Stand Dynamics and Carbon Stock in a Sal (*Shorea robusta* C.F. Gaertn) Dominated Forest in Southern Nepal

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PREFACE

This is my master thesis and my final piece of work on the Master of Science in forestry programme (jägmästarprogrammet) at the Swedish University of Agricultural Sciences (Sveriges lantbruks-universitet) in Umeå and Alnarp, Sweden. My work with this thesis corresponds to 30 credits (högskolepoäng) on the second cycle.

Thanks to everyone involved! Could not have done this without your help. Some of you are mentioned under Acknowledgements, for all others – a great thank you!

Lund, June 2016

Patrik Ulvdal

ABSTRACT

There is a lack of knowledge about the stand dynamics and carbon storage in forests dominated by *Shorea robusta C.F. Gaertn (fam. Dipterocarpaceae)* in southern Nepal, especially in forests managed by local communities. Since *S. robusta* is a major tree species and REDD+ is of growing importance in Nepal, it is necessary to know about these characteristics. This study aimed to explore these stand characteristics, by analysing field data from a 700-hectare big community forest. The data was collected at four occasions, 2005, 2010, 2013, 2015 and consisted of 68 randomly positioned and 500 m^2 big plots, where measurements of diameter at breast height for more than 4000 trees were done, including 10 % of which also had their height measured. Height models were developed through regression analyses for all major species and existing volume equations were used to calculate the volume for all trees. Biomass was estimated by using existing algometric functions. Carbon stock was assumed to be 52 wt.% of the biomass. An additional analysis was done on single tree development of *S. robusta*. The standing volume was found to have increased from 99 to 161 m^3ha^{-1} over the years studied. Thus, the periodic annual increment (PAI) was 5.6 $m^3ha^{-1}year^{-1}$. In 2015, *S. robusta* accounted for 74 % of the volume and a PAI of 4.1 $m^3ha^{-1}year^{-1}$. Recruitment showed a sudden decrease from 43 to 18 trees $ha^{-1}year^{-1}$. The above ground carbon stock of trees increased from 48 tonnes ha^{-1} to 80 tonnes ha^{-1} resulting in a PAI of 2.9 tonnes $ha^{-1}year^{-1}$. Standing volume, carbon stock, volume PAI and carbon stock PAI were at the highest in the diameter range between 10 and 30 cm. The strongest correlations with single tree growth of *S. robusta* were tree volume, tree basal area PAI and current and previous tree basal area. As expected, *S. robusta* dominated many of the processes in the forest. The carbon stock estimation showed that this type of *S. robusta* dominated forest under management of a local community, could be a carbon sink to count with.

Keywords: Forest dynamics, *S. robusta*, Carbon stock, Community forestry, Forest growth.

For a summary in Nepali, see page 37.

SAMMANFATTNING PÅ SVENSKA

Det saknas kunskap rörande beståndsdynamiken och kollagringen i skogar dominerade av *Shorea robusta C.F. Gaertn (fam. Dipterocarpaceae)* i södra Nepal, särskilt i skogar skötta av lokala invånare. Eftersom *S. robusta* är ett viktigt trädslag och REDD+ är på uppgång i Nepal är det viktigt att veta mer om dessa egenskaper. Den här studiens mål var undersöka dessa egenskaper genom att analysera fältdata från en 700 hektar stor byskog. Datat samlades in vid fyra tillfällen, 2005, 2010, 2013, 2015 och bestod av 68 slumpmässigt utlagda och 500 m^2 stora provytor, med diametermätningar för över 4000 träd, varav 10 % även fått sina höjder mätta. Höjdmodeller togs fram genom regressionsanalys för de vanligaste trädarterna och redan existerande volymfunktioner användes för att beräkna volymen för alla träd. Biomassa uppskattades genom användning av redan existerande allometriska funktioner. Kollagret antogs utgöra 52 viktprocent av biomassan. En analys gjordes också på enskild trädtillväxt hos *S. robusta.* Den stående volymen ökade från 99 till 161 m^3ha^{-1} under den studerade perioden, vilket motsvarar en periodisk årlig tillväxt (PAI) på 5,6 $m^3ha^{-1}år^{-1}$. 2015 härrörde 74 % av den stående volymen och 4,1 $m^3ha^{-1}år^{-1}$ av den årliga tillväxten från *S. robusta*. Inväxt minskade kraftigt från 43 till 18 träd $ha^{-1}år^{-1}$. Trädens kollager ovan jord ökade från 48 ton ha^{-1} till 80 ton ha^{-1}, vilket motsvarade en tillväxt på 2,9 ton $ha^{-1}år^{-1}$. Stående volym, kollagret, volym- och koltillväxt var som störst i diameterspannet 10 till 30 cm. De starkaste korrelationer med enskilt trädtillväxt för *S. robusta* uppvisades av trädvolym, trädgrundytetillväxt och nuvarande och tidigare trädgrundyta. Som väntat dominerade *S. robusta* många av processerna i skogen. Kollageruppskattningen visade att denna typ av *S. robusta*-dominerad skog skött genom byskogsbruk kan vara en kolsänka att räkna med.

Nyckelord: skogsdynamik, *S. robusta*, kollager, byskogsbruk, tillväxt

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INTRODUCTION

Forestry in Nepal - status and potential

Nepal is a country rich in forest resources. Around 40 % of the land area is covered with forest and the standing stock is approximately 1064 million cubic metres, out of which only 388 million are reachable due to difficult terrain (DFRS, 2015; Ministry of Forests and Soil Conservation, 2009). The annual contribution from the forest sector to Nepal's GDP is estimated by the Food and Agriculture Organisation of the United Nations (FAO) to be around 3.5 % (average for Asia is 1 %) (Ministry of Forests and Soil Conservation, 2009). This rather big contribution stands in contrast to the annual extraction of round wood, which in total is between 20 000 and 90 000 cubic metres per year, or 0.2 ‰ of the standing volume. The national consumption in 2001 of round wood was 2.2 million cubic metres and the domestic production for the same year was 0.15 million cubic metres – resulting in a deficit of around 2.05 million cubic metres that needed to be imported. Thus, Nepal is a country rich with forests, but it seems like they are a bit under-utilized to their full potential, at least when discussing commercial wood production.

Ownership of forest land in Nepal is almost by 100 % governmental – a result of the nationalisation of forests in 1957 (Acharya, 2002). Since then, the situation has changed – at least when it comes to legal users. The current ownership and user structure of forests in Nepal is shown in Table 1.

Table 1 – Ownership structure of Nepal's forests. Source: Ministry of Forests and Soil Conservation (2009)

Category	**Subcategory**	**Hectares**	**Proportion**
State owned forest	Government-managed forest	3 902 270	66.92%
	Community managed forest	1 200 000	20.58%
	Leasehold Forest	14 730	0.25%
	Religious Forest	543	0.01%
	Protected Forest	711 000	12.19%
Private forest	Private Forest	2 300	0.04%

Apart from the government-managed forests, the most notable subcategory, both by area and by international interest, is the community managed forests. Nepal has a leading role in the global process of handing over management of governmental forests to local communities (Acharya, 2002).

A community managed forest is a forest managed by the local community - often with some kind of lease from the state (Arnold, 2001). As mentioned above, the government of Nepal nationalised all forest land in 1957 (Acharya, 2002). This led to massive depletion of the resource, mostly due to the local communities seeing it like the forest had been robbed from them, and the fact that the people were very dependent on the forests (Jodha, 1990). This in connection to "tragedy of the commons" (Hardin, 1968), i.e. the over use of a common resource as a result of users trying to maximise their personal utility, was devastating for the Nepali forests. In response to this development, the government of Nepal launched a change of policy starting in 1978, recognising the local communities rights to their forests (Acharya, 2002). With the new forest act of 1993, the community forestry was formalised in policy. In short, the policy states that any accessible forest area might be given as a lease to a Community Forest User Group or CFUG (a democratic and equal association of forest users in the local community with its own governing body, bye-laws etc.). The CFUG decides on all management issues in the community forest, but may seek advice from the government if needed. The CFUG distribute forest products, like fodder, NTFPs and fuel wood and income from sales of forest products amongst its members. Thus, the members of the CFUG benefit both from forest usage and additional income from sales.

The overall outcome of the community forestry programme in Nepal has been mostly positive, at least concerning the forest status. But there is development needed in some areas (Pokharel *et al.*, 2012). Especially since the goal of community forestry is not only conserving forests, but also developing rural societies (Arnold, 2001), For example, one of the areas in need of improvement is the inclusion of marginalised groups, such as women and the poor, in decision making and distribution of income. The main focus of the study presented in this thesis is how successful a CFUG has been in restoring the status of the forest and increasing the carbon stock.

Shorea robusta – a dominating tree

The most important tree species in Nepal is the Sal tree, *Shorea robusta C.F. Gaertn (fam. Dipterocarpaceae)*. It's valuable on the global timber market and is the main focus of the small Nepalese timber industry. But, the proper silviculture and ecology of the tree species hasn't been studied thoroughly in Nepal. Neither has growth and yield (Rautiainen, 1999). The same author states that *"There are no on-going, long-term treatment trials in Nepal to study the effects of different growing densities or to develop thinning regimes suitable for Shorea robusta",* which indicates that this is a subject that needs to be addressed. This lack of information in combination with the highly decentralised forest management (Arnold, 1992) might be part of the explanation of why the forest resource in Nepal has such a low degree of utilisation (Kanel & Kandel, 2004).

S. robusta is a tree species that is present both in wet and dry deciduous forests in the sub-tropical and tropical zones of Nepal, India, Bangladesh and Myanmar (Günter, 2011; Rautiainen & Suoheimo, 1997; Orwa *et al.*). It is a deciduous tree, often dominating where it grows and may, in favourable conditions, reach 45 m in height (Rautiainen & Suoheimo, 1997). *S. robusta* is light demanding and regenerates massively, mostly through sprouting, in gaps and other cleared areas (Sapkota *et al.*, 2009a). This ability to regenerate massively and the saplings' way of dying-back[1] if conditions are not appropriate, may be the explanation of its ability to dominate forests (Troup, 1921). In fact, in the southern regions of Nepal, the Terai, *S. robusta* dominates more than half of the forest area (Webb & Sah, 2003). In Nepal as a whole, *S. robusta* is the species with the biggest total volume, 19.28 % or 189 million m^3 (DFRS, 2015).

The specific density of *S. robusta* is approximately 0.83-0.93 kg m^{-3} (Champion & Seth, 1968), which makes the species relatively heavy and quite durable (Orwa *et al.*). Historically the wood has been used for many things – railway sleepers is one example (Troup, 1921). In Nepal today though, the wood of *S. robusta* is mostly used as firewood and construction timber. The seeds are edible, and used to make flour (Orwa *et al.*). The leaves are most commonly used for fodder, but may also be used to make disposable plates.

The growth and dynamics of *S. robusta* has been studied by many over the years, especially during the last century. The studies have mainly been done on the Indian sub-continent, starting with the British colonialization (Sapkota & Meilby, 2009; Narendra & Siddiqui, 2005; Acharya & Acharya, 2004; Acharya *et al.*, 2003; Rautiainen, 1999; Rautiainen, 1995; Tamrakar, 1994; Das *et al.*, 1992; Korhonen *et al.*, 1991; Chaturvedi & Sharma, 1980; Singh, 1980; Chaturvedi, 1973; Griffith & Ram, 1943; Howard, 1926). Though, as Rautiainen (1999) states, only few have studied the growth and dynamics of *S. robusta* in Nepal, namely (Puri *et al.*, 2012; Sapkota & Meilby, 2009; Acharya & Acharya, 2004; Acharya *et al.*, 2003; Rautiainen, 1999; Rautiainen, 1995; Tamrakar, 1994; Korhonen *et al.*, 1991). Some of the above studies have their findings presented in Table 2.

Since *S. robusta* is such an important species, both culturally and economically, it is strange that the dynamics have not been studied very much in Nepal. This study will hopefully help filling this gap.

[1] The sapling's above-ground parts dies-back, but the root system remain salive and grows new shoots next year (Troup, 1921). In this way, the root system is getting more and more developed each year, until there is an oppurtuinity to grow further towars the canopy layer.

Table 2 – Some values on the growth of S. robusta from earlier studies.

Study	Growth
Puri *et al.* (2012)[2]	6.54 $m^3ha^{-1}year^{-1}$ (Volume)
Sapkota & Meilby (2009)	0.87 cm $year^{-1}tree^{-1}$ (Diameter)
Champion & Seth (1968)	4-8 $m^3ha^{-1}year^{-1}$ (Volume)
(Troup, 1921)[3]	0.38[4] cm $year^{-1}tree^{-1}$ (Diameter)

Carbon in forests

Forests are major carbon sinks – in fact, forests store more carbon than the atmosphere (4500 Gt CO_2 compared with 3000 Gt CO_2) (Banskota et al., 2007). At the same time, emissions from deforestation during the last decade of the 20th century have been estimated to be 58 Gt CO_2 $year^{-1}$ (Nabuurs *et al.*, 2007). Thus curving deforestation is being an important part of the strive against global warming. The Intergovernmental Panel on Climate Change (IPCC) has agreed upon that *"Forestry can make a very significant contribution to a low-cost global mitigation portfolio that provides synergies with adaptation and sustainable development.".* A way of achieving this has been the creation of REDD+ programme [Reducing Emissions from Deforestation and forest Degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries].

REDD+

The REDD+ programme has evolved from early agreements in the Kyoto Protocol (Pistorius, 2012). In the Kyoto Protocol, the inclusion of forests as a way of mitigating climate change was debated fiercely – but the final result of the negotiation was that developing countries could to a limited extent use sequestration of CO_2 in forests in their commitment of reduced emissions – for industrialised countries, the same agreement was done, but for re- and afforestation projects, not standing stock. A failure in these negotiations was that deforestation was not included.

In 2005, at the COP11 (Eleventh session of the Conference of the Parties, November 2005), a newly formed alliance of rainforest nations presented a proposition to create a mechanism of compensation for reduced emissions from deforestation, acronymed RED (Pistorius, 2012). I.e. a mechanism giving countries economic incentives to battle deforestation by paying money for each extra tonne of carbon stored in forests. This idea was later evolved to REDD, Reducing

[2] 86% of the total growth were allocated to *S. robusta* on a five year period.
[3] Though, originally from C.M. McCrie, 1910.
[4] Over the first 16 years.

Emissions from Deforestation and Forest Degradation, including degradation of forests in the programme. Now the programme is called REDD+ and has broadened the focus to include restoration, sustainable forest management and development of communities. Globally, it is estimated that forests might mitigate emissions up to 2.7 Gt CO_2eq year^{-1} in 2030. Thus, giving REDD+ a big potential of increasing this number.

The REDD+ programme is a possibility for local communities, e.g. in Nepal, to earn money on re- and afforestation and get powerful incentives to improve the status of forests (Banskota *et al.*, 2007). This makes community forestry a great tool in the fight on climate change. But how is it going? And how well is the community forestry contributing to reduced CO_2 emissions?

Carbon and REDD+ in forests of Nepal and community managed forests

Banskota *et al.* (2007) reported that the annual sequestration of CO_2 in three community forests in Nepal was 1,88 tonnes ha^{-1}year^{-1} and the mean carbon stock was 50.55 tonnes ha^{-1}, giving an increment rate of 3.72 % per year. This is almost half of what the Nepali government calculates the national average per hectare to. DFRS (2015) presents the current national carbon stock of tree components[5] on forest land to be approx. 650 mill tonnes (108.88 tonnes ha^{-1}). The average for Terai is 104.47 tonnes ha^{-1}. According to Baral *et al.* (2009), the average carbon stock for hill *S. robusta* forests in Nepal lies near 97.86 tonnes ha^{-1} with a sequestration rate of 1.3 tonnes ha^{-1}year^{-1}, or 1.33 %. They also report the average in Nepal to be close to be 57.18 tonnes ha^{-1} with an increase of 1.86 tonnes ha^{-1}year^{-1}, or 3.25 %.

Maraseni *et al.* (2014) reports some of the pilot studies of REDD+ in community forests in Nepal. They studied the actual results of REDD+ on the forests, the people and the economy. Unfortunately, the results are rather grim, at least if REDD+ payment is done with the current market based approach, similar to how emission rights are sold and bought in the EU. The rate of US$ 10 per tonne of sequestrated carbon dioxide did not even cover the costs of extra meetings necessary for the implementation. In average, each community forest user group in the study only earned US$ 245. The authors don’t rule out REDD+ completely, but point out that the payments must be more in level with how much the non-harvesting and management activities cost. If REDD+ works, it will be a good incentive for carbon sequestration.

[5] Below-ground biomass and dead trees included.

Objectives

Overall Nepal is rich in forests, but with a possible need to develop its forest industry or to find another income from forests, like REDD+. The local communities have taken more control over the forests thanks to the successful community forest programme, but there is some uncertainty on how well they manage their forests. There have been some studies on carbon storage in community forests and dynamics of *S. robusta* dominated forests. But this study targets to fill some of the current knowledge gaps.

Thus, the aims of this study is to present valuable stand dynamics and carbon stock calculations for *S. robusta*-dominated forests under management of local communities in Southern Nepal.

Assumptions and delimitations

This study only consists of analyses on above ground biomass of trees. Shrubs and understorey are not included. Focus has also been analyses on *S. robusta*, since it dominates the forest in question.

MATERIALS AND METHODS

Study site

The site of this study was a community managed forest in Chainpur Village Development Council, Chitwan District in Nepal (27°39'07.2"N 84°34'12.6"E). The forest is governed by the Kankali Community Forest User Group and consists of circa 700 hectares of Sal dominated secondary forest. The forest is classified as a tropical dry forest and is situated in the transit zone between the Mid-Hills region of the Himalayas and the plains of the Terai in southern Nepal. The maximum and minimum mean monthly temperatures are 35°C (April) and 9°C (January), respectively (Sapkota & Meilby, 2009).

Previous measurements and experimental design

In the year 2005, 66 permanent sample plots were established around the forest as a part of the Community Based Natural Forest Management in the Himalaya programme (ComForM) (Larsen *et al.*, 2014; Puri *et al.*, 2012). The experimental design of this programme is fully presented by Meilby *et al.* (2006). The presentation here only gives the key aspects of the design, those that are connected to this study. For more depth and statistical explanation, go to the article mentioned.

The 66 plots are 20 × 25 m (500 m^2) big, and are located in different forest strata, following the principles of stratified random sampling as discussed by (Meilby *et al.*, 2006). The plots' positions were recorded using a GPS and were also marked in the field by a concrete pillar.

In each plot a grid was established, 25 m along the X-axis and 20 m along the Y-axis (Tribhuvan University & The Royal Veterinary and Agricultural University, 2006). The Y-axis was always placed perpendicular to the contour of the slope. Each tree (above certain sizes, see below) on the plot was given a number and coordinates within the local grid ranging from (0,0), to (0,20), (25,20) and (25,0). In that way, the trees may be individually distinguished from each other at repeated measurements.

The plots have a nested design, and were divided in to multiple sub-plots to allow for inclusion of smaller trees. The sub-plots are shown in Figure 1. Outside sub-plot A and B, trees bigger or equal to 10 cm in DBH[6] were measured and recorded. In plot A, trees bigger than 4 cm in DBH where measured and recorded. In plot B, trees bigger than 2 cm in DBH where measured and recorded. For each tree, DBH,

[6] DBH is the diameter of a tree at breast height (1.3m above ground).

quality[7], crown-code[8], species and health[9] was measured, estimated or recorded. Height was measured on a random (but stratified) sample of trees using clinometers and distance-tapes.

The first measurements were done in 2005 and then in the years 2006 (supplementary measurements for only the height trees), 2010 and 2013. New trees were added to the records, and dead or cut trees were recorded as gone. Due to some of the plots being destroyed by Maoist encampments (there was a civil war in Nepal during this time) and some plots clear cut, these plots had to be abandoned and replaced.

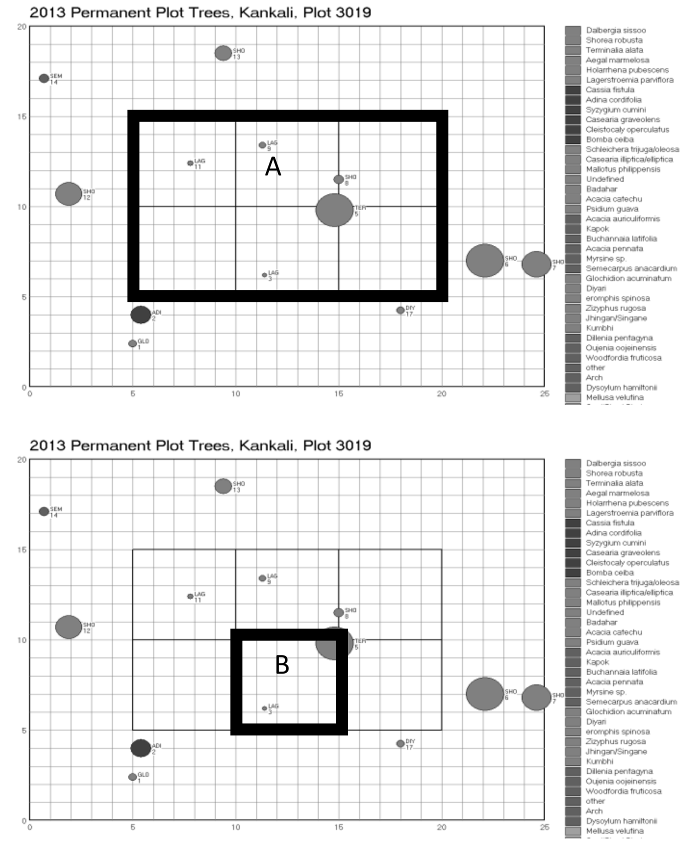


Figure 1 – An example of the plot maps used during the tree measurements. The circles symbolise the trees, their size their DBH and their shade of grey their species. The sub-plots A and B are also marked.

Thanks to the previous measurements, a big set of data on the cond-itions of the forest is available (see appendix). The measurements 2005-2013 were done between growth seasons, during spring. Thus, the data from 2005 shows the status after the growth season of 2004, the data from 2006 the status after the growth season of 2005 and so on.

[7] In three classes, high, other and cull.

[8] A code describing how dominate their emidate surroundings, ranging from suppressed to dominating.

[9]A code describing the health of trees, ranging from healthy, to dead,

New measurements

This study consisted of re-measurements of the permanent sample plots in the autumn of 2015. The method for data collection was the same as previous occasions. The only changes were what kind of equipment that was used. For DBH, a digital calliper was used instead of diameter tape. For height, a digital hypsometer with laser-range-finder was used instead of clinometer and distance tape. In all other aspects, the manual by Tribhuvan University & The Royal Veterinary and Agricultural University (2006) was followed.

For each tree, DBH was measured and species identification was controlled. Tree quality, crown-code, species and health were only recorded for newly recruited trees. Height was measured on the same height trees as the measurements done in 2013. For all trees bigger than 65 cm in DBH, diameter tape was used.
In addition, on a random sample of the plots (n = 7), DBH was measured both with calliper and diameter tape for all trees.

Since the data set consists of over 40 tree species, there would be difficulties to present all results for all species in this report. Therefore, the five most dominant species (according to total volume) will be the main focus. These are *Shorea robusta, Terminalia alata, Lagerstroemia parviflora, Cleistocalyx operculatus and Dalbergia sissoo*,

Statistical analyses

To avoid errors derived from change in equipment, a model describing the relation between DBH measured with a calliper and DBH measured with a diameter tape was developed using Minitab, statistical software. An analysis on the data showed some of the data points to have very large residuals. They were removed. The model looks as follows (R^2-adj= 99.99%, p<0.0001, n=218):

$$\mathrm{DBH}_{Tape} = 0.4958 + 0.9822\ \mathrm{DBH}_{Calliper} + 0.000691\ \mathrm{DBH}^2_{Calliper} \qquad \textit{Eq. 1}$$

where DBH_{Tape} is the diameter measured with diameter tape, and $\mathrm{DBH}_{Calliper}$ is the diameter measured with calliper. This model is valid for all species on the site. The same kind of model was developed for Sal only (R^2-adj= 99.95%, p<0.0001, n=107):

$$\mathrm{DBH}_{Tape} = 0.5166 + 0.9811\ \mathrm{DBH}_{Calliper} + 0.000713\ \mathrm{DBH}^2_{Calliper} \qquad \textit{Eq. 2}$$

The DBH data was transformed with the developed functions.

Modelling and calculations

Height

Height and DBH for all trees and each year were analysed using Minitab. Some of the values were excluded due to un-normal values or large residuals, often derived from leaning or top cut trees. To assign heights to the majority of trees without measured height, a relationship between DBH and height was developed using Minitab. Species specific models were developed for all species with sample number, n, bigger than 50[10]. Care was taken to the comparison of different equations types for height-diameter relationships by Fang & Bailey (1998) and the functions by Puri *et al.* (2012). The form of the chosen model looks as follows:

$$lnH = \mathrm{a} + \mathrm{b}\ lnDBH + \mathrm{c}\ (lnDBH)^2 \qquad \textit{Eq. 3}$$

where H is tree height, a, b and c are parameters, and DBH is tree diameter.

Table 3 – The height models for all species with n > 50 in the form $lnH = a + b\ lnDBH + c\ (lnDBH)^2$.

Species	a	b	c	N	S	R-sq (pred)
T. alata	0.239	0.7463	0	70	0.337704	83.84%
S. robusta	-0.13	1.2388	-0.1039	372	0.229171	83.64%
D. sissoo	0.623	0.6922	0	78	0.163203	79.00%
B. latifolia	-2.372	2.89	-0.4274	54	0.264417	77.22%
H. pubescens	-1.49	2.32	-0.3568	102	0.17202	75.54%
M. philippensis	0.117	0.8029	0	57	0.269387	68.73%
S. anacardium	0.357	0.6795	0	58	0.249802	65.37%
L. parviflora	0.18	0.8291	0	144	0.304988	62.79%
C. graveolens	-0.66	1.956	-0.3278	87	0.21957	56.29%
C. operculatus	-0.071	1.258	-0.1366	137	0.230868	53.01%
Other	0.3071	0.7019	0	199	0.372478	70.85%

The different height models are plotted in Figure 2 and their parameters can be found in Table 3.

[10] The quality of a model increases with increasing sample number n. N above 50 is genarlly considered as a rule of thumb.

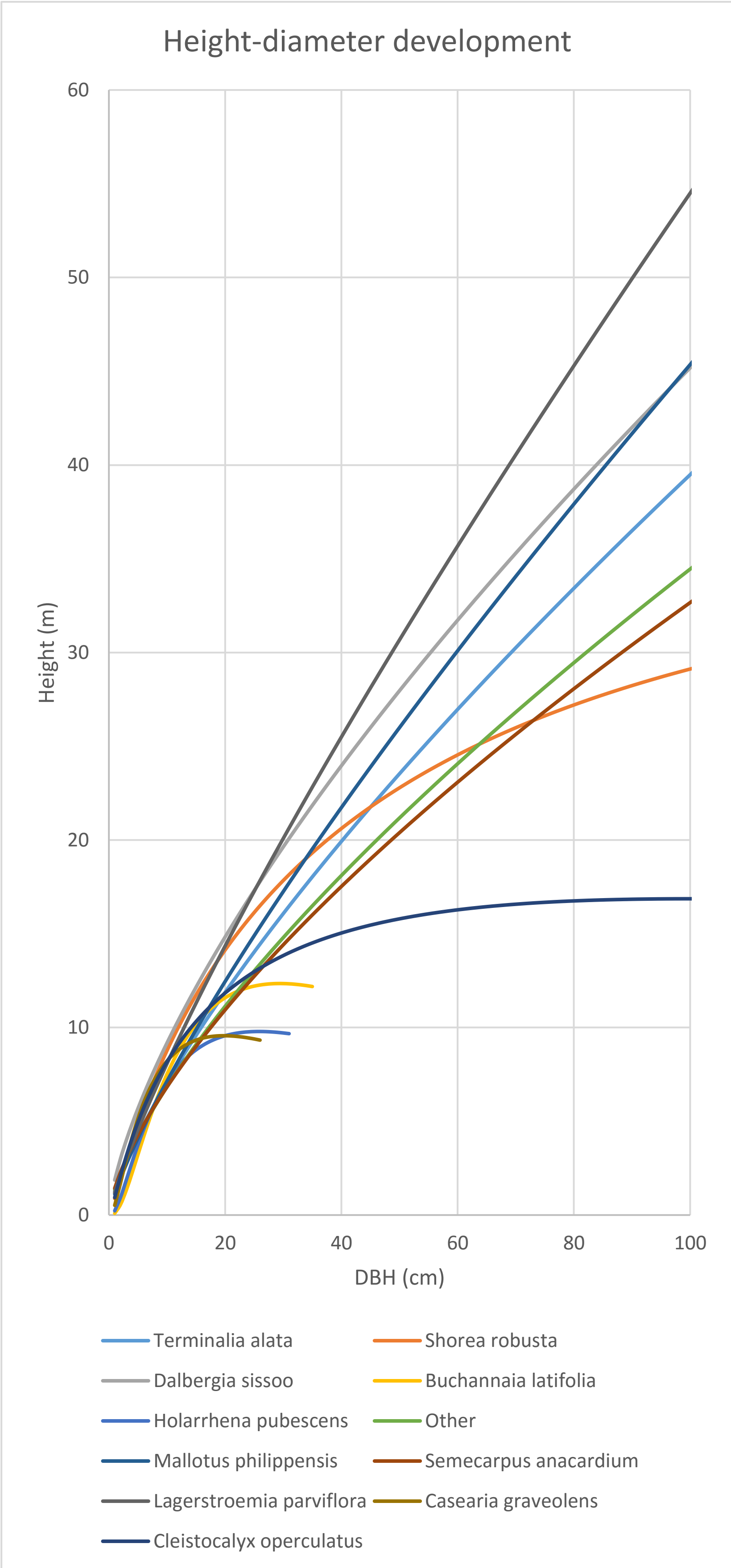


Figure 2 – Height vs diameter development.

Table 4 – The specific density for the main species in this study to estimate carbon stocks. Calculated average means that the species density could not be found in literature, and thus being the mean density of all species on the study site.

Species	**Density ($\rho_{Species}$)**	**Reference**
C. operculatus	0.66	Brown (1997)
D. sissoo	0.659	Calculated average
L. parviflora	0.62	Brown (1997)
S. robusta	0.72	Brown (1997)
T. alata	0.753	Huy (2008-2012)

Volume and biomass estimations

Next, volume for each tree was calculated using the equations by Sharma & Pukkala (1990). For species without any specific model, the average between the models for miscellaneous species in Terai and in the hills was computed, since Kankali is situated in the transition area between the lowlands of Terai and the hills. These functions use height and diameter to estimate tree volume.

For biomass above ground, *Bm*, estimation, three different functions were used. For *L. parviflora* the function presented by Singh & Misra (1978) was applied, for *D. sissoo* the function by Hawkins (1987) was used and for all other species the general function for dry forest stands by Chave *et al.* (2005). All three models describe above ground biomass for single trees (Hawkins (1987) only stem and stump); Singh & Misra (1978) from circumference at 1.3 m above ground level, Hawkins (1987) from DBH only and Chave *et al.* (2005) from height, DBH and specific density. The data on density needed for the second function was taken from Brown (1997) and Huy (2008-2012) for most species. For those species without any recorded density the weighted average of 0.659 g cm^{-3} (from the other species present) was used in the calculations. Specific density values for the main species are shown in Table 4. The functions look as follows:

$$Bm_{D.Sissoo} = e^{(\mathrm{a}+\mathrm{b}*\ln\mathrm{DBH})} * 1000^{-1} \quad \textit{Eq. 4}$$

$$Bm_{L.parviflora} = \left(10^{(c+d*\log(\pi\mathrm{DBH}))} + 10^{(e+f*\log(\pi\mathrm{DBH}))} + 10^{(g+h*\log(\pi\mathrm{DBH}))} + 10^{(i+j*\log(\pi\mathrm{DBH}))}\right) * 1000^{-1} \quad \textit{Eq. 5}$$

$$Bm_{Species} = k * \left(\rho_{Species} * DBH^2 * H\right)^l * 1000^{-1} \quad \textit{Eq. 6}$$

where *Bm* is biomass in tonnes, *a, b, c, d, e, f, g, h, i, j, k* and *l* are function-wise parameters, $\rho_{Species}$ is the specific density for a certain species and *H* is the height of the tree and *DBH* is the diameter of the tree at breast height (1.3 m).

Carbon stock calculation

Fortunately, the carbon content in biomass is fairly constant, making calculation of carbon stock from biomass quite straight forward (Magnussen & Reed, 2004; Schlesinger, 1991). According to Vassilev *et al.* (2010) the mean proportion of atomic carbon in woody biomass is 52.1 wt.%, hence this proportion was used to calculate the carbon content in every single tree. The calculation,

$$C_{content} = 0{,}521 * Bm \qquad \textit{Eq. 7}$$

was done for all trees, where $C_{content}$ is the amount of atomic carbon in tonnes and *Bm* is the biomass in tonnes.

Summarisation

A range of summarisations for the variables volume, biomass and carbon content were done over areas, years, stands, species to compare development. They are shown under *Results*.

Single tree development of *S. robusta*

An investigation on single tree development has also been done. First the periodic annual increment (PAI) of volume was calculated for all *S. robusta* trees. This was done by comparing difference in volume calculations for the different measurement years according to the following calculation:

$$V_{PAI} = \frac{V_{i+n} - V_i}{n} \qquad \textit{Eq. 8}$$

where V_{PAI} is the PAI of volume, V_i is the volume at the beginning of the period and $V_{i+n}$is the volume n years after the beginning of the period. This is as close as you can get to estimate the current annual increment without measurements each year. Since measurements were done 2005, 2010, 2013 and 2015, n are 5, 3 and 3 years (there are actually 3 years between 2013 and 2015 since the last measurement was done after the growth season on the same year, apart from the others, see section *Plot Data* in the appendix).

The transformation above resulted in some negative values. The values equal to or bigger than -0.001$m^3$$year^{-1}$ were removed from the dataset. Values smaller than -0.001$m^3$$year^{-1}$ were set as 0.

Next, regression analyses of V_{PAI} versus tree and stand characteristics were done. The variables used are shown in Table 5. Decision on which model to choose was done through the “Best subset” approach in Minitab – where maximum R-sq and minimum Mallows CP is the goal.

Table 5 – Variables used in regression analysis of V_{PAI}.

Variable name	Explanation
H	Singe tree height, m
V_{Tree}	Single tree volume, m^3
DBH	Tree diameter at 1.3 meter above ground level, cm
Ba_{tree}	Single tree basal area, m^2
N_{Stand}	Stems per hectare
DBH_{Stand}	Arithmetic mean DBH of the stand, cm
DBH_{Ba}	Basal area weighted mean DBH of the stand, cm
DBH_{Min}	Minimum DBH in the stand, cm
DBH_{Max}	Maximum DBH in the stand, cm
Ba_{Stand}	Stand basal area per hectare, m^2ha^{-1}
$N_{S. robusta}$	Number of *S. robusta* stems per hectare in the stand
Ba_{Sal}	Basal area of *S. robusta* per hectare in the stand, m^2ha^{-1}
$N\%_{S. robusta}$	Proportion of *S. robusta* stems in the stand, %
$Ba\%_{Sal}$	Proportion of basal area of *S. robusta* in the stand, %
Slope	The dominant slope of the stand, degrees
Altitude	Altitude above sea level
Aspect	The aspect of the slope, degrees

A total number of 4625 values of V_{PAI} for *S. robusta* were used in the analysis with Minitab, which resulted in this regression (R^2-adj= 68%, p<0.0001, n=4625):

$$V_{PAI} = -0.00718 + 0.001898\,DBH - 1.6424\,BA_{Tree} + 0.15989\,V_{Tree} - 0.000511\,\mathrm{DBH}_{Ba} + 0.000268\,\mathrm{DBH}_{Max} \qquad \textit{Eq. 9}$$

The variables are explained in Table 5.

Last, an analysis on the Pearson's correlation between V_{PAI} and other variables in the data set was conducted, both for V_{PAI} only, and all variables on the same time.

RESULTS

Forest dynamics

The total standing volume in the forest increased from 99 m^3ha^{-1} to 161 m^3ha^{-1} (Figure 3). This corresponded to a periodic annual growth of 5.6 $m^3ha^{-1}year^{-1}$ over the eleven years long period. The PAI (Figure 3) was stable over the two periods 2005-2010 and 2010-2011 (0.5 $m^3ha^{-1}year^{-1}$ lower in the second period).

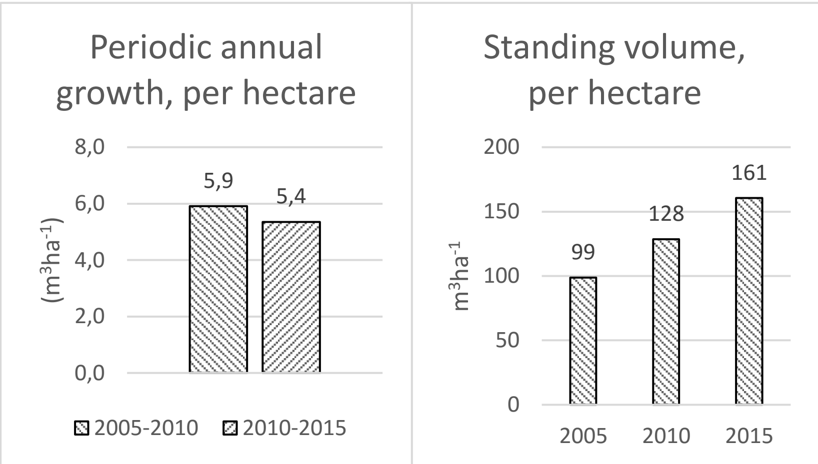


Figure 3 – To the left, the PAI per period. To the right the standing volume in cubic metres per hectare.

The number of stems per hectare changed since 2005. In 2005, there were 918 trees per hectare, in 2010 there were 998 per hectare and finally, in 2015 the number diminished to 835 per hectare (Figure 7). When distributing the standing volume over species (Figure 4) the overall dominance of *S. robusta* was very clear. In 2015, *S. robusta* made up for 74 % of the standing volume. The second most dominant species *T. alata,* only represented 6 % of the standing volume.

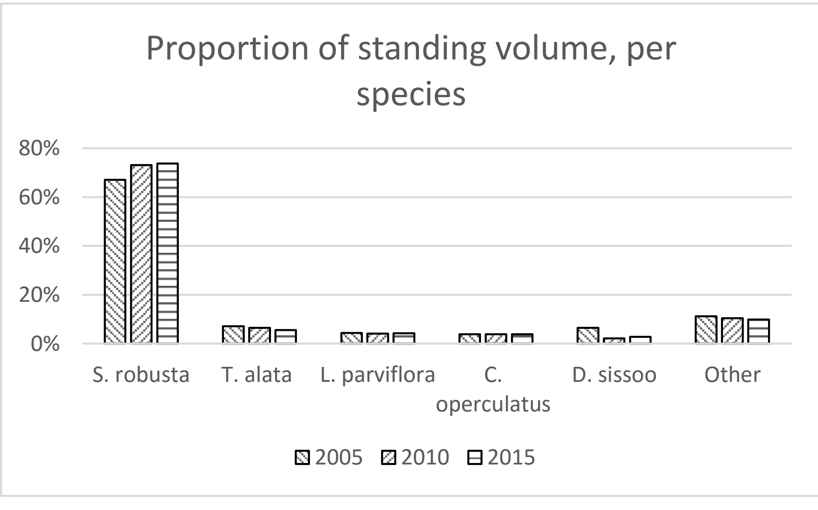


Figure 4 – The proportion of the total standing volume per main species in percent.

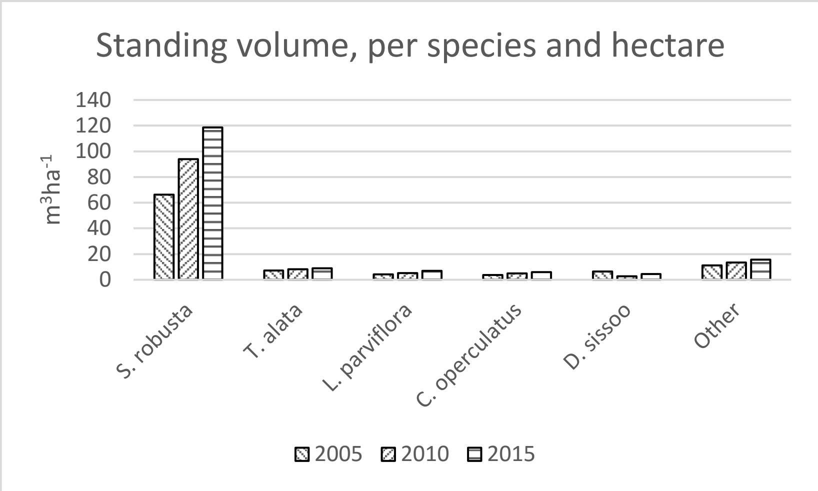
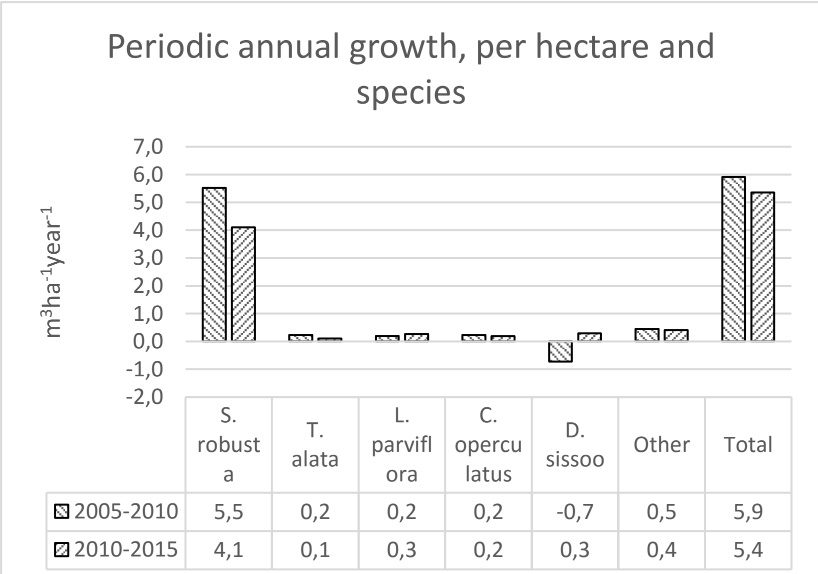


Figure 5 – The standing volume per main species in cubic metres per hectare.

The absolute numbers of standing volume per species (Figure 5) were similar to the proportions in Figure 4– but the absolute increment of *S. robusta* was bigger than the increase in proportion.



	S. robusta	T. alata	L. parviflora	C. operculatus	D. sissoo	Other	Total
2005-2010	5,5	0,2	0,2	0,2	-0,7	0,5	5,9
2010-2015	4,1	0,1	0,3	0,2	0,3	0,4	5,4

Figure 6 – PAI per species.

The distribution of PAI on all species followed the same pattern as standing volume (Figure 5 and Figure 6). *S. robusta* made up for the majority of growth, i.e., 5.5 and 4.1 m^3ha^{-1} $year^{-1}$ out of 5.9 and 5.4 m^3ha^{-1} $year^{-1}$ respectively. Notable was also the negative growth of *D. sissoo* during the first period. *D. sissoo* and *L. parviflora* were the only species that had bigger increments the second period.

When investigating the mortality and recruitment (Table 6), one sees that mortality remained constant. Recruitment though, had quite a drop during the second period, leading to a negative net change. This is shown in Figure 7 displaying stem numbers per hectare and species. For most species, the year 2010 represented the most abundant year – it was only *T. alata* and *D. Sissoo* that showed a different pattern. They were instead declining steadily over both periods.

Table 6 – Mortality and recruitment in stem numbers per hectare and year (only calculated for plots present on all three occasions, not the ones destroyed and replaced).

	2005-2010	**2010-2015**
Mortality	37.4	39.7
Recruitment	42.9	17.9
Net change	5.6	-21.8

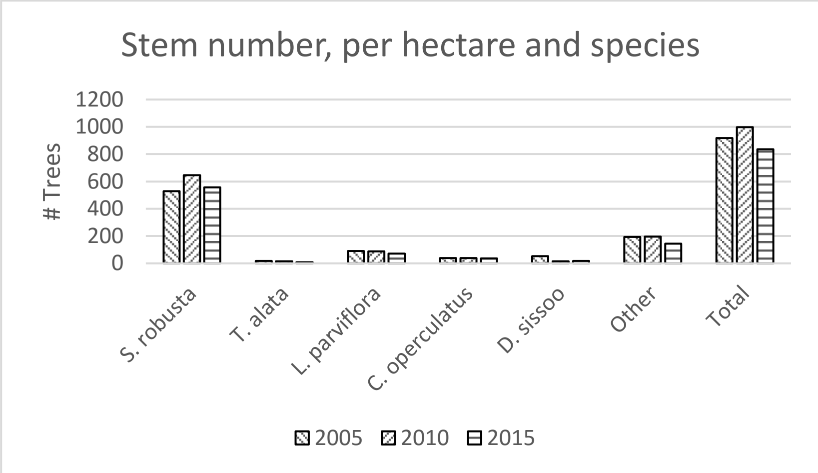


Figure 7 – Stem number per hectare per species.

Basal area (Figure 8) on the other hand increased for all species, except *D. Sissoo.* In total, basal area per hectare increased from 13 to 21 m^2ha^{-1} over both periods, i.e. 0.7 $m^2ha^{-1}year^{-1}$.

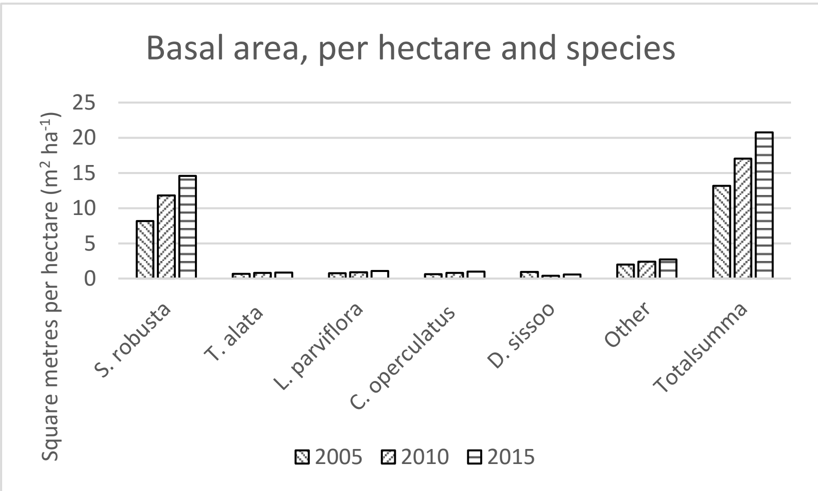


Figure 8 – Basal area per hectare per species in square metres per hectare.

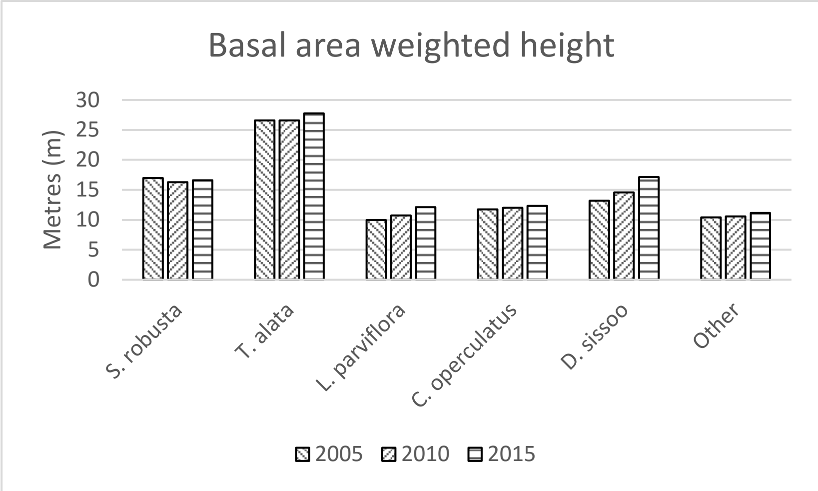


Figure 9 – Basal area weighted height per species in metres.

Basal area weighted height appeared to be quite constant over the years (Figure 9), but there was a big difference between species. *T. alata* had clearly the highest value on the site. Basal area weighted diameter (Figure 10) increased for all but two species, it declined for *S. robusta* and *C. operculatus.*

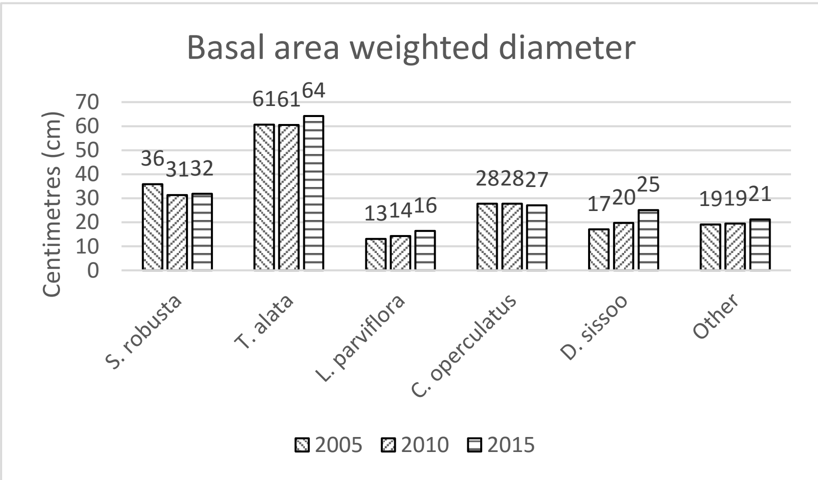


Figure 10 – Basal area weighted diameter per species in centimetres.

The diameter distribution (Figure 11) looked at first like a smooth reversed J-shape, but if an un-logistic scale was applied (Figure 13), one could clearly see the dominance of smaller diameter. This pattern was also very clear in Figure 12 that shows the distribution of volume over diameter classes. Diameter class from 10-30 cm clearly represented the majority of standing volume. As stated before, there was a decline in number of stems (Table 6) – a pattern clearly visible in the smallest diameter class. There was a big increase, both in relative number and absolute volume in the dominating range 10-30 cm over both periods. The biggest development in volume was from 2010 to 2015 in the 20-30 cm class – almost 22.5 m^3ha^{-1} or 2 $m^3ha^{-1}year^{-1}$.

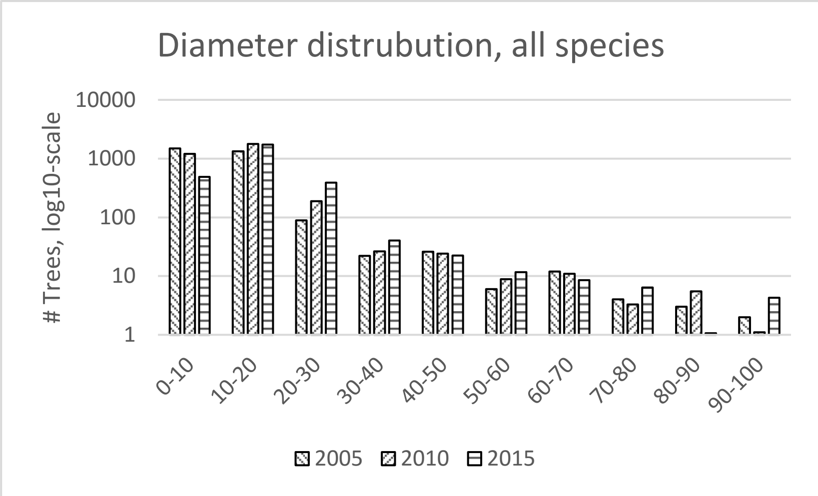


Figure 11 – Diameter distribution of all trees in the study over three occasions. 10 cm wide classes and logarithmic scale.

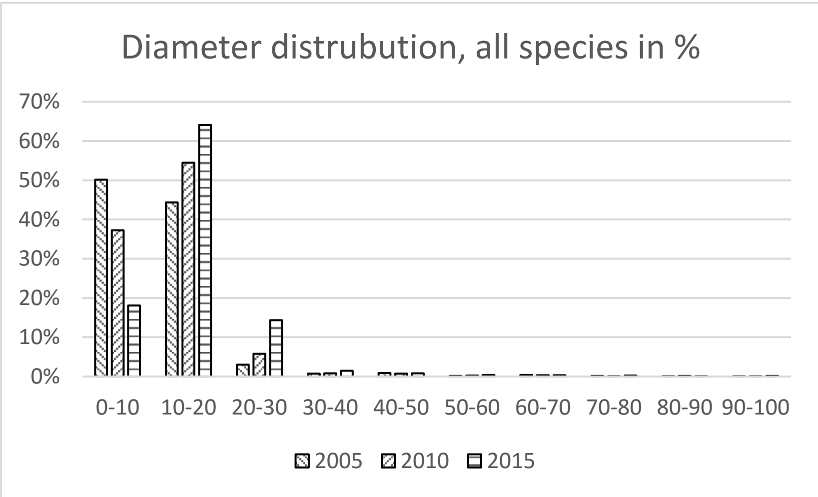


Figure 12 – Diameter distribution of all trees in the study over three occasions in percent of total tree number. 10 cm wide classes.

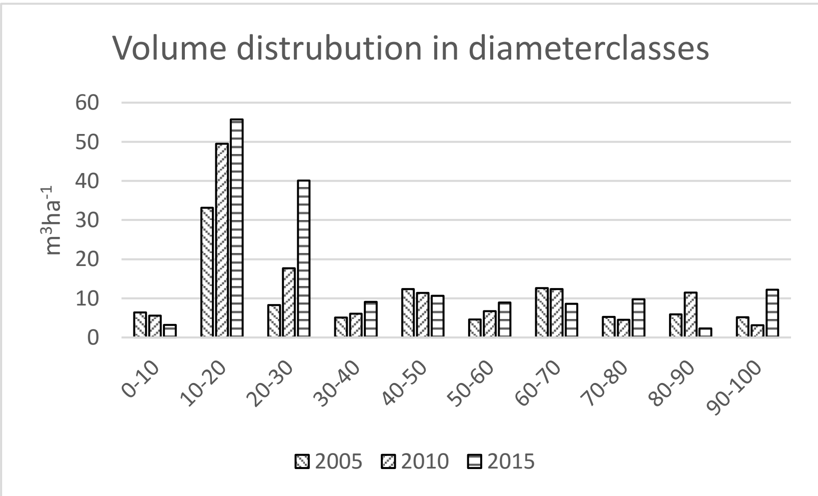


Figure 13 – Distribution of volume per hectare in 10 cm wide diameter classes.

Carbon

The total standing carbon stock in the forest increased from 48 tonnes ha^{-1} to 80 tonnes ha^{-1} (Figure 14). This corresponded to a periodic annual increment of 2.9 tonnes $ha^{-1}year^{-1}$ over the eleven-year long period. The PAI (Figure 14) was more or less stable over the two periods 2005-2010 and 2010-2011 (0.5 tonnes $ha^{-1}year^{-1}$ [1] lower in the second period).

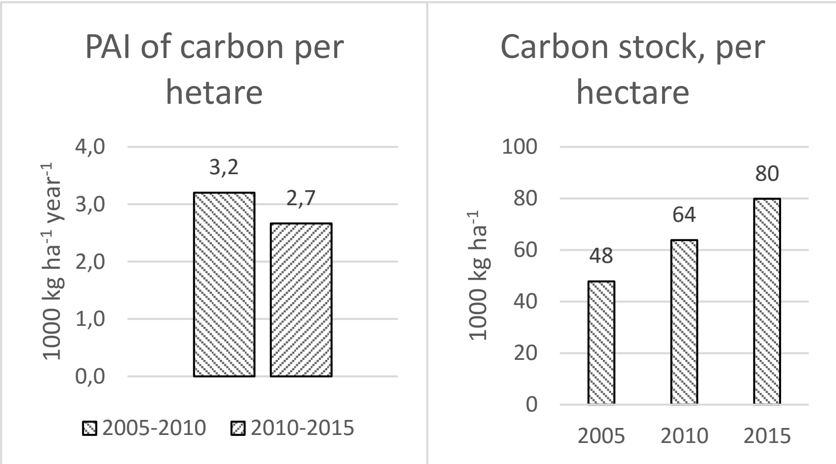


Figure 14 – Periodic annual increment of carbon and total stock of carbon in tonnes per hectare.

The distribution of increment of carbon on all species (Figure 15) followed the same pattern as the distribution of PAI in Figure 6. *S. robusta* made up for the majority of carbon accumulation in the biomass, 2.8 and 2.0 tonnes $ha^{-1}year^{-1}$ out of 3.2 and 2.7 tonnes $ha^{-1}year^{-1}$, respectively. The negative growth of *D. sissoo* was the same as with PAI. *D. sissoo* and *L. parviflora* were the only species that had a higher carbon accumulation in the second period.

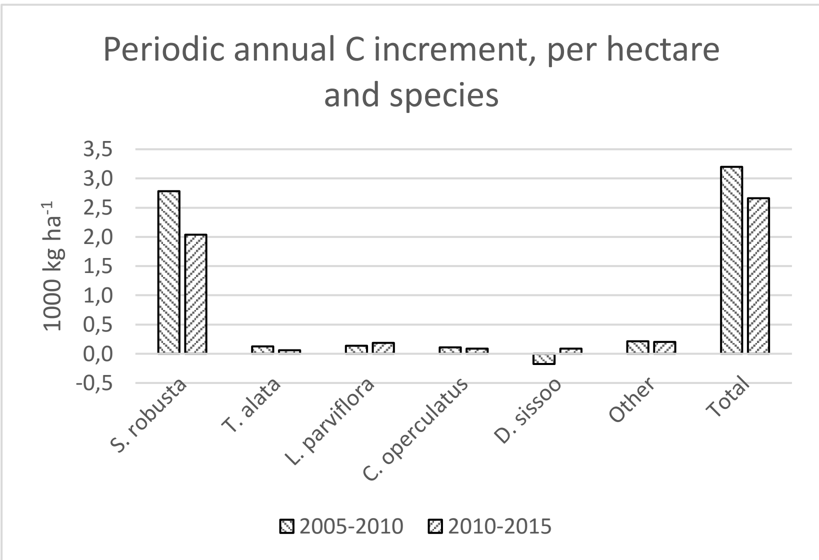


Figure 15 – Periodic annual increment of carbon for the main species. Tonnes per hectare and year.

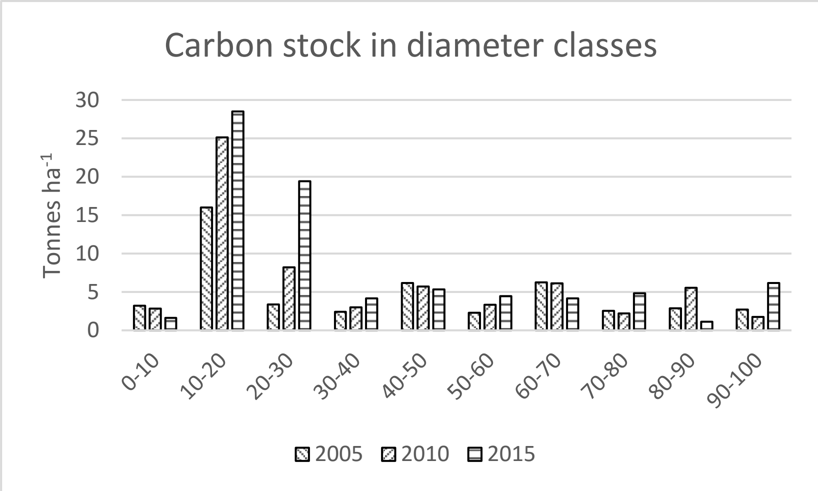


Figure 16 – Carbon stock in tonnes per hectare distributed over 10-cm wide diameter classes.

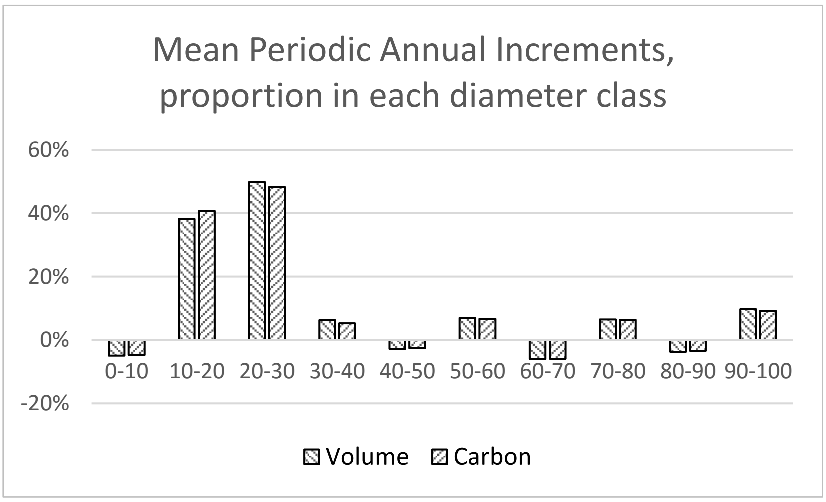


Figure 17 – Proportion of mean periodic annual increment for volume, and carbon in 10-cm wide diameter classes.

The carbon stock was the highest in the diameter classes of 10-30 cm, the same as with standing volume. The same large increase over the years in this span was observed (Figure 13). As shown in Figure 17, the proportion of volume increment and carbon stock increment in each diameter class was very close to each other, with only one or two percentage points difference.

Single tree development

The results from the correlation analysis between V_{PAI} and the other variables are shown Table 7. V_{PAI} had very good correlation with V_{Tree}, Ba_{PAI}, Ba_{tree} and $Ba_{tree(prev)}$ (r > 0.70), fairly good correlation with six variables (r = 0.5 - 0.69) and poor correlation with three variables (r < 0,5). And the results from the cross wise analyses are shown in Table 8.

Table 7 – Correlations between V_{PAI} for S. robusta and other variables in the dataset. Only correlations with a p-value smaller than 0.05 and a coefficient bigger than 0.3 are included. (prev) means the value at the last measurement.

V_{PAI}	Variables	Pearson's correlation coefficient	p-value
	V_{Tree}	0.790	0.0000
	Ba_{PAI}	0.756	0.0000
	Ba_{tree}	0.745	0.0000
	$Ba_{tree\ (prev)}$	0.716	0.0000
	$V_{Tree\ (prev)}$	0.692	0.0000
	DBH	0.631	0.0000
	$DBH_{(prev)}$	0.614	0.0000
	$V_{PAI\ (prev)}$	0.597	0.0000
	H_{PAI}	0.585	0.0000
	H	0.539	0.0000
	$Ba_{PAI\ (prev)}$	0.447	0.0000
	$H_{(prev)}$	0.424	0.0000
	DBH_{PAI}	0.346	0.0000

Table 8 – The strongest correlations between variables in the dataset. Only correlations with a p-value smaller than 0.05 and a coefficient bigger than 0.3 are included. Please observe that three coefficients are negative.

Variable 1	Variable 2	Pearson's correlation coefficient	p-value
DBH_{Stand}	DBH_{Max}	0.957	0.0000
V_{PAI}	V_{Tree}	0.790	0.0000
Ba_{PAI}	V_{PAI}	0.756	0.0000
V_{PAI}	Ba_{tree}	0.745	0.0000
Ba_{PAI}	DBH	0.709	0.0000
DBH_{Stand}	DBH_{Min}	0.688	0.0000
Ba_{PAI}	Ba_{tree}	0.680	0.0000
Ba_{PAI}	V_{Tree}	0.668	0.0000
Ba_{PAI}	H	0.660	0.0000
DBH_{Stand}	Ba_{Stand}	0.631	0.0000
V_{PAI}	DBH	0.631	0.0000
DBH_{Max}	Ba_{Stand}	0.585	0.0000
H_{PAI}	V_{PAI}	0.585	0.0000
H_{PAI}	DBH_{PAI}	0.585	0.0000
V_{PAI}	H	0.539	0.0000
$Ba\%_{Sal}$	Altitude	-0.484	0.0000
DBH_{Min}	Ba_{Sal}	0.455	0.0000
Ba_{Sal}	Altitude	-0.422	0.0000
DBH_{Min}	Slope	-0.305	0.0000

DISCUSSION

Stand dynamics

The fact that the total standing volume has increased quite considerably (99 to 161 m^3ha^{-1}) did not come as such a big surprise when looking at the forest history of the study site. Before the community's take-over from the government in the mid 90's, the forest was very degraded, thus making the first and foremost focus of the community to restock it. This work has been quite successful, and at this date, the forest is dominated by young *S. robusta*. The restocking began with regeneration through coppices, taking advantage of *S. robusta*'s plentiful sprouting ability. Presumably, the trees in the forest, at least the dominating cohort, should be around 20-30 years old since the take-over happened in 1995. Generally speaking, this is the age when forests produce the most and thus making this rapid growth quite expected (Ryan *et al.*, 2004).

The average standing volume of 161 m^3ha^{-1} is exactly the same as DFRS (2015) reports it to be in Terai. The national average of 164 m^3ha^{-1} is also very close. A conclusion to make from this should not be that the Kankali forests is close to its maximum, rather that forests in general in Nepal could be either quite young or historically degraded and at the present in a grow-up phase. The fact that forests of Nepal have been, and still are degraded has been discussed before, e.g. by Bishop (1978). The impact of population growth on the forest status in a community in Nepal has been studied by Fox (1993). His results were quite positive, the forests managed communally in the study increased from a stocking of 8.9 m^3ha^{-1} to 46 m^3ha^{-1} in ten years, even though the population increased by 2.5 % per year. Unfortunately, we cannot present any population data for Kankali, but it is not un-realistic that the village has continued to grow with increasing living standards.

The result of growth of 5.9 and 5.4 161 $m^3ha^{-1}year^{-1}$ corresponds well to earlier studies. Puri *et al.* (2012) reports the PAI in the same forest between 2005 and 2010 to be 7.6 $m^3ha^{-1}year^{-1}$ though – a slightly larger estimation. And since their study is built upon the same data set, the only explanation of the difference should be the different height models. Since this study had access to additional measurements (2013 and 2015), the number of DBH-height relationships is twice as big – a reasonable deduction could be that the height functions by Puri *et al.* (2012) overestimates heights or that the functions in this study underestimates them. Champion & Seth (1968) reports growth in *S. robusta* dominated forest to be in the range of 4-8 $m^3ha^{-1}year^{-1}$, a range where both this study and Puri *et al.* (2012) falls into.

Standing volume per species shows the utter dominance by *S. robusta* in the forest studied. With more than 75 % of the growing volume, *S.*

robusta has an unthreatened lead. Its dominance was not a surprise, since many studies confirm this to be more rule than exception (DFRS, 2015; Puri *et al.*, 2012). Sapkota *et al.* (2009b) presents *S. robusta* to have a pronounced gap regeneration strategy and high light requirements, traits that not quite fit the "*classical succession theory*" by Ellenberg & Mueller-Dombois (1974) very good, even though *S. robusta* at first glance seems to be a "climax species".

An interesting thing to notice is that *S. robusta*'s proportion of standing volume actually decreases from 2010-2015, even though a big increment in absolute numbers is visible (Figure 4 and Figure 5). This must mean that all other species together have had a higher growth during this period. This is supported by results (Figure 6), where it is clearly visible that the growth of all other species is not decreasing in the same pace. If all other species are grouped together, the PAI for 2005-2010 and 2010-2015 would be 0.4 and 1.3 $m^3ha^{-1}year^{-1}$, respectively. *S. robusta*'s growth is thus declining, whilst all other species increase at the same time – resulting in a change of proportions.

That *S. robusta* decreases by almost 1.4 $m^3ha^{-1}year^{-1}$ during the second period could possibly be explained by the crown cover of *S. robusta* beginning to close. It is a common pattern that wood production tends to decrease when the proportion of leaf area declines after closure (Ryan *et al.*, 2004). It is not unlikely that *S. robusta* goes into this phase at 20-30 years of age, but the development of basal area (Figure 8) would have needed to be some years longer to be able to draw any conclusions on crown closure.

Mortality, as shown in Table 6, displays a peculiar development. The actual mortality seems to be quite stable with approx. 37-40 dead trees per hectare and year during both periods. This estimate of mortality should not be taken as an absolute truth though. In Kankali Community Forest, it is illegal to cut any living trees (Constitution of KCFUG), so in theory, all trees not found in repeated measurements could be said to have died naturally. This is not totally true, since the villagers' compliance with the rules is not 100%. But, the truth should not be far away. Recruitment shows a steady drop during the second period, from 43 to 18 trees per hectare and year. This is the main reason why the total number of trees diminishes and the net change turns negative. If the mortality model by Rautiainen (1999) is applied to the plot averages of stem number, and the corresponding DBH_{Ba}, the result is that in average, the plots could increase with 750 trees per hectare, before self-thinning occurs. The conclusion should be that the forest has not begun to close yet. The sudden drop in recruitment could therefore, either meant that the local ban of keeping cattle in the forest is not followed, resulting in low regeneration, or that the local people harvest small diameter trees as fodder or possibly that these saplings (below 4 cm DBH) could be difficult to find in the survey. All these possibilities would lead to a lower recruitment rate. But still, the fact that the forest is getting denser, might affect the in-growth as shown by Sapkota (2009).

Basal area has been increasing for most species. On average the increment of basal area has been 0.7 $m^2ha^{-1}year^{-1}$. The current density of 20 m^2ha^{-1} is in line with the figures reported by Mbaabu *et al.* (2014). Basal area weighted height (Figure 9) has been constant or slowly increasing over the years for all species. For *S. robusta*, it has even decreased slightly. The reason for this could be that the highest *S. robusta* trees are more valuable, and thus more exposed to legal and illegal cutting – even if it is against the by-laws of the CFUG.

Basal area weighted diameter (Figure 10) follows the same pattern as basal area weighted height, i.e. a small increase for most species except *S. robusta*. The same explanation could be applied, that *S. robusta* is quite valuable (16 000 SEK per cubic meter in 2014 in Kathmandu according to Subedi *et al.* (2014)), namely that it is more profitable to cut and sell bigger trees. Another valuable species, *D. sissoo,* does not decrease in either height or diameter though. Possibly, the low abundance of this species makes it easier to protect.

The diameter distribution on a 10-log scale (Figure 11) displays close to reversed J shape (Westphal *et al.*, 2006). Strictly, it is not a reversed-J shaped curve since the smallest diameters are much more abundant than the bigger ones (Figure 12). The diameter range 0-30 centimetres dominates with almost 100 percent of the stems. In this figure, the decline in the smallest class, 0-10 cm, is very clear. The decrease in the smallest class is probably the cause of the increase in the bigger classes, both in absolute numbers and in proportions. The biggest trees are very few, a fact supporting that the forest was indeed degraded a couple of decades back. Hopefully the distribution will smoothen out in due time, but since cuttings are banned by the CFUG, this could take a rather long time. Natural disturbance will of course run its course, but since the forest is very young and very homogeneous, the process will be quite slow. To tackle the decrease in recruitment it is possible to propose thinning in some parts of the forests.

The distribution of tree volume over diameter classes (Figure 13) comes as no surprise since volume will increase with growing DBH and thus smoothen out the curve when the fewer but bigger trees will gather volume exponentially faster than the small trees (Figure 18). There has been a big volume increment in the DBH range from 10 to 30 centimetres – probably because current annual increment is at the highest levels in this range.

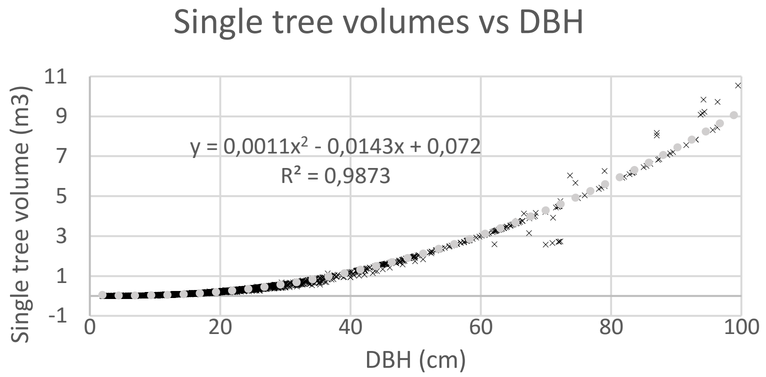


Figure 18 – Data points of single tree volume vs DBH.

Carbon

The total carbon stock (Figure 14) has increased at each measurement occasion. The first estimation in 2005 was 48 tonnes carbon per hectare. In 2010 it was 64 tonnes per hectare. Maraseni *et al.* (2014) estimates the carbon stock to be 35 tonnes per hectare in 2012 in the same forest, this estimate is very moderate in comparison. DFRS (2015) estimates the carbon stock in Terai to be 104.47 tonnes per hectare, which is more close to this study's estimate in 2015 – 80 tonnes per hectare. Mbaabu *et al.* (2014) estimates the carbon stock in community forest to approx. 244 tonnes per hectare, an even higher estimate. Of course there will be differences in estimates since forests never are exactly the same. The mentioned studies have been conducted in different parts of Nepal, except Maraseni *et al.* (2014). It is difficult to examine why there is such a big difference since Maraseni *et al.* (2014) do not present their method of carbon stock estimation.

The carbon increment estimated by Maraseni *et al.* (2014) is also lower compared with this study, 0.24 in relation to 3.2 and 2.7 tonnes per hectare and year (Figure 14). Again, it is difficult to present any theories on why, since the calculations by Maraseni *et al.* (2014) have not been published. It has been difficult to find other estimates of carbon stock increments in Nepal. In general, community forestry could maintain a higher stock than other forest types, as reported by Mbaabu *et al.* (2014), since these often are better protected by the local people.

In general, the development of carbon stock and carbon increment follows the same pattern as volume, since biomass is strongly correlated with volume and carbon stock is a proportion of biomass. The periodic increment of carbon per hectare and species in Figure 15 shows the same dominance by *S. robusta* (2.8 and 2.0 compared with 3.2 and 2.7 tonnes per hectare and year) as in other figures. If carbon stock is distributed over diameter classes (Figure 16), we again see the dominance of classes 10-20 and 20-30.

When comparing proportion of total increment in both carbon stock and standing volume (Figure 17), a strong correlation is clearly visible. The difference is not bigger than two percentage points between them. There are some diameter ranges that have negative increments, 0-10, 40-50, 60-70 and 80-90. In the smallest class, this is due to lower recruitment, and in others, it is probably due to either natural mortality or illegal logging.

Single tree development

The correlations between V_{PAI} for *S. robusta* and other variables do not show any unexpected results (Table 7). The strongest correlation with V_{Tree} is not unexpected, since big trees tend to grow faster, a relationship explained by Zeide (1993). The other correlations follow this pattern. Volume increases with basal area and height and basal area increases with DBH. Correlation between present growth and past growth in *S. robusta* were also found by Sapkota & Meilby (2009). We should see some negative correlations with increasing basal area or stem density as this is a strong measure for competition. Daniels *et al.* (1986) showed this with loblolly pine trees in Canada and the relationship between tree basal area as a proportion of mean basal area with basal area increment.

The results of cross-correlations between all variables shows the strongest relationships in the dataset (Table 8). The strongest correlation of them all is the one between DBH_{Stand} and DBH_{Max} – which is not a big surprise since the mean will increase considerably if there are some very big individual trees. That DBH_{Stand} and DBH_{Min} are correlated too might be explained by the narrow diameter span, i.e. the difference between minimum and maximum DBH is not very big. The only negative correlations are between percentage of *S. robusta* and altitude, basal area of *S. robusta* and altitude and also between DBH_{Min} and slope. The conclusion to make by this could be that *S. robusta*'s dominance is weaker in higher altitudes, possibly because of lower fertility or less available water closer to the hill tops. The decrease in DBH_{Min} should be interpreted as that the smallest trees get smaller with increasing slope gradient. Possibly an adaption due to the physical difficulties to be a big tree in a steep slope or that bigger trees tend to dominate even more with increasing slope.

Conclusions

The subject of stand dynamics in *S. robusta* dominated forests have been studied before. Nonetheless, this study has shed some light over the dynamics in a community managed forest. As expected, *S. robusta* dominates many of the processes taking place.

The estimation of carbon stock in this study shows that this type of *S. robusta* dominated forest under management of a community could be a carbon sink to count with. To make the increment of carbon stock permanent and thus helping in mitigating CO_2-emissions, REDD+ could be a way forward. But as Maraseni *et al.* (2014) stated, the economical compensation needs to be reasonably high to make REDD+ an attractive option for CFUGs. In many cases, additional use of forest product is needed to fill the community's needs (Karky & Skutsch, 2010).

Further research on the dynamics and carbon storage of *S. robusta* forests is recommended. Especially cornering age estimations of *S. robusta*.

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SUMMARY IN NEPALI - नेपालीमा सारांश

दक्षिणी नेपालको साल प्रजातिको हावी भएको वनमा रुख समूह गतिशीलता र कार्बन मौज्दात

साल प्रजातिको बाहुल्यता भएका, दक्षिणी नेपालमा अवस्थित, विशेष गरी स्थानीय समुदायद्वारा व्यवस्थापन गरिएका वनमा विद्यमान गतिशिलता तथा कार्वन सञ्चितिकरण सम्बन्धि ज्ञानको अभाव छ। साल मुख्य रुख प्रजातिका रुपमा रहेको र नेपालमा रेडप्लसको महत्व वृद्धि हुँदै गएकाले यस किसिमका ज्ञान हासिल गर्न जरुरी छ । यस अध्ययनको मुख्य उद्देश्य ७०० हेक्टर क्षेत्रफलमा फैलिएको सामुदायिक वनबाट संकलित तथ्यांकलाई विश्लेषण गरी यसका विशेषताहरु अन्वेषण गर्नु हो । स्थलगत तथ्यांकहरू सन् २००५, २०१०, २०१३ र २०१५ गरी ४ भिन्न समयमा संकलन गरिएको थियो, जसका लागि यादृच्छिक रुपमा अवस्थित ५०० वर्गमीटरका ६८ वटा प्लटमा परेका ४००० वटा भन्दा बढी रुखहरुको व्यास तथा त्यसमध्ये १० प्रतिशतको उचाइ समेत मापन गरिएको थियो । रिग्रेसन विधि मार्फत् प्रमुख सबै प्रजातिको 'उचाई नमूना' विकास गरियो र विद्यमान समीकरणहरुको प्रयोग गरी सम्पूर्ण रुखहरुको आयतन तथा जैविक पिण्डको आँकलन गरियो । जैविकपिण्डको ५२ प्रतिशत कार्वन हुन्छ भन्ने आँकलन गरियो । सालको 'एकल रुख विकास' सम्बन्धि एउटा अतिरिक्त विश्लेषण गरियो । यस अध्ययन अवधिमा खडा रुखको आयतन ९९ घनमीटर प्रति हेक्टरबाट बढेर १६१ घनमीटर प्रति हेक्टर पुग्यो । यसरी आवधिक वार्षिक वृद्धि ५.६ घनमीटर प्रतिहेक्टर रह्यो । सन् २०१५ मा सालले कुल आयतनको ७४ प्रतिशत ओगटेको तथा यसको आवधिक वार्षिक वृद्धि ४.१ घनमीटर प्रतिहेक्टर पाइयो । वार्षिक भर्ती रोपण भने ४३ रुख प्रति हेक्टरबाट एक्कासी घटेर १८ रुख प्रति हेक्टरमा आइपुग्यो । जमिन माथिको कार्वन मौज्दात ४८ बाट बढेर ८० टन प्रति हेक्टर पुगी आवधिक वार्षिक वृद्धि २.९ टन प्रति हेक्टर रह्यो । व्यास १० देखि ३० सेमीसम्मका रुखमा आयतन, कार्वन मौज्दात, आयतन र कार्वनको आवधिक वार्षिक वृद्धि सबैभन्दा उच्च पाइयो । सालको एकल रुखको वृद्धिसँग यसको आयतन, आधार क्षेत्रफल, आधार क्षेत्रफलको आवधिक वार्षिक वृद्धि, हाल तथा विगतको आधार क्षेत्रफलको एकदम बलियो सहसम्बन्ध देखियो । अपेक्षा गरे अनुरुप साल प्रजाति सबै प्रक्रियामा हावी भएको पाइयो । कार्वन मौज्दातको यो आँकलनले स्थानीय समुदायको मातहतमा व्यवस्थापन गरिएको यस प्रकारको साल प्रजाति हावी भएको वन कार्वन सञ्चितिकरणका दृष्टिले महत्वपूर्ण हुने कुरा देखायो ।

मूल शब्द : वन गतिशीलता, साल, कार्वन मौज्दात, सामुदायिक वन, वन बृद्धि

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