Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 110, No. 1, 2009, pages 9–22

How Do "Renewable Products" Impact Biodiversity and Ecosystem Services – The Example of Natural Rubber in China

M. Cotter *[1], **K. Martin** [1] and **J. Sauerborn** [1]

Abstract

This paper aims to present the implications brought by the expansion of "renewable products" plantation systems in the tropics with cultivation of rubber (*Hevea brasiliensis*) as a main focus. Throughout South East Asia, natural forest is being replaced by rubber or oil palm (*Elaeis guineensis*) plantations, with severe consequences for the local flora and fauna. Main aspects of this review are: i) The provision of an overview over renewable resources in general and rubber in particular, with eco-physiological and agronomical information concerning rubber cultivation. ii) The effect of rubber plantations on biodiversity and species composition under different rubber farming approaches. In addition we debate the possible influences of such large scale land cover transformations on ecosystem services. iii) The conversion of natural forests into rubber plantations releases considerable amounts of carbon dioxide into the atmosphere. We estimated these values for different land cover types in southern China and assessed the carbon sequestration potential of local rubber plantations.

Keywords: biodiversity, renewable products, rubber, ecosystem services, carbon sequestration, ecophysiology

1 Introduction

Ever since, mankind has been dependent on natural resources. From the timber used to build houses to the materials for clothing or the construction of tools, most of these were renewable products obtained from the direct environment. These days, with fossil fuels and minerals to be on the decline, the large scale use of renewable resources is given an increasing degree of importance for a fast-growing human population.

The natural forests of the humid tropics are particularly rich in flora and fauna forming several hotspots of biodiversity. In South East Asia's forests, deforestation rates are highest, mainly because of an increasing agricultural expansion in order to meet the economic and nutritional needs of a growing population. Two of the main contributors are rubber and oil palm plantations. The bulk of rubber plantations in the Greater

---

* corresponding author: Cotter@uni-hohenheim.de

[1] Dipl.-Biol. Marc Cotter, Dr. rer. nat. Konrad Martin, Prof. Dr. Joachim Sauerborn, University of Hohenheim, Institute for Plant Production and Agroecology in the Tropics and Subtropics, 70593 Stuttgart, Germany

Mekong Subregion replace primary and secondary natural forest, threatening the unique wildlife and disturbing ecosystem services.

In this article, we highlight the possible impacts of large scale use of renewable products with the example of rubber cultivation in South East Asia, especially in southern China. Of particular interest are the implications of the replacement of tropical rainforest by rubber plantations concerning biodiversity, ecosystem services and carbon sequestration potential.

2 Renewable Products

The world demand for renewable resources is constantly growing because of an increasing need by a rising human population. Renewable resources are defined as materials produced by living organisms (plants, animals, microbes) used for purposes other than food and feed. Such materials include timber, natural fibre, oil and grease, sugar, starch, natural rubber, colorants, pharmaceuticals, and others containing special substances like resin, tannin, wax and/or natural protective compounds against pests and diseases (Tab. 1).

Table 1: Selected tropical plants for industrial and energetic use

Plant	*Raw material*	*Final product*
Tectona grandis (Teak) *Swietenia* spp. (Mahogany) *Shorea laevis* (Yellow Balau)	timber	construction wood, furniture, toy, veneer, paper
Agave spp. (Sisal) *Gossypium* spp. (Cotton) *Corchorus* spp. (Jute)	natural fibre	textile, packaging material, carpet, yarn, rope, sack, paper
Elaeis guineensis (Oilpalm) *Butyrospermum parkii* (Shea nut) *Ricinus communis* (Castor oil)	oil	cosmetics, pharmaceuticals, hydraulic fluid, detergent, biodiesel
Saccharum officinalis (Sugarcane) *Siraitia grosvenorii* (Arhat fruit)	sugar	ethanol fuel, pharmaceuticals, cosmetics
Manihot esculenta (Cassava) *Dioscorea* spp. (Yam)	starch	ethanol fuel, pharmaceuticals, detergent
Hevea brasiliensis (Rubber) *Parthenium argentatum* (Guayule) *Manilkara bidentata* (Balata)	natural rubber	tyre, condom, mattress, rubber profile, conveyor belt
Bixa orellana (Annatto) *Lawsonia inermis* (Henna)	colouring	colour, dyeing of leather, hair, fingernails, etc.
Cinchona spp (Quinine) *Rauvolfia serpentine* (Indian Snakeroot) *Zingiber zerumbet* (Ginger)	bioactive chemicals	pharmaceuticals

The cultivation of these renewable resources can contribute substantially to the improvement of a local and regional economic situation but it can also result in biodiversity loss and environmental degradation.

3 Natural rubber as a renewable resource

Natural rubber extracted from the tree *Hevea brasiliensis* (Willd. Ex A. Juss.) Muell. Arg. distinguishes itself from all other raw materials, for it is elastic and at the same time reversible and hence inimitable. To gain rubber the bark of the rubber tree is cut so as to collect the latex, a milky sap from the latex vessels localised in the inner bark. Latex is an emulsion that contains e.g. water, proteins, resins, tannins, and rubber in varying quantities. The Mayas called the tree "Caa-o-chu", that means "weeping tree" (Tab 2).

Table 2: Characteristics of the rubber tree

Name:	natural rubber
scientific name:	*Hevea brasiliensis* (Willd. Ex A. Juss.) Muell. Arg.
family:	Euphorbiaceae
habitus:	tree (may reach heights of more than 20 m within a forest)
fertilisation:	mainly allogamy by small insects such as midges and thrips, autogamy occurs to various degrees
centre of origin:	Amazon basin in South America
natural range:	humid tropics
propagation:	vegetative
first harvest:	5 – 7 years after planting
economic life span:	about 30 years
production unit:	plantation / family farming
predominant constituent harvested:	latex, timber
actual yield of dry rubber:	$\sim 3 - 4.5$ kg tree^{-1} year^{-1}
potential yield of dry rubber:	about 8.5 kg tree^{-1} year^{-1} (Ong *et al.*, 1994)
major disease:	South American leaf blight of rubber (*Microcyclus ulei* (Henn.) Arx

Not until industrialisation, natural rubber became a basic material. Nowadays, it provides the basis for many high-performance products which we come across in cars, trains, airplanes and ships, in engines and industrial plants. Wherever elastic motion is required and where it is essential to seal, convey, mount, insulate, transmit power or to damp vibration, rubber is of importance.

4 Ecophysiology of Natural Rubber

Hevea brasiliensis is a tropical tree. It grows best at temperatures of 20 – 28°C with a well distributed annual precipitation of 180 – 200 cm. Traditionally, *H. brasiliensis* has been cropped in the equatorial zone between 10°N and 10°S. Urged by a growing world demand rubber has now spread successfully to the latitudes 23°N (China) and 21°S (Brazil) and is cultivated up to 1200 m above sea level (Tab. 3).

Table 3: Characteristics for suitable cultivation of Hevea brasiliensis

	Minimum	*Optimum*	*Maximum*
mean temperature (°c)	< 20	25 – 28	34
mean precipitation (cm)	< 150	200 – 250	400
rainy season (months)	9	11 – 12	-
moisture deficits (months)	-	0	> 3
sunshine (hours d^{-1})	3	6	> 7
water logging	-	none	3 days
rooting depth (cm)	> 50	> 150	-
pH	< 3.5	4 – 5	> 6
soil carbon (%)	> 0.5	> 2.5	-
soil fertility	low	very high	-

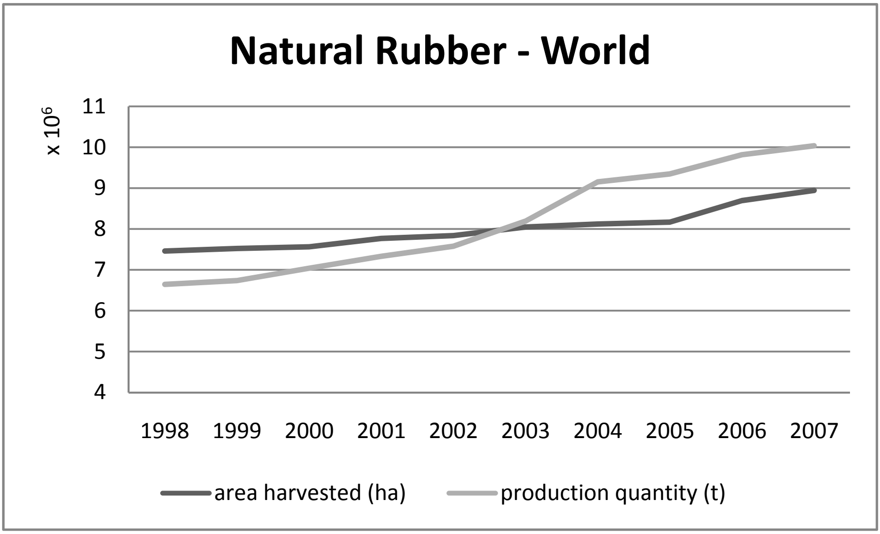
Today, natural rubber provides about 40% of the world rubber demand and is used in the manufacture of over 40,000 products (Ray, 2004). Synthetic rubber, invented at the beginning of the 20th century, covers about 60 % of the current consumption. The world production of natural rubber is constantly growing from about 2 million tons in the 1960s to more than 10 million tons in 2007 (FAOSTAT, 2008) (Fig. 1).

In its centre of origin, the Amazon basin, H. brasiliensis is consistently endangered by the fungus Microcyclus ulei (South American leaf blight of rubber). The pathogen so far inhibits plantation growth of rubber trees in South America (Lieberei, 2007). Beneficiaries of this situation are located in South East Asia where the fungus has not spread to date. Thailand, Indonesia and Malaysia are the main rubber producers followed by Viet Nam and China (FAOSTAT, 2008) (Tab. 4).

Table 4: Major natural rubber producers of the world (data of 2007)

Country	*Area harvested (1000 ha)*	*Yield (t ha^{-1})*	*Production quantity (1000 t)*
China	475	1.1	545
Indonesia	3175	0.8	2540
Malaysia	1400	0.9	1270
Thailand	1763	1.7	3122
Viet Nam	512	1.0	550

Figure 1: Natural Rubber – World (Source: FAOSTAT, 2008)



Microcyclus ulei remains the Achilles' heel of natural rubber production. Not only that its introduction to South East Asia would cause an economic loss to the producers but it would precipitate a crisis within the many industries (medical, transportation, defence, etc.) which are dependent on natural rubber in the manufacturing of their commodities.

Rubber production systems and the conservation of natural biodiversity Natural forest vegetation in the humid tropics is dwindling in an alarming rate, and the loss of biodiversity due to the decline of such habitats is a well-known fact. The level of deforestation in SE-Asia is the highest among tropical areas (Sodhi *et al.*, 2004). The major reason for this is the increasing agricultural expansion, especially due to oil palm and rubber cultivation.

The expansion of rubber plantations in SE-Asia largely takes place by the reduction of primary and secondary natural forest areas. The loss of natural forests is especially serious in the major rubber production areas of Asia, because they are located within the so called Indo-Burma hotspot, one of the 34 global biodiversity hotspots identified by Conservation International (2007). This region largely corresponds with the Lower Mekong catchment area and also includes parts of southern and western Yunnan as well as southern Chinese offshore islands such as Hainan.

The replacement of any type of forest by a rubber monoculture results in a reduction of natural tree species diversity to zero, because the rubber tree is not even native to that region. Many studies also confirm significant reductions of fauna in plantations compared to natural forest. For example, Danielsen and Heegaard (1995) found that conversion of primary forest to rubber and oil palm in Sumatra led to simple, species-poor and less diverse animal communities with fewer specialized species and fewer species of importance to conservation. In the plantations, only 5-10% of the primary-forest bird species were recorded. Primates, squirrels and tree-shrews disappeared except for one species. Similarly, Peh *et al.* (2005) found reductions in primary-forest species of more than 70% in such habitat types in Malaysia.

There are two approaches to reduce biodiversity losses in rubber and other types of monoculture plantations. The first is the diversification in terms of plant species richness and vegetation structure of the plantation itself, and the other is the preservation of landscape diversity, specifically the maintenance of natural forest patches within plantation areas.

Diversification of rubber plantations is realized in a variety of cropping systems. From southern Yunnan (China), Wu *et al.* (2001) classified the existing rubber plantations into four types. These are

(a) monoculture rubber, representing the most common type,

(b) temporarily intercropped rubber plantations, with annual crops (e.g. upland rice, corn pineapple, passionflower) established between young rubber trees before canopy closing,

(c) rubber plantations of multiple species and layers of shrubs and perennial herbaceous plants such as tea, coffee, cardamom and vanilla, and

(d) mixed rubber plantations based on the principles of traditional home garden systems with perennial plants including tea, coffee, fruit trees bamboo and bananas, which are mainly established in aging rubber plantations.

In this sequence, there is an increase in structural as well as plant diversity, but most or all of these plant species do not represent natural forest species. Although no studies on faunal diversity have been conducted in these types of plantations, it can be expected that it is still very low and do not support significant numbers in forest species. In terms of plant species diversity and structure, such polyculture systems are probably similar to the mixed-rural landscapes in Malaysia, consisting of agricultural land, oil palm, rubber and fruit tree stands (Peh *et al.*, 2005).

More complex and more diversified is the so-called "jungle rubber", "rubber garden" or "rubber agroforest" system of Indonesia, specifically Sumatra and Kalimantan. It can be defined as a balanced, diversified system derived from swidden cultivation, in which man-made forests with a high concentration of rubber trees replace fallows. Most of the income comes from rubber, complemented with temporary food and cash crops during the early years (Gouyon *et al.*, 1993). In its structure, they resemble secondary forest with wild species tolerated by the farmer.

Beukema *et al.* (2007) compared plant and bird diversity of the Indonesian jungle rubber agroforestry system to that of primary forest and pure rubber plantations. They found that species richness in jungle rubber was slightly higher (in terrestrial pteridophytes) similar (in birds) or lower (in epiphytes, trees and vascular plants as a whole) than in primary forest. For all groups, species richness in jungle rubber was generally higher than in rubber plantations. The authors conclude that the jungle rubber system does support species diversity in an impoverished landscape increasingly dominated by monoculture plantations. From a more specific study on terrestrial pteridophytes (ferns and fern allies) in jungle rubber and primary forest, Beukema and van Noordwijk (2004) conclude that jungle rubber systems can play a role in conservation of part of the primary rain forest species, especially in areas where primary forest has already disappeared.

Of economic reasons, however, the most common type of rubber cultivation is the monoculture system. In such landscapes, natural biodiversity can only be conserved in remaining plots of natural vegetation, which should be preserved as reservation areas. Several aspects of this approach needed to be considered for practical implementations (Debinski *et al.*, 2001):

(a) The frequency and spatial distribution of habitat fragments and patches determines species distribution patterns.

(b) Species populations may be separated on patches of their habitat within a landscape of less suitable habitat, and

(c) Species dispersal patterns may interact with patch size and patch context to determine species distributions within and among patches ("patch context" describes the habitat type adjacent to a patch)

Derived from this, a concept for measuring landscape structure has been developed, named "landscape connectivity" (Merriam, 1991). It describes the degree to which the landscape facilitates or impedes movement of species populations among habitat or resource patches. An important question related to this is whether the size and structure of the landscape matrix acts as a corridor or barrier between patches.

All these points also apply to forest patches within monoculture rubber plantations. However, no study dealing with matrix effects on species movements in such landscapes has been conducted so far. Specifically, there is no information on the arthropod diversity of rubber plantations in comparison to forests. In order to develop species conservation concepts in rubber dominated landscapes, research needs to address this question.

5 Ecosystem Services

Ranging from the provision of clean drinking water to the pollination of fruit crops, mankind is deriving benefits from a wide array of processes and interactions that take place in our environment. These services are vital to the functioning of our ecosystems, and vital to the livelihood of men, as they provide not only the basis for human life, but also additional attendances like food and health security or cultural and spiritual values. The total amount of these services can only be estimated, but cautious predictions state a yearly value of 33 trillion (10^{12}) US$ (Costanza *et al.*, 1997; Eamus *et al.*, 2005).

Generally, ecosystem services can be grouped into four categories. (1) Provisioning services that include goods taken from the ecosystem like food, fiber, fuel, genetic resources, fresh water and biochemicals. (2) Regulating services take place on a more global scale; they include climate regulation, pest and disease regulation, natural hazard protection, water purification. (3) Cultural services include recreation and aesthetic values, knowledge system, spiritual and religious values. (4) Supporting services comprise soil formation and retention, provision of habitat, primary production, water and nutrient cycling (Millennium Ecosystem Assessment, 2005).

Ecosystem goods and services are in danger as the human impact on the environment is constantly increasing (IPCC, 2007). Deforestation and the increase of agricultural areas, water pollution and rising fresh water demand, degradation and unsustainable use have put many ecosystems on the brink of collapse.

6 Impacts of rubber cultivation on ecosystem services

In South-East Asia large areas of natural vegetation with their plentiful diversity of flora and fauna have been put under great pressure from the establishment of plantations. Rubber is playing a great role in this process, as the anticipated revenues are appealing to farmers and policy makers alike. In China's Yunnan province, more than 11% of the total area is covered with rubber (Li *et al.*, 2007), but there are townships where rubber cultivation contributes to more than 45% of the land cover (Hu *et al.*, 2007). For one of these townships, Menglun, Hu *et al.* (2007) estimated the value of ecosystem services provided. According to this report covering land use change over a period of 18 years, the total value of ecosystem services dropped by US$ 11.4 million (28%). The services most affected were nutrient cycling, erosion control and climate regulation. The biodiversity service of "habitat/refugia" had not been covered, but considering the detrimental effect of monoculture plantation systems on species richness and the corresponding ecosystem services, the total value of ecosystem services for the research area can be expected to be even lower than reported.

This effect seems to be alleviated by the fact that the townships gross domestic product increased, leading to a ratio of 1:1.39 for increase in GDP to loss of ecosystem services in US$ (Hu *et al.*, 2007).

7 Deforestation due to rubber expansion

The increasing demand for natural rubber products has lead to a wide spread replacement of natural forest vegetation with rubber. Li *et al.* (2007) states that, between 1976 and 2003, tropical seasonal rain forest in Yunnan was reduced by 67%, mainly due to the planting of rubber. Lowland rain forests are the most affected forest types due to the climatic needs of the rubber tree. But also mountain rainforests and other forest communities of higher elevations are seriously under pressure, as agricultural production shifts into these regions.

According to the recommendations given by the International Panel of Climate Change (Houghton *et al.*, 1997) as used by Germer and Sauerborn (2007), we assessed the potential amounts of carbon and carbon dioxide emission that are expected when preparing land for the conversion into rubber plantations.

Again, the data from the Yunnan Institute of Forest Inventory and Planning Li *et al.* (2008) served as a basis for our biomass assumptions. As basis for the distribution of below to above ground biomass, we used a BGB to AGB ratio of 1:1.13 as given by the HOUGHTON *et al.* (1997).

For the emission of CO_2 during decomposition, we assume that after 30 years under humid subtropical conditions, all cleared biomass, above and below ground, will be decomposed. HOUGHTON *et al.* (1997) suggests a vegetation independent forest carbon stock estimate of 50% of the biomass. Carbon (12 g/mol) will mostly be released as carbon dioxide (44 g/mol). One ton of cut forest biomass would release 0.5 t of carbon through decomposition, resulting in the emission of 1.8 t CO_2.

As an example, the average carbon content of one hectare of undisturbed tropical seasonal rainforest in Yunnan was reported to be 121.74 t, which is an estimated 243.5 t of biomass, assuming a forest stock carbon content of 50% (HOUGHTON *et al.*, 1997). The complete decomposition of this amount would lead to the emission of (243.5 t × 1.8) = 438.3 t CO_2.

Table 5: Emission of CO_2 equivalents by forest clearing.

	Carbon content (t ha^{-1})	*Above ground biomass (t ha^{-1})*	CO_2 *emissions decomp. (t ha^{-1})*
TSRF	121.74	212	438
TSRF anth.	75.17	131	271
SEBF	105.24	183	379
SEBF anth.	71	124	256
Grass	5.32	4.4	19.2
Shrub	14.56	25.3	52.4

TSRF: tropical seasonal rainforest; *SEBF*: subtropical evergreen broadleaf forest (57% of Yunnan forests); *TSRF anth.*, *SEBF anth.* both with strong anthropogenic influences (e.g. selective logging); *Grass*: grassland, *Shrub*: shrubland. Carbon content values from LI *et al.* (2008), other values calculated following IPCC guidelines.

8 Carbon sequestration potential of rubber

Properly managed rubber plantations that are supplied with sufficient amounts of fertilizer have a high potential to act as a continuous sink for atmospheric carbon dioxide (CHENG *et al.*, 2007). This is mainly due to their high sequestration rates and the fact that there is a constant export out of the production system by means of tapping.

CHENG *et al.* (2007) reported a 30 years lifetime carbon sequestration of 272 t C ha^{-1} in rubber plantations on the island of Hainan. Comparing this to the sequestration rates of rain forests and secondary forests on Hainan, 234 and 150 t C ha^{-1} over the same period, the high productivity of a rubber plantation becomes discernable. Nevertheless, more than 57% of the sequestrated carbon ends up in easily decomposed litter. This decomposition process returns considerable amounts of carbon back to the atmosphere, up to fifty percent of the total carbon content in the first year (ANDERSON and SWIFT, 1983).

Based on the equation used by CHENG *et al.* (2007), we were able to derive carbon sequestration values for rubber plantations (C_R) in Yunnan province, China's second biggest rubber producer. We can calculate C_R as:

$$C_R = C_{Bi} + C_{La} + C_{Li},$$

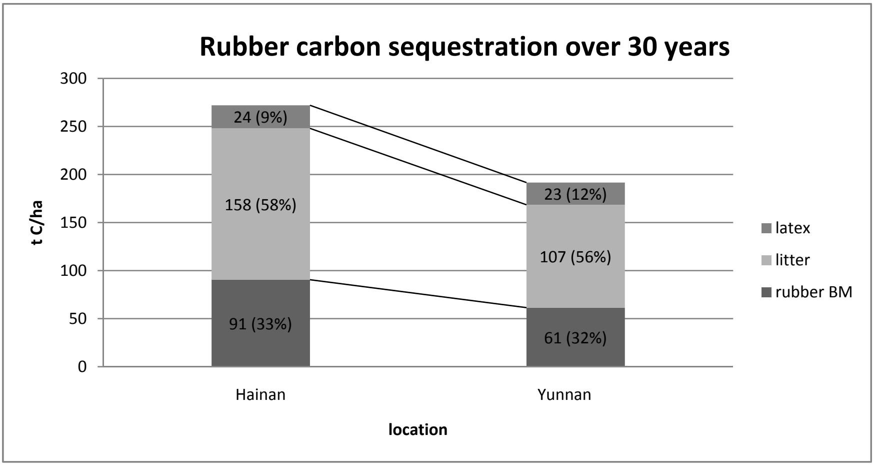
with the carbon content of biomass (C_{Bi}), carbon content of latex yield C_{La}, and the carbon content of litter (C_{Li}).

Data from the Yunnan Institute of Forest Inventory and Planning published by LI *et al.* (2008) were used to obtain information about local forest biomass and its carbon content ($C_{Bi} =$ 61.48 t C ha^{-1} for rubber plantations below 800m).

The amount of sequestrated carbon that is removed from the field during latex tapping was estimated by multiplying average values of latex carbon content by latex yield per hectare (FAOSTAT, 2008) by the economic lifetime of a rubber plantation in years (C_{La}). Due to suboptimal climate conditions rubber tapping in Yunnan usually begins seven years after establishment of the plantation, in comparison to an average of five years reported for Hainan. This results in a slightly lower average economic lifetime. In order to estimate the amount of litter produced over 30 years we proportionally adjusted the values for Hainan litter biomass per hectare to the lower total biomass of Yunnan rubber plantations (C_{Li}).

Based on these calculations, the estimated carbon sequestration during a 30 years lifetime for rubber plantations below 800m elevation in Yunnan province is 192 t C ha^{-1}, which consists of an estimated litter mass of 107 t C ha^{-1} and a latex output of 23 t C ha^{-1}.

Figure 2: Total carbon sequestration by rubber over 30 years per hectare. Total values are divided into latex production, litter production and rubber biomass (non-litter)



These estimates do not consider the soils potential to release and sequestrate carbon under different management regimes. In this context, the dynamics of carbon cycling regarding the substantial amounts of litter produced by rubber plantations should be put to further investigation, as these results could lead to a clearer picture of the overall carbon sequestration potential of rubber.

9 CO_2 balance in plantation establishment

During its lifetime of 30 years, a rubber plantation in Yunnan province can sequester an estimated 192 t of carbon or 703 t CO_2 per hectare (based on an atomic weight ratio of 1:3.66). Plantations in Hainan province can be expected to achieve about 272 t of C sequestration, mostly due to their higher biomass and litter production. These values are, as stated above, comparable to the 30 years sequestration potential of Hainan rainforests.

When comparing these vegetation types concerning their CO_2 balance, one decisive fact has to be considered. Rubber plantations are man-made ecosystems which replace local floral communities entirely. In most cases, this is done by clearing the forest for the plantation establishment.

Based on our estimates, if one hectare of relatively undisturbed tropical seasonal rainforest in Yunnan province is cleared, this process releases about 438 t of CO_2 into the atmosphere. A fully grown rubber plantation on the same spot would need around 20 years to re-sequester this amount of CO_2 . Although after several decades a net gain in carbon fixation could be achieved, the loss in biodiversity and ecosystem resources would be persistent.

Table 6: Carbon sequestration over 30 years and annually

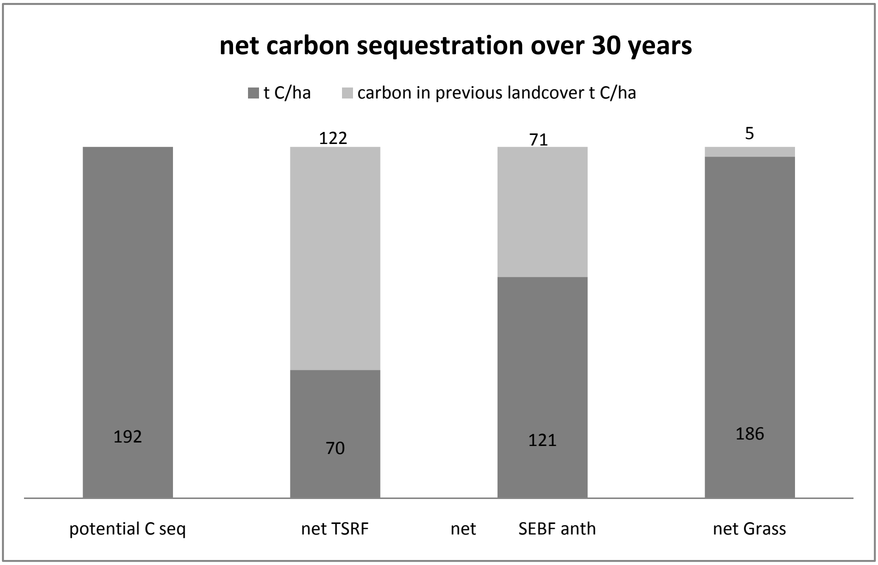
		Rubber	*Rainforest*	*Secondary*
Hainan				
	C_{seq}30 ha^{-1}	272 t	234 t	150 t
	av. C_{seq} a^{-1} ha^{-1}	9.1 t	7.8 t	5.0 t
Yunnan				
	C_{seq}30 ha^{-1}	192 t	165 t est.	106 t est.
	av. C_{seq} a^{-1} ha^{-1}	6.4 t	5.5 t est.	3.3 t est.

Carbon sequestration rates per hectare over 30 years and annual average. Data for Hainan were published by CHENG *et al.* (2007); values for Yunnan Rainforest and Secondary forest were derived proportionally from Hainan sequestration rates and Yunnan biomass values.

10 Rubber and grassland rehabilitation

In order to find more sustainable locations for the establishment of rubber plantations, disturbed ecosystems like degraded grassland and abandoned fallows from swidden agriculture could be used. These land uses are rather scarce in the elevation levels that are suitable for rubber plantation in Yunnan province, but nevertheless it is a promising concept for other regions nearby. All throughout the tropics and subtropics, the transformation of agricultural areas to grassland ecosystems is a common problem. These areas are often dominated by very competitive grass species that effectively prevent natural succession into secondary woodlands and forests. The conversion of these land use types into rubber plantations would not only increase the farmers' welfare but also secure important ecosystem services that grassland and fallows have difficulties to provide (LI *et al.*, 2008). In addition, the establishment of plantations on these degraded areas would emit decisively less carbon dioxide than the conversion of forests. CO_2 release into the atmosphere during land preparation is estimated to amount to about 110 t ha^{-1} for shrubland in Yunnan, and 19 t ha^{-1} for grassland, in comparison to the 438 t ha^{-1} for Yunnan seasonal rainforest. Compared to the values reported above, this would lead to a faster and significantly higher net gain in CO_2 sequestration by rubber plantations when used to rehabilitate grassland. Similar results have been published for oil palm plantations (GERMER and SAUERBORN, 2007).

Figure 3: Carbon sequestration by rubber grown below 800 masl. over a period of 30 years in Yunnan province, compared to net carbon sequestration considering the release of CO_2 during plantation establishment. C seq. is the estimated carbon sequestration potential of rubber (above); previous land cover: TSRF is tropical seasonal rainforest, SEBF anth is subtropical evergreen broadleaf forest with anthropogenic influence and Grass is grassland.



References

Anderson, J. M. and Swift, M. J.; Decomposition in tropical forests; in: *Tropical rain forest: ecology and management*, edited by Sutton, S. L., Whitmore, T. C. and Chadwick, A. C.; 287–309; Blackwell, Oxford, UK; 1983.

Beukema, H., Danielsen, F., Vincent, G., Hardiwinoto, S. and van Andel, J.; Plant and bird diversity in rubber agroforests in the lowlands of Sumatra, Indonesia; *Agroforestry Systems*; 70:217–242; 2007.

Beukema, H. and van Noordwijk, M.; Terrestrial pteridophytes as indicators of a forest-like environment in rubber production systems in the lowlands of Jambi, Sumatra; *Agriculture, Ecosys. Environ.*; 104:63–73; 2004.

Cheng, C., Wang, R. and Jiang, J.; Variation of soil fertility and carbon sequestration by planting Hevea brasiliensis in Hainan Island, China; *J. Environm. Sci.*; 19(3):348–352; 2007.

Conservation International; Biodiversity Hotspots - Indo-Burma; 2007; URL `http://www.biodiversityhotspots.org/xp/hotspots/indo_burma/`.

Costanza, R., D'Arge, R. and de Groot, R.; The value of the world's ecosystem services and natural capital; *Nature*; 387:253–260; 1997.

Danielsen, F. and Heegaard, M.; Impact of logging and plantation development on species diversity – a case study from Sumatra; in: *Management of tropical forests: towards an integrated perspective*, edited by Sandbukt, O.; 73–92; Centre for Development and the Environment, University of Oslo, Norway; 1995.

Debinski, D. M., Ray, C. and Saveraid, E. H.; Species conservation and the scale of the landscape mosaic: do scales of movement and patch size affect diversity?; *Biodiv. Conserv.*; 98:179–190; 2001.

Eamus, D., Macinnis-Ng, C. M. O., Hose, G. C., Zeppel, M. J. B., Taylor, D. T. and Murray, B. R.; Ecosystem services: an ecophysiological examination; *Austr. J. Bot.*; 53(1):1–19; 2005.

FAOSTAT; 2008; URL `http://faostat.fao.org/site/567/default.aspx`.

Germer, J. and Sauerborn, J.; Estimation of the impact of oil palm plantation establishment on greenhouse gas balance; *Environment, Development and Sustainability*; 10(6):697–716; 2007.

Gouyon, A., de Foresta, H. and Levang, P.; Does 'jungle rubber' deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra; *Agroforestry Systems*; 22(3):181–206; 1993.

Houghton, J. T., Meira Filho, L. G., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D. J. and Callender, B. A., (Eds.) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories - Workbook (Volume 2)*; IPCC-NGGIP/OECD/IEA; 1997; URL `http://www.ipcc-nggip.iges.or.jp/public/gl/invs5.html`.

Hu, H., Liu, W. and Cao, M.; Impact of land use and land cover change on ecosystem services in Menglun, Xishuangbanna, Southwest China; *Environmental Monitoring and Assessment*; 146:147–156; 2007.

IPCC; Technical summary; in: *Climate change 2007 – The physical science basis*; Cambridge University Press, Cambridge UK, and New York, USA; 2007.

Li, H., Aide, T. M., Ma, Y., Liu, W. and Cao, M.; Demand for rubber is causing the loss of high diversity rain forest in SW China; *Biodiv. Conserv.*; 16:1731–1745; 2007.

Li, H., Ma, Y., Aide, T. M. and Liu, W.; Past, present and future land-use in Xishuangbanna, China and the implications for carbon dynamics; *For. Ecol. Manag.*; 255:16–24; 2008.

Lieberei, R.; South American leaf blight of the rubber tree (*Hevea* spp.): New steps in plant domestication using physiological features and molecular markers; *Annals of Botany*; 100:1125–1142; 2007.

Merriam, G.; Corridors and connectivity: animal populations in heterogenous environments; in: *Nature conservation 2: The role of corridors*, edited by Saunders, D. A. and Hobbs, R. J.; 133–142; Surrey Beatty & Sons, Chipping Norton, Australia; 1991.

Millennium Ecosystem Assessment; *Ecosystems and human well-being: Synthesis*; Island Press, Washington D.C., USA; 2005.

Ong, S. H., Ramli, O., Othman, H., Mesahuling, B. and Naimah, I.; Rubber breeding progress and strategies to meet the future needs of the plantation industry; in: *Management of enhanced profitability in plantations*; 53–70; Incorporated Society of Planters, Kuala Lumpur, Malaysia; 1994.

Peh, K. S., De Jong, J., Sodhi, N. S., Lim, S. L. and Yap, C. A.; Lowland rainforest avifauna and human disturbance: persistence of primary forest birds in selectively logged forests and mixed-rural habitats of southern Peninsular Malaysia; *Biol. Conserv.*; 123:489–505; 2005.

Ray, D. T.; Natural Rubber; in: *Encyclopedia of Plant and Crop Science*; 778–780; Marcel Dekker Inc. NY, USA; 2004.

Sodhi, N. S., Koh, L. P., Brooke, B. W. and Ng, P. K.; South East Asian biodiversity: an impeding disaster; *Trends Ecol. Evol.*; 19:654–660; 2004.

Wu, Z. L., Liu, H. M. and Liu, L. Y.; Rubber cultivation and sustainable development in Xishuangbanna, China; *Intern. J. Sust. Develop. World Ecol.*; 8:337–345; 2001.