# Simulation of rattan harvests in Indonesia

## - Different harvesting pressures and the resulting patterns -

Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; From forest to market.pdf

**Bastian Hess**

Supervisors: Rodolphe Sabatier (Georg-August-University Göttingen, Germany)
Lars Drössler (Swedish University of Agricultural Science, Alnarp)

**Swedish University of Agricultural Sciences**

Master Thesis no. 208

Southern Swedish Forest Research Centre

Alnarp 2013

# Simulation of rattan harvests in Indonesia

**- Different harvesting pressures and the resulting patterns -**

Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; From forest to market.pdf

**Bastian Hess**

Supervisors: Rodolphe Sabatier (Georg-August-University Göttingen, Germany)
Lars Drössler (Swedish University of Agricultural Science, Alnarp)

Examiner: Eric Agestam

Swedish University of Agricultural Sciences
Master Thesis no. 208
Southern Swedish Forest Research Centre
Alnarp 2013

MSc Thesis in Forest Management – Euroforester Master Program,
30 ECTS, Advanced level (A2E), SLU course code EX0630

## Abstract

The objectives of this research were to determine whether the natural rattan resources in Sulawesi, Indonesia can cope with the strongly increased harvesting pressure that has occurred over the last centuries. I was furthermore looking for patterns in the rattan population dynamics that might give a hint on how the harvesting system could be improved to ensure a maximum sustainable yield. To answer these questions, I developed an individual-based model to analyse the dynamics of rattan growth in connection with rattan harvests by locals to identify sustainable levels of rattan harvests around villages in Sulawesi, Indonesia. Scenarios with different harvesting intensities were run to compare the change in harvest amount. For a given harvesting pressure, scenarios with a high number of harvesters and a low harvesting frequency had the same effect as scenarios with high harvesting frequencies and a low number of harvesters. Scenarios with a high harvesting pressure led to a rapid decline of the harvested rattan amounts. Simulations showed that a maximum sustainable yield can be obtained as long as a harvesting pressure of 1.13 harvesting actions per month in an area of 7.07 $km^2$ was not exceeded. Comparing the current harvesting situation with the different scenarios from the model, a long-term sustainable harvest seems unlikely, especially when considering that there is an increasing worldwide rattan demand, for which specialized rattan-harvesting groups intensify their harvesting actions. To avoid further overexploitation of Indonesia's rattan resources there is a need to manage rattan harvests.

**Keywords:** *Calamus zollingeri*, harvesting strategies, Non-Timber Forest Products (NTFP), Modelling, Rattan, Sustainability, Individual based model (IBM), Sulawesi, Indonesia

## Abstrakt

Målet med denna undersökning var att finna ut om de naturliga rottingresurserna i Sulawesi, Indonesien kan klara av kraftigt ökat skördetryck som skett under de senaste århundradena. Jag sökte dessutom mönster i rottingpopulationens dynamik som kan ge en antydan om hur avverkningen skulle kunna förbättras för att säkerställa en maximal hållbar avkastning. För att besvara dessa frågor utvecklade jag en individbaserad modell för att analysera dynamiken i rottingtillväxt i samband med rottingskördar av lokalbefolkningen. Målet var att identifiera hållbara nivåer av rottingskördar omkring byarna i Sulawesi, Indonesien. Scenarier med olika skördeintensiteter simulerades för att jämföra förändringen i skördemängderna. För en förinställd skördeintensitet hade scenarier med många skördare och en låg skördefrekvens samma effekt som scenarier med höga skördefrekvenser och ett lågt antal skördare. Scenarier med en hög skördeintensitet ledde till en snabb nedgång av skördemängderna. Simuleringarna visar att en maximal hållbar avkastning kan erhållas så länge som en skördeintensitet på 1,13 skördeåtgärder per månad i ett område på 7,07 $km^2$ inte överskreds. När man jämför den aktuella skördesituationen med de olika scenarierna från modellen, verkar en långsiktig hållbarhet av rottingskördar mycket osannolikt; särskilt med tanke på att det finns en ökande global rottingefterfrågan för vilken specialiserade rottingskördetrupper intensifierar sina skördar. För att undvika ytterligare överexploatering av Indonesiens rottingresurser finns det ett behov av att styra rottingskördarna.

**Nyckelord:** *Calamus zollingeri*, skördestrategier, Non-Timber Forest Products (NTFP), modellering, rotting, hållbarhet, Sulawesi, Indonesien

## Zusammenfassung

Ziel dieser Arbeit war es zu untersuchen ob die natürlichen Rattanvorkommen in Sulawesi, Indonesien dem über die letzten Jahrzehnte stark angestiegenen Erntedruck standhalten können. Außerdem wurde nach Mustern in der Populationsdynamik von Rattan gesucht, die Rückschlüsse auf eine mögliche Optimierung der Ernte zulassen. Um diese Fragen zu beantworten, entwickelte ich ein individuenbasiertes Modell, das das Rattanwachstum und die Rattanernte durch lokale Dorfbewohner simuliert. Dieses Modell sollte den Bereich aufzeigen, in denen eine nachhaltige Rattannutzung im Umkreis der Dörfer in Sulawesi, Indonesien möglich ist. Verschiedene Szenarien mit unterschiedlichen Ernteintensitäten wurden simuliert um die Entwicklung und Unterschiede der Erntemengen vergleichen zu können. Dabei gab es keine Unterschiede zwischen Szenarien mit einer großen Anzahl von Rattansammlern und einer geringen Erntefrequenz und Szenarien mit einer hohen Erntefrequenz und einer kleinen Anzahl von Rattansammlern. In Szenarien mit einer hohen Ernteintensität kam es nach kurzer Zeit zu einem drastischen Rückgang der Rattan-Erntemengen. Die Simulationen zeigten, dass eine maximale nachhaltige Erntemenge möglich war, solange ein Ernte-Intensitäts-Index von 1,13 Ernteeinsätzen pro 7,07 $km^2$ und Monat nicht überschritten wurde. Vergleicht man die momentane Erntesituation auf Sulawesi mit den verschiedenen Szenarien des Modells, scheint eine langfristig nachhaltige Rattanernte nicht möglich. Besonders unter Berücksichtigung der steigenden weltweiten Rattannachfrage, die zu einer intensivierten Ernte von einer zunehmenden Anzahl von spezialisierten Rattansammlertrupps führt. Um einen weiteren Raubbau an den indonesischen Rattanressourcen zu vermeiden, sollten die Rattan-Ernten einheitlich geregelt werden.

**Schlagwörter:** *Calamus zollingeri*, Erntestrategie, Nicht-Holz-Wald-Produkte, Non-Timber Forest Products (NTFP), Modellierung, Rattan, Nachhaltigkeit, Individuen basiertes Modell (IBM), Sulawesi, Indonesien

## Contents

## Introduction

### 1.1 Rattan – Properties and Uses

Rattans are climbing plants that belong mainly to the genus *Calamus* or other genera of the subfamily *Calamoideae* (Schütt et. al. 2002, Siebert 2005). They can be found in the tropical regions of Asia, Africa and Australasia (see Fig. 1) (Shaanker et al. 2004).

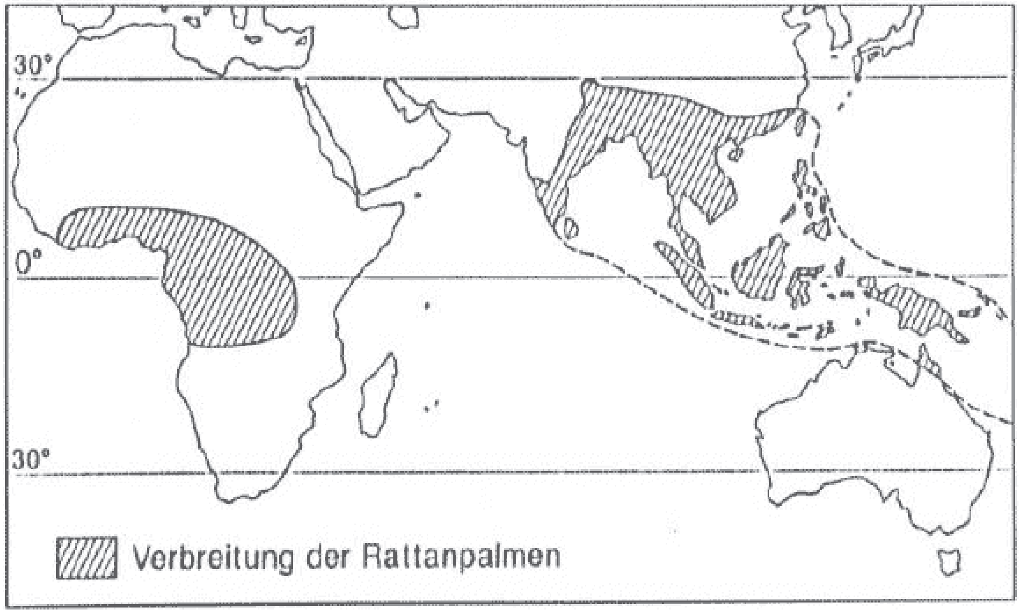


**Fig. 1: Distribution of rattan in Asia, Africa and Australasia (from Wiener, Liese 1993)**

Of the approximately 600 species that exist in the world, 10 – 20 percent are commercially used (Dransfield et al. 2002, Shaanker et al. 2004, Stiegel et al. 2011). The 300 rattan species that are being harvested in Indonesia make up 80 – 90 % of the total worldwide rattan production (Stiegel et al. 2011, Shaanker et al. 2004). This makes Indonesia the number one country to harvest and export rattan (FAO 2011). Rattans can be found in diameters between 3 mm to 20 cm (Dransfield et al. 2002) and are divided into small and large diameter canes. Both are used by locals for everyday commodities, but this study focuses mainly on the large diameter species *Calamus zollingeri*, because it is one of the commercially most important species (Siebert 2004). According to Siebert (1993, 2004, 2005) they are the main large diameter canes harvested by the villagers in villages in and around the Lore Lindu National Park in Sulawesi, Indonesia (Siebert 2005). Rattan is used for many things. It is widely used for making furniture, household items, baskets, and even bridges (see Fig. 2 and Fig. 3) (Siebert 2004).

**Fig. 2: Furniture made from rattan. (Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; From forest to market.pdf)**

**Fig. 3: A basket made of rattan splits (left) and a bridge made from rattan (Calamus leptostachys) and wooden boards (right). (Pictures: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; Rattan in village life and livelihood context.pdf)**

Certain rattan species are edible and others can be used as medicine (Siebert 2004). In summary, rattans are a very valuable non timber forest product for the everyday life of the local residents. As a trailer and climber, rattan needs trees to reach up into the canopy where light conditions are better than on the ground (Shaanker et al. 2004). The scaly rattan stem that is referred to as a cane, can reach a length of 100 to 200 metres and has many long and pointy thorns and spines (see also Fig. 4 and Fig. 5) which allows it to conquer its climbing habitat (Shaanker et al. 2004). Since rattan plants are dieocious, i.e. either male or female (Shaanker et al. 2004) and only flower after they have reached a length of 30 metres (Siebert 2004), under intense harvesting pressure they can only regenerate vegetatively (Clough et al. 2010). This makes them very vulnerable to the destruction of their habitat (Shaanker et al. 2004).


**Fig. 4: Calamus sp. growth forms: "(A) Bare section of old stem, (B) Young shoot, (C) Spiny leaf sheath, (D) Flagellum." (Johnson 1998)**

**Fig. 5: The long, pointy spines on rattan (here: Daemonorops robusta) make the harvest very difficult. (Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; Research collaborators, methods and TEKP.pdf)**

## 1.2 Rattan demography

It is hard to find exact and comparable information about the number of rattan canes per hectare in the literature (Dransfield et al. 2002). This is due to several reasons: It is not always clear whether authors talk about the genet, which is the clonal entity of several ramets that originated through vegetative reproduction, or about the ramets themselves. One genet of *Calamus zollingeri* for example, can be comprised of up to 50 ramets according to Siebert (2005). Locals distinguish one single species into a low and high elevation form which each have different names. So for *Calamus zollinger*i for example, we can find “batang” which is the lowland form and “lelut” which describes the populations at higher elevations (Siebert 2005). Some authors talk about the number of rattan plants per hectare, but do not differentiate between species. Additionally, there are small and big diameter species and some species that are not suitable for processing. This makes it even more complicated to find the exact number of rattan canes per hectare. Also, the portion of harvestable canes is often unclear and differs a lot depending on site and harvesting history. In a study about the abundance and site preferences of rattan, Siebert (1993) recorded 38 *Calamus zollingeri* plants per hectare with a total number of 642 canes per hectare of which only 86 were harvestable canes (i.e. a ratio of 2.26 harvestable canes per plant). Harvestability differs because of different light regimes under which the rattan plants grow (De Steven 1989). Rattan plants that grow in complete shade might not produce any harvestable cane at all, whereas rattan plants that grow “in intermittent sunlight at subcanopy level” seem to produce harvestable canes at a ratio of 0.84 harvestable canes per plant (De Steven, D., 1989). For *C. zollingeri* plants that grow in full sunlight in the upper canopy or in canopy gaps this ratio increases up to 2.8 to 3.05 (see also Fig. 6). In Siebert’s paper from 2004 however, there were only ratios between 0.16 to 0.8 harvestable canes per plant.

**Fig. 6: „Calamus zollingeri in a canopy gap near Moa.“ (Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; From forest to market.pdf)**

## 1.3 Reproduction and Mortality

Sexual reproduction does not play a major role for *C. zollingeri* because fruition occurs only after about 10 - 14 years (Shaanker et al. 2004), only on genets with >= 10 ramets and only on more than 30 metres long ramets that reach up into the canopy where good light conditions are found (Siebert 2004). These specific canes are, due to the high harvesting pressures in the past, very rare, if not non-existent at all (Siebert 2005). However, when a cane is cut vegetative reproduction occurs.

The natural mortality of *C. zollingeri* can be neglected, because it is much more likely that the canes are harvested before dying naturally. Also the genet will most likely produce a new ramet to replace the old one. Low harvesting pressure even stimulates cane production (Siebert 2004). Bad harvesting practice, i.e. damaging of genet during harvest, occurs according to Siebert (2004) only very seldom and is therefore also not an important factor. The only serious threat to the rattan population is the destruction of their habitat i.e. the rainforest, through (illegal) logging, natural tree fall and land slides (Siebert 2004).

## 1.4 Rattan Growth

There are very different growth rates mentioned in the literature (Hirschberger 2011). Some studies talk about annual increments of up to four metres for *C. zollingeri* (Powling 2004) but these increments are only possible on disturbed sites with very good light conditions. A seedling growth experiment in coffee and cacao agroforests in Sulawesi showed rattan growth rates between 10.7 to 14.7 cm in eight months i.e. approximately 0.19 m/year for the early growth stages (Siebert et al. 2001). The growth in the rosette stage is very slow because the canes gradually increase in stem diameter, which can take up to several years depending on species and light conditions and only then start to show a higher longitudinal increment (van Valkenburg 2002, Shaanker et al. 2004). When growing from 0.5 to 5 metres, the rattan plants grow faster. They will reach better light conditions and start climbing host trees (Powling 2004). Powling (2004), gives growth values for this period of 1.35 m/year with a standard deviation of 1.26. But it is also mentioned that C. zollingeri shows great variability between the different plants (Powling 2004). Siebert (1993) however states that the *C. zollingeri* canes were 12 years old when harvested at a length of 10 metres. When we exclude the first 2.5 years in which the cane grew very slow, we are left with a cane that grew 9.5 metres in 9.5 years. This computes to an average growth rate of 1 metre/year, but we can distinguish two growth phases during these 9.5 years: canes between 5-9 metres have an annual increment higher than 1 m/year (Siebert 2004), and therefore the growth for canes between 0.5 – 5 metres should be less than 1 metre/year. According to Siebert (2004), rattan canes that are between 5 to 9 metres long have an annual increment of 1.4 metres per year (standard deviation +/- 0.7m). This equates to a monthly increment of 0.1167 metres and constitutes the maximum increment for *C. zollingeri* because the plants reach better light conditions. “Soils in the region [studied by Siebert were] Ultisols derived from volcanic and metamorphic rocks, the climate is humid and precipitation averages 3000 – 4000 mm $yr^{-1}$“ (Siebert 2001). There is very little information about the growth rates of canes longer than 9 metres. This is mainly due to the fact that only very few long canes can be found and studied because they are harvested as soon as they reach 10 metres in length. Hence, the increments in this area have to be viewed with caution. Single canes can grow up to a maximum of about 150 m length (Weinstock 1983).

### 1.5 Rattan harvests

Rattan harvests require only simple tools (Ngo-Samnick 2012). Canes are being harvested as they reach 10 metres or more (Siebert 2004). The canes are cut close to the ground with a bush knife and pulled down out of the canopy by hand (Abdul Razak 2001, Ngo-Samnick 2012). This is very hard work because the spiky canes are stuck with their thorns in the crowns of the supporting trees and sometimes the harvesters even have to climb these trees to loosen the rattan canes in their top (Abdul Razak 2001, Ngo-Samnick 2012). The harvested canes are then cut to 4 metres length and tied to bundles with a total weight of 50-60 kg (see Fig. 7 and Fig. 8) (Siebert 2001). Because rattan harvests are such an aggravating, risky work, they are mainly done by unemployed persons and poor farmers (Engineers without borders undated, Siebert et al. 2001).

Thus, rattan harvests are an important income factor for the local villagers in Sulawesi (Siebert et al. 2001, Siebert 2004, Siebert 2005). The harvested rattan is sold to the rattan industry or (home-) manufactured into furniture and basic commodity to earn money (Sunderland et al. 2001). Therefore the sustainability of the rattan resources is vital to the economic wellbeing of village populations (Sunderland et al. 2001).

**Fig. 7: Harvesters cut and tie the harvested canes into 4 metres bundles with a total weight of 50-60 kg (Siebert 2001). (Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; From forest to market.pdf)**

**Fig. 8: Three rattan cane bundles. (Picture: Stephen Siebert; http://www.cfc.umt.edu/rattan/topics.html; From forest to market.pdf)**

## 1.6 Impacts of rattan harvests

Because of the increasing international rattan demand, overexploitation is becoming a serious threat to rattan populations (ITTO et al. 2007, Sunderland et al. 2001, FAO 2007, Siebert 2004). The current harvest rates are already exceeding the growth and yield of the rattan populations (Siebert 2004). The overexploitation of rattan might lead to serious effects on biodiversity and the rich endemic flora and fauna in Indonesia (Siebert et al. 2002). Therefore, it is very important to find ways to improve the current harvesting situation. An improved understanding of the rattan populations' growth behaviour in conjunction with the harvest behaviour of the villagers and the resulting effects on the rattan populations as well as the outcome of the harvest amounts might give an indication on how the system can be optimized. Also the possibility to gain a higher yield with a smaller harvesting pressure has to be tested. It would be desirable to find a maximum sustained yield that supplies sufficient harvest material, but at the same time does not endanger the rattan populations (Lande et al. 1997).

To answer this question, I decided to use a modelling approach because it is a rather quick and cheap way to analyse the underlying principles of the interactions between population dynamics and rattan harvests. Experiments can easily be reproduced and it is also possible to explore uncommon scenarios. Complex systems can be studied and, if desired or necessary, split up into several sub systems. Long term field studies are quite hard to conduct because of interference by the local residents and illegal harvesting operations. In a simulation model, these unwanted interferences and external influences can simply be excluded and thus allow us to focus on the essential (Baker 2004).

## 2 Materials and Methods

### 2.1 General Information about the model

To answer my questions, I modelled the harvesting of rattan with an individual-based model. With this model I created a simplified copy of real forests, like they can be found in Indonesia. A good model is necessarily a simplification of reality that only includes the main processes related to the question raised, and neglects less-influential processes (Fig. 10). This leads to an abstract and simplified image of reality that allows us to reproduce certain natural behaviours and phenomena. In the model we find a village in the centre, surrounded by forests in which rattan grows and that is the resource for the villagers who are collecting rattan canes (Fig. 9). The rattan grows with different increments and the villagers harvest with different intensities.

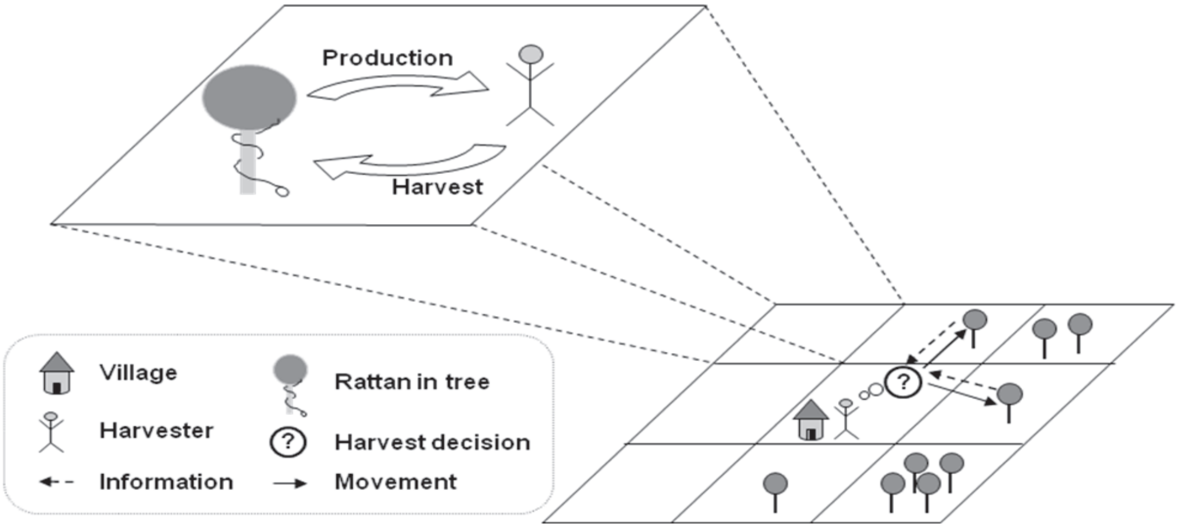


**Fig. 9: Overview of the rattan model**

The main focus of my rattan model is on the rattan harvest which is influenced by the number of harvesters, how often these harvesters harvest per month, how much they can carry and how far they are willing to walk. Also there are some harvesting restrictions and mannerisms of the local harvesters that were observed during field studies near the Lore Lindu National Park (Siebert 2004) and that I implemented in the model. Considering the resources, the harvest amount is mainly influenced by the available number of rattan canes and the rattan length. The number of rattan canes per patch has a fixed value in this model. All rattan canes have a certain longitudinal increment depending on their length and in reality also on the light conditions at their site. The only growth restriction implemented in my model is a length restriction of 150 m (Shaanker et al. 2004, Weinstock 1983).

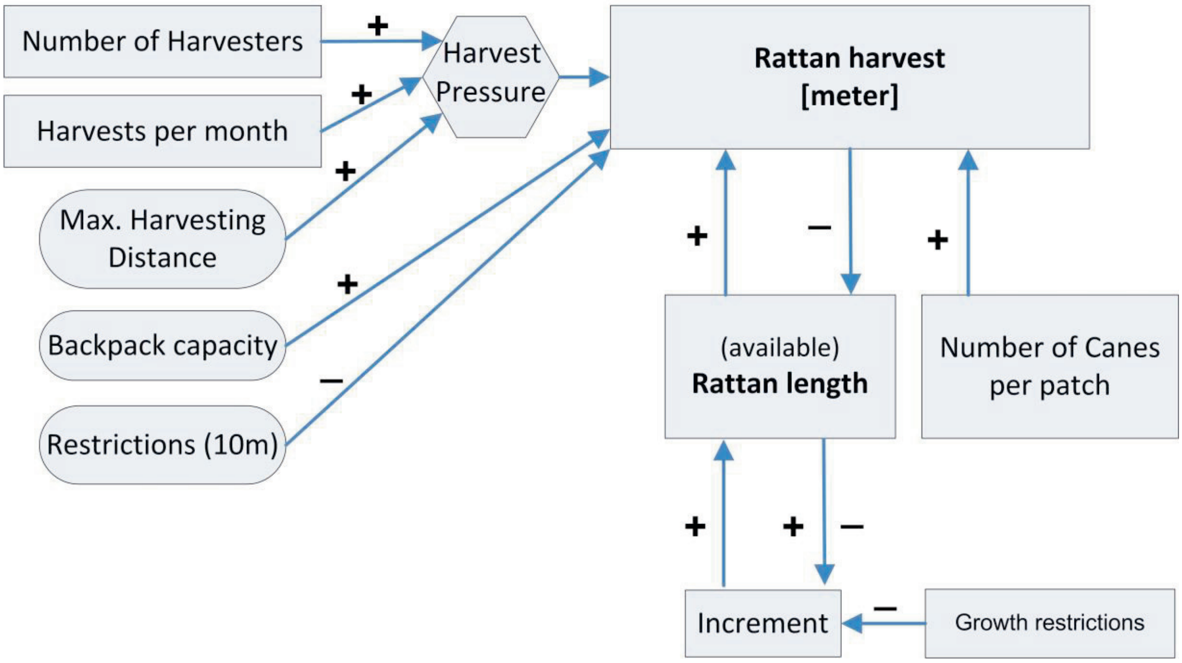


**Fig. 10: Causal diagram of the rattan model**

## 2.2 Set-up / Landscape

The simulated *world* (i.e. landscape) consists of 1089 patches. Each patch has a size of 100 x 100 metres (i.e. 1 ha), creating a total spatial area of 10.89 km$^2$. This ensures that a villager can walk up to a maximum distance of 1.5 km in each direction during the simulations. Studies showed that the harvesters in Sulawesi walk up to 6 km away from their village to harvest rattan (depending on the current prize of rattan) (Siebert 2004), but due to limited computing capacity the size of the simulated world has been scaled down. From the qualitative point of view, this should however have minor influence on the results. I therefore used relative values to describe the harvesting pressure. On set-up, the desired number of harvesters is placed in the centre of the simulation environment. This patch represents the village and is therefore not included in any harvesting or growing actions. To simplify the land use type of the patches in the model I distinguished only between "village" and "rainforest with rattan". The time simulated in the model covers 500 months (i.e. approximately 41 years), each time step represents one month. This time span was chosen to see the long term impact of the harvests and to exclude any short term effect and initial fluctuations.

## 2.3 Rattan demography

Considering the information mentioned in chapter 1.2, I decided to work with Siebert's (2005) number of rattan plants of all species per hectare (314 plants/ha) and assumed that each plant produces one harvestable, marketable rattan cane. So when initializing the model, each patch is randomly stocked with 242-424 rattan canes that have a random length between 0 and 49 metres. The initial rattan length was deliberately set to a rather short average, implying that there were no very old and thus very long canes in the simulation environment since we wanted to recreate a system in which harvests have been present for a long time and nearly all rattan genets have been harvested in the past at some stage. The colour in the world output window of the user interface represents the total length of rattan on that patch. Since sexual reproduction and mortality of the rattan plants can be neglected, as mentioned in chapter 0, they were not implemented in the model.

## 2.4 Rattan Growth

The growth function of the model defines the longitudinal increment in metres per month (see Eq. 1, Tab. 1 and Fig. 11). It is influenced by the increment per step ($\boldsymbol{\lambda_{(L)}}$), the current length ($\mathbf{L_{(t)}}$) and the length reduction through harvests ($\mathbf{Harvest_{(t)}}$).

$$L_{(t+1)} = \lambda_{(L)} + L_{(t)} - Harvests_{(t)}$$

***Equation 1: Growth function for rattan; L Length, λ growth increment***

Differing and partially incomplete data about the growth rates (see also chapter 1.4) make it hard to parameterise the model. When there was a lot of variation listed in the literature, I decided to use rather conservative increments to assure that I do not overestimate the actual growth of the rattan canes.

**Table 1: Parameters for growth calculations; L: length, λ: monthly increment; all values rounded to the second decimal place**

| L [metre] | λ [m month$^{-1}$] | Increment [m year$^{-1}$] |
|---|---|---|
| L<0.5 | 0.02 | 0.19 |
| 0.5<L<5 | 0.08 | 1 |
| 5<L<9 | 0.12 | 1.4 |
| 9<L<150 | 0.11 | 1.3 |

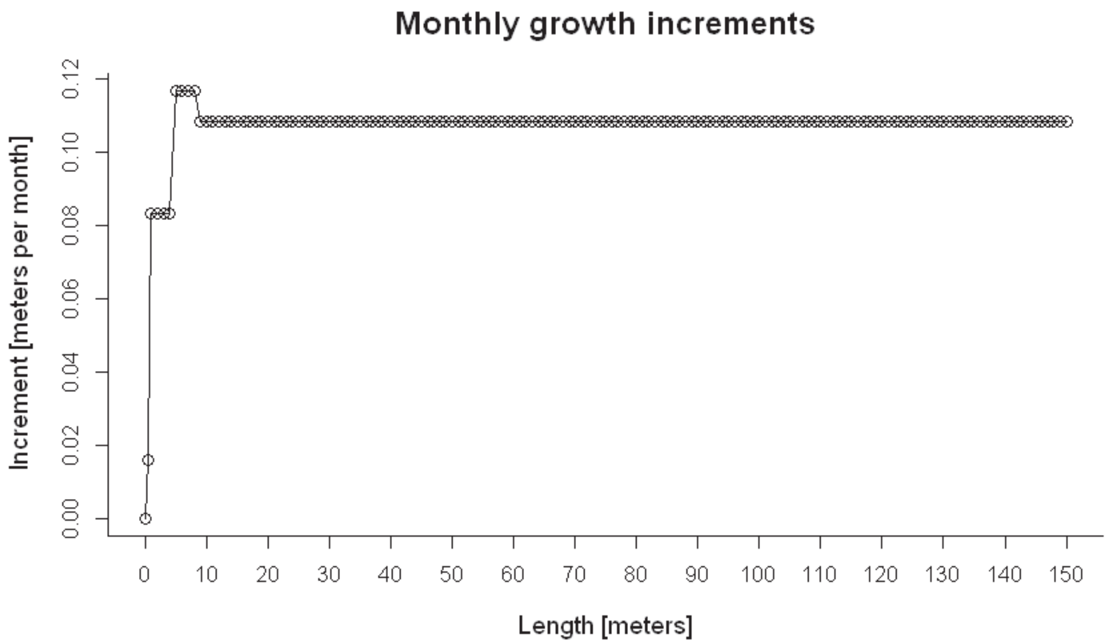


**Fig. 11: Longitudinal increment of rattan canes depending on their length**

All parameters and circumstances connected to the simulated rattan harvest were chosen so that they recreate the situation around the Lore Lindu National Park in Sulawesi, Indonesia as close a possible. But because of limited information on e.g. growth parameters, data from studies of rattan plants in other areas of the world (see also chapter 1.4) were used additionally. The colours of the patches represent the mean cane length on the patch.

## 2.5 Harvesting Pressure

Different parameter settings can be chosen to represent different income scenarios. Few harvesters that seldom go into the forest to harvest rattan would represent a situation where the villagers have sufficient alternative income. A setting of many harvesters that harvest very often each month represent a situation where alternative income is insufficient, for example due to a poor harvest of agricultural crops. To be able to compare these different parameter combinations, I used the harvesting pressure as the central variable in this study (see Equation 2 and Fig. 12). In the current version of the model, the harvesting pressure is defined as the number of harvesting actions per month in an area of 7.07 $km^2$.

$$\text{Harvesting Pressure} = \frac{(n * hpm)}{\pi * r^2}$$

***Equation 2: Harvesting pressure, number of harvesters (n), harvests per month (hpm), max. harvest radius (r)***

Simulations with different harvesting pressures were run to get an overview of the behaviour of the system. In harvesting pressure areas where a small change in harvesting pressure led to large changes in rattan yield, I choose to run more simulations (See appendix for a table with all the simulations).

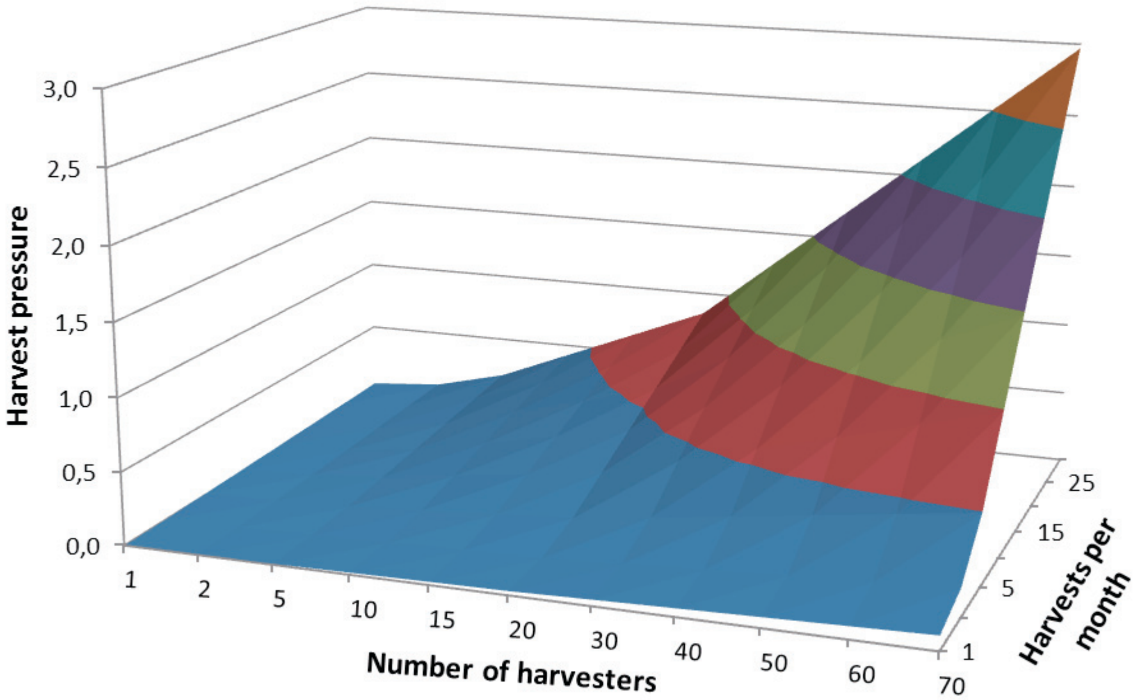


**Fig. 12: Harvest pressure as combination of the numbers of harvesters and the harvests per month. The maximum harvesting distance is constant at 1.5 km**

## 2.6 Harvesting procedure

The villagers will harvest as many times per month as set by the user on the Interface, with a maximum of 30 harvests per month. Simulations with more harvests per month could in reality be accomplished if the harvesting site was very close to the place where the rattan is brought to be picked up for transport so that the harvesters have enough time to do the trip, say, twice a day. After harvesting they will return to the village and start another harvesting trip until the selected number of harvests per month is reached. The harvesting procedure starts with the "scanning" of all patches within the maximum harvesting distance (i.e. a 15 patches radius), searching for the patch with the longest total length of rattan. I presume that the harvesters have complete knowledge of the rattan stock on each patch. This can be explained by the harvesters' experience from recent harvests on different patches around the village and by information exchange with other harvesters and family members. The villager then moves to the patch with the highest sources and checks if the longest rattan cane is above the harvesting threshold (i.e. 10 metres; Siebert 1993, Siebert 2004). If so, he selects this cane for harvesting. The villager will harvest as many four metre pieces of the cane as he needs to reach his harvesting capacity of 40 metres (Siebert 2001) or until the rattan cane is completely harvested. In the latter case, he then moves to the next longest cane on the same patch and continues his harvesting actions. The 10 m threshold and the 40 m "backpack capacity" as well as the 4 m harvest length were defined as global variables in the model and are thereby easy to change to desired different harvesting scenarios.

## 2.7 Simulations

I ran many simulations with different numbers of harvesters (ranging from 1 to 200) and harvests per month (ranging from 1 to 30; for a detailed list of the simulation runs and the results see appendix). All other parameters were kept constant, i.e. the maximum harvesting distance was always 15 patches, the minimum length of restriction of harvestable canes was 10 metres, the backpack capacity was 40 metres and the time span was 500 month. In addition I picked three different representative scenarios to clarify the effects of different harvesting pressures. The model was implemented in NetLogo 5.0 (Fig. 13), an agent-based programmable modelling environment (Wilensky 1999). NetLogo is great to simulate complex behaviours on a micro scale and examine the resulting macro-scale patterns. The data analysis and graphs were done using R software (The R Foundation for Statistical Computing 2012).


**Fig. 13: Screenshot of the rattan modell's interface**

# 3 Results

## 3.1 Average cane length per patch

The histograms with the distribution of the average cane length per patch (Fig. 14) show three moments (at 0, 200 and 500 month) of one simulation run (50 harvesters, 30 harvests per month, 1.5 km max. harvest radius, harvesting pressure 2.12, 500 total time steps, sample scenario B). The initial distribution of rattan cane length were 1088 patches with an average of 25 metres and the village patch with 0 metres of rattan. After 200 month, two classes of patches developed. Patches on which rattan harvests occurred (709 patches), with an average rattan cane length of 0 to 10 metres and those not harvested (380 patches), with an average cane length of 40 to 50 metres. After 500 month the difference between the two classes became even bigger. There are still the 709 freshly harvested patches with 0 to 10 metres and then the patches with further grown canes with an average cane length between 70 to 80 metres (373 patches) and between 80 to 90 metres (7 patches). This difference between the harvested and unharvested patches can also be seen in Fig. 15. The area within the maximum harvesting distance is after 200 month nearly white, representing the very low average cane length on these patches. The corner regions of the simulated area in contrast have a darker green colour, implying that the average rattan cane length on these patches is high.

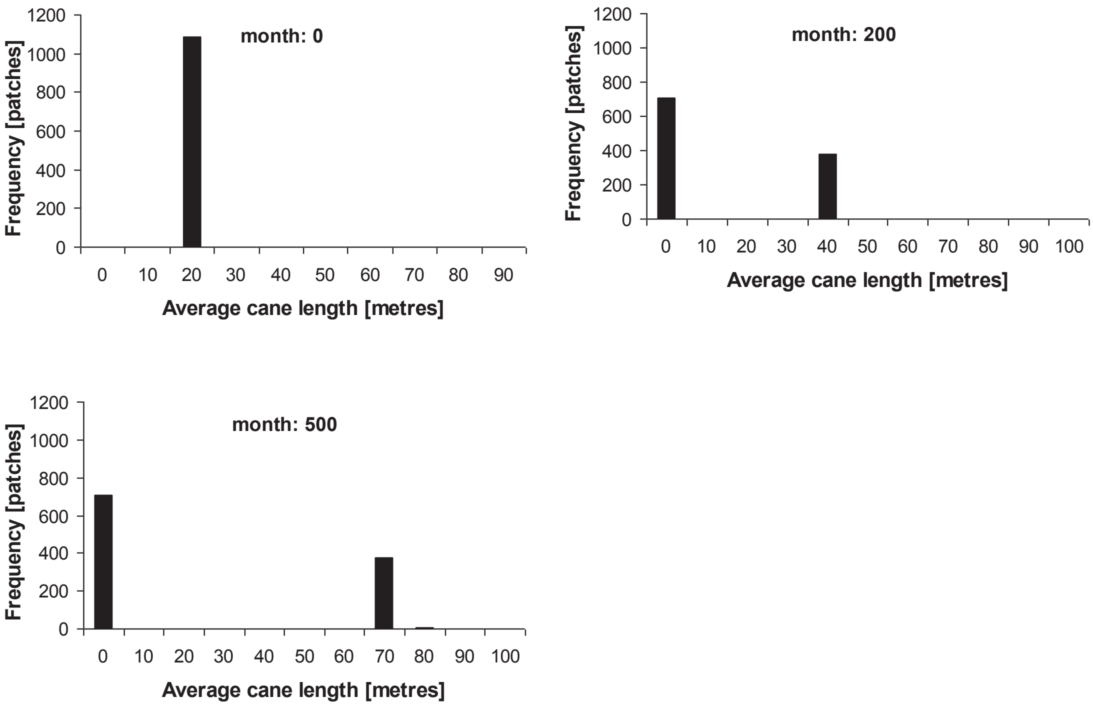


**Fig. 14: Frequency of average cane length per patch for scenario B (50 harvesters, 30 harvests per month, harvesting pressure 2.12, 1.5 km max. harvest radius) at 0, 200 and 500 months**

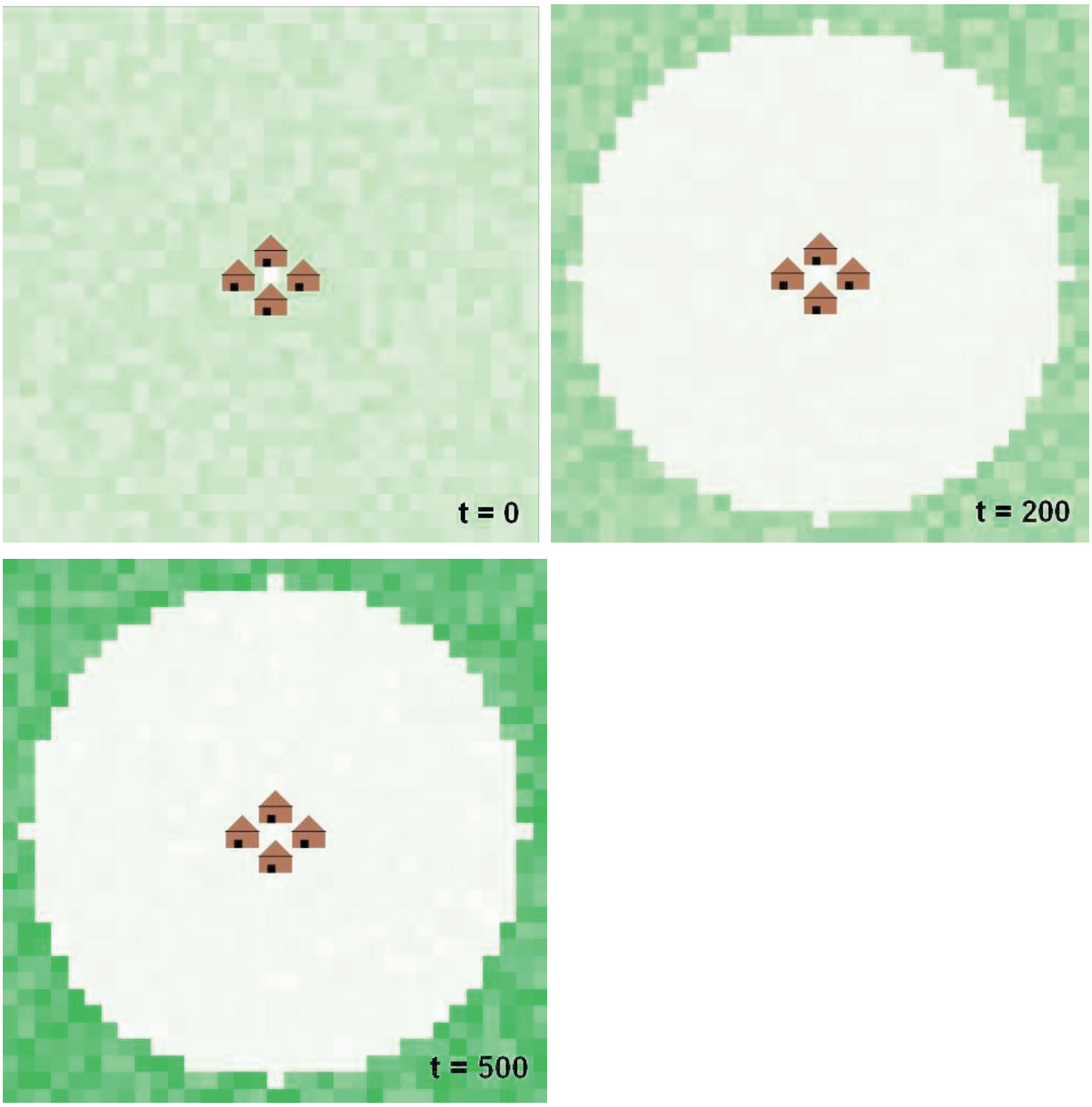


**Fig. 15: Average cane length per patch after 0, 200 and 500 month; Centre patch represents the village and is not stocked with rattan; the darker the green, the more rattan is on the patch**

## 3.2 Mean total harvest per month and harvest per trip

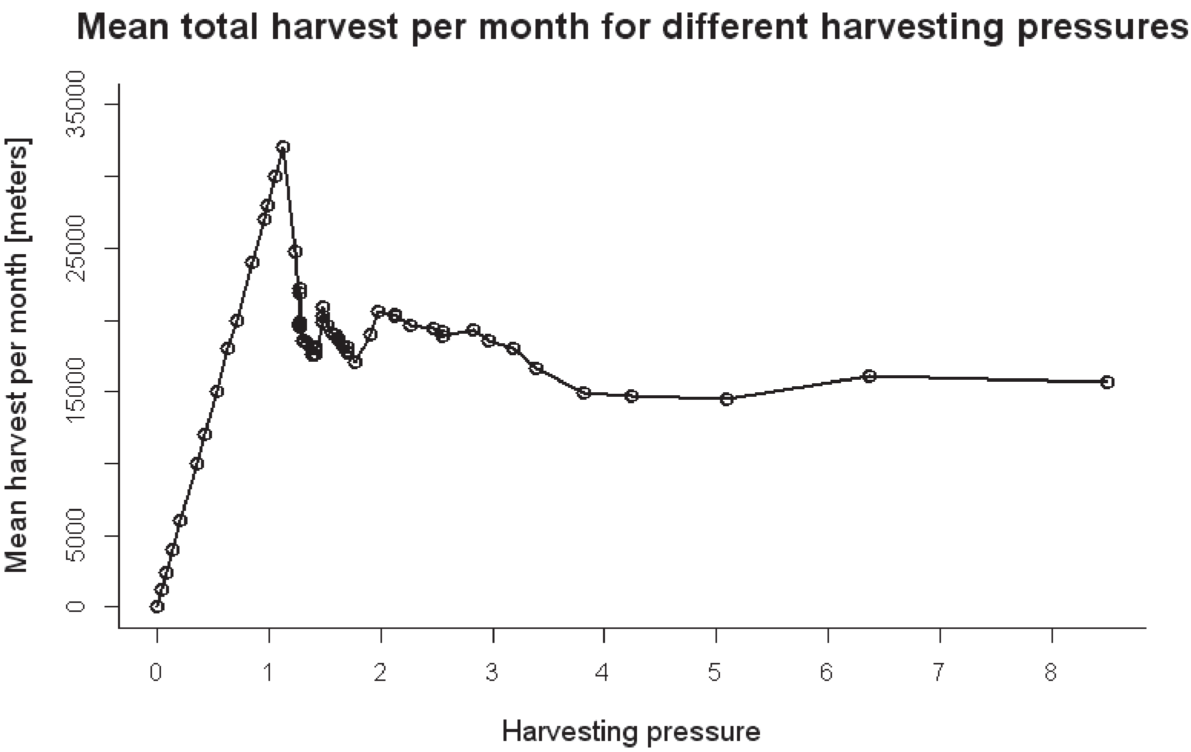


**Fig. 16: Mean total harvest for the whole village per month of the last 100 simulated months (year 33 – 41) for different harvesting pressures (in units [(harvesting actions / month) / 7.07 km2)]**

When looking at the mean total harvest of all harvesters for the different harvest pressures i.e. the mean of all harvests from all harvesters during the last hundred months of each simulation (Fig. 16), one can see a linear increase at the beginning, from 40 metres/month of rattan at an harvesting pressure of 0.001 up to a maximum of 32,000 metres/month at an harvesting pressure of 1.13. This calculates to a maximum sustained yield harvesting potential of 543.26 metres $ha^{-1}$ $year^{-1}$. The more harvesters there are, or the more often each harvester harvests, the higher the total yield. This linear increase however only proceeds to a harvesting pressure of about 1.13 harvesting actions per month. Thereafter, the system shows an abrupt decline in total harvest. The yield fluctuates then around a value between 20,000 to 15,000 metres up to a harvesting pressure of about 2.5. The mean harvest per month for harvesting pressures between 2.5 to 8.5 stays consistently low around 16.000 metres.

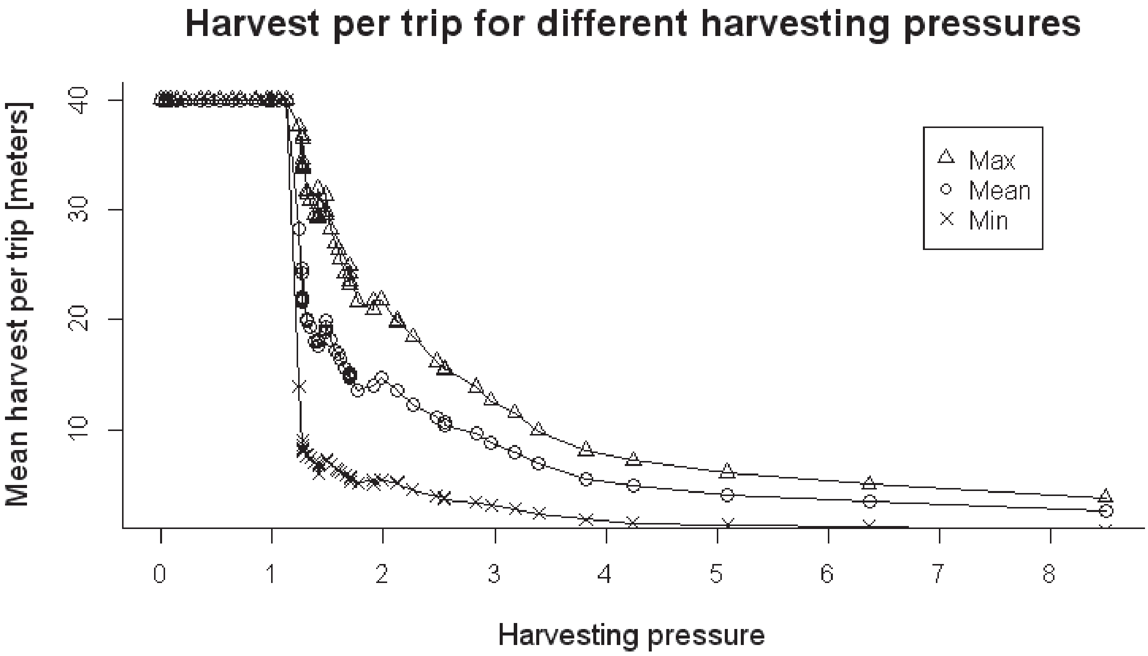


**Fig. 17: Harvest per Trip per harvester for different harvesting pressures (40 m = backpack capacity)**

The same pattern can be seen on the individual scale (Fig. 17). The values show the max, mean and min amounts of rattan harvested per trip and harvester during the last 100 months of the simulations. Up to a harvesting pressure of 1.13 all harvesters are able to harvest as much as they can carry (i.e. 40 m of rattan). This harvest however drops quickly to a mean of around 20 metres of rattan and then declines slowly further to a miminum of 2.6 m (mean), 3.84 m (maximum) and 0.73 m (mininum) at a harvesting pressure of 8.49.

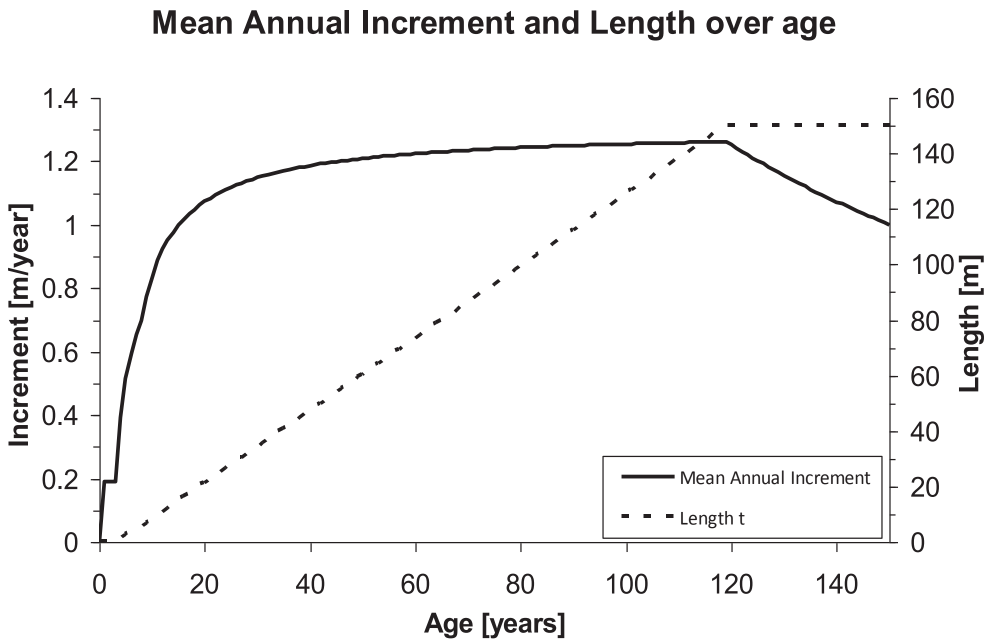


**Fig. 18: Mean Annual Increment (prim. y-axis) and length (sec. y-axis) over age for one single rattan cane**

When plotting the mean annual increment (length to time *x* divided by years) of a single rattan cane over time (Fig. 18), we can see a drastic increase to an age of about 20 years. In the period between 20 to 120 years we see a slight increase with a maximum mean annual increment of 1.3 m/year between 91 and 120 years. After 120 years the mean annual increment decreases linearly.

## 3.3 Sample scenarios

To understand the different scenarios better, I picked three different representative scenarios to clarify the different effects of the harvesting pressure. The three scenarios were: Scenario A has a harvesting pressure of 1.13 with 40 harvesters that harvest 20 times each month. This is the highest pressure where all harvesters can fill their backpacks completely with 40 metres of rattan every time over the complete simulation period (Fig. 19).

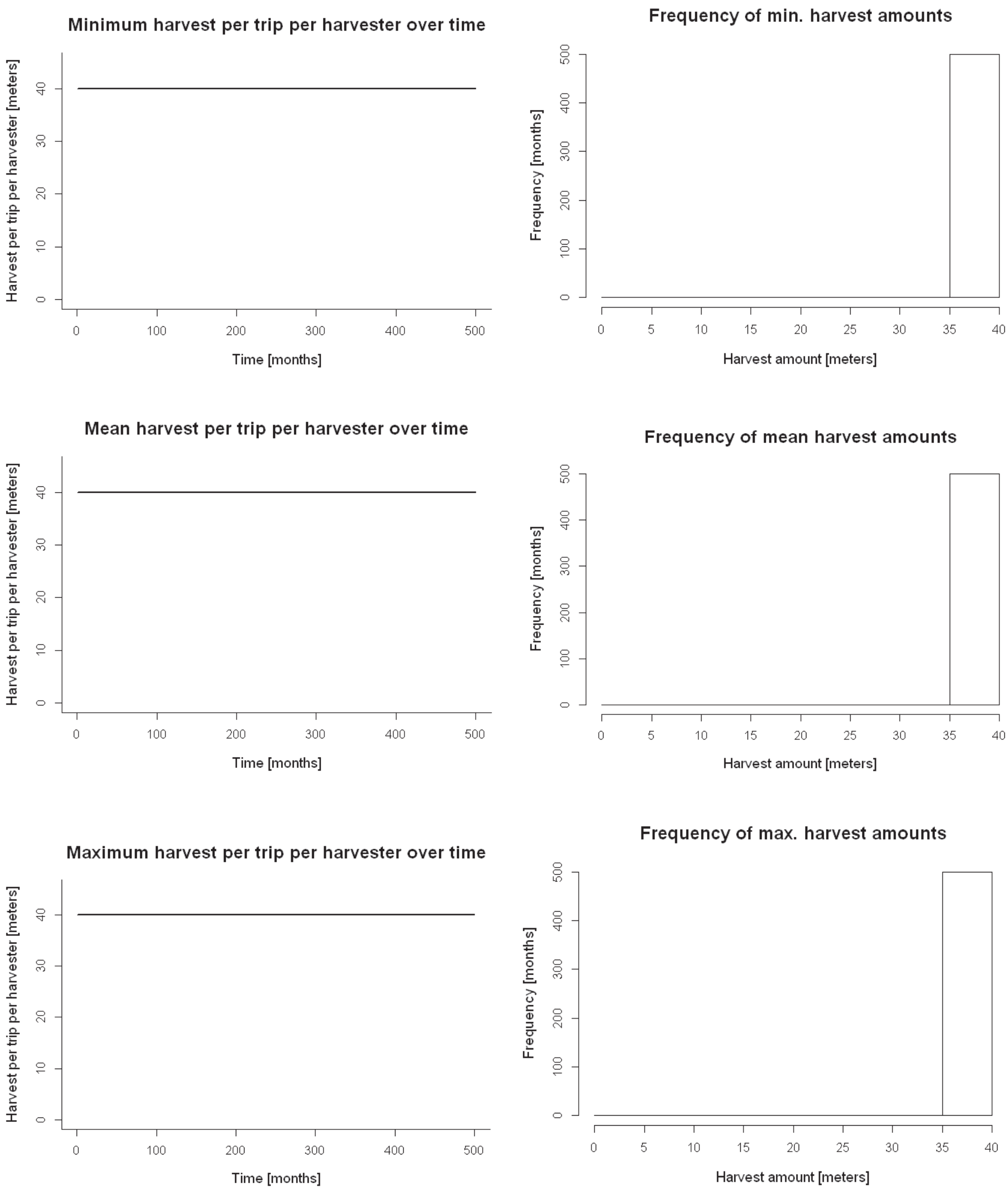


**Fig. 19: Scenario A (40 harvesters, 20 harvests per month, harvesting pressure 1.13, 1.5 km max. harvest radius, 500 time steps): Min, mean and max. harvests per trip per harvester over time and Frequency of harvest amounts respectively. On the left hand figures, one can see the development of the harvests over the 500 month period. The harvesters can each carry up to 40 metres of rattan. Their goal is to take every time 40 metres home with them. Only when they do not find enough rattan to harvest, the harvest amount will drop to values below 40 metres. On the right hand figures, one can see the frequency of how often a certain amount was harvested by the villagers over the 500 month period. Min, max and mean refer to the harvest amount of a single harvester during one time step. The minimum value for time step one, for example, is the smallest harvest amount that one harvester brought home, of all harvesters during all their trips in the first time step.**

In scenario B with 50 harvesters that harvest 30 times each month (harvesting pressure 2.12) there are already some harvesters who are not able to fill their backpack every time they go out to harvest. After approximately 120 months the harvest amount drops considerably and at 130 months there are already some harvesters who cannot bring home any rattan at all. Except for a few times around 200 months, there are always harvesters who are not able to harvest any rattan. The mean harvester however is able to harvest between circa 5 and 30 metres of rattan until the end of the simulation. Except for approximately 100 months, there are always harvesters who are able to completely fill their backpacks with the maximum capacity of 40 metres of rattan during the whole simulation period (Fig. 20).

In scenario C with 150 harvesters that harvest 30 times each month (harvesting pressure 6.37) only very few harvesters are able to fill their backpacks up to the top every time they go out harvesting (Fig. 21). This scenario shows a rapid decline after only about 30 months. The minimum of the rattan harvests is, after the short initial phase, always zero, so there are always harvesters that do not get any rattan at all. There are still quite often (approximately in 370 months) some harvesters that always can fill their backpack. But the mean harvester can harvest seldom more than 20 metres of rattan per harvesting trip. More often he harvests 10 metres or less, if even any at all.

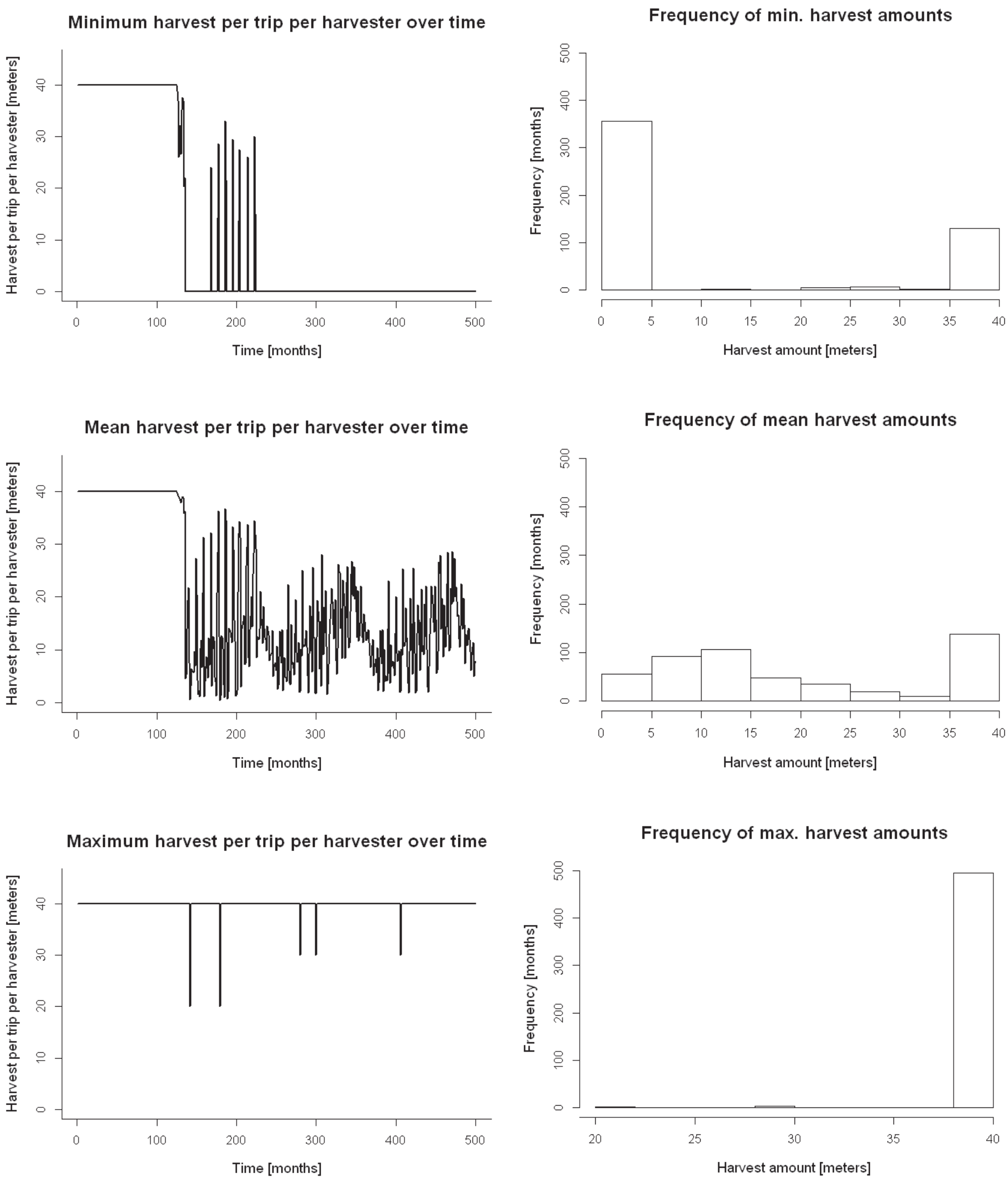


**Fig. 20: Scenario B (50 harvesters, 30 harvests per month, harvesting pressure 2.12, 1.5 km max. harvest radius, 500 time steps): Min, mean and max. harvests per trip per harvester over time and Frequency of harvest amounts respectively**

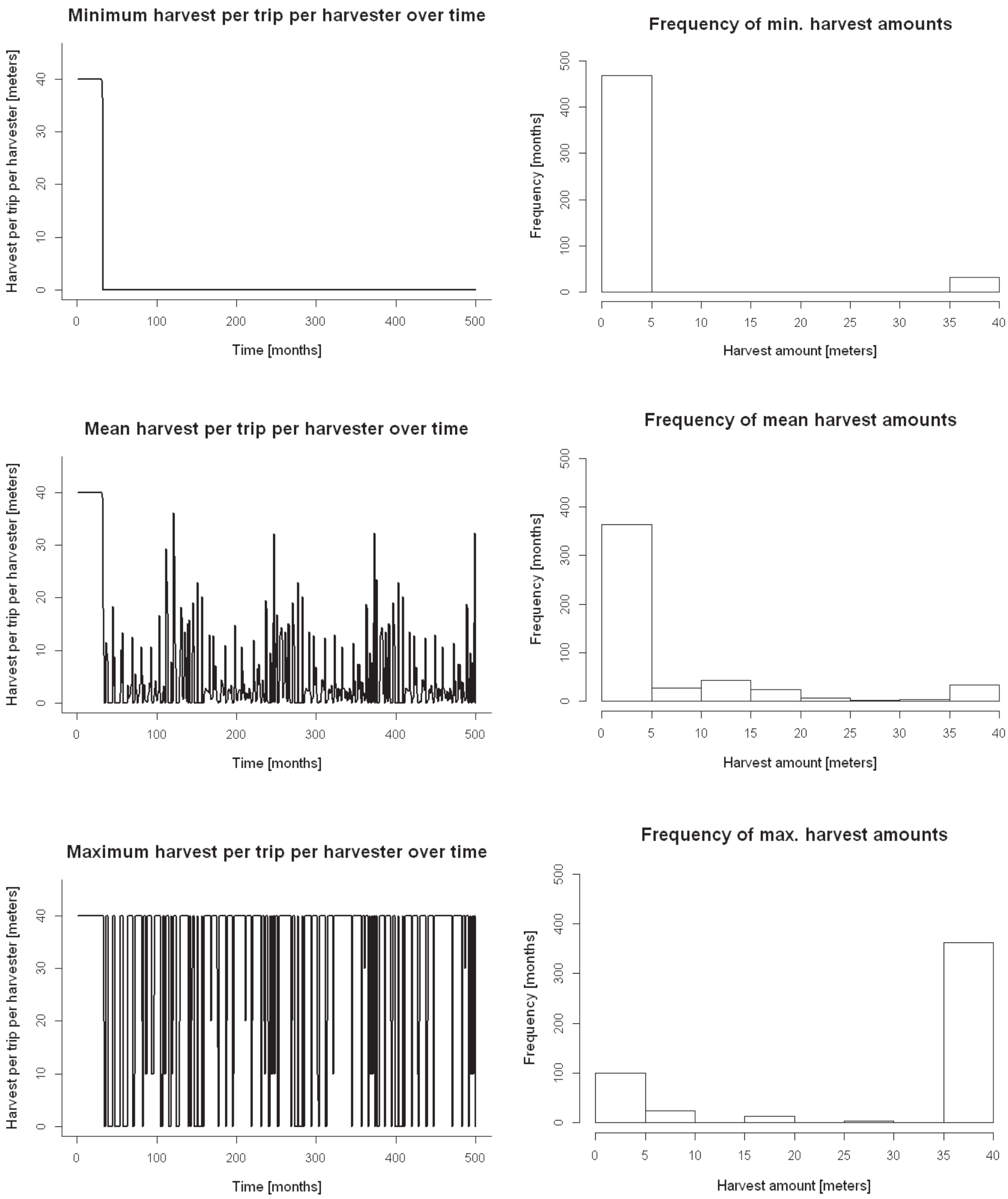


**Fig. 21: Scenario C (150 harvesters, 30 harvests per month, harvesting pressure 6.37, 1.5 km max. harvest radius, 500 time steps): Min, mean and max. harvests per trip per harvester over time and Frequency of harvest amounts respectively**

# 4 Discussion

## 4.1 Harvest per Trip per harvester for different harvesting pressures:

The complex growth and harvesting situation of rattan in Indonesia was simulated and the results show clearly a harvesting threshold at a harvesting pressure of 1.13 leading to a decreased amount of harvestable rattan with increasing harvesting pressure (Fig. 16 and Fig. 17). Exceeding this harvesting pressure, the mean harvest per month drops dramatically to only two thirds of the maximal reached harvest amount. This drop in yield can be explained with the growth dynamics of the rattan canes and the harvesting behaviour of the villagers. When applying low harvesting pressure, there will always be some rattan canes left on the patches that are long and thus have a high growth increment. This increment assures that there will be plenty of rattan that can be harvested in the next time steps. When exceeding the critical harvesting pressure of 1.13, the harvesters will cut off all canes that reached 10 metres in length or more. By this, all canes will be put into a little-growth-increment stage resulting in much smaller total harvest yields in the following time steps. The overall mean growth increment of all the canes in the harvested area is now considerably less than it was when not all of the canes that were 10 metres or more long were harvested. The harvest amount of around 15,000 to 20,000 metres is exactly the quantity of rattan cane that exceeds the 10 m restriction and that is directly skimmed off by the harvesters, leaving no canes left with more than 10 metres in length and thus setting the increment of the harvested canes to the lowest value, leaving only the canes that were not harvested (i.e. below 10 metres long) in a better increment stage. We see that the harvesting restriction of 10 metres is crucial to the regrowth of new rattan resources. In reality the drop would not be as drastic because in the simulations it is due to the strictly applied 10 m restriction during the harvests. If it were possible to increase this restriction to values of 20 or 30 metres, the threshold for the extreme harvest drop would shift more to the right and thus increase the maximum sustainable yield, allowing a greater proportion of harvesters to fill their backpacks. The drop after the threshold would also not be as drastic if we had a smoother rattan growth function. But none of these changes would lead to the complete disappearance of the threshold and such a threshold in harvesting pressure after which the harvest amount decreases should be observable in reality.

The differences between simulations with the same harvesting pressure but different numbers of harvesters and harvests per month combinations, as well as the differences between repeated unchanged scenarios are due to the randomness of quantity and length of rattan canes when stocking the patches at the beginning of the simulations.

From a village community point of view, it would be very desirable to restrict harvesting to a harvesting pressure below the critical threshold as this assures the highest sustainable harvest for the village. Only with a collective management through harvest restrictions for example, the village is able to profit optimally from the rattan resources in the surrounding forests. This is made more difficult, because the rattan industry hires harvesting troops who move for several weeks into a certain area and harvest all the rattan they can find in the surrounding forests, and then move on to another area without consideration of the local population and their needs for rattan. Because of this selfish act the community will lose. This is the typical problem of the "tragedy of the commons" (Hardin 1968). When each individual optimizes its behaviour based on the available resources, the common good is exploited and the collective loses. Similar system behaviour can be found in other biotic systems like fisheries and wild game populations (Castello et al. 2011, Ruth et al. 2011).

### 4.2 Harvest per trip per harvester for different harvesting intensities

After the threshold at a harvesting pressure of 1.13 the average harvester cannot harvest as much rattan as he needs to fill his backpack (Fig. 17). Whether there are more harvesters or more harvests per month, exceeding this harvesting pressure, none of the harvesters is able to always fill his backpack. On first thought one might expect a linear decrease of the individual harvest amount. The negative exponential decline we see in Fig. 17 can be explained with the regrowth dynamics of the rattan canes. Up to a harvesting pressure of 1.13 there are always some long canes left that have a high increment. Exceeding the threshold, all canes are below 10 metres in length and have a smaller total average increment than the canes > 10 metres. Under high harvesting pressure, the villagers have to wait until any of the canes reach the 10 metres length that is necessary for harvest. This fact, in combination with the division of the harvest among increasingly more harvesters or harvest trips, is the cause of the shape of the graph. The graph clearly shows that if the threshold is exceeded, the higher the harvesting pressure, the more each harvester loses. In reality, this drop may set in a bit earlier and be slightly less drastic if harvesters do not have perfect knowledge of the rattan resources in the landscape.

### 4.3 Mean annual increment of rattan canes:

The harvests around the villages in Indonesia keep the rattan canes very short. When harvesting pressure is high, the villagers already harvest the canes as soon as they reach 10 metres (at an age between 11 to 12 years). However, this is a suboptimal harvesting rule because the mean annual increment of rattan is quite low at this age (Fig. 18). The economic optimal harvesting time will be at a later time, depending on the current rattan prize. To be able to get a maximum sustainable yield, the harvesters should wait with their harvests until the optimal length is reached. Only then will they receive the highest possible output from the rattan populations.

### 4.4 Sample scenarios:

The representative scenarios (shown in Fig. 19 to Fig. 21) illustrate the three main harvesting outcomes. In a scenario with a harvesting pressure of 1.13, every harvester can harvest as much rattan as he can carry (40m). This implies a sustainable harvest because the rattan resources and their increment are sufficient to satisfy the needs of the local village populations over time.

This changes as we reach a harvesting pressure of 2.12. Here most harvesters can only harvest around 10 metres of rattan per trip. At least one harvester almost always gets to fill up his “backpack” all the way, but a few harvesters do not harvest any rattan at all over the last 200 months. This leads to fallbacks in the average monthly harvested rattan amount and is thus a sign for unsustainable harvest. This deficit might already become problematic for the local villagers as they need the extra income from the rattan harvests to e.g. buy food in case their self grown food crop is not sufficient due to a crop failure. The development of the average cane length per patch (Fig. 14 and Fig. 15) also shows the high impacts of the harvests. All canes within maximum harvest distance reach were harvested. The harvested canes have, after 200 and 500 month, an average length of 0 to 10 metres. The canes that were not harvested grew in contrast to average lengths between 40 to 50 metres (after 200 month) and 70 to 90 metres (after 500 month). This shows the potential lengths and rate of growth that could be obtained when the rattan canes were not harvested so soon.

When reaching harvest intensities of 4.24 or higher, the mean monthly harvest drops further to almost zero. After the initial phase there are always harvesters each month that are not able to harvest anything at all. Since rattan harvests are mainly done by the very poor people and in emergency situations, this result is very alarming because livelihoods depend on it. Also the mean harvest per month is very low and after the initial phase only very few harvesters can reach mean harvest amounts around 10 metres. The wave-like patterns, i.e. unstable amounts of harvests, make the reliability on future harvests and budgeting of the resulting income impossible. And even the maximum harvest amount in some months is zero, so in some months there are no rattan canes at all that could be harvested. This will again have drastic consequences for the villagers that depend on their rattan harvests. They may have to restrict the building of new houses, furniture and every day objects or use different materials. This then may lead to the exploitation of another natural resource such as timber. It is therefore important to find a way to avoid this shift from rattan to wood, to protect the forests from illegal logging.

The impacts of such a high harvesting pressure on the rattan populations are intense. The rattan canes are kept very short and all canes exceeding the 10 metres restriction are directly cut off. This means that there will be no sexual reproduction of the rattan plants and with this, the plants are not able to conquer new sites and to evolve and adapt genetically to changing environmental conditions. This may lead to decreasing prosperity as the effects of climate change become more appreciable.

### 4.5 Consequences

It is important to educate local people about the harvesting threshold found in this study. Overexploitation of the rattan resources could be avoided by compensational payments from the government for harvesting less rattan. A way to stabilise the rattan resources and reduce the risk of overexploitation is by planting new rattan plants into the forests or in coffee and cacao agroforests. There are already some rattan nursery programs that show promise (Siebert 2000). Another way to avoid overexploitation is through the influence and guidance of the big companies that buy the rattan canes from the harvesters. These companies could request some harvesting certificates like the Forest Stewardship Council, FSC, (Meidinger et al. 2003) from the villagers, that assures that the canes were not illegally harvested and do not come from protected sites. In terms of the corporate environmental and social responsibility the companies should not only focus on economical aspects, but also on social factors when dealing with their raw material suppliers (Garriga et al. 2004). For example, they can steer the harvesting behaviour by only buying raw materials that assuredly have been harvested under good resolutions such as no child labour, no illegal harvesting, no harvesting in protected areas, as well as consultation and cooperation with forest management agencies. They reach these goals by paying farmers compensational payments and providing their children with schools and education. This system quickly pays off for the harvesters, as they can now apply company-suggested harvesting and tendance methods that might reduce the yield in the first couple of years, but that exceed the standard yield in the following years, without having to be afraid of a very small or no income as a result from small yield. These methods are already used by big companies like Tchibo, IKEA and U.S. retailers like Home Depot (Porter et al. 2006, Edvardsson et al. 2009). Also governments of importing countries can influence the harvest behaviour in the exporting countries. For instance the U.S. government changed their Lacey Act in 2008 to stop the imports of illegally harvested plant material and of products made from illegally harvested plants (Hirschberger 2011).

Direct comparisons of the models' output values with literature values should be viewed with caution. The maximum sustainable harvest from my simulations calculates to an amount of 543.26 metres $ha^{-1}$ $year^{-1}$. Siebert (2004) suggests a sustained yield harvesting potential of 56 and 101 metres $ha^{-1}$ $year^{-1}$ for two studied villages (Moa and Au) in Sulawesi, Indonesia. Circumstances like the number of plants per patch, the harvesting history in the area, the often unknown size of the harvested area and the accessibility to the rattan canes differ a lot and make comparisons hard. They are also most likely accountable for the difference between my output values and Siebert's approximation. When comparing the rattan populations with other endangered species e.g. in the Yellowstone National Park, we can see similarities concerning the accessibility of the resource by humans. There is for example an increased morality risk for cougars with increasing density of roads (Ruth et al. 2011). The easier it is for humans to reach resources, the more likely it is that they will be exploited. We can also see this in the rattan harvesting behaviour in form of the maximum harvesting distance. Depending on the prize, the harvesters are only willing to walk a certain distance. Therefore distance to humans and other obstacles that complicate accession, like steep lopes or swampy grounds are of benefit for vulnerable species. Due to their intrinsic growth, the rattan is spared the catastrophic shifts, which for some species can be irreversible such as in coral reefs and other unstable ecosystems (Scheffer et al. 2001).

## 4.6 Possible extensions for future study

**Reproduction and Death:**

It would be interesting to include sexual reproduction and natural death in the model. Sexual reproduction and death do not play an important role in the current situation but it would be interesting to study what happens if some plants are left unharvested so that they can mature and reproduce. Maybe these new plants will show a different growth behaviour. They might be fitter and evolutionary better adapted to the site they grow on or to climate change. The sexual reproduction might also raise the numbers of plants per hectare more than the vegetative reproduction. However, before this could be included in the model, further field studies are necessary.

**Forest rangers and fines for illegal harvesting:**

Rattan harvests within the borders of national parks are forbidden (Siebert, Belsky 2002). It would be interesting to study the change in harvest behaviour if forest rangers that check for illegal harvests are introduced into the model and villagers, that get caught harvesting, have to pay a fine.

**Elevation:**

When a 3D landscape is modelled there will be very interesting patterns concerning hills and mountains. Different rattan species have their optimum growth in different heights (Siebert 2005) so that the growth will be restricted in certain areas. The steeper the area, the harder it will be to harvest the rattan canes there, if not impossible. So in these areas, the harvesting would be a big challenge for the villagers that they will probably only take up when there is a very high demand for rattan. Also slopes are unsuitable for rice production and unfavourable for oil palm and cacao plantations so this actually is where most rattan can be found. But how high do the rattan prices need to be, to make the villagers harvest on extremely steep slopes?

**Two different types of harvesters**

It would be very interesting to implement two different types of harvesters into the model. One type is the average villager that collects rattan around the village. He will stay within a maximum distance of 6 km to the village and will return home every evening after harvesting. The other type of harvester is a team of villagers or hired men that help each other to maximize their harvesting outcome. They will leave their village for several days up to a couple of months to go to rich harvesting grounds, where they set up a camp and harvest the spots around them. Then they go to the next close by harvesting spot and begin harvesting in that region.

**Spatial distance matters**

Since humans try to optimize processes, they would rather like to harvest rattan patches that are close to their village to save travelling time. This harvesting pressure change could be implemented into the model by using an exponential decay distribution of harvests decaying from the village outwards. Patches would be assigned different distance values and the harvesting function would contain a part that makes the villagers choose a trade off between walking small distances often and harvesting little versus walking a long distance not that often and getting big harvest amounts.

**Interactions between trees and rattan**

Ecosystems are very complex and there are a lot of interactions between the various species found in rainforests. The rattan plants depend on trees for climbing upwards into the canopy. One could introduce this interaction by changing the growth increments and density of rattans per patch, depending on the number of trees found on the respective patch. In this context it would also be interesting to study the effects of disturbances on rattan growth. On a deforested site for example, the rattan growth will initially be very high because there is a lot of light reaching the rattan plants on the ground. But since these cannot reach upwards, because there are no supporting trees, the growth will probably stagnate quickly as the area on the ground is soon covered with rattan canes and pioneer vegetation.

# 5 Conclusions

## 5.1 Model behaviour and output

My simulation model has been used to determine the behaviour of rattan resources and rattan population dynamics under different harvesting intensities. The pronounced decline in total harvest amount per month after the critical harvesting pressure threshold was exceeded was unexpected and illustrates the power of models to reveal complex behaviours of ecological systems. My results support the hypothesis that even though rattan does not die off that simply, there is still a non-linear decrease in harvest amounts when the resources are overexploited. On the one hand the data shows clearly that the harvesters were still able to harvest some rattan even under intense harvesting pressure. But on the other hand, variations in harvest amount per month and per villager varied considerably, making it hard for the villagers to plan their future income.

## 5.2 Effects on nature, harvest sustainability and villagers

According to Siebert (2004), rattan harvests in Indonesia are not sustainable. My simulation model helps to understand the underlying basic principles and makes it possible to find a possible starting point to improve the current rattan overexploitation. As we see from the model outputs, after a certain threshold, the harvest amount drops. Suspecting that the threshold is already exceeded, it would be good to determine the exact pressure at which the threshold exists in villages like Moa and Au which have been studied by e.g. Siebert. With this, the parties involved in rattan harvest and trade, can try to guide the rattan harvests to concrete, safe amounts of rattan cane extraction. Even though there is an increasing rattan demand, the villagers should carefully consider how much rattan they extract from the forests, making sure the amount does not exceed the threshold, because then the total harvest for all villagers will be severely diminished. If this becomes the case, the primary forests could become worthless to them and they might start to think about cutting it down and sell the wood.

## 5.3 Generality

I have demonstrated that, in principal, the model behaviour can be applied to similar harvesting systems such as fisheries and wild game hunting systems. I have talked about the similarities and differences between these systems and their impacts on the populations. The advantage of rattan is that it regrows vegetatively and is thus not likely to experience catastrophic shifts sensu Scheffer et al. (2001).

## 5.4 Final conclusion

In conclusion, my rattan harvest model has provided an interesting insight to the behaviour of rattan growth and harvesting dynamics: with increasing harvesting pressure there is a threshold beyond which rattan harvest declines dramatically, both at the collective level of the village and the individual level of the harvester. However there were limitations to the model that should be resolved in future studies. For example should the development of the rattan growth increments be refined to provide a smoother transition between the different increment stages. The harvesting behaviour, especially the decision on which patch to harvest, should be studied further to be able to recreate more realistic simulations.

Concerning the rattan situation in Indonesia, it can be said that there is a need to manage rattan harvests, whether it might be by community agreements, political restrictions or compensational payments, or through certification programs introduced by rattan-processing companies. To me, this seems to be the only way to assure that the harvesting pressure does not exceed the threshold that leads to a smaller, unstable total harvest amount. This again makes it more likely that the villagers in Sulawesi will protect the primary forests and do not start to cut it down for immediate monetary benefit and then replace it with agricultural plantations. This will inter alia ensure rainforest margin stability, maintain an important $CO_2$ sink and guard the rich and diverse flora and fauna of the Indonesian primary forests.

# 6 Acknowledgements

The present work benefited from the input of Rodolphe Sabatier, Kerstin Wiegand, Katrin Meyer, Lars Drössler and Eric Agestam who provided valuable ideas and comments to the model and writing of this study. Also I thank Helen McDonald, Marianne Broermann and Vladimir Gonzalez Gamboa for helpful ideas, comments and discussions and my parents Ursula and Wolfgang and my sister Mareike for the support during my studies and the writing of this thesis.

This study was part of the DFG-funded research projects "Environmental and land-use change in Sulawesi, Indonesia: Socioeconomic and ecological perspectives" (PAK 569, WI1816/12) and CRC 990-EFForTS (Ecological and socioeconomic functions of tropical lowland rainforest transformation systems (Sumatra, Indonesia)).

## 7 Literature

**Abasolo, W. P., Lomboy, O. C. 2009:** Influence of Growth Rate, Elevation and Sunlight on the Anatomical and Physico-Mechanical properties of Plantation-Grown Palasan (*Calamus merrillii* Becc.) Canes; Philippine Journal of Science Vol. 127: 55-65

**Abdul Razak, M. A., Raja Barizan, R.S. 2001:** Country report on the status of rattan resources and uses in Malaysia; in: Rattan: current research issues and prospects for conservation and sustainable development; Non-wood forest products Vol. 14; edited by Dransfield, J., Tesoro, F.O., Manokaran, N.; FAO: 151-166

**Baker, A. 2004:** Simplicity; Stanford Encyclopedia of Philosophy, California; Stanford University

**Castello, L., Stewart, D. J., Arantes, C. C. 2011:** Modeling population dynamics and conservation of arapaima in the Amazon; Reviews in fish biology and fisheries Vol. 21: 623-641

**Clough, Yann Abrahamczyk, S., Adams, M. O., Anshary, A., Ariyanti,N., Betz, L., Buchori, D., Cicuzza, D., Darras, K., Putra, D. D., Fiala, B., Gradstein, S. R., Kessler, M., Klein, A.-M., Pitopang, R., Sahari, B., Scherber, C., Schulze, C. H., Shahabuddin, Sporn, S., Stenchly, K., Tjitrosoedirdjo, S. S., Thomas C. WangerT. C., Weist, M., Wielgoss, A., Tscharntke, T. 2010:** Biodiversity patterns and trophic interactions in human-dominated tropical landscapes in Sulawesi (Indonesia): plants, arthropods and vertebrates; in: Tropical Rainforests and Agroforests under Global Change; Environmental Science and Engineering; Springer-Verlag Berlin Heidelberg: 15-71

**Dransfield, J., Tesoro, F.O., Manokaran, N. 2002:** Rattan – Current research issues and prospects for conservation and sustainable development; Non-Wood forest products Vol. 14; Food and agriculture organization of the united nations: 272p

**Edvardsson, B., Enquist, B. 2009:** Values-based Service for Sustainable Business: Lessons from IKEA; Routledge, London: 131p

**Engineers without borders undated:** Non-timber forest products – Cultivation, harvesting and processing of African rattan – palmae Calamoideae; Practical guide; http://www.isf-cameroun.org/african%20rattan-good.pdf Nov. 2012: 9p

**FAO 2011:** Indonesia: call to revamp trade and export of rattan; Non-wood news Vol. 22; edited by Etherington, T., Muir, G., Mitchell, R. Lazarev, A., Fanego, D.: 7

**FAO 2007:** Halting the rapid disappearance of the world's rattan resources; Non-wood news Vol. 15; edited by Etherington, T., Rivero, S., Mitchell, R., Fanego, D.: 37-38

**Forest Inventory and Mapping Centre undated:** Forest resources monitoring in Indonesia; Forest Planning Agency, Ministry of forestry of republic of Indonesia; FRMA Document Serial Number 08: 2p

**Garriga, E., Melé, D. 2004:** Corporate Social Responsibility Theories: Mapping the Territory; Journal of Business Ethics Vol. 53: 51–71

**Hardin, G. 1968:** The Tragedy of the Commons; Science Vol. 162: 1243 – 1248

**Hirschberger, P. 2011:** Global Rattan Trade: Pressure on Forest Resources – Analysis and Challenges; WWF Austria: 2p

**ITTO, Ministry of Forestry Republic of Indonesia 2007:** Inventory of standing stocks in natural forest and plantation; Development of sustainable rattan production and utilization through participation of rattan smallholders and industry in Indonesia: 29p

**Johnson, D. 1998:** Tropical Palms; Non-wood forest products Vol. 10; FAO: 166p

**Lande, R., Sæther, B.-E., Engen, S. 1997:** Threshold harvesting for sustainability of fluctuating resources; Ecology Vol. 78: 1341-1350.

**Laurance, W. F., Lovejoy, T. E., Vasconcelos, H. L., Bruna, E. M., Didham, R. K., Stouffer, P. C., Gascon, C., Bierregaard, R. O., Laurance, S. G. and Sampaio, E. 2002:** Ecosystem Decay of Amazonian Forest Fragments: a 22-Year Investigation; Conservation Biology Vol. 16: 605–618

**Meidinger, E., Elliott, C., Oesten, G. 2003:** The Fundamentals of Forest Certification; in: Social and political dimensions of forest certification; edited by Meidinger, E., Elliott, C., Oesten, G. Verlag www.forstbuch.de: 3-26

**Myers, N. 1988:** Threatened biotas: 'hot spots' in tropical forests; Environmentalist Vol. 8: 187–208

**Ngo-Samnick, E. L. 2012:** Rattan – production and processing; Pro-Agro Collection; CTA and ISF: 28p
http://www.isf-cameroun.org/en/content/rattan-production-and-processing
http://www.isf-cameroun.org/sites/default/files/rattan-eng_LoRes.pdf

**Ometto, J., Nobre, A. D., Rocha, H. R., Artaxo, P. & Martinelli, L. A. 2005:** Amazonia and the modern carbon cycle: lessons learned. Oecologia Vol. 143: 483–500

**Porter, M. E., Kramer, M. R. 2006:** Strategy & society – The link between competitive advantage and corporate social responsibility; Harvard Business Review: 76-93

**Powling, A. 2004:** Rattans: taxonomy and ecology; Indonesian Institute of Sciences (LIPI); report: 4p

**Ruth, T. K., Haroldson, M. A., Murphy, K.M., Buotte, P.C., Hornocker, M.G., Quigley, H.B. 2011:** Cougar Survival and Source-Sink Structure on Greater Yellowstone's Northern Range; The Journal of Wildlife Management Vol. 75: 1381–1398

**Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., Walker, B. 2001:** Catastrophic shifts in ecosystems; Nature Vol. 413: 591–596

**Schütt, P., Aas, G. 2002:** Lexikon der Baum- und Straucharten; Nikol; Hamburg: 581p

**Shaanker, R., Uma, Ganeshaiah, K.N., Srinivasan, K., Ramanatha Rao, V. Hong, L.T. 2004:** Bamboos and Rattans of the Western Ghats – population biology, socio-economics and conservation strategies; Ashoka Trust for Research in Ecology and the Environment (ATREE); Bangalore: 203p

**Siebert, S.F. 1993:** The abundance and site preferences of rattan (Calamus exilis and Calamus zollingeri) in two Indonesian national parks; Forest Ecology and Management Vol. 59: 105–113

**Siebert, S. F. 2000:** Survival and growth of rattan intercropped with coffee and cacao in the agroforests of Indonesia; Agroforestry Systems Vol. 50: 95–102

**Siebert, S. F. 2001:** Tree cutting to float rattan to market: a threat to primary forests?; J. Bamboo and Rattan, Vol. 1: 37-42

**Siebert, S. F., Belsky, J. M., Mogea, J. 2001:** Final Report: Managing Rattan Diversity for forest conservation; U.S. Agency for International Development; Bureau for Global Programs, Field Support and Research; Centre for Economic Growth: 23p

**Siebert, S.F., Belsky, J.M. 2002:** Livelihood Security and Protected Area Management; International Journal of Wilderness; Vol. 8: 38 – 42

**Siebert, S. F. 2004:** Demographic Effects of Collecting Rattan Cane and Their Implications for Sustainable Harvesting; Conservation Biology Vol. 18: 424-430

**Siebert, S. F. 2005:** The abundance and distribution of rattan over an elevation gradient in Sulawesi, Indonesia; Forest Ecology and Management Vol. 210: 143-158

**Steffan-Dewenter, I.; Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., Erasmi, S., Faust, H., Gerold, G., Glenk, K., Gradstein, S. R., Guhardja, E., Harteveld, M., Hertel, D., Höhn, P., Kappas, M., Köhler, S., Leuschner, C., Maertens, M., Marggraf, R., Migge-Kleian, S., Mogea, J., Pitopang, R., Schaefer, M., Schwarze, S., Sporn, S. G., Steingrebe, A., Tjitrosoedirdjo, S. S., Tjitrosoemito, S., Twele, A., Weber, R., Woltmann, L., Zeller, M., Tscharntke, T. 2007:** Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification; edited by Turner, M. G.; PNAS Vol. 104: 4973-4978

**Steven, D.D. 1989:** Genet and Ramet Demography of *Oenocarpus Mapora SSP. Mapora*, a Clonal Palm of Panamanian Tropical Moist Forest; Journal of Ecology Vol. 77: 579–596

**Stiegel, S., Kessler, M., Getto, D., Thonhofer, J., Siebert, S.F 2011:** Elevational patterns of species richness and density of rattan palms (*Arecaceae: Calamoideae*) in Central Sulawesi, Indonesia; Biodiversity and Conservation Vol. 20, 1987–2005

**Sunderland, T. C. H, Dransfield, J. 2001:** Species profiles rattans (Palmae: Calamoideae); in: Rattan: current research issues and prospects for conservation and sustainable development; Non-wood forest products Vol. 14; edited by Dransfield, J., Tesoro, F.O., Manokaran, N.; FAO: 9-22

**The R Foundation for Statistical Computing 2012:** Version 2.15.2; www.r-project.org

**van Valkenburg, J. L. C. H. 2002:** Rattan in east Kalimantan, Indonesia: Species composition, abundance distribution and growth in some selected sites; in: Rattan: current research issues and prospects for conservation and sustainable development; Non-wood forest products Vol. 14; edited by Dransfield, J., Tesoro, F.O., Manokaran, N.; FAO: 199-223

**Wiener G., Liese,W. 1993:** Anatomische Untersuchungen an Westafrikanischen Rattan Palmen (Calamoideae); Flora (1994) 189: 51 - 61

**Wilensky, U. 1999:** NetLogo 5.0; http://ccl.northwestern.edu/netlogo; Center for Connected Learning and Computer-Based Modeling; Northwestern University, Evanston

**Weinstock, J.A. 1983:** Rattan: Ecological Balance in a Borneo Rainforest Swidden; Economic Botany Vol. 37: 58-68

# 8 Appendix

## 8.1 Overview of all simulations and main outcomes

**Tab. A1: Overview of all simulations and main outcomes**

| Harvest pressure | number of harvester | harvests per month | max harvest amount per trip | mean harvest amount per trip | min. harvest amount per trip | sum of all harvesters per trip | total harvest per month |
|---:|---:|---:|---:|---:|---:|---:|---:|
| 0.001 | 1 | 1 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 |
| 0.042 | 1 | 30 | 40.00 | 40.00 | 40.00 | 40.00 | 1200.00 |
| 0.085 | 2 | 30 | 40.00 | 40.00 | 40.00 | 80.00 | 2400.00 |
| 0.141 | 10 | 10 | 40.00 | 40.00 | 40.00 | 400.00 | 4000.00 |
| 0.212 | 5 | 30 | 40.00 | 40.00 | 40.00 | 200.00 | 6000.00 |
| 0.354 | 10 | 25 | 40.00 | 40.00 | 40.00 | 400.00 | 10000.00 |
| 0.424 | 10 | 30 | 40.00 | 40.00 | 40.00 | 400.00 | 12000.00 |
| 0.424 | 60 | 5 | 40.00 | 40.00 | 40.00 | 2400.00 | 12000.00 |
| 0.531 | 15 | 25 | 40.00 | 40.00 | 40.00 | 600.00 | 15000.00 |
| 0.637 | 15 | 30 | 40.00 | 40.00 | 40.00 | 600.00 | 18000.00 |
| 0.707 | 20 | 25 | 40.00 | 40.00 | 40.00 | 800.00 | 20000.00 |
| 0.707 | 50 | 10 | 40.00 | 40.00 | 40.00 | 2000.00 | 20000.00 |
| 0.849 | 20 | 30 | 40.00 | 40.00 | 40.00 | 800.00 | 24000.00 |
| 0.849 | 30 | 20 | 40.00 | 40.00 | 40.00 | 1200.00 | 24000.00 |
| 0.849 | 40 | 15 | 40.00 | 40.00 | 40.00 | 1600.00 | 24000.00 |
| 0.849 | 60 | 10 | 40.00 | 40.00 | 40.00 | 2400.00 | 24000.00 |
| 0.955 | 45 | 15 | 40.00 | 40.00 | 40.00 | 1800.00 | 27000.00 |
| 0.990 | 35 | 20 | 40.00 | 40.00 | 40.00 | 1400.00 | 28000.00 |
| 0.990 | 70 | 10 | 40.00 | 40.00 | 40.00 | 2800.00 | 28000.00 |
| 1.061 | 30 | 25 | 40.00 | 40.00 | 40.00 | 1200.00 | 30000.00 |
| 1.061 | 50 | 15 | 40.00 | 40.00 | 40.00 | 2000.00 | 30000.00 |
| 1.061 | 150 | 5 | 40.00 | 40.00 | 40.00 | 6000.00 | 30000.00 |
| 1.132 | 40 | 20 | 40.00 | 40.00 | 40.00 | 1600.00 | 32000.00 |
| 1.132 | 80 | 10 | 40.00 | 40.00 | 40.00 | 3200.00 | 32000.00 |
| 1.238 | 35 | 25 | 37.60 | 28.29 | 13.96 | 990.16 | 24753.90 |
| 1.273 | 30 | 30 | 33.98 | 22.06 | 8.36 | 661.81 | 19854.30 |
| 1.273 | 30 | 30 | 33.69 | 21.76 | 8.23 | 652.74 | 19582.30 |
| 1.273 | 30 | 30 | 33.84 | 21.90 | 8.30 | 657.13 | 19713.90 |
| 1.273 | 36 | 25 | 34.13 | 21.98 | 8.27 | 791.25 | 19781.20 |
| 1.273 | 45 | 20 | 36.40 | 24.67 | 9.04 | 1110.06 | 22201.10 |
| 1.273 | 60 | 15 | 34.59 | 22.05 | 8.17 | 1322.74 | 19841.10 |
| 1.273 | 60 | 15 | 34.07 | 21.67 | 8.04 | 1300.18 | 19502.70 |
| 1.273 | 90 | 10 | 36.70 | 24.30 | 8.63 | 2187.38 | 21873.80 |
| 1.309 | 37 | 25 | 31.68 | 20.07 | 7.69 | 742.77 | 18569.20 |
| 1.316 | 31 | 30 | 31.49 | 19.90 | 7.70 | 616.87 | 18506.20 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.344 | 38 | 25 | 30.79 | 19.31 | 7.45 | 733.88 | 18346.90 |
| 1.379 | 39 | 25 | 29.48 | 18.06 | 7.09 | 704.51 | 17612.70 |
| 1.415 | 40 | 25 | 29.19 | 18.07 | 7.02 | 722.74 | 18068.50 |
| 1.415 | 50 | 20 | 29.42 | 18.14 | 6.97 | 906.91 | 18138.10 |
| 1.415 | 100 | 10 | 30.59 | 18.13 | 6.74 | 1813.05 | 18130.50 |
| 1.415 | 200 | 5 | 31.88 | 17.61 | 6.08 | 3522.58 | 17612.90 |
| 1.485 | 35 | 30 | 29.48 | 18.95 | 7.14 | 663.16 | 19894.90 |
| 1.485 | 35 | 30 | 29.85 | 19.30 | 7.24 | 675.39 | 20261.80 |
| 1.485 | 70 | 15 | 31.32 | 19.95 | 7.26 | 1396.49 | 20947.30 |
| 1.528 | 36 | 30 | 28.21 | 18.13 | 6.86 | 652.62 | 19578.70 |
| 1.570 | 37 | 30 | 26.96 | 17.23 | 6.51 | 637.58 | 19127.40 |
| 1.592 | 45 | 25 | 26.31 | 16.87 | 6.33 | 759.35 | 18983.80 |
| 1.613 | 38 | 30 | 25.54 | 16.40 | 6.22 | 623.37 | 18701.00 |
| 1.655 | 39 | 30 | 24.22 | 15.57 | 5.93 | 607.16 | 18214.90 |
| 1.698 | 40 | 30 | 23.20 | 14.78 | 5.69 | 591.07 | 17732.10 |
| 1.698 | 60 | 20 | 23.56 | 14.85 | 5.56 | 891.04 | 17820.70 |
| 1.698 | 80 | 15 | 24.23 | 15.14 | 5.54 | 1211.25 | 18168.70 |
| 1.698 | 120 | 10 | 24.90 | 15.10 | 5.34 | 1811.64 | 18116.40 |
| 1.768 | 50 | 25 | 21.64 | 13.63 | 5.21 | 681.45 | 17036.20 |
| 1.910 | 45 | 30 | 20.94 | 14.07 | 5.40 | 633.33 | 18999.90 |
| 1.910 | 90 | 15 | 21.77 | 14.04 | 5.10 | 1263.61 | 18954.10 |
| 1.981 | 70 | 20 | 21.79 | 14.69 | 5.44 | 1028.21 | 20564.10 |
| 2.122 | 50 | 30 | 19.73 | 13.52 | 5.23 | 676.02 | 20280.70 |
| 2.122 | 60 | 25 | 19.96 | 13.61 | 5.15 | 816.60 | 20415.00 |
| 2.264 | 80 | 20 | 18.45 | 12.30 | 4.54 | 983.84 | 19676.70 |
| 2.476 | 70 | 25 | 16.21 | 11.07 | 4.00 | 775.22 | 19380.60 |
| 2.546 | 60 | 30 | 15.44 | 10.67 | 3.89 | 640.26 | 19207.90 |
| 2.546 | 90 | 20 | 15.58 | 10.48 | 3.70 | 943.10 | 18862.00 |
| 2.829 | 80 | 25 | 13.88 | 9.63 | 3.39 | 770.56 | 19263.90 |
| 2.971 | 70 | 30 | 12.64 | 8.84 | 3.19 | 618.49 | 18554.80 |
| 3.183 | 90 | 25 | 11.53 | 8.00 | 2.83 | 719.63 | 17990.80 |
| 3.395 | 80 | 30 | 9.89 | 6.94 | 2.42 | 554.99 | 16649.60 |
| 3.820 | 90 | 30 | 8.10 | 5.52 | 1.90 | 497.24 | 14917.10 |
| 4.244 | 100 | 30 | 7.22 | 4.89 | 1.54 | 488.53 | 14655.90 |
| 5.093 | 120 | 30 | 6.11 | 4.02 | 1.35 | 482.17 | 14465.20 |
| 6.366 | 150 | 30 | 5.02 | 3.57 | 1.20 | 535.48 | 16064.30 |
| 8.488 | 200 | 30 | 3.84 | 2.61 | 0.76 | 522.59 | 15677.60 |