Carbon Sequestration of Rubber (*Hevea brasiliensis*) Plantations in the Naban River Watershed National Nature Reserve in Xishuangbanna, China

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Introduction

Deforestation and land use change are responsible for large offsets of carbon to the atmosphere, which is considered as a major contributor to the current climatic variability and climate change (FAO, 2010 AND BERNSTEIN ET AL., 2007). The study site that was selected to evaluate the impacts of land use change on carbon sequestration is the Naban River Watershed National Nature Reserve (NRWNNR) that is located in the Dai Autonomous Prefecture of Xishuangbanna in Yunnan province, which lies in southwest China. The NRWNNR is hilly and lies between 500 and 2304 m.a.s.l. (LI ET AL., 2008). Compared to traditional rubber cultivation areas, it has overall unfavourable climatic conditions regarding lower average annual temperatures at medium (680 to 800 m.a.s.l.) and high (870 to 1050 m.a.s.l.) elevations, lower and irregular rainfall, lower atmospheric humidity during the dry season, and higher elevation (TUTIEMPO AND GUARDIOLA CLARAMONTE ET AL., 2010). Despite this, over 10% of the NRWNNR is covered by rubber (*Hevea brasiliensis*) plantations. The largest perennial land uses are rubber and primary and secondary forests, and therefore the largest contributors to carbon sequestration. The largest annual land uses include paddy rice and maize (COTTER, 2011); however, their carbon sequestration capacity is much lower than in the perennials. Land use change in the area is strongly driven by the fast rate of rubber expansion, whereby rubber mainly replaces primary and secondary forests (FOX ET AL., 2009 and COTTER, 2011). The carbon sequestration potential in Xishuangbanna is changing as a result of the area's land use change (YANG ET AL., 2005), and needs to be evaluated. Therefore, it is important to estimate the biomass of forests and rubber plantations at three elevation ranges, i.e. low, medium and high.

Materials and Methods

Using the studies of JIA (2006) and SONG AND ZHANG (2010) as a reference to set different elevation ranges, this study differentiates among low (530 to 650 m.a.s.l.), medium, and high elevations. Since available data to estimate the biomass of rubber trees at low and high elevations in the NRWNNR could not be assessed by the authors, alternative information from a literature review (YANG ET AL., 2005; SONG AND ZHANG, 2010; TANG ET AL., 2009; BAO ET AL., 2008 AND JIA, 2006) concerning biomass data of rubber trees in Xishuangbanna in general

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are used here. The biomass at medium elevations was estimated with data from 2009 and 2010 of 142 trees from the NRWNNR from which GBH (girth at breast height), height, ages (9, 10, 11, 12, 15, 16, 21, 22, 23 and 24 years), and elevations (680 to 700 m) were available (GOLBON, 2012, personal communication). This is further supported with data from literature. The biomass estimation of rubber considers allometric relationships, as well as the elevation gradient, which is an important determinant for climate variation (especially temperature) that significantly influences rubber tree biomass development. The biomass in kg per rubber tree is computed using the allometric equation from Ketterings (KETTERINGS ET AL., 2010)

$$B = aD^b \tag{1}$$

where B is biomass per tree in kg, a and b are the parameters to be estimated, and D is the DBH (diameter at breast height) of each tree in cm. Ketterings' allometric equation is suitable as its parameters a and b can be set for the studied location specifically. The elevation gradient is comprised in the parameter b, which shows a relationship between the DBH and height of a tree in m at each chosen elevation range (KETTERINGS ET AL., 2001).

Furthermore, the beta growth function

$$w = c_m t \left(\frac{2t_e - t_m - t}{2t_e - t_m}\right) \left(\frac{t}{t_m}\right)^{\frac{t_m}{t_e - t_m}} \tag{2}$$

where w is the biomass in t per ha, c_m is the maximum growth rate in t per ha that is reached at time t_m, t is the plant's age, and t_e is the time at the end of the growth period (YIN ET AL., 2003); was used to express the age-dependent rubber growth in t per ha for a tree density of 450 trees per ha (YANG ET AL., 2005 AND JIA, 2006), which is based on the biomass results of applying Ketterings' equation. The biomass estimates of primary and secondary forests, as well as of the other land uses in the area are derived from an exhaustive literature review and the analysis of primary and secondary sources.

Results and Discussion
During a life span of 38 years, rubber plantations in the NRWNNR can build up a biomass of 233.78±12.64, 193.02±10.05, and 92.79±4.75 t per ha at low, medium, and high elevations (Figure 1), i.e. 116.89±6.32, 96.51±5.03, and 46.40±2.38 t C per ha, respectively. The average annual biomass accumulation is 6.34±0.22, 6.11±0.11 and 3.10±0.05 t per ha at low, medium and high elevations. If the biomass of rubber plantations per ha at low, medium and high elevations is averaged, than their average biomass is of 173.20 t per ha, i.e. 86.60 t C per ha, and a yearly biomass increment of 5.18 t per ha.
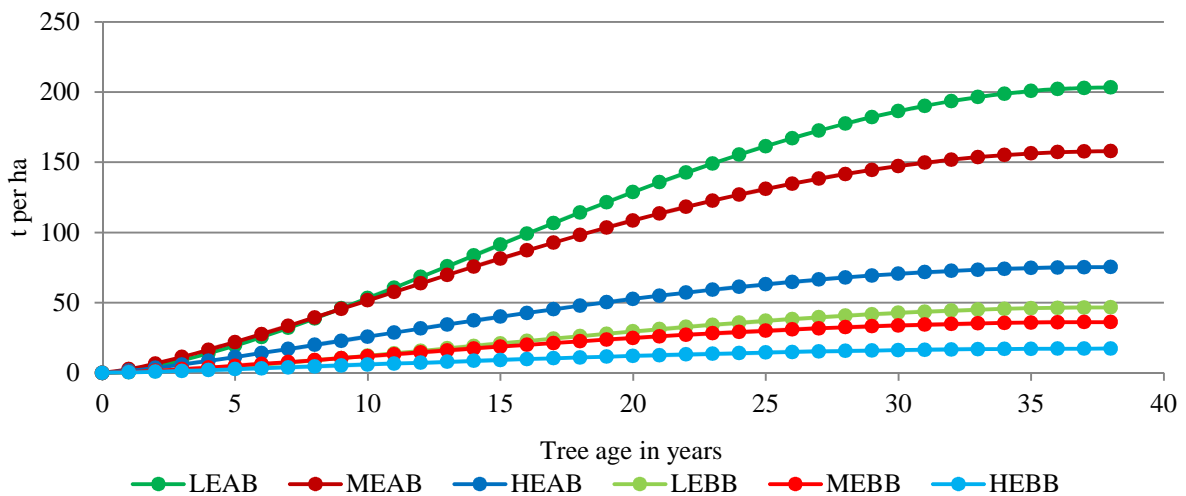

Figure 1: Aboveground (AB) and belowground (BB) biomass in t per ha of 0 to 38 year old rubber plantations at low (HE), medium (ME) and high (HE) elevations in Xishuangbanna

Figure 1 shows that the biomass accumulation of rubber plantations is significantly higher (< 0.05) at low > medium > high elevations, which can be mainly explained by the reduction of temperature as elevation increases (BAO ET AL., 2008). Lower temperatures have a tendency to restrict rubber biomass development, such that even flowering and consequently fruiting are not possible at high elevations (JIA, 2006). The biomass accumulation of rubber plantations in the NRWNNR is significantly affected by the different elevations ranges, which is confirmed by the results for Xishuangbanna of JIA (2006) and SONG AND ZHANG (2010). Several studies show that usually lower elevations have a larger biomass increase than higher elevations, as the temperature tends to be higher, which increases the growing season. A longer growing season contributes to improve the metabolic activity of a plant, such that photosynthesis rate and cell growth can further increase. The temperature is usually lower at higher elevations, whereby biomass development may be restricted (SONG AND ZHANG, 2010).

Furthermore, the biomass accumulation in different plant organs is generally higher at low > medium > high elevations. As an example, the biomasses of 14 year old trees at low, medium and high elevations correspond to 70.21, 55.11 and 36.39 t per ha in the stem, 10.60, 16.55 and 11.47 t per ha in the branches, and 2.84, 3.96 and 2.59 t per ha in the leaves (Figure 2). The difference between stem biomasses can be partially attributed to the different average heights of 14 year old trees, which are 16.27±0.54 m at low, 15.08±1.06 m at medium, and 9.75±0.35 m at high elevations (JIA, 2006). When stem, branch, and leaf biomass are taken into account separately, they show to be significantly different (< 0.05) at the different elevations ranges. Nevertheless, they do not follow the pattern of aboveground and belowground biomass partitioning (Figure 1), where biomass is higher at low, than at medium, and than at high elevations.
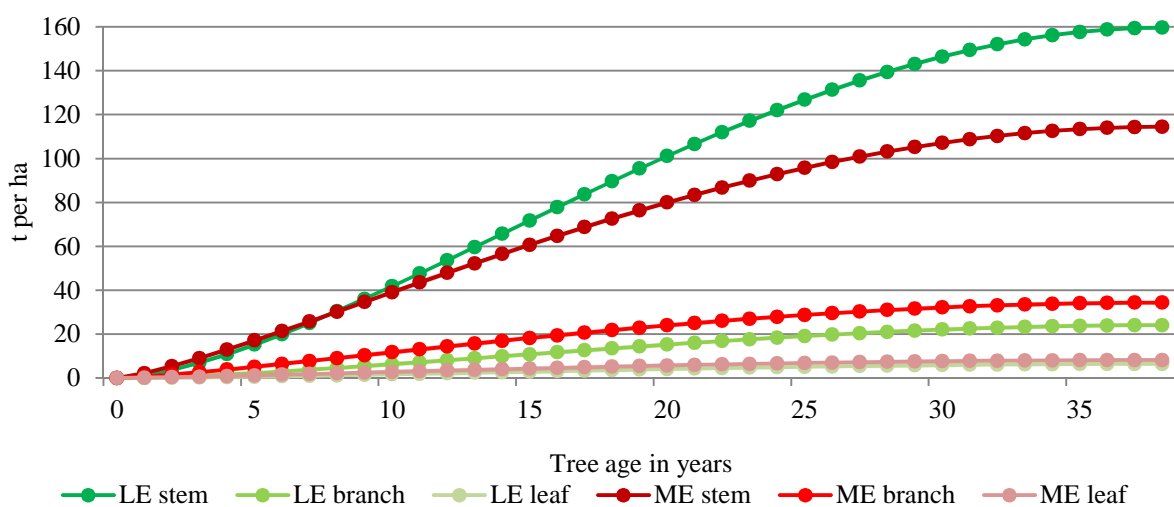

Figure 2: Stem, branch and leaf biomass in t per ha of 0 to 38 year old rubber plantations at low (LE) and medium (ME) elevations in Xishuangbanna

An exception was observed in branch and leaf biomasses, which were overall higher at medium than at low elevations (Figure 2). This can be partially explained by the biomass allocation at medium elevations, which compared to low elevations is greater to branches and leaves, and simultaneously lower to stems. It can also be partly explained by the winter temperature inversion in the area, which occurs over 80% of the days between the beginning of December and the end of February (JIANG, 1981). This possibly influences faster developing plant organs, such as branches and leaves, and enables them to accumulate more biomass at medium elevations, where the beginning of leaf growth occurs around the 10th of February, i.e. already about 9 days earlier than at low elevations. Nevertheless, there is no frequent temperature inversion during the rest of

the year, which then explains the significantly higher stem biomass accumulation at low elevations compared to medium and high elevations. Stems develop more slowly, and at medium elevations they may not benefit from the temporary temperature inversion for sufficient time to surpass stem biomass at low elevations.

As a means of comparison with mature rubber plantations (38 years old) that store 86.60 t C per ha when averaging t C per ha of mature rubber at low to high elevations, the average carbon sequestration of the different land uses in the NRWNNR, in ascending order, is 5.41 t C per ha in paddy rice – 93.75% less than in rubber, 66.02 t C per ha in mature secondary seasonal tropical and montane rainforests – 23.76% less, 71.00 t C per ha in mature secondary subtropical evergreen broadleaf forests – 18.01% less, 116.24 t C per ha in primary tropical montane rainforests – 34.23% more, 122.08 t C per ha in primary subtropical evergreen broadleaf forests – 40.97% more, and 183.16 t C per ha in primary tropical seasonal rainforests – 104.32% more (Figure 3; LI ET AL., 2008; WEHNER, 2007; DEVEVRE and HORWATH, 2000; ZHENG ET AL., 2006; LU ET AL., 2006; Lü ET AL., 2010; FENG ET AL., 1998; BAO ET AL., 2008 AND TANG ET AL., 1998).

Furthermore, rubber has a 38 year life cycle, in which it is unable to compensate the biomass carbon loss when replacing primary tropical seasonal rainforests or primary subtropical evergreen broadleaf forests in the study area. Primary tropical montane rainforests located at medium and high elevations and rubber plantations at low elevations have almost the same amount of biomass (Figure 3). However, since primary tropical montane rainforests are located at medium and high elevations, rubber plantations at those elevations are unable to compensate the biomass carbon loss of replacing primary tropical montane rainforests.This means that there would be no gain in biomass carbon sequestration if primary forests were replaced with rubber plantations, only a loss. Nonetheless, already 18 up to 21 years after rubber is planted at low and medium elevations, it is able to compensate the biomass carbon loss when replacing a mature secondary tropical seasonal and montane rainforest, and a mature secondary subtropical evergreen broadleaf forest, respectively. Therefore, rubber plantations at low and medium elevations in the middle of their life cycle are able to surpass the biomass carbon sequestration capacity of mature secondary forests. Only rubber plantations at high elevations cannot compensate for the biomass carbon loss of replacing neither primary nor secondary forests.
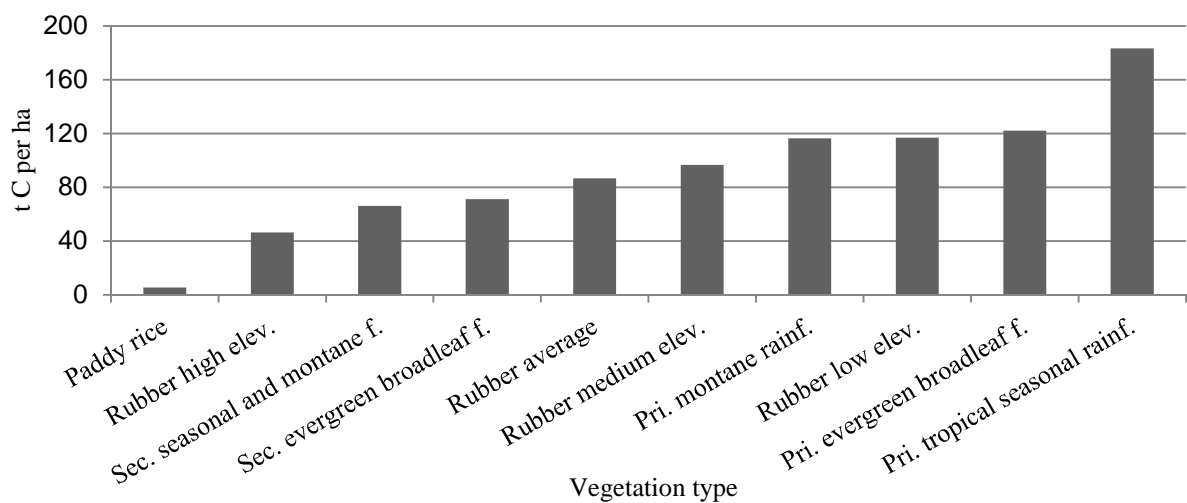

Figure 3: Biomass carbon estimations in t C per ha of mature rubber, paddy rice, and primary and secondary forests in Xishuangbanna. All vegetation except rubber is based on data from LI ET AL., 2008; WEHNER, 2007; DEVEVRE and HORWATH, 2000; ZHENG ET AL., 2006; LU ET AL., 2006; Lü ET AL., 2010; FENG ET AL., 1998; BAO ET AL., 2008 AND TANG ET AL., 1998

Conclusion

The biomass accumulation of rubber plantations in the NRWNNR is significantly affected by the different elevations ranges, and shows a negative correlation as elevation increases. Furthermore, there is a winter temperature inversion in the area, which contributes to the higher biomass accumulation of faster growing plant organs, such as leaves and branches, at medium elevations than at low elevations. Moreover, rubber plantations cannot reach the same biomass amount of the primary forests in the area. However, rubber at low and medium elevations is able to reach the same biomass carbon of secondary forests at around the middle of their life cycle. Additionally, at the end of their life cycle they are able to surpass biomass carbon stocks of secondary forests by 31.56 to 43.52%, making rubber an important contributor to carbon sequestration in the area. However, it cannot be suggested that the expansion of rubber plantations is an appropriate solution to increase carbon sequestration in the area, as other important factors need to be carefully considered first, such as impacts on biodiversity and on other ecosystem components that may be negatively affected, such as water availability.

References

BAO, Y., LI, Z., MA, Y., DONG, Y., SONG, G. AND WANG, H. (2008). Effects of Rubber Plantation on Tropic Rainforest Ecosystem in Nabanhe River Basin. *Ecology and Environment* 17(2):734-739.

BERNSTEIN, L., BOSCH, P., CANZIANI, O., CHEN, Z., CHRIST, R., DAVIDSON, O. ET AL. (2007). *Climate Change 2007: Synthesis Report* (IPCC Fourth Assessment Report). Geneva.

COTTER, M. (2011). *Developing a Biodiversity Evaluation Tool and Scenario Design Method for the Greater Mekong Subregion*. Doctoral thesis. University of Hohenheim, Stuttgart.

DEVEVRE, O.C. AND HORWATH, W.R. (2000). Decomposition of Rice Straw and Microbial Carbon Use Efficiency under Different Soil Temperatures and Moistures. *Soil Biology & Biochemistry* 32:1773-1785.

FAO. (2010). Challenges and Opportunities for Carbon Sequestration in Grassland Systems. A Technical Report on Grassland Management and Climate Change Mitigation. *Integrated Crop Management* Vol. 9. Rome.

FENG, Z., ZHENG, Z., ZHANG, J., CAO, M., SHA, L. AND DENG, J. (1998). Biomass and its Allocation of a Tropical Wet Seasonal Rain Forest in Xishuangbanna. *Acta Phytoecologica Sinica* 22(6):481-488.

FOX, J., FUJITA, Y., NGIDANG, D., PELUSO, N., POTTER, L., SAKUNTALADEWI, N. ET AL. (2009). Policies, Political-Economy, and Swidden in Southeast Asia. *Hum Ecol Interdiscip J.* 37(3):305–322.

GOLBON, R. (2012). Hohenheim University, personal communication.

GUARDIOLA CLARAMONTE, M., FOX, J., GIAMBELLUCA, T.W. AND TROCH, P.A. (2010). "Changing Land Use in the Golden Triangle: Where the Rubber Meets the Road". In Roumasset, J., Burnett, K.M. and Molina Balisacan, A. (Eds.), *Sustainability Science for Watershed Landscapes*, Singapore: ISEAS Publishing.JIA, 2006

JIA, K. (2006). *Study on Growth Change of the Rubber Plantation Along an Altitudinal Gradient in Xishuangbanna, Southwest China*. Dissertation.

JIANG, A. (1981). Temperature Inversion and Vegetation Inversion in Xishuangbanna, Southwestern Yunnan, People's Republic of China. *Mountain Research and Development* 1(3):275-280.

KETTERINGS, Q.M., COE, R., VAN NOORDWIJK, M., AMBAGAU, Y. AND PALM, C.A. (2001). Reducing Uncertainty in the Use of Allometric Biomass Equations for Predicting Above-ground Tree Biomass in Mixed Secondary Forests. *Forest Ecology and Management* 120:199-209.

LI, H., MA, Y., AIDE, T.M. AND LIU, W. (2008). Past, Present and Future Land-use in Xishuangbanna, China and the Implications for Carbon Dynamics. *Forest Ecology and Management* 255:16–24.

LU, X. AND LIN, S., 2010. Discussion Paper for Roundtable Session "Rubber Expansion in Xishuangbanna", Expansion of Rubber in Montane Mainland Southeast Asia: What are the Prospects for Small Holders? Revisiting Agrarian Transformation in Southeast Asia: Empirical, Theoretical, and Applied Perspectives. RCSD/ChATSEA International Conference. Chiang Mai.

Lü, X., YIN, J., JEPSEN, M.R. AND TANG, J. (2010). Ecosystem Carbon Storage and Partitioning in a Tropical Seasonal Forest in Southwestern China. *Forest Ecology and Management* 260:1798–1803.

SONG, Q.H. AND ZHANG, Y.P. (2010). Biomass, Carbon Sequestration and its Potential of Rubber Plantations in Xishuangbanna, Southwest China. *Chinese Journal of Ecology* 29:1887-1891.

TANG, J., PANG., J., CHEN, M., GUO, X. AND ZENG, R. (2009). Biomass and Its Estimation Model of Rubber Plantations in Xishuangbanna, Southwest China. *Chinese Journal of Ecology* 28(10):1942-1948.

TANG, J., ZHANG, J., SONG, Q., CAO, M. AND FENG, Z. (1998). A Preliminary Study on the Biomass of Secondary Tropical Forest in Xishuangbanna. *Acta Phytoecologica Sinica* 22(6):489-498.

TU TIEMPO. *Climate Jinghong* [Online]. Available: http://www.tutiempo.net/en/Climate/ [2012, August 1].

WEHNER, S. (2007). *Villages in the Naban River Watershed National Nature Reserve, Xishuangbanna, China. Background Data on Land-Use and the Socio-Economic Situation* (Working Paper No. 13). Passau: Lehrstuhl für Südostasienkunde, Universität Passau.

YANG, J., HUANG, J., TANG, J., PAN, Q. AND HAN, X. (2005). Carbon Sequestration in Rubber Tree Plantations Established on Former Arable Lands in Xishuangbanna, SW China. *Acta Phytoecologica Sinica* 29(2):296-303.

YIN, X., GOUDRIAAN, J., LANTINGA, E.A., VOS, J. AND SPIERTZ, H.J. (2003). A Flexible Sigmoid Function of Determinate Growth. *Annals of Botany* 91:361-371.

ZHENG, Z., FENG, Z., CAO, M., LI, Z. AND ZHANG, J. (2006). Forest Structure and Biomass of a Tropical Seasonal Rain Forest in Xishuangbanna, Southwest China. *Biotropica* 38(3):318–327.