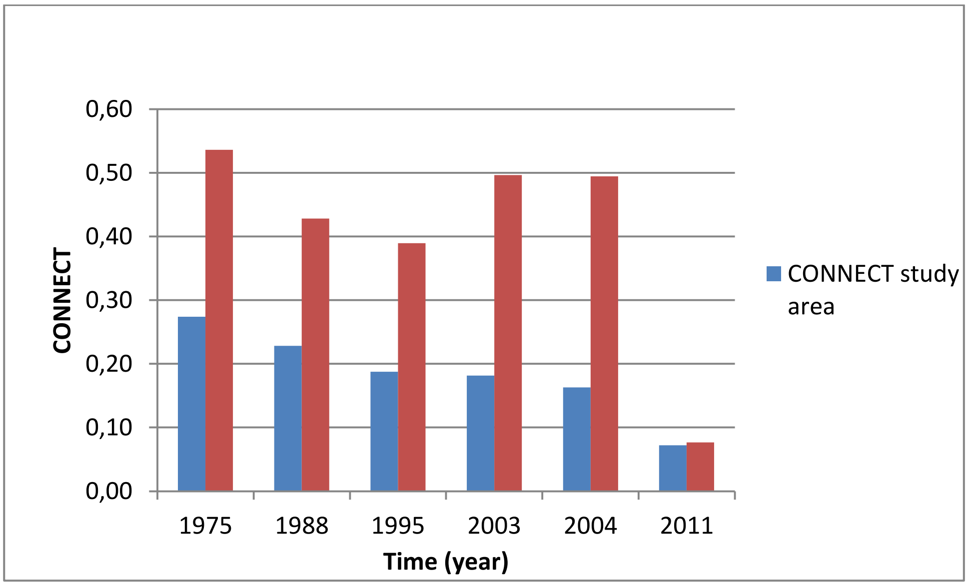

Figure 2.2.33: Connection index values in the study area.

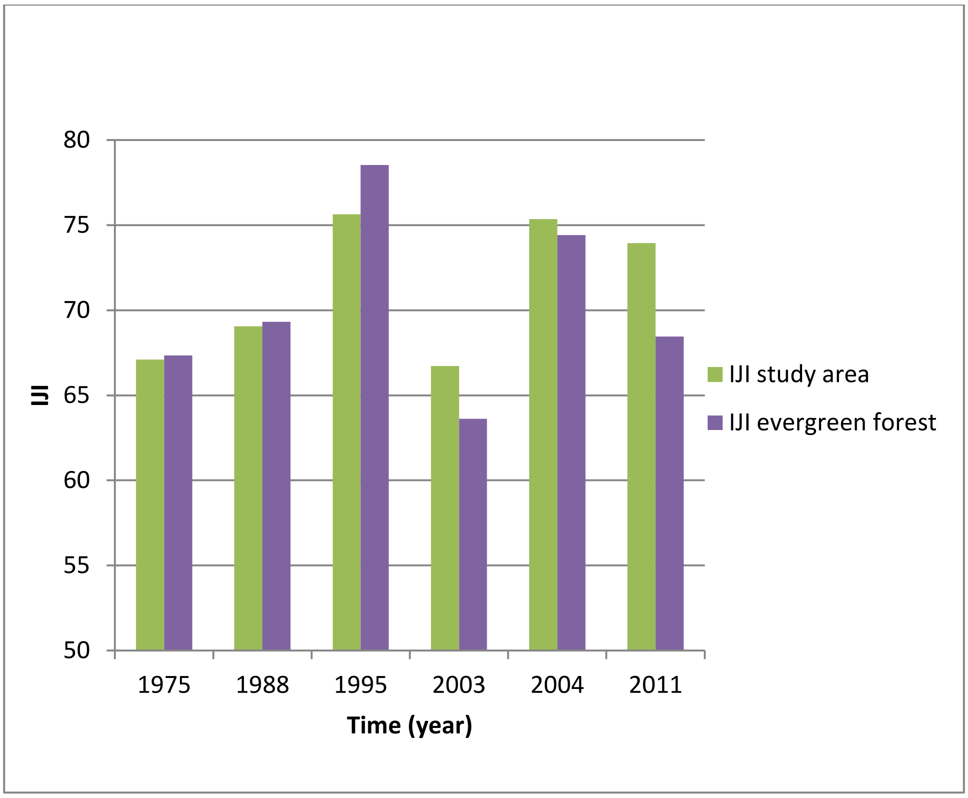

Figure 2.2.34: Interspersion and Juxtaposition Index values in the study area.

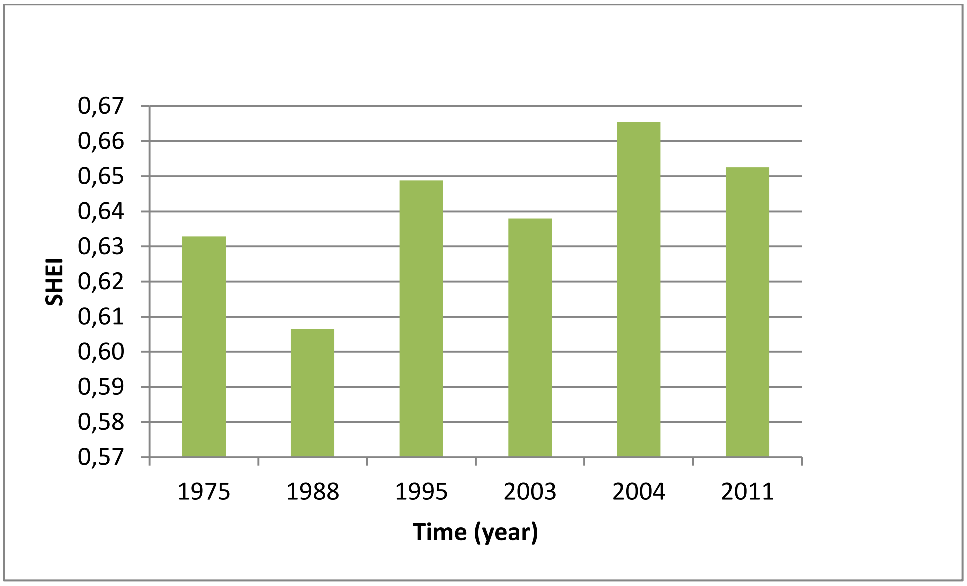

Figure 2.2.35: Shannon's Evenness Index values in the study area.

In the LPI (Figure 2.2.30), a decrease is observed during each time period. The stronger decreases between 1975 and 1988 and between 2004 and 2011 could be explained by the fact that the resolution decreases in these periods. The decrease in MPS (Figure 2.2.31) throughout the years is clear, but could also be attributed to a change in resolution of the satellite images. Between 1975 and 1888 and between 2004 and 2011, the resolution of the LU/LC maps increases, which can cause the MPS to decrease because the pixel size becomes smaller. The change in size of forest patches is larger than the change in size of the other patches from 1975 to 1988 and from 2004 to 2011. The trend of TCA (Figure 2.2.32) in the study area should be compared to the trend within forest area (Figure 2.2.12). If the periods are observed in which the percentage core area for evergreen forest feature a stronger decrease than for the total study area, the effects of the change in resolution are compensated for. If the difference in TCA is solely related to a change in resolution, the change in TCA of the study area would be proportional to the change in TCA within the class of evergreen forest. This is the case between 1995 and 2003, and between 2004 and 2011. The connection (Figure 2.2.33) of forest patches is biggest in 1975, 2003 and 2004. After 2004, the connection decreases drastically. The IJI (Figure 2.2.34) shows that between 1995 and 2003 and between 2004 and 2010, the mixture of patches decreases. The mixture of forest patches with other LU/LC classes decreases even stronger. In the same years the SHEI (Figure 2.2.35) decreases, indicating increasing dominance of one or a few LU/LC classes.

2.2.3 Change prediction

2.2.3.1 Spatial analysis of change without driving variables

The transition probability matrices for the Markov analysis of 2016 and 2018 are shown in Tables 2.2.2 and 2.2.3. Based on these transition probabilities, predictions for the year 2016 and 2018 were made. One iteration a year was made. Figures 2.2.36 and 2.2.37 provide the result of this prediction.

The areas in the different LU/LC classes are provided later, but it is as yet clear, that just as in the period between 2004 and 2011, rubber is expanding to higher elevations. Deciduous forest along the riverside is also increasing in area. The water class is also expanding. However, between 2004 and 2011, this was the case because the Jinghong dam was built. After 2011, the class of water will probably not expand because the conditions remain stable. The conventional Markov method cannot include this information and will thus overestimate the class of water. However, by means of a prediction with the use of driving variables (see section 2.2.3.2), this shortcoming can be overcome. In this way it is possible to incorporate knowledge about the driving forces causing the changes, resulting in a better prediction.

Table 2.2.2: Transition probabilities for 2016 from Markov analysis

TO	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
FROM									
Class 1	**0.0000**	0.1635	0.7144	0.0778	0.0000	0.0003	0.0433	0.0000	0.0007
Class 2	0.0000	**0.6351**	0.0996	0.0000	0.1478	0.0395	0.0779	0.0000	0.0001
Class 3	0.0000	0.0305	**0.8918**	0.0255	0.0341	0.0003	0.0010	0.0030	0.0139
Class 4	0.0000	0.1054	0.3623	**0.3574**	0.0096	0.0000	0.0085	0.0497	0.1069
Class 5	0.0000	0.1967	0.0896	0.0000	**0.6492**	0.0434	0.0211	0.0000	0.0000
Class 6	0.0000	0.0000	0.0014	0.0000	0.0025	**0.9960**	0.0001	0.0000	0.0000
Class 7	0.0000	0.1898	0.0540	0.3907	0.0395	0.0165	**0.1029**	0.1885	0.0183
Class 8	0.0000	0.1491	0.0743	0.4219	0.0131	0.0000	0.0472	**0.1522**	0.1422
Class 9	0.0000	0.0127	0.1212	0.4525	0.0190	0.0010	0.0363	0.1453	**0.2121**

Table 2.2.3: Transition probabilities for 2018 from Markov analysis

TO	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
FROM									
Class 1	**0.0000**	0.1561	0.7054	0.0722	0.0196	0.0033	0.0355	0.0010	0.0069
Class 2	0.0000	**0.5642**	0.1327	0.0010	0.1719	0.0551	0.0739	0.0001	0.0012
Class 3	0.0000	0.0414	**0.8601**	0.0309	0.0436	0.0014	0.0026	0.0043	0.0156
Class 4	0.0000	0.1141	0.4085	**0.3022**	0.0230	0.0001	0.0121	0.0463	0.0937
Class 5	0.0000	0.2204	0.1190	0.0021	**0.5743**	0.0589	0.0252	0.0000	0.0000
Class 6	0.0000	0.0001	0.0020	0.0000	0.0033	**0.9944**	0.0002	0.0000	0.0000
Class 7	0.0000	0.1979	0.1262	0.3404	0.0515	0.0207	**0.0818**	0.1471	0.0344
Class 8	0.0000	0.1591	0.1514	0.3716	0.0267	0.0000	0.0424	**0.1238**	0.1250
Class 9	0.0000	0.0432	0.1981	0.4017	0.0251	0.0015	0.0321	0.1215	**0.1769**

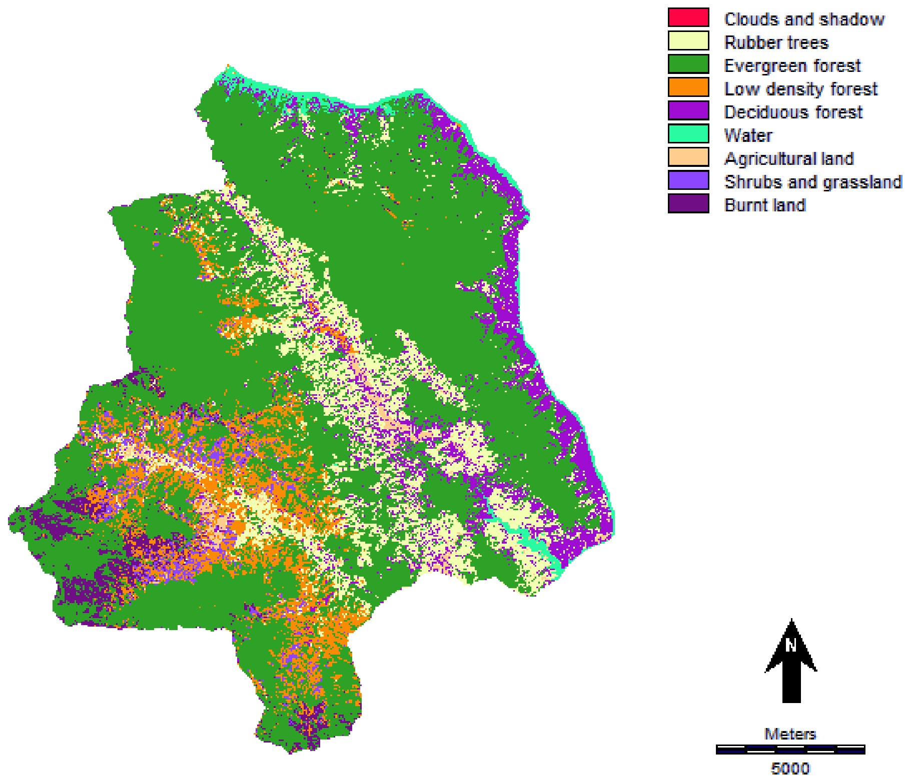

Figure 2.2.36: Prediction of LU/LC without driving variables for 2016

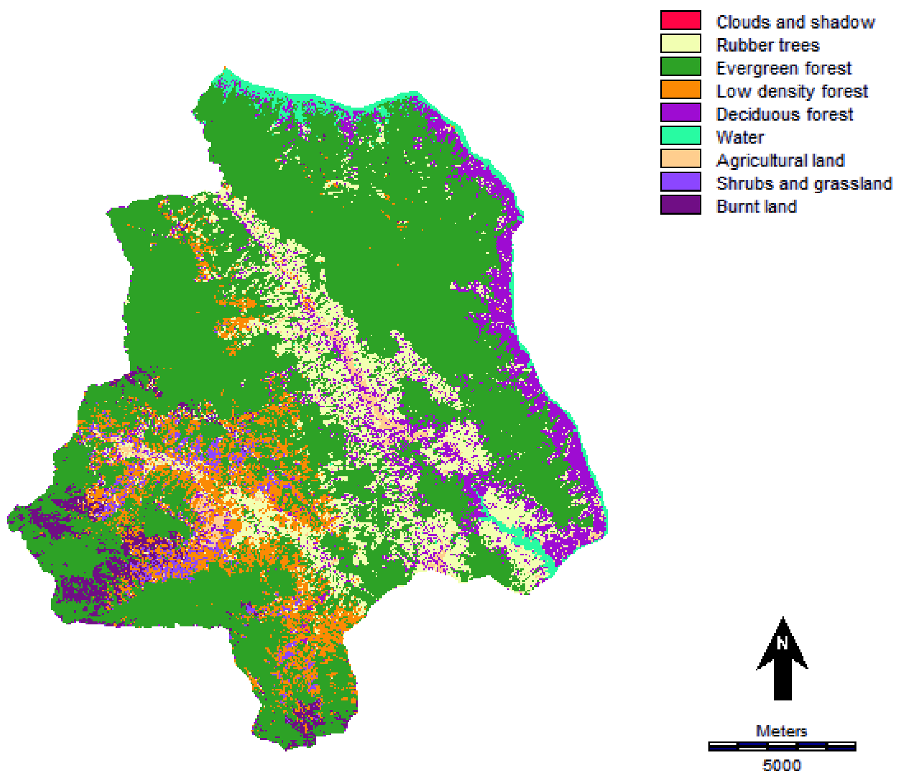

Figure 2.2.37: Prediction of LU/LC without driving variables for 2018

2.2.3.2 Spatial analysis of change with driving variables

Table 2.2.4 lists the explanatory power of the factors for the different LU/LC classes. In Table 2.2.5 the factors used in the different submodels are given. For the submodel *forest to rubber*, the DEM, forest ownership rights, distance from urban land as well as the distance from young rubber were included because these factors were all considered to be relevant driving variables. The distance from previous changes (in the period from 2004 to 2011) from evergreen forest to rubber trees was also included. For the submodel *deforestation*, the distance from young rubber was not included, because rubber is of no importance in these changes. Similarly, for *reforestation*, the distance from rubber as well as the distance from urban land was not included as driving variables. For the submodel *plantations* (that is, the conversion to rubber trees), the DEM, distance from urban, distance from young rubber and distance from disturbance were used. The forest ownership rights variable seemed to have an explanatory power that was low for a few LU/LC classes. Therefore, the model was tested with and without the use of this variable, and since it performed slightly better without the forest ownership rights, this variable was not included. The accuracy rates and the RMS of the models are listed in Table 2.2.6. The result of the prediction for 2016 and 2018 is displayed in Figures 2.2.38 and 2.2.39.

Table 2.2.4: Explanatory power of the factors determining change in function of the LU/LC classes

	Evergreen forest	Deciduous forest	Low density forest	Rubber trees	Agricultural land	Burnt land	Shrubs and grassland
DEM	0.3903	0.4864	0.3957	0.3683	0.1578	0.4578	0.2565
Forest ownership	0.4790	0.0783	0.3438	0.3663	0.1594	0.1287	0.2239
Distance from urban	0.5254	0.0868	0.2973	0.2413	0.3134	0.0666	0.2392
Distance from young rubber	0.4336	0.1027	0.2295	0.3620	0.1638	0.2555	0.1121
Distance from disturbance (forest to rubber)	0.0809	0.1931	0.1847	0.2352	0.0154	0.2318	0.1548
Distance from disturbance (deforestation)	0.1665	0.0279	0.1654	0.0329	0.0898	0.0205	0.0960
Distance from disturbance (reforestation)	0.2395	0.0808	0.1845	0.1458	0.0479	0.0985	0.0923
Distance from disturbance (plantations)	0.3785	0.2079	0.1343	0.2810	0.1042	0.1980	0.0590

Table 2.2.5: Factors included in the different submodels

Submodel	**Factors included**
Forest to rubber	DEM Forest ownership Distance from urban Distance from young rubber Distance from disturbance (forest to rubber)
Deforestation	DEM Forest ownership Distance from urban Distance from disturbance (deforestation)
Reforestation	DEM Forest ownership Distance from disturbance (reforestation)
Plantations	DEM Distance from urban Distance from young rubber Distance from disturbance (plantations)

Table 2.2.6: Accuracy and RMS of the models

	Accuracy (%)	**RMS**
Forest to rubber	94	0.23
Deforestation	81	0.31
Reforestation	59	0.26
Plantations	69	0.26

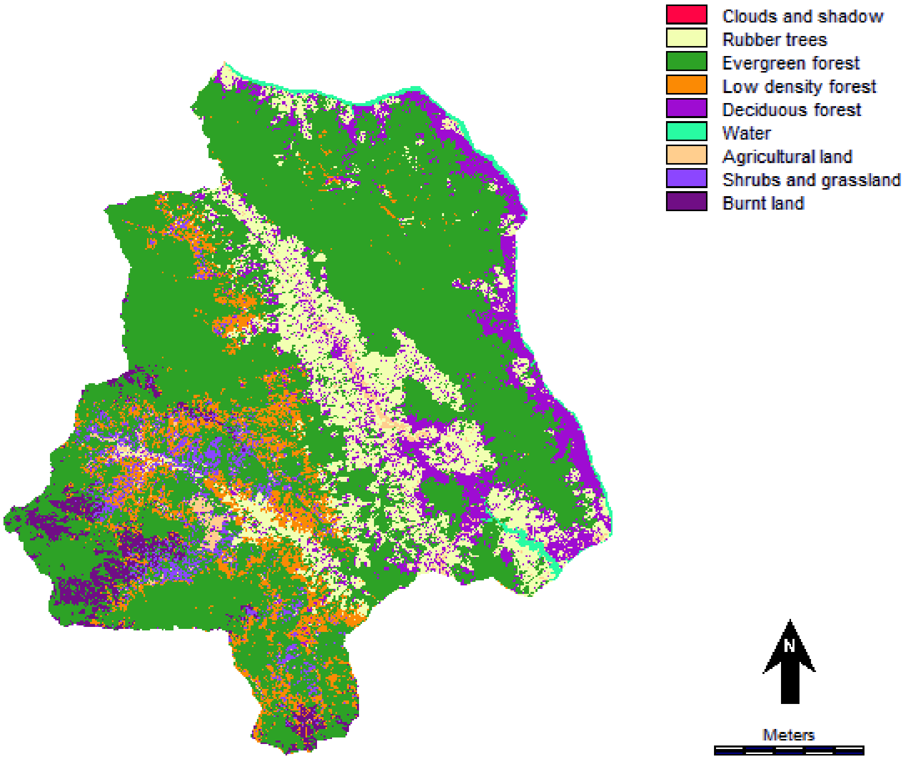

Figure 2.2.38: Prediction with the use of driving variables for the year 2016

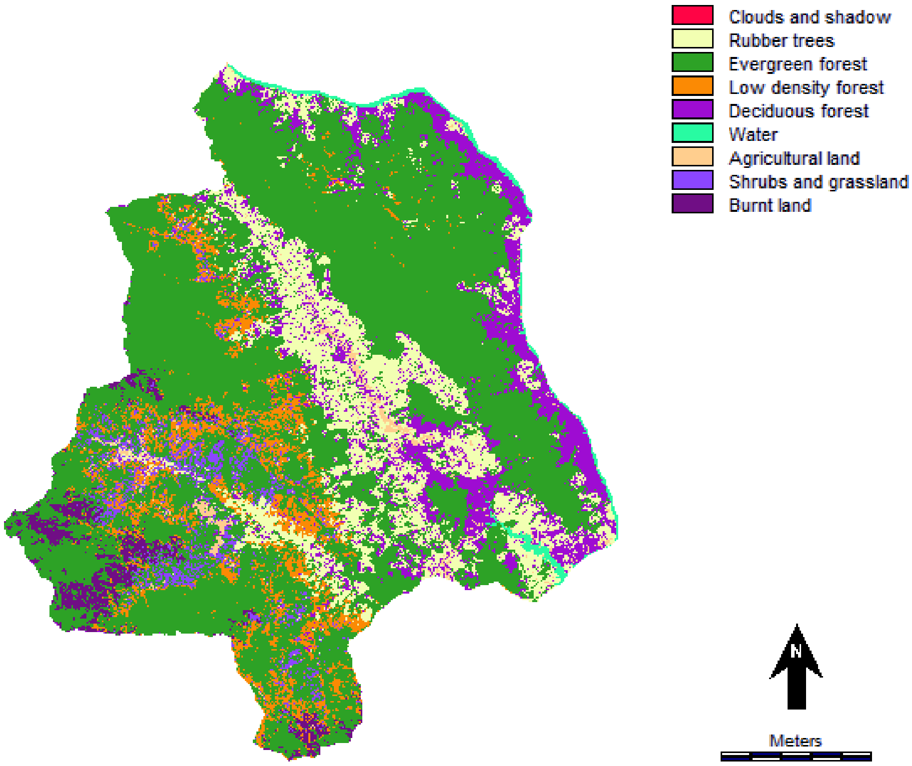

Figure 2.2.39: Prediction with the use of driving variables for the year 2018

Chapter 2.3: Discussion

2.3.1 Change analysis

The NDVI values show that between 1995 and 2003 a large area lot of rubber has been planted. Explanations for this trend can be found in different factors. First of all, the prospect to the Jinghong dam, which was started to build in 2004 and became operational in 2008 (Zhang, 2011), opened the prospect of more water in the valleys. The increase in young rubber trees could originate from this change in bio-physical growth conditions. But also socio-economic drivers can be the cause of the trends in NDVI and rubber planting. In 1998, the NFPP became operational (Li *et al.,* 2007). This plan includes rubber plantations in the definition of forest. The Forestry Law of the People's Republic of China states that forests can be classified in five categories. Rubber plantations are in this law included in “economic forests: woods with the production of fruits, edible oils, drinks, flavorings, industrial raw materials and medicinal materials as the main aim” (china.org.cn). Following Li *et al.* (2009), large amounts of arable land at higher elevations were converted to forest between 1998 and 2003 to meet the objectives of the NFPP.

Further explanation of the trends pertains to the variation of rubber prices. Since 2001 the rubber prices increased strongly and a second increase is noted since 2008 (Figure 2.3.1). This increase was also observed by the farmers. According to farmer interviews, the rubber prices mostly lie around 24 yuan/kg (€2.88). In 2009, the farmers could sell their rubber at the rarely seen price of 33 yuan/kg (€3.96). If these trends in the rubber prices are compared to Figure 2.2.9 (the area of rubber throughout the years), the ‘kickstarts’ in rubber planting (between 1998 and 2003 and between 2004 and 2011) follow the trend of the rubber prices. The steep increase in prices causes the farmers to expand to less suitable sites to plant rubber.

Figure 2.3.1: Rubber prices from 1992 to 2012 (Indexmundi, 2013)

With respect to the relation between rubber and elevation and the relation between rubber and forest ownership rights, it has to be pointed out that the different parts in the study area subjected to certain ownership rights are largely parallel to differences in altitude. The lowest areas, where agriculture was the main activity before the household responsibility system came into use, are now household forest or community forest. The highest areas, which were always forested, are still nationally managed. Due to this interaction it is difficult to know the reasons for change in specific areas. The ideal elevation for rubber trees is not exceeding 200 m (Priyadarshan *et al.,* 2003). However, high yields can also be obtained in marginal sites. Moreover, the use of hybrid clones, more resistant to low temperature, wind, moisture deficit, diseases and also higher altitude is subject of research (Priyadarshan *et al.*, 2003).

In general, the two key periods of rubber planting are thus between 1995 and 2003 and between 2004 and 2011. The trends in landscape metrics in these periods can now be compared to these in the periods of strong rubber expansion. The clearest trends observed are that in periods of rubber expansion, the percentage core area of evergreen forest decreases if compared to the percentage core area in the study area, and both the IJI and the SHEI decrease. Other indices appear to be too dependent on the resolution of the images or show contradictory trends. The decrease in core area of evergreen forest means that the edge effects become stronger and is a clear indicator of forest fragmentation. The decreasing of the IJI indicates that the landscape is 'less intermixed', this means, the class of evergreen forest is more clustered. This could be an indication that rubber expansion causes aggregation of natural versus anthropogenic landscapes. Since the new rubber plantations are mostly small-scale, it is important they are close to urban land. Shoyama *et al.* (2010) conducted research about land cover change and fragmentation in Japan, and found that high values of IJI were observed in periods of both cultivation and reforestation. Interspersion was thus affected by cultivation (increase in agricultural land) and reforestation. They argued that the IJI is therefore not a good pattern metric to describe fragmentation. In the periods of strong rubber expansion, a decrease in the Shannon's evenness index is observed. This means there is a higher dominance of one or some LU/LC classes, or a less evenly divided (among patch types) landscape when rubber becomes more abundant.

2.3.2 Change prediction

The areas in the different LU/LC classes in 2004, 2011, the prediction without the use of driving variables (Figures 2.2.36 and 2.2.37) and the prediction with the use of driving variables (Figure 2.2.38 and 2.2.39) are listed in Table 2.3.1.

Table 2.3.1: Areas (in ha) in the LU/LC classes in 2004, 2011 and the predictions through Markov and in the LCM in 2016 and 2018

	2004 (observed)	**2011 (observed)**	**2016 (without driving variables)**	**2016 (with driving variables)**	**2018 (without driving variables)**	**2018 (with driving variables)**
Clouds and shadow	128	0	0	0	0	0
Rubber trees	2216	3119	3335	3651	3373	3725
Evergreen forest	15267	15994	16379	16116	16448	16061
Low density forest	2838	3056	2430	2035	2221	1953
Deciduous forest	1407	1981	2276	2597	2393	2777
Water	38	307	527	307	616	307
Agricultural land	2126	548	454	415	463	371
Shrubs and grassland	1376	839	561	839	500	839
Burnt land	1407	958	844	842	790	768

From this table, the difference between the two procedures of prediction can be compared. The amount of rubber trees has increased between 2004 and 2011, and increases more in the predictions, both with and without the driving variables. However, when including the driving variables, the expansion is more distinct. The same trend is visible in the class of agricultural land and burnt land: because its area decreased in the first period, it also decreases in the next, and this is more pronounced in the prediction with the driving variables. Evergreen forest increased slightly between 2004 and 2011, as is the case in the predictions, but the increase is lower when including the driving variables. Between 2016 and 2018, the amount of evergreen forest even decreases in the analysis with the driving variables. In this case, the driving forces analysis showed that the change predicted by the Markov procedure was too large. Low density forest expanded between 2004 and 2011. However in the predictions it decreases in area. This is explained by the fact that most of the area changing to low density forest is coming from agricultural land, shrubs and grassland and burnt land. Since these LU/LC classes have decreased between 2004 and 2011, their contribution to the increase in low density forest will also be less. Moreover, these changes are part of the submodel 'shifting cultivation' in the analysis with the driving variables, and this submodel has not been included in the analysis, causing the areas to remain the same in this procedure. For this reason also the area in shrubs and grassland stays the same as in 2011 in the analysis with the driving variables, while in the analysis without the driving variables, the trend observed between 2004 and 2011 is continued. The same is true for the area in water.

In general, it is clear that the analysis in the LCM is more distinct and the changes are bigger. Because it is possible to implement the knowledge from the field and from general knowledge about the driving forces, the prediction can be made with more background and certainty. However, because the two procedures start with a Markov chain analysis, the quantity of change (reflected in the transition probability matrices) is the same for the two procedures. The only difference is found in the next step, namely the translation of the transition probabilities in maps. Because in the LCM this is done for each change separately, and based on the driving forces, the amount of change will differ. The changes that are not included in the analysis in the LCM will also not be recalculated, and thus the area will stay the same (for example shrubs and grassland).

The spatial configuration of the prediction maps with the Markov procedure and in the LCM is quite alike. However, it is clear that the predictions in the LCM are less interrupted, have less of a 'salt and pepper' effect because the distance to disturbance and distances to certain LU/LC categories could be included in the model.

Manandhar *et al.* (2009) performed a study on the LU/LC change in New South Wales, Australia. Therefore, they made a prediction of the LU/LC in 2005 using the LCM in Idrisi, and compared it to a map of the observed LU/LC in 2005. They found significant errors in some areas, which could be attributed to the fact that only historical information can be implemented in the model. Policy changes or other new factors cannot be taken into account in the driving forces analysis. In a quickly changing area such as Xishuangbanna, and in a land with quickly changing policies such as China, this makes LU/LC prediction uncertain.

If no policy changes occur, and the part of the area that is under shifting cultivation stays like that, the most important changes that will occur in the near future are related to rubber expansion in higher regions and increase in secondary forest (deciduous forest), together with a slight decrease in evergreen forest and a drastic agricultural land. Evergreen forest appears to first still increase a little, but quickly reaches its peak in area and starts to decrease.

Attention must also be paid to the alteration of soil physics and chemistry and hydrological aspects. If these alter because of the changes in LU/LC (for example by the increased use of water by the rubber trees), this may influence the future changes in LU/LC. If the increased water use causes the evergreen forest to have less water available, the area could decrease more quickly than predicted. These changes can be linked to the ESS they deliver. In the next chapter, the consequences of these changes on the ESS of the study area will be searched for.

3. Ecosystem services

Chapter 3.1: Materials and methods

3.1.1 Ecosystem services in Xishuangbanna

The Millennium Ecosystem Assessment (MA) is a project of the United Nations, assessing the link between ESS (and the change in ESS) and human well-being. The MA describes an ecosystem as a 'dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit' (Liu, 2005). Ecosystem functions are the processes or properties of ecosystems. The functions that can be beneficial to humans are called Ecosystem services (Constanza *et al.*, 1997). ESS can be divided in provisioning, regulating, cultural and supporting (Liu, 2005). Figure 3.1.1 gives an overview of the ESS and describes the benefits humans receive.

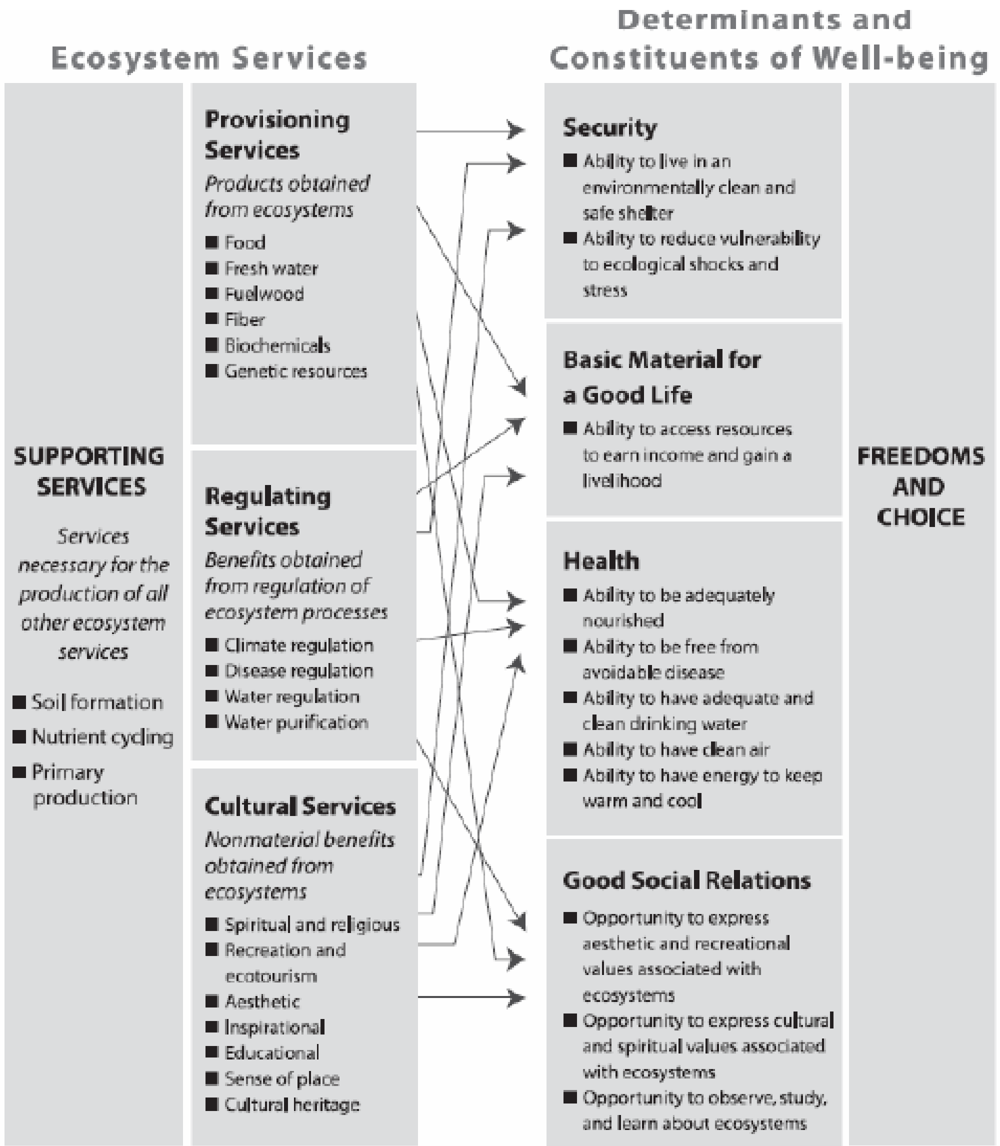

Figure 3.1.1: Ecosystem services and the benefits for humans (Liu, 2005)

ESS can be valuated to quantify the benefit obtained from a certain ecosystem. Economic valuation methods are based on asking people for their willingness-to-pay for the service (stated preference methods) or on estimating the willingness-to-pay based on the relationship between demand and supply (revealed preference methods). The appropriate valuation method is selected in function of the nature of the ESS (Xi, 2009).

Changes in LU/LC imply changes in ecosystems and therefore changes in services delivered. Hence it is useful to map ESS (Burkhard *et al*., 2012). Supply of ESS, delivered by the ecosystem, and demand of ESS, requested by society, can be compared in spatial terms. The visualization hereof on an LU/LC map can be useful for decision makers.

In this research, the main LU/LC changes having an effect on the ESS are deforestation and increase of areas with rubber plantations. The main ESS delivered by Xishuangbanna tropical forest are, according to Xi (2009), the provision of Non Timber Forest Products (NTFP), recreation and tourism, plant genetic resources, agro-biodiversity, climate regulation, water regulation, soil erosion protection, nutrient cycling, micro-climate functions, air purification, pollination, biodiversity, the existence value of the forest itself, and the cultural/spiritual value. The services that are of most importance to this research are the ones that are influenced by rubber plantations. Rubber plantations of course provide raw materials, in the form of rubber. But next to this benefit, which also causes rubber to be economically so advantageous, the impact on other ESS is clear. Xi (2009) reports the impact on water resources, soil erosion, decline in biodiversity, water and soil contamination and a negative impact on pollination and seed dispersal. Hu *et al.* (2008) adds the effect on nutrient cycling and climate regulation.

Forests are often referred to as a 'sponge' due to their water regulating capacity. The effect of deforestation on water resources is dependent on the LU/LC after the conversion, and can be of different forms, both in terms of water quality and water quantity. Water quality may deteriorate due to erosion, sedimentation and nutrient outflow, while water quantity pertains to total water yield, seasonal flow, storm flow response and groundwater recharge.

Different studies were performed, in Xishuangbanna (Xi, 2009), Western China (Liu *et al.*, 2009), South-east Asia (Bruijnzeel, 2004) and in Thailand, Australia and South America (Aylward, 2005). The conclusions can be summarized as follows: downstream sediment levels and outflows of nutrient and chemicals increase when the forest was converted (Aylward, 2005), an increase in total water yield (Aylward, 2005 and Bruijnzeel, 2004), a decrease in the delay in flood peak after a storm event as a result of soil compaction (Liu *et al.,* 2009 and Xi, 2009), a decrease in mean catchment resident times (the time a water molecule stays in the catchment) (Liu *et al.,* 2009), a reduction of rainfall infiltration and hence an increase in the flood potential due to certain LU/LC that induce soil compaction (Bruijnzeel, 2004), and a decrease in replenishment of water in the rainy season with decreased dry season flows as a consequence (Bruijnzeel, 2004 and Xi, 2009). Closely related to the water regulation function is the service of erosion control. Forests serve as a protection layer of the ground, thereby reducing volume and velocity of the rainfall reaching the ground by intercepting rain. The soil is therefore protected from soil loss and runoff, and sedimentation losses are restricted (Xi, 2009). Fertility is maintained because soil loss can imply a loss of N, P, K and organic matter. Therefore, the forest has a function of nutrient cycling (Xi, 2009).

On a more global scale, forests play a role in climate regulation. In 2007, the UN launched the Reduction of Emissions from Deforestation and Land degradation (REDD) program. REDD is aimed at encouraging carbon sequestration by boosting investments in reforestation and forest protection (Xi, 2009). According to Xi (2009), carbon sequestration is the biggest ESS in Xishuangbanna. When forests grow, carbon is removed from the atmosphere. On the other hand, when forests are cleared, the carbon that was stored in the trees is released and when soils are cultivated, the organic matter in the soil decays and is released to the atmosphere (Houghton, 2002). Cotter *et al*. (2009) researched the conversion of forest to rubber plantation and found that rubber plantations act as a sink for carbon dioxide if they are properly managed. However, if forest is cleared to start the plantation, so much carbon is lost that the rubber trees need around 20 years to compensate this. Moreover, the carbon sequestrated in rubber plantations is mainly (57 %) converted in litter that is easily decomposable, causing it to return to the atmosphere quickly (Cotter *et al*., 2009).

3.1.2 Valuation of the ESS in Xishuangbanna

These ESS can now be quantified in terms of economic value. Different techniques exist to valuate the ESS. If the value of an ESS can be calculated accurately, the changes in the value as a consequence of LU/LC can be monitored. The methods can include contingent valuation method, hedonic prices, direct estimation of opportunity costs, replacement costs, cost savings, threshold values, depending on the type of ESS (Xi, 2009).

The value of the biodiversity corridor established between Naban River Nature Reserve and Mangao subreserve was calculated by Xi (2009) in terms of NTFP, climate regulation, water regulation, soil erosion protection, nutrient cycling and air purification.

NTFP include food, medicinal, fuel, materials, oils, orchids and genetic resource products (Liu, 2005). Based on a market analysis, Xi (2009) estimated the value of NTFP on 420 US$ per household per year. Taking into account the number of households living in the corridor (1938), the ESV of NTFP in the corridor was estimated at 813 960 US$/year. Climate regulation consists of the sequestration of carbon and the generation of oxygen. The thus obtained ESS value for CO_2 sequestration in the corridor is 58 983 205 US$. The total ESS value for 0_2 generation for the corridor is 25 216 831 US$. Water regulation consists of quantity and quality aspects. The total ESS values for water quantity and quantity in the Naban-Mangao corridor are respectively 15 449 395 US$ and 28 967 615 US$. The erosion is calculated by calculating the cost of sediment removal from rivers and reservoirs. The value for the ESS of erosion in the corridor is 6 774 164 US$. Nutrient cycling is mostly correlated to losses of N, P, K and organic substance and the associated soil fertility. The total value of this ESS is 35,986,089 US$. Air purification consists of the absorption of harmful gases (for example SO_2, NOx, HF, CL_2) and the reduction of particles and pollutants as well as sterilization, noise reduction, the release of oxygen and terpene materials. The value of air purification in the Naban-Mangao corridor is 28,535,792 US$.

The total value of all these ESS in the corridor is 200 million US$. It is clear that carbon sequestration has the biggest value in this area. Cotter *et al.* (2009) performed a research on the impact of rubber plantations on ESS in China, with special focus on carbon sequestration. They argue that, because of deforestation, large amounts of CO_2 are sent into the atmosphere. In Yunnan, the CO_2 released from the deforestation of one hectare of tropical rainforest is estimated at 438 ton. On the other hand, the rubber plantation replacing the forest sequestrates carbon, estimated at 6.4 ton C / (ha*year) or 23 ton CO_2/ (ha*year), compared to 5.5 ton C / (ha*year) for tropical rainforest. This means that a fully grown rubber plantation needs around 20 years to re-sequestrate the CO_2 released from the deforestation. Hence, if only climate regulation is taken into consideration, after 20 years a net gain can be achieved.

Constanza *et al.* (1997) developed coefficients for the different ESS supplied by each LU/LC class, using demand and supply curves. The coefficients are based on different ecosystem services: Gas regulation, climate regulation, disturbance regulation, water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetic resources, recreation and cultural. The total value of an area can be estimated by formula 3.1.1 (Hu *et al.*, 2008):

$$ESV = \sum (A_k * V_{ck}) \qquad \text{(Formula 3.1.1)}$$

With

ESV the Estimated Ecosystem Service Value

A_k the area of a certain LU/LC class (ha) of the LU/LC class k

V_{ck} the coefficient (US $ / (ha* yr)) for the LU/LC class k

Using this formula, Hu *et al.* (2008) calculated both the total ESV and the ESV for the different ESS separately for Menglun Township. The total ESV dropped from 41.2 million to 29.7 million US $ between 1988 and 2006. The same method was used to calculate the total ESV of Naban River Nature Reserve in section 3.2.1.

Chapter 3.2: Results and discussion

3.2.1 Valuation of the ESS in Naban River Nature Reserve

In Table 3.2.1, the ESV for the year 2004 and 2011 and for the predictions in the LCM of 2016 and 2018 are listed for all LU/LC classes separately. Figure 3.2.1 shows the total ESV from 1975 till 2011 and the predictions of 2016 and 2018.

Table 3.2.1: ESV (US$) for the LU/LC classes for 2004, 2011 and the predictions for 2016 and 2018

	Ecosystem service coefficient (US$/(ha*year)	**Ecosystem service value (US$)**				
			2004	2011	2016	2018
Clouds and shadow	0		0	0	0	0
Rubber trees	315		698169	982447	1150005	1173284
Evergreen forest	2007		30640066	32099757	32345013	32234628
Low density forest	2007		5695705	6134255	4083723	3920293
Deciduous forest	2007		2824551	3975486	5212821	5574402
Water	8498		323491	2612574	2607688	2607688
Agricultural land	92		195582	50452	38151	34100
Shrubs and grassland	232		319320	194761	194759	194759
Burnt land	232		326459	222227	195279	178191
SUM			**41023344**	**46271959**	**45827440**	**45917345**

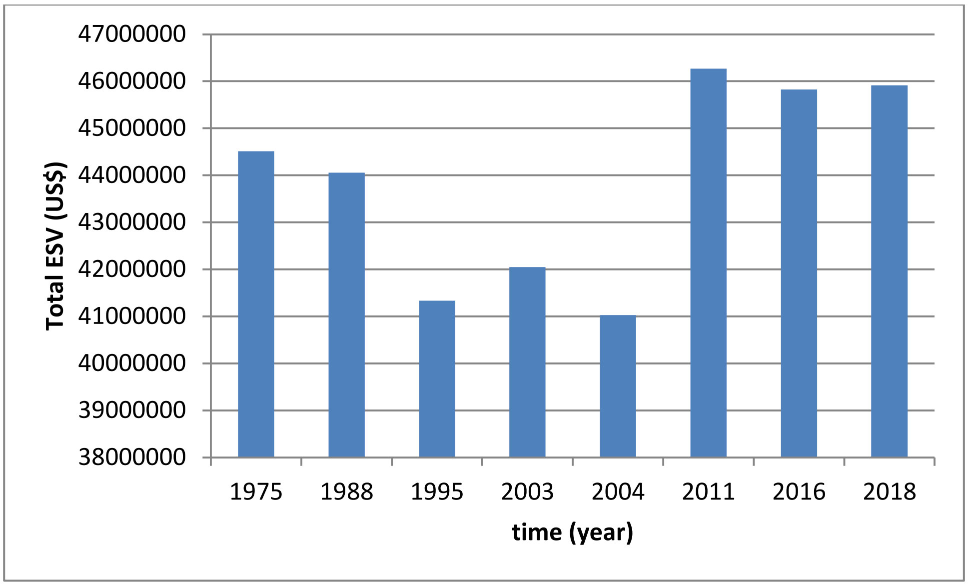

Figure 3.2.1: Total ESV (US$) from 1975 till 2011 and for the predictions of 2016 and 2018

From Figure 3.1.2, a large increase is noticed between 2004 and 2011. If this is compared to Table 3.2.1, it is clear that this increase mainly comes from the increase in area of water, which has a very high ESS coefficient. Between 1975 and 2004, an overall decrease in total ESV is the case. Between 2011 and the predictions of 2016 and 2018, a small decrease is again noticed.

The ESS coefficients for the different types of forest are the same. Constanza *et al.* (1997) did only differentiate between tropical and temperate/boreal forest, and not between primary and secondary forest or between evergreen and conifer forest. However, Xi (2009) used different values for carbon sequestration, because the biomass density is not the same for tropical rainforest as for conifer forest in the same area. Taking this into account, it can be presumed that the actual ESS coefficients differ between forest types and that the coefficients used are strongly simplified.

Conclusions

Based on satellite images and field data, a highly accurate LU/LC map of 2011 was obtained. Time series analysis allowed for the quantification of LU/LC changes between 1975 and 2011. From this time series and the analysis of the NDVI, the most striking observation is that the area that is changing to another LU/LC class becomes larger in the more recent periods. A constant increase in rubber is noticed. This rubber expansion comes at the expense of areas covered by forest as well as agricultural land. From the predictions for 2016 and 2018, it is clear that the area in rubber plantations continues to increase, however at a less rapid rate. Rubber also increasingly occurs at altitudes higher than 800 m above sea level. In these areas however, unfortunately the greatest risks are taken when cultivating rubber. Additionally, colder temperatures at higher altitudes constitute a serious risk for damage to the trees.

During the periods of increase in rubber prices, as compared to other crops, also the greatest expansion in area of rubber plantations is noticed. This can also be linked to the hypothesis that farmers take more risks when prices are higher and when the likelihood of earning more money increases. This is the case between 1995 and 2003, and between 2004 and 2011.

From the pattern metrics it is also clear that the main periods of rubber planting feature the highest level of forest fragmentation. The percentage of core area of evergreen forest decreases and the edge effects become stronger. Apart from that, also the dominance of some LU/LC classes increase.

The value of ecosystem services show a strong increase between 2004 and 2011 following the introduction of the Jinghong dam, resulting in bringing more water in the study area. During the other periods however, an overall decrease in ESS value is noticed.

Overall, rubber expansion as well as forest degradation is obvious during the last decades. These trends are likely to continue in the next years. To be sure about the fact if these changes imply a degradation of ecosystems and a subsequent decrease in ESS value in them, further research is needed.

Further research

The observations from valuating the ESS by the method of Constanza *et al.* (1997) are certainly useful, but should be verified. For example, by valuating the ESS for a larger area, the changes due to the Jinghong dam will influence the results to a lesser extent, so they will be more relevant. Another method (for example the one of Xi, 2009) could also be used to calculate the ESS and to compare the result to the one obtained by the method of Constanza *et al.* (1997). A differentiation should be made between the different types of forest in terms of ESS value. Also, it must be checked if the increase in water causes a proportional increase in ESS.

To be able to also study the ESS in the future, and to manage the area better, more detailed predictions can be made. If the driving variables are defined in more detail and for example climate changes, rubber prices and population changes can be included, a more reliable prediction can be made and reliable projections towards the future can be produced.

Because the expansion in rubber is ongoing, research about how to manage this area is needed. Research on intercropping (for example tea in the understory of rubber plantations) and the effects on ESS (for example hydrology, erosion) and sustainable agriculture in the area can be of great importance. If measures like these don't seem to be enough for the proper management of the area, political as well as economic measures can be taken. The incorporation of economic forests (amongst others rubber plantations) in the Chinese law has a considerable influence on the LU/LC in the area, so research can be focused on scenarios in function of altering this law. On economic basis, the influence of measures like taxes on rubber or subsidies for reforestation, where subsidies are in many cases proven to be more efficient and more easy to control, can be investigated.

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Appendices

Appendix 1: GPS-points used

Latitude	Longitude
2448595	675186
2447906	676827
2449215	675666
2453530	670833
2454367	671483
2454655	672454
2459237	663755
2459119	664271
2458903	664216
2468207	689821
2465875	687789
2486197	676306
2466651	688352
2474106	678791
2490017	682036
2471365	678536
2465973	693227
2459663	674690
2449295	666037
2452346	685745
2472898	685987
2446460	674092
2453777	670359
2452572	672111
2450834	672273
2464608	666215
2464608	666215
2464396	666604
2464316	666836
2464217	667182
2464129	667527
2464056	667671
2464040	667805
2463982	667964
2463962	668052
2463849	668100
2463720	668103
2463680	668052
2463339	668128
2463157	667651

2463124	668191
2463071	667144
2463069	667957
2463059	667621
2463056	668012
2463041	667038
2463036	667409
2463011	667300
2463003	667808
2462973	668227
2462925	667669
2462917	666929
2462890	668302
2462842	666912
2462773	666581
2462720	666768
2462625	666707
2462564	666674
2462377	666649
2462246	666626
2461933	666611
2461926	666611
2461920	666488
2461920	666526
2461903	666435
2461852	666394
2461832	666303
2461698	666261
2461608	666238
2461555	666180
2461539	666054
2461527	666011
2461494	665925
2461464	665905
2461423	665902
2461274	665879
2459500	663015
2459457	663081
2459346	662783
2459228	662364
2458470	667636
2454241	661819
2454092	662470
2454087	662351
2454084	662460

2453880	662798
2453683	662881
2453564	662929
2453509	662990
2453201	663421
2453049	665228
2451944	666806
2451836	666846
2450995	672671
2450980	672704
2450937	672411
2450899	672345
2450882	672189
2450740	671990
2450490	668156
2449380	669425
2448769	670039
2448711	669890
2448640	669721
2448300	669557
2447593	670059
2447149	670803
2447073	670834
2447043	670902