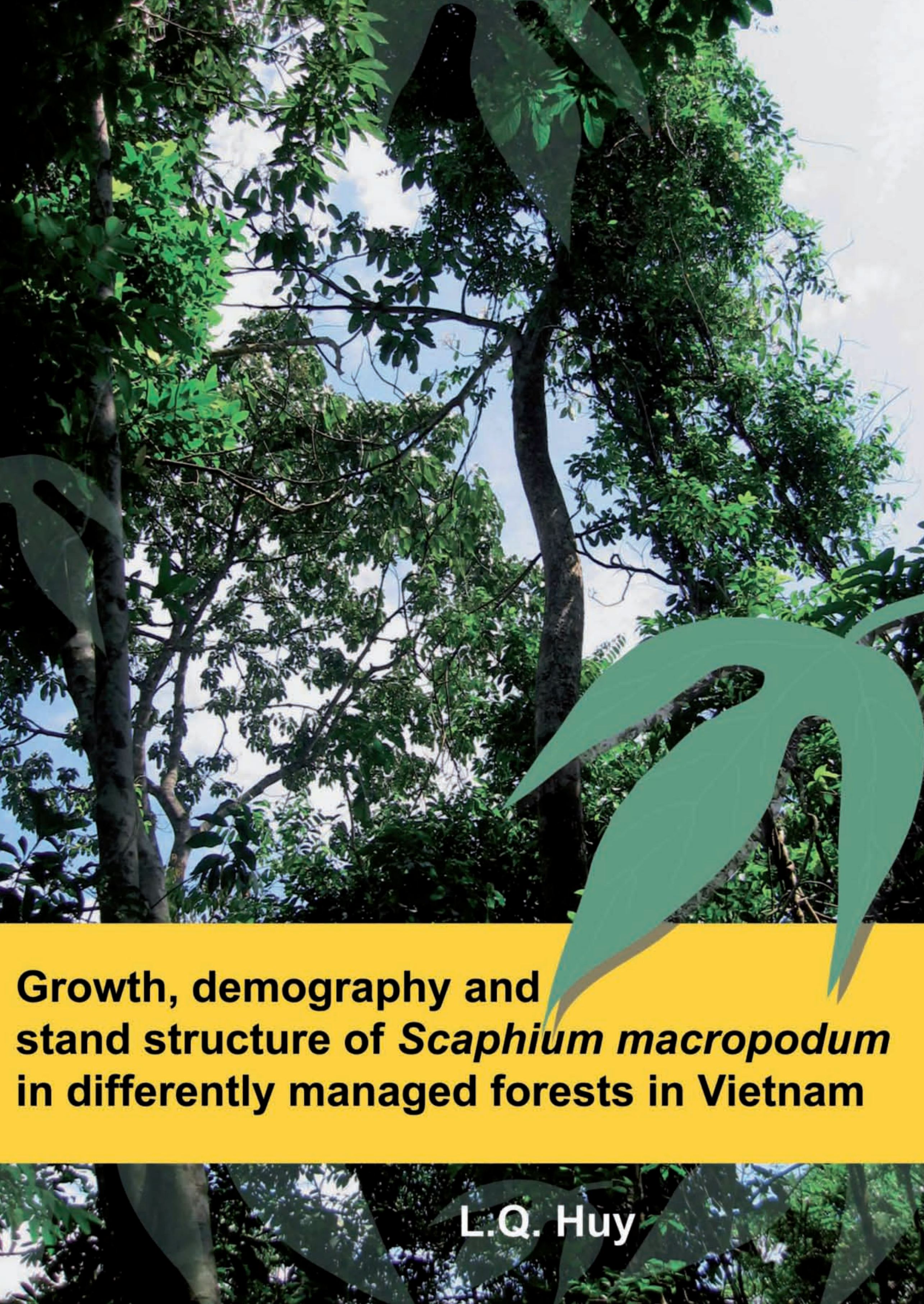

# Growth, demography and stand structure of *Scaphium macropodum* in differently managed forests in Vietnam

L.Q. Huy

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# Growth, demography and stand structure of *Scaphium macropodum* in differently managed forests in Vietnam

Groei, demografie en structuur van verschillend beheerde *Scaphium macropodum-bossen* in Vietnam

(met een samenvatting in het Nederlands)

Cấu trúc lâm phần, động thái quần thể và sinh trưởng của cây Ươi (*Scaphium macropodum)* tại một số rừng khác nhau ở Việt Nam

(phần tóm tắt bằng tiếng Việt nam)

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aan de Universiteit Utrecht
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door

**Le Quoc Huy**

geboren op 10 oktober 1962 te Phu Tho, Vietnam

Promotoren: Prof. dr. M.J.A. Werger
Prof. dr. R.G.A. Boot
Prof. dr. N.H. Nghia

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*To Trang and Bop*

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Our working team at *Scaphium macropodum* site in Bachma National Park, Thua Thien Hue, Vietnam (July 2009).

# Chapter 1
# General introduction

## Vietnam Forestry Development Strategy

Vietnam has a surface area of over 33.12 million hectares, of which 12.6 million ha of forests and 6.16 million ha of open land (i.e. areas of which the land-use has not yet been determined) are targeted for agriculture and forestry production (MARD 2007). Thus, the forestry sector has been managing and running production activities on a much larger area of land than other sectors in the national economy. The forest land area is distributed mainly in the mountainous and hilly areas of the entire country, where 25 million people from different ethnic groups live. These people have low education levels and backward farming practices, and experience slow economic development and many livelihood problems.

Due to unsustainable management and a very high need for conversion of forest land and the need of forest products for the socio–economic development of the country, the forest area and forest quality of Vietnam have been continuously decreased over the years. Documents show that in 1943 Vietnam had 14.3 million ha of forests, which amounts to a forest cover of 43% of the country. By the year 1990 only 9.18 million ha remained, which implies a forest cover of 27.2% (MARD 2007). During the period 1980 – 1990, the average forest lost was more than 100,000 ha each year. But from 1990 to the present, the forest area has been increased gradually, due to afforestation and rehabilitation of natural forest (with exception of some areas, like the Central Highlands and the South-East region, where the forest area still tends to decrease. According to the officially proclaimed Decision No. 1970/QD/BNN-KL-LN of MARD, dated 6 July 2006, up to 31 December 2005 (MARD 2005), the total nation-wide forested area was 12.61 million ha (which means a forest cover of 37%), of which natural forest amounted to 10.28 million ha and plantation forest to 2.33 million ha. Together they fall into 3 forest categories as follows:

- Special-use forest: 1.93 million ha, or 15.2%;
- Protection forest: 6.20 million ha, or 49.0%; and
- Production forest: 4.48 million ha, or 35.8%.

For above-mentioned reasons the Vietnam Forestry Development Strategy (FDS) for the period 2006 – 2020 has been released, serving as a basic orientation for the long-term development of forest resources in Vietnam. Its objectives are to sustainably establish, develop and use 16.24 million ha of forest land; to increase the forest cover till up to 42 – 43% by year 2010 and 47% by 2020 for an increased contribution to the socioeconomic development, biodiversity conservation and environmental services supply, reduce poverty and improve the livelihoods of rural mountainous people (Vietnam FDS 2006 – 2020, Decision No. 18/2007/QD-TTg, dated 5 February 2007, by the Prime Minister) (MARD 2007).

## Sustainable Forest Management in Vietnam

Concepts of Sustainable Forest Management (SFM) have been developed for global, regional and national applications. Most concepts for SFM have focused to elaborate a set of specific criteria, indicators and guidance approaches, and take relevant issues of social, economic and environmental importance into consideration. But in practice SFM has not yet functioned (Peters 1996, Wilkie et al. 2003), particularly not in Vietnam, where the concrete concepts and approaches for SFM might be somewhat different as compared to others regions.

In Vietnam more than 5 million hectares of natural forests have been lost during the last 50 years. Total national forest area of the country was 12.61 million hectares, of which 10.28 million hectares were natural forests and 2.33 million hectares were planted forests (MARD 2005). The main causes for deforestation are the conversion of forests to agricultural lands, including shifting cultivation, over logging, road construction, housing and settlement (Huy et al. 2006). Forest loss and degradation have caused seriously economic, social and environmental consequences such as an increasingly reduced supply of forest products and more frequent natural hazards. Together with deforestation the habitats for wildlife have been seriously degraded or lost and this was the main reason for the depletion of biological diversity, genetic resources and extinction of many valuable fauna and flora species (Huy et al. 2006).

To achieve an effective SFM in Vietnam, the following needs must be taken into consideration, besides practically defined SFM criteria and indicators:

- A clear policy that would motivate local people to participate in the SFM process and facilitate them to access the forest resources in a sustainable manner,
- A clearly defined governmental policy, taking the total economic value of the forests into account, and aimed at developing market mechanisms and stimulate the proper use of ecological services, thus providing incentives and motivations,
- An improvement of the public and local awareness regarding the SFM.

For that purpose, the Vietnam Forest Development Strategy (2006-2020) has been issued with the clear *Objective for SFM and a Development Program in order* "to manage and use forests sustainably for the basic demands of forest product consumption and export, contributing to the national economic and social development, particularly in mountainous regions, while ensuring the protection functions and the biodiversity conservation, and providing environmental services for a sustainable national development. (Vietnam FDS 2006 – 2020, Decision No. 18/2007/QD-TTg, dated 5 February 2007, by the Prime Minister).

In this context *Scaphium macropodum* provides a good example of a multipurpose forest tree species in Vietnam of which the products are highly valued, but the availability thereof has strongly declined because of years of unsustainable exploitation.

## Current status of *Scaphium macropodum*, its management and utilization

*S. macropodum* is defined as a common shade-tolerant emergent tree species in tropical rain forests (Yamada and Suzuki 1997). It is deciduous and flowers on bare twigs during the leafless period (Kostermans 1953).

The tree produces wind-dispersed fruits with a boat-shaped wing derived from a dehiscing follicle. All fruits are one-seed (Yamada and Suzuki 1996). It is a timber tree that can reach 40 m in height and 1m in diameter (DBH) (Kostermans 1953, Yamada et al. 2000). Its natural range of distribution comprises the tropical rain forests in Myanmar, Laos, Cambodia, Thailand, Indonesia and Vietnam.

*S. macropodum* is native to Vietnam. Its fruiting occurs unevenly, normally with 4 to 5 year intervals. Each year only about 10 to 20 % of the mature population bears fruits, and many mature trees apparently never bear any fruit (Huy et al. 2010a). It flowers from February and disperses its fruits from April to July varying between different locations (Hy 2005, Huy et al. 2010a).

*S. macropodum* is a valuable multipurpose tree species in Vietnam, whose main products are fruits for tonic and medicinal beverages and light timber. It was once very abundant in the natural forests from Bachma National Park (Thua Thien Hue) southward to Cattien National Park in Dong Nai province (Hy 2005, Huy et al. 2010a). Due to improper management practices and overharvesting, the species is now endangered (MoST 2007) and urgently needs a proper, integrated solution for sustainable use, its conservation, and an increased growth of this species. This is also in line with the National Forestry Strategy (NFS) for the period 2006 – 2020.

A good mature tree of *S. macropodum* in Vietnam can, in a good fruiting year, produce 40-60 kg of fruit, currently bringing a price of about 160-200 $ US,(3-5 $ US/1kg) (Hy 2005, Huy et al. 2010a). Under favorable conditions, at least 5-6 *S. macropodum* trees/ha could be sustainably harvested for fruits and provide an annual income of 12-16 million VND (about 600-800 $ US) for the local farmers. As the species was once very abundant in natural forests, local communities significantly benefited from its valuable products. Unfortunately, due to seriously improper management and harvesting, large areas of *S. macropodum* have been cut down for only a single harvesting of its fruits (Hy 2005, Huy et al. 2010a). This bad situation is being continued at many places and has brought about a serious decline of this species in terms of forest area supporting this species, number of populations, individuals, and their quality of growth (Huy et al. 2010a).

Most remaining populations of *S. macropodum* found now are small, scattered and occur only in protected areas of natural reserves and in very remote natural forest stands where local people either are not be allowed to cut them down for fruit harvesting or cannot easily reach the trees (Huy et al. 2010a).

Thus, the main reasons for the strong decline of the *S. macropodum* populations are the following:

- High profits from the valuable fruits of this species led to irresponsible fruit harvesting methods, including the cutting down of the entire trees or of major branches,
- Lack of basic knowledge, technical skills and awareness of relevant stakeholders regarding the overall roles and sustainable management of the plant resources, and lack of participatory and joint management approaches within local communities.
- This situation asks for effective changes in the management of the remaining natural populations of *S. macropodum* as well as in the enrichment forests where *S. macropodum* is newly planted. For a sustainable solution of the decline of *S. macropdum* several important questions should be answered. At the population level we have to understand how the population dynamics of this species will develop under different management and exploitation practices. Next we have to assess what criteria should be met to ensure sustained growth and fruit production under management. And since it is an endangered species, what are the basic criteria to conserve the species? And, very importantly, how can local communities and stakeholders be involved in a joint management approach? In this dissertation we can answer only part of these questions.

## Objectives of this study

The general objective of the study is to acquire necessary basic knowledge on the ecology and demography of *S. macropodum* which is of relevance for the development of proper management guidelines for the sustained management of this species. The aim is that this will benefit the stakeholders of plant resources in Vietnam.

**The specific objectives of the study are:**

- To quantify the species diversity of the *Scaphium macropodum* forest at sites studied with 3 levels of disturbances: strong, medium and little disturbance.
- To analyze the dynamics of *S. macropodum* populations in the three study sites and evaluate population growth in response to the different sites and with different fruit harvesting practices,
- To determine the effects of light regimes on overall growth rate and the light demands of seedlings of *Scaphium macropodum* and assess the ability to recover from its main shoot breakage,

- To analyze the growth of *S. macropodum* planted in a field enrichment trial in a secondary poor forest in Bachma National Park in which belt gaps of different sizes have been made.

(*i*) High disturbance site in Cattien National Park with brach cut fruit harvesting practice, bamboo invasion and cultivating encroachment,
(*ii*) Least disturbance site in Dakuy special use forest
(*iii*) Medium disturbance site in Bachma National Park
(*iv*) Medium to high disturbance site in M'drak Forest Enterprise

*Figure 1. Study site*

## Outline of the Thesis

This Thesis contains six chapters that are briefly described as follows:

**Chapter 1** is this introduction

**Chapter 2** gives a quantitative analysis of the community structure and species diversity of *S. macropodum* forests under different levels of disturbance in four study sites (Figure 1). It analyses the abundance, density and dominance of species, and quantifies the species diversities of the sites using various diversity measures.

**Chapter 3** analyses the population dynamics of *S. macropodum* in three study sites. Demographic field studies in these sites provide basic data for constructing matrix models, which are used for the projection of population growth and the determination of the most critical stages in the growth of the population. These results are expected to form an important basis for the recommendation and development of measures for sustainable management and utilization of the plant resources.

**Chapter 4** analyses plant growth of *S. macropodum* in greenhouse experiments under effects of different light intensities and physical breakage. Photosynthetic characteristics of the species are also reported. This may provide estimates of optimal values for light demand and assess the ability of *S. macropodum* to recover from the breakage disturbance at the nursery stage.

**Chapter 5** analyzes growth of *S. macropodum* in a field enrichment planting trial under different treatments of cut-belt width, established in a secondary poor forest in Bachma National Park.

**Chapter 6** summarizes the main results of the study and discusses recommendations for further research and management practices.

## Framework of this study

This study has been conducted as a joint research project and a part of Cooperative Project Agreement among Tropenbos International (TBI), acting through the TBI Vietnam Program, the Forest Science Institute of Vietnam (FSIV), and the Institute of Environmental Biology, Utrecht University (UU), under the title "Capacity Development and institutional support to FSIV through PhD, and Post-Doc research". Within this framework, the field research surveys and experiments on ecology of *S. macropodum* for sustainable development were carried out in Vietnam, under management and supervision of the FSIV and with funding from the Ministry of Agriculture and Rural Development (MARD). Additional analyses and final evaluation of the results have been done at the Institute of Environmental Biology, Ecology and Biodiversity, Utrecht University. Tropenbos International handled all organizational research work and supplied funding for study activities in Vietnam and in The Netherlands.

Tropenbos International (TBI) is a non-governmental organization (NGO) based in the Netherlands. It was established in 1986 in response to the ongoing concern about the disappearance and degradation of tropical rain forests worldwide. TBI has carried out multi-disciplinary research programs in cooperation with research institutions, government agencies and other stakeholders in partner countries in the tropics, amongst others in the Congo Basin, Cameroon, Ghana, Indonesia, Viet Nam, Colombia, Suriname, Guyana and Bolivia (visit *www.tropenbos.org* for details). The goal of TBI is to make sound and adequate information available to forest actors in the partner countries for use in formulating appropriate policies and managing tropical forests for conservation and sustainable development. The main objective is to ensure that knowledge is used effectively in the formulation of appropriate policies and the management of forests for conservation and sustainable development.

Tropenbos International Vietnam (TBI Vietnam) has been working in Viet Nam since 2002 under an agreement between MARD and Tropenbos Foundation. The objective of TBI Vietnam is that government and forest organizations in Vietnam use sound and adequate information for developing and implementing forest policies and practices that will improve forest-based livelihoods and the conservation of the country's forests. TBI Vietnam has now focused its efforts on tropical forest research and building capacity of individuals and organizations by providing them a series of institutional support and training programs. It also supports counterparts to conduct research projects on conservation and sustainable development of forest resources in Vietnam. The results thereof are subsequently supported to be transferred into policy and forest management practices (visit *www.tropenbos.org* for details).

The Forest Science Institute of Vietnam (FSIV) was founded in 1988 according to in line with Decision No. 137 HDBT/30/8/1988 of the Prime Minister of Viet Nam and became a National Organization. It is the only national institution for a broad spectrum of scientific research work and forest services in Vietnam. It established a national-wide organizational system with its professional and regional research centers located throughout the country from North to South. Now the FSIV is under the direction and management of the Ministry of Agriculture and Rural Development (MARD). The FSIV is now being institutionally upgraded, as decided by the Government, and by the end of this year, 2010, it will become the National Forest Academic Institution of Vietnam.

The Institute of Environmental Biology (IEB) is a major research institute of the Faculty of Science of the Utrecht University (UU) now hosting over 100 plant scientists. Together, they cover a broad range of fundamental plant biological disciplines ranging from the ecosystem, population and plant level to the cellular and molecular level. The IEB collaborates with other top research institutes all over the world, resulting in important joint publications in leading journals. The IEB's ambition is to further develop national and international leadership in integrated biological studies of plants, environmental signaling and ecosystem functioning, and to create a stimulating, competitive environment for talented young scientist (visit *http://www.uu.nl/faculty/science/en/research/researchinstitutes/ioeb/Pages/default.aspx* for details).

## Acknowledgements

I would like to thank Marinus Werger and Rene Boot for valuable discussions and comments on the formulation of this chapter.

A *Scaphium macropodum* study site in Bachma National Park, Thua Thien Hue, Vietnam

A *Scaphium macropodum* study site in Cattien National Park, Dong Nai, Vietnam

# Chapter 2
# Species diversity analysis of tree plant community in *Scaphium macropodum* forest under different levels of disturbance

*With M.J.A. Werger, R.G.A. Boot and N.H. Nghia; Submitted*

## Abstract

Maintenance of biodiversity in forest ecosystems is an increasing concern, especially in complex forest systems containing multiple components and functions. Dealing with these complex forest systems, single important species should not be considered separately, but rather the whole community for a better understanding of functions and mutual interactions.

*Scaphium macropodum* is a valuable multipurpose forest tree species in Vietnam, utilized for tonic and medicinal beverages and timber. Due to seriously improper management, the species is now endangered. We

quantified species diversity of *S. macropodum* plant communities at four sites: Cattien, with high disturbance due to over-harvesting of fruits, bamboo invasion, and forest encroachment, Bachma and M'drak with medium to high disturbances, and Dakuy, with least disturbance. Across these sites, the Shannon-Wiener index (H') ranged from 2.63-5.08; IVI values for *S. macropodum* ranged from 17.5-80.0 (IVI total: 300). The highest values of H' were found at the medium disturbance sites, where the D-D curve strongly suggests a lognormal series and *S. macropodum* seems to thrive best.

We analyzed the regression relationship between tree diversity and the relative importance of *S. macropodum* in the community (proportion of *S. macropodum* basal area to total basal area- SBA/TBA) and found that, while species richness at our study sites was not related to SBA/TBA, H' was significantly inversely related to SBA/TBA (p= 0.021, $r^2$ = 0.42), and SBA showed a linear relation to TBA (p= 0.004, $r^2$ = 0.45). We also found that there were strong and positive linear correlations between the Shannon diversity (H') and species richness (SR) ($r^2$ = 0.70; p< 0.001). The relationship between H' and the site disturbance index (SDI) strongly fitted a quadratic regression model ($r^2$ = 0.76, p< 0.001) and the H' diversity peaked at moderately disturbance (SDI of 0.45) in our study sites.

In Cattien, the Dominance Diversity (D-D) curve clearly suggests a strong geometric series and thus niche preemption (Whittaker, 1975; Pandey, 2002) with a steep slope for two dominant species viz. *S. macropodum* and *Bambusa procera* (IVI 80.0 and 63.0 res.). Here as much as 60 % of the species recorded have A/F ratios between 0.025 – 0.05; their distribution pattern is random and Cattien has the lowest H' values (1.19 – 3.32) among the study sites.

The D- D curve of Bachma strongly suggests a lognormal series in that much richer community (56 tree species) with a very gradual shift in importance between the species. Their IVI values, from the most important species (22.8) to the least one (0.9), did not suggest preemption (Whittaker, 1975; Pandey, 2002). 62.5% of the species at the site had A/F>0.05, and showed a contagious pattern, indicating that the site was stable and had the highest H' diversity (4.69-5.08).

The D-D curves for the Dakuy and M'drak sites also suggests geometric series for the dominant species, but with somewhat less steep slopes, especially for M'drak, as compared to that of Cattien. Their H' diversity ranges from 3.01 to 3.71.

**Key words:** Tree plant community, *S. macropodum*, Importance Value Index (IVI), Species diversity, Shannon-Wiener index (H'), Dominance Diversity (D-D) curve.

## Introduction

The past hundred years have seen a major reduction in global forest cover, especially in the tropics. Natural forests have been seriously depleted and replaced by a variety of simple agricultural monocultures such as rice or industrial forest monocultures made up of fast- growing exotic species (Lam 2003). Around the world, biological communities that took millions of years to develop are being devastated (Sharma 2003) and maintenance of biodiversity in managed forest ecosystem is an increasing concern (Jobidon et al. 2004). About 20 per cent of all species are expected to be lost within 30 years and 50 per cent or more by the end of 21st century (Sharma 2004). The current decline in biodiversity is largely the result of human activities, ranging from habitat destruction, over-harvesting, and pollution, to inappropriate introduction of exotic plants and animals. The diversity of natural ecological communities has never been more valued than it is now, as it becomes increasingly threatened by the environmental crises. Efforts are, therefore, needed to conserve biological resources and utilize them on a sustainable basis, and maintain genes, species and ecosystems (Verma 2000). According to (FAO 2005), biodiversity is one of six important functions of forest resources. Currently worldwide forests are being managed as (*i*) 34 % for production, (*ii*) 34 % for multipurpose goals, (*iii*) 11 % for biodiversity conservation, (*iv*) 9 % for soil and water protection, (*v*) 4 % for recreation and education, and (*vi*) and the 8 % remaining has not been identified yet for any specific function (FAO 2005).

Vietnam has been acknowledged as one of the most prioritized countries for global conservation due to its richness in biodiversity. Since 1994, Vietnam has officially joined the Convention of Biological Diversity (CBD), the "ecosystem approach" which endorses principles of negotiated local governance and adaptive management (Vermeulen and Koziell 2002) and committed itself to conserve and utilize its biodiversity in a sustainable way. Since then the government has realized significant activities and contributions to fulfill its commitments and obligations to the Convention. The first National Biodiversity Action Plan (NBAP) of Vietnam was approved by the Prime Minister in 1995 and its modified version in 2007 (MONRE 2007). This is a legal document that directs biodiversity conservation activities in Vietnam. Furthermore, the National Assembly has recently ratified the Law on Biodiversity and it has been put into effect on July 1st, 2009 (MONRE 2008).

Biodiversity can make a significant contribution to the national economy of Vietnam by ensuring food security, maintaining gene resources, and providing materials for fuel, medicine and construction. However, biodiversity resources in Vietnam and their conservation management are currently facing many threats and problems. Integrated approaches for the conservation of forest genetic resources, sustainable forest management and biodiversity conservation should bedeveloped to achieve better results (Nghia 2004, 2009). The increase of the population, over-exploitation of natural resources, rapid development as well as climate change, have led to big damages and losses in natural habitats, species compositions, and natural landscapes. The fast increase in forest coverage might be a good sign, but actually half of the increased area consists of mono-plantations and regeneration forests are of low biodiversity. Meanwhile, little remains of rich and primary forests and they continue to be depleted. Besides that, there are still many shortcomings in biodiversity management in Vietnam, like weak management bodies, unsystematic and inconsistent legislations, poor community participation, and limited investment in biodiversity conservation (MONRE 2007).

*S. macropodum* is an important multipurpose timber species in Vietnam. *S. macropodum* once was very abundant in the natural forests of Vietnam. Along with the decline of the *S. macropodum* plant resources, due to improper harvesting practices as well as other disturbances, its natural forests have been significantly degraded regarding their stand structure, abundance and biodiversity (Hy 2005, Huy et al. 2010a). In the past, studies on biological diversity have been concentrated on higher spatial scales, e.g. regional and global scales (Sharma 2004). A great deal of time and expertise has been spent, but our understanding of the structure and functioning of communities has remained meager. The current focus of ecological studies, therefore, is shifting from the higher scales to locally manageable scales (Sharma 2004, Daniel 2005).

In this paper we present research on the quantification of plant species diversity of *S. macropodum* forests in 4 study sites under different levels of site disturbances in Vietnam. This study aimed to support the management and conservation of the forest resources and biodiversity with important basic data and information.

We addressed the following questions in this study:

i. What are the dominance ranking structures of the plant communities studied, and how do they relate to the importance of *S. macropodum* in the forest stand structure?

ii. What are the species diversity indices and species aggregation patterns of the tree communities studied at the different sites?
iii. To what degree are the various sites disturbed and how do the stand characteristics relate to the site disturbance?

## Methods

### *Study species*

In this study, we dealt with all tree species in the *S. macropodum* plots occurring at each study site (Cattien National Park, Dakuy Special use forest, Bachma National Park and M'drak Forest Enterprise, respectively). *S. macropodum* is the main study species in the whole thesis study. We added, as an exceptional case, Bambusa procera at the Cattien and M'drak sites due to its strong involvement in the studied *S. macropodum* plant community.

### *Study sites*

We selected 4 representative sites of natural forest with *S. macropodum* for this study (Figure 1):

1. In Cattien National Park, Dinh Quan district, Dong Nai province,
2. In Dakuy Special use forest, Dak Ha district, Kon Tum province,
3. In Bachma National Park, Nam Dong district, Thua Thien Hue province, and
4. In M'drak forest enterprise, K'rong A commune, M'drak district, Daklac province.


*Figure 1. Study site*

### *1. Site of Cattien National Park*

The site is located in the southern part and on the edge of the National Park, near the boundary with Cattien Forest Enterprise. The meteorological observations from Xuan Loc station showed that the mean annual temperature of the area is 25.4°C, mean maximum temperature 30.8°C and mean minimum temperature 21.3°C. Annual rainfall in the area is 2,185 mm and the mean annual relative humidity 83.6 %. Topographic conditions of the study area show gentle slope gradients of less than 10°.

Most of the study area lies at altitudes between 150- 300 m and thus the site is rather flat and easy to access. These conditions, on the one hand can be considered as advantages for management of the site, but on the other hand they are also very challenging regarding protection of the site from illegal logging, harvesting and encroachment. The major soil type of the site area is red soil developed from bazan mother rock (Fk), but small scattered parts of the site have soil developed on sandy mother rock (Fs); and old accumulated loamy soil (Fp) is distributed along the sides of Dong Nai river and other streams (Que and Thang 2009).

It is reported that, all *S. macropodum* trees of the study site have been allocated to specific local farmers for better management and utilization, but the whole area has strong traces of high human disturbances from the harvesting of *S. macropodum* fruits in the conventional way and also shows dense bamboo invasion and traces of harvesting of the bamboo, while agricultural activities encroach upon the area (Huy et al. 2010a). All these have been considered as serious problems for management and conservation of the forest biodiversity resources.

**Table 1. Characteristics of four study sites**

| Characteristics | Site in Cattien NP | Site in Dakuy SUF | Site in Bachma NP | Site in M'Đrak FEP |
|---|---|---|---|---|
| Coordinates (study site) | N: 11°22'12" | N: 14°33'15" | N:16°7.9'66" | N: |
| | E: 107°15'18" | E: 107°54'65" | E:107°46'77" | E: |
| Mean ann. temp. (°C) | 25.4 | 23.4 | 25.3 | 26.4 |
| Max. temp. (°C) | 30.8 | 29.7 | 29.1 | 30.8 |
| Min. temp. (°C) | 21.3 | 18.7 | 22.1 | 23.7 |
| Mean ann. rainfall (mm) | 2,185 | 1,804 | 4,000 | 1,359 |
| Mean ann. rel. humidity (%) | 83.6 | 78.0 | 81.0 | 80.0 |
| Altitude (m) | 150- 300 | 640- 662 | 500- 700 | 400-500 |
| Slope (°) | < 10 | < 10 | 15-25 | >15 |

### 2. *Site of Dakuy Special Use Forest (SUF)*

This site, at altitudes of 640-662 m, also is rather flat, has very gentle slope gradients, and is easy to access. However, the whole area of the Dakuy SUF has been put under very strict protection from all activities of illegal logging, fruit harvesting and encroaching cultivation. This is much different from the situation at Cattien. At this site local farmers can only collect fruits of *S. macropodum* from the ground for their consumption and for selling, the so-called "natural collection"; they are neither allowed to cut the trees nor their branches for harvesting, as commonly occurs at Cattien. The meteorological observations showed that the mean annual temperature of the area is 23.4°C, mean maximum temperature 29.7°C and mean minimum temperature 18.7°C. Annual rainfall in the area is 1,804 mm, and most rain comes in the wet season from June to October; the mean annual relative humidity is 78 %.

### *3. Site of Bachma National Park*

The site is located in the Nam Dong district, Thua Thien Hue province, at altitudes of 500- 700 m. The area belongs to the Bachma National Park. Meteorological observations from Bachma station showed that the mean annual temperature is 25.3°C, mean maximum temperature 29.1°C and mean minimum temperature 22.1°C. The mean annual relative humidity is 81 %. Mean annual rainfall in the area is as high as 4,000 mm. Its topographic conditions show rather steep slope gradients of 20-25 degree, while the area is rather strongly divided by valleys and streams, and rather difficult to access. Here also local farmers can collect fruits of *S. macropodum* from the ground, sometimes in combination with fruit harvesting by way of branch cutting. This is called "combination of natural collection and improved conventional harvesting". The *S. macropodum* trees at the site have been allocated to local farmers for better management.

### *4. Site of M'Đrăk Special Use Forest*

The site is located in K'rong A commune of Dinh Quan district, Dak Lak province, at altitudes of 400-500 m. The area belongs to the M'drak Forest Enterprise. Meteorological observations in this region show a mean annual temperature of 26.4°C, mean maximum temperature of 30.8 °C and mean minimum temperature of 23.7°C. The mean annual relative humidity is 80 % and the mean annual rainfal 1.359 mm, making it the driest of the 4 sites. The site in M'drak has rather steep slope gradients of 15-25 degree, and is divided by small valleys and streams, providing rather difficult access. Local farmers have caused a medium rate of disturbance due to fruit harvesting (by collecting and cutting). This study area is under joint management and protection of the Forest enterprise and local farmers.
Estimating the Site disturbance index (SDI)

To give quantitative estimates of disturbances at the plot sites, we defined the activities of conventional fruit harvesting, bamboo invasion and cultivation encroachment as 3 major disturbances and assigned to them 3 weighted scores (Site disturbance index, SDI) of 0.55, 0.25 and 0.10, respectively (Naveh and Whittaker 1979, Acharya 1999). Each major disturbance was divided into different sub-variables, the total giving a score of 1.00 (Table 2).

A plot is defined as highly disturbed if its SDI value > 0.5, moderately disturbed if its SDI value falls between 0.3 to 0.5, and little disturbed if its value < 0.3.

**Table 2. Site disturbances index definition**

| # | Disturbance variables | SDI value |
|---|---|---|
| **1** | **Conventional fruit harvesting** | **0.55** |
| | - Cutting fruit branches off | 0.55 |
| | - Combining cutting branches off with natural collection | 0.30 |
| | - Natural collection (gather fallen fruits from forest floor) | 0.15 |
| **2** | **Bamboo invasion** | **0.25** |
| | - High | 0.25 |
| | - Moderate | 0.15 |
| | - Little | 0.05 |
| **3** | **Cultivation encroachment** | **0.10** |
| | - High | 0.10 |
| | - Moderate | 0.05 |
| | - Little | 0.00 |
| **4** | **Other (bamboo cutting, grazing, natural damage…)** | **0.10** |
| | **Maximum Total** | **1.00** |

### *Data collection*

Data collection at the Cattien, Dakuy and M'drak sites was done in 2008, and that in Bachma in 2009.

To answer the research questions of the study, the necessary data of all tree species in the studied plant community were measured in sets of 3 or 4 sampling plots (quadrats) at each *S. macropodum* study site. The plots were layed out in an uphill direction in 3 positions: a plot low on a hill (LHP), in the middle part of a hill (MHP) and high on a hill (HHP). The size of each sampling plot was 1,000 $m^2$ (25 m x 40 m).

In each sampling plot, we assessed the following variables:

i. Name of all tree species occurring in the sampling plots; specimens of unidentified plant species were collected for identification
ii. Number of individuals of each occurring tree species
iii. Total height (H) and Diameter at breast height (DBH) of each individual stem with height ≥ 1 m
iv. Canopy cover, degree of disturbance, topographic features

These data were used to calculate relative density, frequency, abundance and dominance of the species; and from those values the Importance Value Indices (IVI) and Species diversity indices were calculated.

***Data analyses***

**i. Importance Value Index (IVI):**

In order to express the dominance and biological success of any species with a single value, the concept of Importance Value Index (IVI) has been developed by Curtis and McIntosh (1950), Phillips (1959) and Mishra (1968) . Rastogi (1999) and Sharma (2003) have reported the IVI as a better expression of relative ecological importance of a species than an absolute measure such as frequency, density or dominance. IVI of each species was obtained by summing the three relative values, i.e. relative density (RD), relative frequency (RF) and relative dominance or relative basal area (RBA):

$$IVI = RD + RF + RBA \qquad (1).$$

Importance percentage is obtained by dividing the IVI-value by 3.

**Relative density**

Density denotes the average number of individuals of a given species out of the total of samples examined in a study area (Oosting 1942, Rastogi 1999, Sharma 2003). The Relative Density (RD) of a species is then calculated as

$$\textbf{Relative Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of all individuals of all species}} \times 100\ (\%)$$

**Relative frequency**

Frequency indicates the number of sampling plots (sites) in which a given species occurs as a percentage of all sampling plots. This is just based on the presence or absence of a species (Raunkaier 1934, Rastogi 1999, Sharma 2003). Relative Frequency (RF) then is calculated as:

$$\textbf{Relative Frequency} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100\ (\%)$$

**Relative dominance or relative basal area (RBA)**

Dominance is defined as the sum of basal areas of all individuals of a species. The basal area refers to the ground actually covered by the stems (Rastogi 1999, Sharma 2003, Huy 2005b). Relative Basal Area (RBA) is then calculated as:

$$\textbf{Relative Basal Area} = \frac{\text{Basal area of a species}}{\text{Total Basal area of all species}} \times 100\ (\%)$$

**ii. Species abundance**

Values of abundance (A) were calculated following Curtis and McIntosh (1950)

$$\textbf{Abundance} = \frac{\text{Total number of individuals of a species in all plots}}{\text{No. of sampling plots in which the species occurred}}$$

The ratio of abundance to frequency (A/F) of a species assesses the aggregational pattern of the species in the community. The distribution of a species is considered regular if its A/F ratio < 0.025. This kind of distribution often is found at sites, where the competition among species is strong. A random pattern is indicated by an A/F in between 0.025 - 0.05. This pattern normally is found at sites with unstable environmental conditions. A contagious pattern is indicated by an A/F higher than 0.05. This is the most common pattern in nature and always occurs in sites with stable conditions (Curtis and Cottam 1956, Odum 1971, Verma 2000).

**iii. Dominance Diversity curve (D-D)**

To analyze species dominance patterns and ascertain the resource apportionment among the species at a site, Dominance Diversity curves (D-D) were developed wherein the IVI was used as a measure of the niche of a species its and resource apportionment thus was treated as an expression of the relative niche size.

This is based on the assumption that there is some correspondence between the share in community resources and community space utilized by a species (Whittaker 1975, Pandey et al. 2002).

**Niche space partitioning and resource sharing**

We followed Naveh and Whittaker (1979), Verma (2000) and Pandey (2002) for the analysis of the vegetation stands in terms of two dominance pattern models, as follows:

- **Geometric series:** this kind of D-D curve is typical for sites where one species highly dominates the site. This highly dominant species thus possesses a high IVI value and is considered to occupy the top niche. It takes a large share to the available resources. The next important species takes a similar proportion of the resources left by the first species, and so on. This is the so-called niche preemption hypothesis (Whittaker 1975, Pandey et al. 2002). This kind of curve represents a geometric series with a very steep slope: the dominant species is the most competitive, followed by the other species that are subsequently proportionally less competitive and thus take proportionally less of the total resources. Communities with this pattern usually have a low species diversity (Preston 1948, Naveh and Whittaker 1979). This geometric series would also suggest that the vegetation of the site is not stable, and often other species can invade the community (Pandey et al. 2002).

- **Log-normal distribution:** this kind of D-D curve occurs on sites where none of the species possess high IVI values and none strongly dominates the site. Plant communities showing a log-normal distribution, are thought to more equally share the resources in a gradual ranking order from the most important species to the least important one. This log-normal distribution also suggests that at the site species are fairly equally competitive. Such communities have high diversities, and the vegetation of the site is considered rather stable (Verma 2000, Pandey et al. 2002).

**iv. Species diversity indices**

In the present study, to produce quantitative measures of vegetative diversity in the four *S. macropodum* forest sites studied, we examined plant diversity using two indices: *species richness* (SR) and *species diversity* (H') calculated according to Shannon and Wiener (1963).

**Species Richness (SR)**

At its simplest level, diversity can be defined as the number of species found in a plot, a measure known as Species Richness. In this study, the species richness of trees was calculated as the number of species per study plot area (Whittaker 1975).

**Shannon-Wiener Diversity (H')**

The Shannon-Wiener Diversity (H') is the most successful method and is based on the information theory equation of Shannon and Wiener (1963).

The Diversity Index (H') has not only a variety component but also an equitability component; it accounts for the distribution of individuals among the species present. This means that information content is maximal if each individual belongs to a different species and minimal if all belong to the same species (Rolan 1973).

Species diversity (H') was calculated following Shannon and Wiener (1963) as:

$$H' = -\sum_{i=1}^{s} \{Ni/N\} \log_2 \{Ni/N\}$$

where S is the number of species in the sample, Ni = the total number individuals of species i, and N = the number of individuals of all species in that site.

***S. macropodum* basal area proportion**

We quantified the basal area of *S. macropodum* (SBA) as a measure of species dominance and the total basal area (TBA) for each plot, then used the ratio SBA/TBA to represent the proportion of *S. macropodum* species to the tree community of the whole plot.

**v. ANOVA pairwise multiple comparison test and regression analyses**

We used analyses of variance (ANOVA) followed by post hoc Tukey pairwise multiple comparisons to test if the 4 study sites in Cattien, Dakuy, Bachma and M'drak differed significantly in their parameters of species diversity and community characteristics (Coroi et al. 2004, Kharkwal 2009). The vegetation parameters tested were the mean values of species richness (SR), Shannon diversity index (H') and *S. macropodum* BA proportional to TBA of each study site.

In practical management there is a common idea that there is a trade-off between the production of a stand and its species diversity. To investigate whether this holds in our *S. macropodum* stands we fitted regressions to describe the relationship between species richness (SR) and H' and the ratio of *S. macropodum* basal area (SBA) to total basal area (TBA) (SBA/TBA) and H'. We selected the best fitting regression model based on regression curve estimates and polynomial regression analysis.

# Results

## *Importance Value Index (IVI)*

The inventories showed that *S. macropodum* and Shorea thorelii were common to all four study sites, *Dipterocarpus alatus* and *Syzygium Sp.*1 common to Cattien, Dakuy and M'drak, *Lithocarpus dealbatus* and *Phoebe cuneate* common to Dakuy and M'drak, and *Bambusa procera* was common to Cattien and M'drak (Table 3).

**Table 3. Importance value index of important common species in the study sites**

| | Tree species | Cattien | Dakuy | Bachma | M'drak |
|---|---|---|---|---|---|
| **Local name** | **Scientific name** | | | | |
| Ươi | *S. macropodum* | 80.0 | 63.9 | 17.5 | 29.6 |
| Lồ ô | *Bambusa procera* | 65.3 | - | - | 42.4 |
| Trắc | *Dalbergia cochinchinensis* | - | 50.9 | - | - |
| Tung | *Hernandia nymphiifolia* | 25.6 | - | - | - |
| Chai | *Shorea thorelii* | 12.5 | 9.5 | 1.9 | 52.4 |
| Dầu rái | *Dipterocarpus alatus* | 8.1 | 13.4 | - | 8.1 |
| Long não | *Cinnamomum camphora* | - | 10.3 | - | - |
| Trâm roi | *Syzygium Sp.1* | 5.8 | 10.3 | - | 26.2 |
| Lim xẹt | *Peltophorum pterocarpum* | 4.1 | - | - | - |
| Lim xanh | *Erythrophloeum fordii* | - | - | 7.1 | - |
| Trâm vối | *Syzygium cuminii* | - | - | 5.6 | - |
| Bời lời nhớt | *Litsea glutinosa* | - | - | 4.8 | - |
| Huỷnh | *Tarrietia javanica* | - | - | 4.6 | - |
| Táu | *Vatica odorata* | - | - | - | 12.0 |
| Dẻ đá | *Lithocarpus dealbatus* | - | 3.6 | - | 11.4 |
| Dẻ đỏ | *Lithocarpus ducampii* | - | 7.6 | - | - |
| Dẻ bộp | *Lithocarpus fissus* | - | - | 3.4 | - |
| Trò nâu | *Dipterocarpus retusus* | - | - | 2.7 | - |
| Dẻ | *Lithocarpus Sp.1* | - | - | 2.4 | - |
| Kiền kiền | *Hopea pierrei* | - | - | 2.4 | - |
| Kháo ngứa | *Phoebe cuneata* | - | 4.8 | - | 9.8 |
| Cẩm lai | *Dalbergia oliveri* | - | - | - | 4.0 |
| Sến mật | *Madhuca pasquieri* | - | - | 2.1 | - |
| Gõ đỏ | *Afzelia xylocarpa* | - | - | 2.1 | - |

Detailed IVI analysis of the tree species at different study sites is presented in Table 4.

At Cattien, where all study plots were assessed as highly disturbed with SDI values ranging from 0.60 to 0.75, *S. macropodum* and *Bambusa procera* were found to be the co-dominant species in the ranking dominance order of 30 tree species found at the study site. *S. macropodum* had the highest IVI (80.0), followed by the bamboo (IVI = 65.3) and *Hernandia nymphiifolia* (25.6). The minimum IVI of 1.5 was noted for *Dillenia indica* and *Acacia sp*. At this site *S. macropodum* was once very abundant, but as a result of the dynamics caused by disturbance and bamboo invasion, it is likely that *S. macropodum* will still further decline and ultimately be replaced, while the bamboo will strongly dominate the site. This issue will be further discussed in later sections on species diversity and *S. macropodum* demography.

At Dakuy, under strict protection and management, the environmental conditions of the site have been very little disturbed, its SDI values ranging narrowly from 0.25 to 0.30. *S. macropodum* and *Dalbergia cochinchinensis* had the highest IVI values (63.9 and 50.9, respectively) and were co-dominant. The lowest IVI had *Terminalia corticosa*, *Macaranga denticulate* (2.5) and an unidentified tree species (1.7). This site is characterized by a rather high abundance of the *S. macropodum*, with young populations and little disturbance as a result of harvesting of fruit from the forest floor.

The Bachma site was remarkably different from the Cattien and Dakuy sites and the number of tree species was significantly higher (56 compared to 30 and 34, respectively). There was no species with a very high IVI value and thus no strongly dominant species. The tree species gradually differed in their IVI values (Table 4) with Dao (sp.) having the highest IVI value (22.8), followed by Tam lang (sp.) (20.7) and *S. macropodum* (17.5).

The lowest IVI had *Nephelium lappaceum* (1.0) and an unidentified tree species (0.9). This site was moderately disturbed because of fruit harvesting and other activities, its SDI is ranging from 0.40 to 0.50 (Table 6).

To some extent the study plots in M'drak were similar to those of Bachma regarding their IVI structure, but they significantly differed in their species number, abundance and degree of site disturbance. Here *Shorea thorelii* had the highest IVI value (52.4), followed by *Bambusa procera* (42.4). The two species can be considered as co-dominants. *S. macropodum* ranked third with 29.6. The lowest IVI values had the very valuable and rare timber species *Dalbergia oliveri* (4.0) and an unidentified tree species (2.8). The site is moderately to highly disturbed because of fruit harvesting and other activities.

**Table 4. Importance Value Index (IVI) and A/F Ratio of tree species in 4 study sites**

| | CATTIEN | | | | DAKUY | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Species | | A/F | IVI | Species | | A/F | IVI |
| | Local name | Scientific Name | | | Local name | Scientific Name | | |
| 1 | Ươi | *Scaphium macropodum* | 0,428 | 80,0 | Ươi | *Scaphium macropodum* | 0,320 | 63,9 |
| 2 | Lồ ô | *Bambusa procera* | 0,820 | 65,3 | Trắc | *Dalbergia cochinchinensis* | 0,127 | 50,9 |
| 3 | Tung | *Hernandia nymphiifolia* | 0,050 | 25,6 | Dầu con rái | *Dipterocarpus alatus* | 0,037 | 13,4 |
| 4 | Chai | *Shorea thorelii* | 0,018 | 12,5 | Long não | *Cinnamomum camphora* | 0,020 | 10,3 |
| 5 | Chiết tam lang | | 0,053 | 8,8 | Trâm roi | *Syzygium Sp.1* | 0,023 | 10,3 |
| 6 | Dung giấy | *Symplocos laurina* | 0,045 | 8,2 | Chai | *Shorea thorelii* | 0,013 | 9,5 |
| 7 | Dầu rái | *Dipterocarpus alatus* | 0,035 | 8,1 | Keo | *Acacia auriculiformis* | 0,023 | 8,8 |
| 8 | Hậu phát | *Cinnamomum polyadelphum* | 0,030 | 7,3 | Kơnia | *Irvingia malayana* | 0,010 | 7,8 |
| 9 | Cuống vàng | | 0,028 | 7,2 | Dẻ đỏ | *Lithocarpus ducampii* | 0,023 | 7,6 |
| 10 | Ba soi | *Mallotus paniculatus* | 0,067 | 6,9 | Đa rừng | *Ficus Sp.1* | 0,017 | 7,6 |
| 11 | Sp2 | | 0,030 | 6,2 | Móng bò | *Bauhinia purpurea* | 0,010 | 7,5 |
| 12 | Bụp lá lớn | *Hibiscus macrophylla* | 0,053 | 6,0 | Vả | *Ficus roxburghii* | 0,010 | 7,3 |
| 13 | Trâm roi | *Syzygium Sp.1* | 0,036 | 5,8 | Họ dầu | *Dipterocarpus Sp.1* | 0,020 | 7,1 |
| 14 | Hu đay | *Trema orientalis* | 0,027 | 5,1 | Bạch đàn | *Eucalyptus Sp.1* | 0,017 | 6,7 |
| 15 | Mán đỉa | *Archidendron clypearia* | 0,027 | 5,1 | Cà phê | *Coffea arabica* | 0,017 | 6,1 |
| 16 | Họ trâm | | 0,040 | 4,6 | Quếch | *Chisocheton paniculatus* | 0,010 | 5,7 |
| 17 | Sp3 | | 0,020 | 4,3 | Sao đen | *Hopea odorata* | 0,010 | 5,5 |
| 18 | Sp1 | | 0,020 | 4,1 | quế | *Cinnamomum cassia* | 0,010 | 5,3 |
| 19 | Lim xẹt | *Peltophorum pterocarpum* | 0,080 | 4,1 | Họ đậu | | 0,030 | 5,0 |
| 20 | Màng tang | *Litsea cubeba* | 0,050 | 3,7 | Ớt rừng | *Micromelum minutum* | 0,010 | 5,0 |
| 21 | Ngái | *Ficus hispida* | 0,060 | 3,7 | Kháo ngứa | *Phoebe cuneata* | 0,030 | 4,8 |
| 22 | Bìn lìn giấy | | 0,040 | 3,4 | Mít rừng | | 0,015 | 4,3 |
| 23 | Sổ | *Dillenia scabrella* | 0,030 | 3,2 | Sp11 | | 0,015 | 4,3 |
| 24 | Thẩu tấu | *Aporosa dioica* | 0,080 | 1,7 | Trắc dây | *Dalbergia rimosa* | 0,015 | 4,0 |
| 25 | Sp6 | | 0,040 | 1,5 | Hậu phát | *Cinnamomum polyadel-phum* | 0,015 | 3,9 |
| 26 | Sp5 | | 0,040 | 1,5 | Chò chang | *Dipterocarpus turbinatus* | 0,030 | 3,8 |
| 27 | Sp7 | | 0,040 | 1,5 | Dung giấy | *Symplocos laurina* | 0,015 | 3,7 |
| 28 | Sp4 | | 0,040 | 1,5 | Dẻ đá | *Lithocarpus dealbatus* | 0,015 | 3,6 |
| 29 | Sổ bà | *Dillenia indica* | 0,040 | 1,5 | Sp1 | | 0,030 | 3,4 |
| 30 | Keo | *Acacia auriculiformis* | 0,040 | 1,5 | Duối nhám | *Streblus asper* | 0,030 | 3,3 |
| 31 | 30 species | | | 300 | Mây | *Calamus Sp.1* | 0,060 | 3,0 |
| 32 | | | | | Chiêu liêu ổi | *Terminalia corticosa* | 0,060 | 2,5 |
| 33 | | | | | Ba soi | *Macaranga denticulata* | 0,060 | 2,5 |
| 34 | | | | | Sp12 | | 0,030 | 1,7 |
| 56 | | | | | 34 species | | | 300 |

## Table 4. Importance Value Index (IVI) and A/F Ratio of tree species in 4 study sites (cont.)

| | BACHMA | | | | M'DRAK | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Species | | A/F | IVI | Species | | A/F | IVI |
| | Local name | Scientific Name | | | Local name | Scientific Name | | |
| 1 | Đào | | 0,210 | 22,8 | Chai | *Shorea thorelii* | 0,057 | 52,4 |
| 2 | Tam lang | | 0,203 | 20,7 | Lồ ô | *Bambusa procera* | 0,450 | 42,4 |
| 3 | Ươi | *Scaphium macropodum* | 0,083 | 17,5 | Ươi | *Scaphium macropodum* | 0,067 | 29,6 |
| 4 | Trâm đỏ | | 0,250 | 14,1 | Trâm roi | *Syzygium Sp.1* | 0,023 | 26,2 |
| 5 | Sơn | *Sophora subprostrata* | 0,167 | 11,8 | Họ dầu | *Dipterocarpus Sp.1* | 0,045 | 15,3 |
| 6 | Nấm lửa | | 0,263 | 11,5 | Táu | *Vatica odorata* | 0,060 | 12,0 |
| 7 | Bách bệnh | *Eurycoma longifolia* | 0,263 | 10,4 | Dẻ đá | *Lithocarpus dealbatus* | 0,038 | 11,4 |
| 8 | Ngát | *Gironniera subacqualis* | 0,137 | 9,4 | Kháo ngứa | *Phoebe cuneata* | 0,030 | 9,8 |
| 9 | Trám chủa | | 0,170 | 9,1 | Ngái | *Ficus hispida* | 0,045 | 8,3 |
| 10 | Trâm chủy | | 0,123 | 7,8 | Dầu rái | *Dipterocarpus alatus* | 0,023 | 8,1 |
| 11 | Dẻ sạn | | 0,120 | 7,6 | Giổi | *Manglietia Sp.1* | 0,015 | 7,9 |
| 12 | Lim xanh | *Erythrophloeum fordii* | 0,240 | 7,1 | Sp9 | | 0,090 | 7,9 |
| 13 | Cơi | *Pterocarya tonkinensis* | 0,390 | 6,9 | Dầu lông | *Dipterocarpus intricatus* | 0,015 | 7,4 |
| 14 | Cồn | | 0,100 | 6,9 | Bông gòn | *Ceiba pentandra* | 0,015 | 6,8 |
| 15 | Cau rừng | *Areca catechu* | 0,157 | 6,8 | Thanh thất | *Ailanthus triphysa* | 0,015 | 6,4 |
| 16 | Máu chó | *Knema globularia* | 0,147 | 6,7 | Máu chó | *Knema pierrei* | 0,015 | 5,9 |
| 17 | Trường đại | | 0,147 | 6,6 | Sòi | *Sapium sebiferum* | 0,015 | 5,7 |
| 18 | Vè ve | | 0,057 | 6,2 | Ba soi | *Macaranga denticulata* | 0,015 | 5,7 |
| 19 | Trâm vối | *Syzygium cuminii* | 0,043 | 5,6 | Bưởi bung | *Acronychia pedunculata* | 0,015 | 5,6 |
| 20 | Mía tượng | | 0,093 | 5,5 | sp3 | | 0,030 | 5,4 |
| 21 | Trám trắng | *Canarium album* | 0,067 | 5,5 | Họ đậu | *Leuguminosae sp.* | 0,060 | 5,1 |
| 22 | Bứa | *Garcinia oblongifolia* | 0,070 | 4,9 | Sp8 | | 0,060 | 5,0 |
| 23 | Mít nai | *Artocarpus rigidus* | 0,037 | 4,9 | Cẩm lai | *Dalbergia oliveri* | 0,060 | 4,0 |
| 24 | Bạn | | 0,128 | 4,8 | Sp10 | | 0,030 | 2,9 |
| 25 | Bời lời nhớt | *Litsea glutinosa* | 0,165 | 4,8 | Dung dẻ | | 0,030 | 2,8 |
| 26 | Huỷnh | *Tarrietia javanica* | 0,023 | 4,6 | 25 species | | | 300 |
| 27 | Bù hòn | *Nephelium chryseum* | 0,203 | 4,1 | | | | |
| 28 | Trâm bầu | *Combretum parviforum* | 0,057 | 4,1 | | | | |
| 29 | Trâm bói | | 0,043 | 4,0 | | | | |
| 30 | Trường ngân | *Amesiodendron chinense* | 0,023 | 3,8 | | | | |
| 31 | sp15 | | 0,038 | 3,4 | | | | |
| 32 | Dẻ bộp | *Lithocarpus fissus* | 0,045 | 3,4 | | | | |
| 33 | Trám đen | *Canarium littorale* | 0,045 | 3,3 | | | | |
| 34 | …… | ……. | ….. | …. | | | | |
| 56 | 56 species | | | 300 | | | | |

### *A/F ratios of the study sites*

The ratio of abundance to frequency (A/F) of different species was determined and used to assess the aggregation patterns of the species in the communities (Table 5).

**Table 5. A/F ratios of the study sites**

| # | Site | A/F Ratio | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | < 0.025 | | 0.025 - 0.05 | | > 0.05 | | Total | |
| | | No. species | % | No. species | % | No. species | % | No. species | % |
| 1 | Cattien | 4 | 13.3 | 18 | 60.0 | 8 | 26.7 | 30 | 100 |
| 2 | Dakuy | 23 | 67.6 | 6 | 17.6 | 5 | 14.7 | 34 | 100 |
| 3 | Bachma | 11 | 19.6 | 10 | 17.9 | 35 | 62.5 | 56 | 100 |
| 4 | M'drak | 11 | 44.0 | 6 | 24.0 | 8 | 32.0 | 25 | 100 |
| **All together** | | **49** | **36.2** | **40** | **29.9** | **56** | **34.0** | **145** | **100** |

At Cattien 60.0 % of the tree species had A/F ratios between 0.025 - 0.05 and thus showed a random pattern, while only 13.3 % had ratios < 0.025, showing a regular pattern, and 26.7 % > 0.05, showing a contagious pattern. This would suggest that the environmental conditions of the site were unstable (Curtis and Cottam 1956, Odum 1971, Verma 2000, Cong and Huy 2009), and this result is consistent with the site disturbance analysis, showing a SDI > 0.60, typical of highly disturbed sites.

At Dakuy 67.6 % of the species had A/F ratios < 0.025 (regular), 17.6 % had ratios between 0.025 - 0.05 (random), and 14.7 % > 0.05 (contagious). Some authors (Verma 2000, Pandey et al. 2002) argue that this indicates that the plants in this community at Dakuy severely compete for resources.

At Bachma 62.5 % of the species had A/F values > 0.05 (contagious), 19.6 % A/F values < 0.025 (regular) and 17.9 % between 0.025 - 0.05 (random). This is the most common pattern in nature according to Curtis and Cottam (1956), Odum (1971) and Verma (2000). This result indicates that the community at Bachma grows under rather stable environmental conditions. This implication does not conflict with SDI values of 4.0 to 5.0 for this site, qualifying it as moderately disturbed.

At M’drak 44.0 % had A/F values of < 0.025 (regular), 24.0 % between 0.025 - 0.05 (random) and 32 % > 0.05 (contagious), again indicating the conditions of strong competition among plant species.

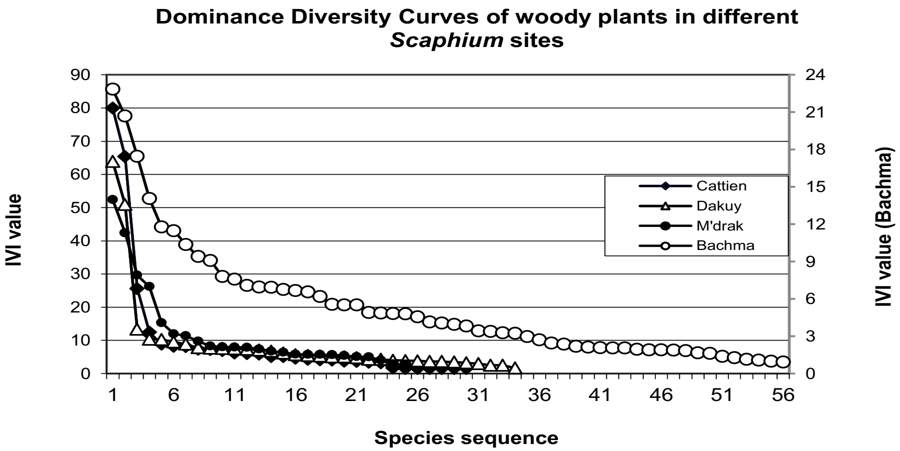



*Figure 2. Dominance-diversity curves for all tree species in 1000 m$^2$ samples of the S. macropodum study sites at Cattien, Dakuy, Bachma and M'drak, 2008-2009. Importance value indices on the ordinates (IVI of Bachma site on right ordinate) and species in sequence from the most important to the least important on the abscissa. The curves indicate different series with different slopes. For Cattien the curve strongly suggests a geometric series with a steep slope for the dominant species. The curves for Dakuy and M'drak are similar, but with slightly less steep slopes. The curve for Bachma strongly suggests the lognormal series which is typical for a much richer community, showing a gradually sloping curve.*

### *Dominance Diversity (D-D) curves and vegetative distribution pattern*

As far as the dominant species are concerned the curve for Cattien suggests a geometric series (Preston,1948) with a very steep slope. This hints that niche preemption (Whittaker 1975, Pandey et al. 2002) is taking place among the dominant species in this community. Here *S. macropodum* has the highest IVI, preempting the available resources at the site, followed by *Bambusa procera* and the subsequently less dominant species each taking their proportional part of the remaining resources. There are also a fair number of subordinate species not following the pattern of a geometric series. A community showing a geometric series is usually a community with a low species diversity, a high dominance and a weak niche differentiation between those species (Preston 1948, Naveh and Whittaker 1979). Authors also suggested that it points to a less efficient use of resources. This then would also suggests that the vegetation of the site was not stable, and actually often other species invade this community (Pandey et al. 2002, Huy and Seghal 2004, Cong and Huy 2009).

The curves for the Dakuy and M'drak sites also suggests geometric series for the dominant species, but with somewhat less steep slopes, especially for M'drak, as compared to that of Cattien. Both Dakuy and M'drak are less disturbed than Cattien.

At Bachma the stituation was very much different from the Cattien, Dakuy and M'drak sites, as regards community richness, slope of the dominance-diversity curve and its pattern. The dominance-diversity curve strongly suggests a lognormal series in the much richer community with much less dominance and a very gradual shift in importance between the species. The number of tree species at this site (56), being much higher than in the other study sites, and their IVI values, did not suggest preemption (Whittaker 1975, Pandey et al. 2002). This pattern is interpreted as typical for a plant community with strong niche differentiation between its species.

### *Diversity*

The results of the analysis of the species diversity in the studied plots are presented in Table 6. Species richness (SR) clearly is highest at Bachma (56), followed by Dakuy (34), Cattien (30) and M'drak (25).

**Table 6. Diversity and vegetation structure parameters of different *S. macropodum* forest sites**

| # | Site | Plot | SR | H' | SBA | TBA | SBA/ TBA | SDI |
|---|---|---|---|---|---|---|---|---|
| 1 | Cattien NP | LHP | 11 | 1.19 | 10229 | 19061 | 0.54 | 0.78 |
| 2 | | MHP1 | 23 | 2.86 | 8769 | 29360 | 0.30 | 0.75 |
| 3 | | MHP2 | 14 | 2.13 | 25040 | 33637 | 0.74 | 0.77 |
| 4 | | HHP | 27 | 3.32 | 8421 | 24586 | 0.34 | 0.68 |
| 5 | | APT | 30 | 2.63 | 52460 | 106644 | 0.49 | 0.75 |
| 6 | Dakuy SUF | LHP | 28 | 3.46 | 5746 | 26316 | 0.22 | 0.25 |
| 7 | | MHP | 24 | 3.01 | 4952 | 21005 | 0.24 | 0.30 |
| 8 | | HHP | 28 | 3.44 | 4344 | 22960 | 0.19 | 0.32 |
| 9 | | APT | 34 | 3.64 | 15042 | 69632 | 0.22 | 0.29 |
| 10 | Bachma NP | LHP | 45 | 4.91 | 2816 | 58184 | 0.05 | 0.48 |
| 11 | | MHP | 39 | 4.69 | 6167 | 21840 | 0.28 | 0.45 |
| 12 | | HHP | 41 | 4.78 | 4727 | 23405 | 0.20 | 0.40 |
| 13 | | APT | 56 | 5.08 | 13710 | 106884 | 0.13 | 0.44 |
| 14 | M'drak FEP | LHP | 14 | 2.26 | 3297 | 31207 | 0.11 | 0.75 |
| 15 | | MHP | 15 | 3.68 | 652 | 9916 | 0.07 | 0.55 |
| 16 | | HHP | 17 | 3.71 | 2570 | 15741 | 0.16 | 0.50 |
| 17 | | APT | 25 | 3.48 | 6518 | 59819 | 0.11 | 0.60 |

***Note**: LHP : Low hill plot; MHP: Medium hill plot; HHP: High hill plot; APT: All plots together; SR: Species richness; H': Shannon diversity index,; SBA: S. macropodum basal area in cm$^2$; TBA: Total basal area in cm$^2$; SDI: Site disturbance index.*

Bachma also had the highest Shannon index (H'), ranging from 4.69 to 5.08, followed by the plots of Dakuy and M'drak with their ranges from 3.01 to 3.71 and the plots of Cattien which ranged from 1.19 to 3.32 (Table 6). The large differences in Shannon H' among the study sites reflect their differences in ecological site conditions and disturbance. There seems to be a gradient of increasing H' values from south to north. Cattien is located in the South Eastern region, far from Bachma in the middle of Vietnam. Furthermore, the Cattien plots were assessed as highly disturbed (SDI from 0.68 to 0.78), whereas the Bachma plots were only moderately disturbed (SDI from 0.40 to 0.48).

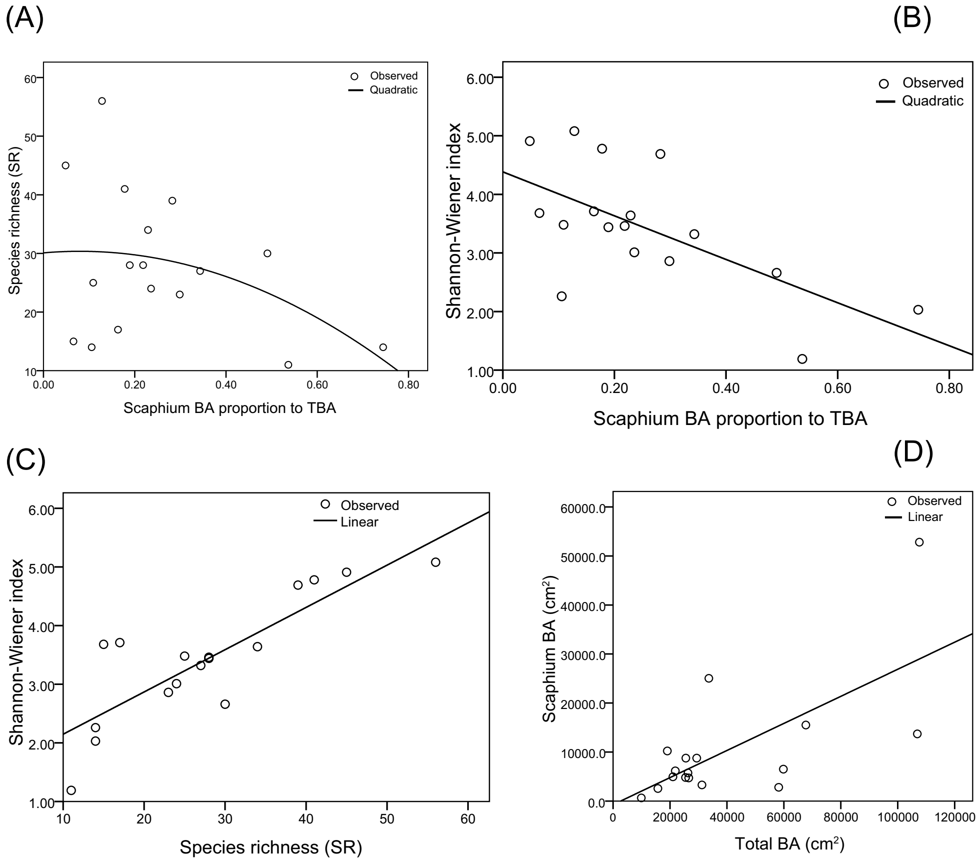
Analyses of variance (ANOVA) followed by post hoc Tukey pairwise multiple comparisons showed that the four study sites differed significantly at the 5 % level ($p \leq 0.001$) in their species richness, Shannon index and the ratio of *S. macropodum* basal area to total basal area of the community (F-values 14.1, 10.3, 13.2 and 10.4, respectively). However, their total basal area (TBA) was not different at the 5 % level ($p=0.72$).

Regression analyses were applied to evaluate the relationships between the diversity measures and vegetation structure characteristics of the four studied sites. (Table 7, Figure 3).

**Table 7. Regression models describing the relationships between species richness (SR) and the ratio of *S. macropodum* basal area (SBA) to total basal area (TBA), Shannon diversity index (H') and SBA/TBA, SBA and TBA and H' and SDI.**

| Models | *n* | $r^2$ | *p* | Corresponding figures |
|---|---|---|---|---|
| SR = 30.096 + 6.678 (SBA/TBA) -41.903 $(SBA/TBA)^2$ | 17 | 0.15 | 0.316 | Fig. 3A |
| H' = 4.384 -3.767 (SBA/TBA) + 0.070 (SBA/ $TBA)^2$ | 17 | 0.42 | 0.021 | Fig. 3B |
| H' = 1.427 + 0.072 SR | 17 | 0.70 | <0.001 | Fig. 3C |
| SBA = 0.276 TBA | 17 | 0.45 | 0.004 | Fig. 3D |
| H' = -1.381 + 25.095 SDI – 27.441$SDI^2$ | 17 | 0.76 | <0.001 | Fig. 3E |

***Note**: SR: Species richness; H: Shannon diversity index,; SBA: S. macropodum basal area; TBA: Total basal area*



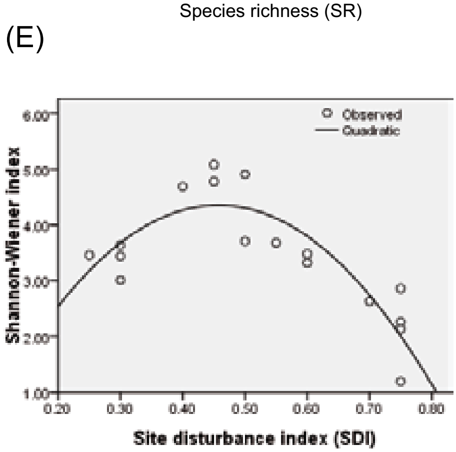




*Figure 3. Relationship between species richness (SR) and ratio of Scaphium basal area (SBA) to total basal area (TBA) of the forest communities studied (SBA/TBA) (Fig. 3A), Shannon diversity index (H) and SBA/TBA (Fig. 3B), H and SR, SBA and TBA and H' and SDI (Fig. 3C, 3D and 3E, respectively). Regression models are presented in Table 7.*

Using regression analysis the relationship between tree diversity and the proportion of *S. macropodum* in the community (SBA/TBA) was investigated. Results revealed that, while species richness at our study sites was not related to SBA/TBA ($p = 0.316$, $r^2 = 0.15$), species diversity H' was significantly inversely related to SBA/TBA and their quadratic correlation was presented in Fig. 3B ($p= 0.021$, $r^2 = 0.42$). The SBA showed a linear relation to TBA (Fig. 3D) ($p= 0.004$, $r^2 = 0.45$).

This present study also found that there was a strong and positive linear correlation between Shannon diversity (H') and species richness (SR) ($r^2 = 0.70$; $p< 0.001$) (Fig. 3C).

The relationship between H' and the site disturbance index (SDI) strongly fitted a quadratic regression model ($r^2 = 0.76$, $p< 0.001$) (Fig. 3E). It indicates that species diversity as measured by H' peaked at moderate disturbance (SDI of 0.45) in our study sites.

## Discussion

### *Relative importance of S. macropodum at different study sites*

Importance Value Index (IVI) of a species represents the relative dominance of the species in a community, which further indicates how important the species is with respect to its associates in terms of resource utilization. In the present study, *S. macropodum* was common to all four study sites, however its relative importance was significantly different from site to site (Table 3).

In Cattien, *S. macropodum* was recorded with the highest IVI (80.0) and found to be the co-dominant species in the ranking dominance order. All study plots of Cattien were assessed as highly disturbed with SDI values ranging from 0.60 to 0.75 as serious consequences of improper fruit harvesting practices of *S. macropodum*, invasion of *Bambusa procera* and cultivation encroachment. With the current dynamics, it is clear that *S. macropodum* will further decline and ultimately be replaced, while the bamboo will strongly dominate the site.

The plots of Dakuy have been very little disturbed, its SDI values ranging narrowly from 0.25 to 0.30. *S. macropodum* had the highest IVI value (63.9) and was found to be co-dominant along with *Dalbergia cochinchinensis* (50.9). The population of *S. macropodum* here is young and meets little disturbance as a result of strict protection and its fruit collection from the forest floor, which is relatively harmless.

At Bachma, *S. macropodum* was the third in the dominance ranking order of 56 tree species found at the plots (with IVI 17.5). There was no species with a very high IVI value and thus no strongly dominant species

(Table 4). This site was moderately disturbed because of fruit harvesting and other activities, its SDI ranging from 0.40 to 0.50 (Table 6). To some extent the plots in M'drak were similar to those of Bachma regarding their IVI structure, but they significantly differed in their species number, abundance and degree of site disturbance. *S. macropodum* also ranked the third with an IVI value of 29.6. The site is moderately to highly disturbed because of fruit harvesting and other activities.

***Dominance diversity curves and stability of the site conditions of the S. macropodum stands***

Dominance diversity curves were developed with the IVI as a measure of niche size and an indicator of species/resource apportionment in relation to the stability of environmental conditions at the site of a community.

At Cattien, the curve strongly suggested a geometric series for the dominant species (Preston 1948) which means proportional resource preemption by a sequence of these species (Whittaker 1975, Pandey et al. 2002). *S. macropodum* and *Bambusa procera* strongly dominated and occupied the top niches and *Bambusa* invaded the site. Resource and niche preemption is indicative of sites that are subject to strong disturbances, and invasion of species is common at such sites, as well as a low species diversity of the plant community (Preston 1948, Naveh and Whittaker 1979). The conclusion is then that the vegetation of the site is not at all stable. The instability of the environmental conditions and the plant species composition at the Cattien site is also indicated by the results of our analysis of the A/F ratio: as many as 60.0 % species of the tree species in the community had A/F ratios between 0.025 - 0.05, indicating a random pattern which is typical for sites with unstable environmental conditions (Curtis and Cottam 1956, Odum 1971, Verma 2000, Cong and Huy 2009). And finally, this instability is also confirmed by the high site disturbance index (SDI >0.60) of the site.

The Bachma site, on the contrary, was very much different from the Cattien site regarding its community richness, dominance diversity curve and its species aggregation. The dominance diversity curve strongly suggested a lognormal series with a much richer community, and a more gentle slope (Figure 2). In the very rich plant community at Bachma (56 species in the plots), there was no suggestion of preemption (Whittaker 1975, Pandey et al. 2002) and dominance. The A/F ratios at Bachma, with 62.5 % of the species having values of > 0.05, showed that the aggregation is contagious. This is the most common pattern under natural conditions according to Curtis and Cottam (1956), Odum (1971) and Verma (2000). Thus this indicated that the habitat and plant community at Bachma occurred under rather stable environmental conditions and this is consistent with the moderate disturbance as given by SDI values of 4.0 to 5.0.

The Dakuy and M'drak sites showed similar patterns as Cattien, though somewhat less severe. The sites experience much less disturbances than Cattien and there is no sign of invasion of certain species. At the present management regimes the sites conditions and species composition appear rather stable.

***Species diversity in relation to the proportion of S. macropodum (SBA/TBA ratio)***

The Shannon-Wiener index combines variety and equitability components. In practical management it is presumed that there is a curved relationship between production and diversity of a site with a clear optimum (Jobidon et al. 2004).

In our sites the relationship between the proportion of *S. macropodum* on diversity (SR, H') was not clear, however, although there was a significant linear relationship between SBA and TBA. With an increase in SBA proportional to TBA in the community, the species diversity decreased (Fig. 3B), though not linearly. Based on these results it is not possible to identify an optimum value for the presence of *S. macropodum* that would maximize diversity. The present study also indicated that there was no correlation between species richness (SR) and the SBA/TBA ratio. Accordingly, our study does not indicate any support for the above-mentioned optimum relationship.

***Species diversity in relation to the site disturbance index (SDI)***

Across these sites of the study, the Shannon-Wiener index (H) ranged from 2.63-5.08. The large differences in Shannon H' among the study sites reflect their differences in ecological site conditions and disturbance. The highest values of H' were found at the medium disturbance site. Risser and Rice (1971) reported that, tropical rain forests were found to have a much higher plant species diversity than temperate forests. In temperate forests, highest values for Shannon diversity were recorded at 2.0 to 3.0 while Braun (1950) reported tree diversities between 1.7 and 3.4 in forest in eastern North America. For tropical rain forests, a higher diversity (5.4) was found by Knight (1975), while Anh et al. (2008) and Cong and Huy (2009) reported tree species diversities (H') of natural rain forest in Huong Son natural reserve in Vietnam of 3.83 to 5.50. These latter results are consistent with the present study.

The present study revealed a strong quadratic relationship between the Shannon diversity index (H') and the site disturbance index (SDI) (Table 7, Fig. 3E). H' increased and peaked at a SDI of 0.45 and then declined at increasing disturbance. These findings are consistent with the intermediate disturbance hypothesis (IDH) that predicts that local species diversity is maximized at an intermediate level of disturbance (Grime 1973, Connell 1978, Huston 1979, Sheil 1999). Huston (1979) revealed that under conditions where either the rate of competitive displacement is low or high, diversity will increase and maximize as an increasing frequency of disturbance keeps the community further from competitive equilibrium and the diversity will then decrease as the frequency rises and some competitors are unable to recover.

However, this interpretation of our results is not completely certain. Figure 3 shows the strong curvilinear relationship with SDI, but the plots of each particular study site cluster at specific positions along the SDI-axis. Thus there is the possibility that the pattern does not so much reflect the intensity of site disturbance, but that some other unmeasured site-specific conditions determine the pattern.

Furthermore, our results are also consistent with those reported by Naveh and Whittaker (1979), that plant diversity strongly relates with site disturbances (in their case grazing): namely, diversity initially clearly increases with site disturbance, but at a certain level of disturbance diversity peaks and thereafter declines. This was also found by During and Willems (1984), Acharya (1999), and Huy et al. (2010b). Beyond this optimum strong dominance by woody plants or taller, highly productive grasses reduce diversity. Similarly, severe grazing pressure reduces diversity.

Bongers et al. (2009) specified that in tropical forests diversity peaks at intermediate disturbance levels, but that this relationship differs for dry compared to wet forests because of their structural and functional differences, leading to distinct species distribution responses.

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**Annex 1:** Importance Value Index (IVI) of woody tree species in Cattien site

| No. | Species | | Quadrat | | | | |
|---|---|---|---|---|---|---|---|
| | Local name | Scientific Name | 1 | | 2 | | 3 |
| | | | Stem | BA (cm²) | Stem | BA (cm²) | Stem |
| 1 | Ươi | *Scaphium macropodum* | 15 | 10229 | 60 | 8769 | 38 |
| 2 | Lồ ô | *Bambusa procera* | 131 | 3985 | 78 | 1366 | 67 |
| 3 | Tung | *Hernandia nymphiifolia* | 0 | 0 | 2 | 12036 | 0 |
| 4 | Chai | *Shorea thorelii* | 1 | 1257 | 1 | 1964 | 1 |
| 5 | Chiết tam lang | | 2 | 41 | 12 | 103 | 3 |
| 6 | Dung giấy | *Symplocos laurina var. acuminata* | 2 | 7 | 5 | 31 | 4 |
| 7 | Dầu rái | *Dipterocarpus alatus* | 4 | 153 | 1 | 113 | 6 |
| 8 | Hậu phát | *Cinnamomum polyadel-phum* | 2 | 52 | 3 | 6 | 2 |
| 9 | Cuống vàng | | 1 | 5 | 4 | 40 | 1 |
| 10 | Ba soi | *Mallotus paniculatus* | 0 | 0 | 10 | 274 | 2 |
| 11 | Sp2 | | 0 | 0 | 2 | 2847 | 0 |
| 12 | Bụp lá lớn | *Hibiscus macrophylla* | 0 | 0 | 5 | 37 | 3 |
| 13 | Trâm roi | *Syzygium* | 0 | 0 | 3 | 277 | 1 |
| 14 | Hu đay | *Trema orientalis* | 0 | 0 | 1 | 38 | 1 |
| 15 | Mán đỉa | *Archidendron clypearia* | 0 | 0 | 2 | 53 | 1 |
| 16 | Họ trâm | *sp* | 1 | 3318 | 0 | 0 | 0 |
| 17 | Sp3 | | 0 | 0 | 0 | 0 | 1 |
| 18 | Sp1 | | 0 | 0 | 1 | 1134 | 0 |
| 19 | Lim xẹt | *Peltophorum pterocarpum* | 0 | 0 | 2 | 70 | 0 |
| 20 | Màng tang | *Litsea cubeba* | 0 | 0 | 3 | 120 | 0 |
| 21 | Ngái | *Ficus hispida* | 0 | 0 | 2 | 18 | 0 |
| 22 | Bìn lìn giấy | | 0 | 0 | 3 | 55 | 0 |
| 23 | Sổ | *Dillenia scabrella* | 0 | 0 | 2 | 8 | 0 |
| 24 | Thẩu tấu | *Aporosa dioica* | 2 | 12 | 0 | 0 | 0 |
| 25 | Sp6 | | 0 | 0 | 0 | 0 | 0 |
| 26 | Sp5 | | 0 | 0 | 0 | 0 | 0 |
| 27 | Sp7 | | 0 | 0 | 0 | 0 | 0 |
| 28 | Sp4 | | 0 | 0 | 0 | 0 | 0 |
| 29 | Sổ bà | *Dillenia indica* | 1 | 3 | 0 | 0 | 0 |
| 30 | Keo | *Acacia* | 0 | 0 | 1 | 2 | 0 |
| Total | 30 species | | 162 | 19061 | 203 | 29360 | 131 |

| Quadrat | | | Total stem | Basal area ($cm^2$) | Occ. | Den. | Fre. (%) | RD (%) | RF (%) | RBA (%) | IVI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 4 | | | | | | | | | | |
| BA ($cm^2$) | Stem | BA ($cm^2$) | | | | | | | | | |
| 25040 | 58 | 8421 | 171 | 52460 | 4 | 42,8 | 100,0 | 25,3 | 5,5 | 49,2 | 80,0 |
| 5636 | 52 | 1116 | 328 | 12104 | 4 | 82,0 | 100,0 | 48,5 | 5,5 | 11,3 | 65,3 |
| 0 | 3 | 11560 | 5 | 23596 | 2 | 1,3 | 50,0 | 0,7 | 2,7 | 22,1 | 25,6 |
| 1257 | 4 | 1886 | 7 | 6363 | 4 | 1,8 | 100,0 | 1,0 | 5,5 | 6,0 | 12,5 |
| 8 | 4 | 99 | 21 | 251 | 4 | 5,3 | 100,0 | 3,1 | 5,5 | 0,2 | 8,8 |
| 40 | 7 | 29 | 18 | 107 | 4 | 4,5 | 100,0 | 2,7 | 5,5 | 0,1 | 8,2 |
| 239 | 3 | 109 | 14 | 613 | 4 | 3,5 | 100,0 | 2,1 | 5,5 | 0,6 | 8,1 |
| 5 | 5 | 5 | 12 | 68 | 4 | 3,0 | 100,0 | 1,8 | 5,5 | 0,1 | 7,3 |
| 13 | 5 | 39 | 11 | 96 | 4 | 2,8 | 100,0 | 1,6 | 5,5 | 0,1 | 7,2 |
| 36 | 3 | 263 | 15 | 573 | 3 | 3,8 | 75,0 | 2,2 | 4,1 | 0,5 | 6,9 |
| 0 | 1 | 320 | 3 | 3168 | 2 | 0,8 | 50,0 | 0,4 | 2,7 | 3,0 | 6,2 |
| 29 | 4 | 36 | 12 | 102 | 3 | 3,0 | 75,0 | 1,8 | 4,1 | 0,1 | 6,0 |
| 7 | 4 | 266 | 8 | 551 | 3 | 2,0 | 75,0 | 1,2 | 4,1 | 0,5 | 5,8 |
| 33 | 4 | 37 | 6 | 109 | 3 | 1,5 | 75,0 | 0,9 | 4,1 | 0,1 | 5,1 |
| 5 | 3 | 50 | 6 | 108 | 3 | 1,5 | 75,0 | 0,9 | 4,1 | 0,1 | 5,1 |
| 0 | 0 | 0 | 1 | 3318 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 3,1 | 4,6 |
| 1288 | 1 | 26 | 2 | 1314 | 2 | 0,5 | 50,0 | 0,3 | 2,7 | 1,2 | 4,3 |
| 0 | 1 | 9 | 2 | 1143 | 2 | 0,5 | 50,0 | 0,3 | 2,7 | 1,1 | 4,1 |
| 0 | 6 | 68 | 8 | 138 | 2 | 2,0 | 50,0 | 1,2 | 2,7 | 0,1 | 4,1 |
| 0 | 2 | 115 | 5 | 235 | 2 | 1,3 | 50,0 | 0,7 | 2,7 | 0,2 | 3,7 |
| 0 | 4 | 21 | 6 | 39 | 2 | 1,5 | 50,0 | 0,9 | 2,7 | 0,0 | 3,7 |
| 0 | 1 | 35 | 4 | 90 | 2 | 1,0 | 50,0 | 0,6 | 2,7 | 0,1 | 3,4 |
| 0 | 1 | 11 | 3 | 19 | 2 | 0,8 | 50,0 | 0,4 | 2,7 | 0,0 | 3,2 |
| 0 | 0 | 0 | 2 | 12 | 1 | 0,5 | 25,0 | 0,3 | 1,4 | 0,0 | 1,7 |
| 0 | 1 | 27 | 1 | 27 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 0,0 | 1,5 |
| 0 | 1 | 14 | 1 | 14 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 0,0 | 1,5 |
| 0 | 1 | 13 | 1 | 13 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 0,0 | 1,5 |
| 0 | 1 | 11 | 1 | 11 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 0,0 | 1,5 |
| 0 | 0 | 0 | 1 | 3 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 0,0 | 1,5 |
| 0 | 0 | 0 | 1 | 2 | 1 | 0,3 | 25,0 | 0,1 | 1,4 | 0,0 | 1,5 |
| 33637 | 180 | 24586 | 496 | 106.644 | | 169 | 1.825 | 100 | 100 | 100 | 300 |

## **Annex 2:** Importance Value Index (IVI) of woody tree species in Dakuy site

| No. | Species | | Quadrat | | | |
|---|---|---|---|---|---|---|
| | Local name | Scientific Name | 1 | | 2 | |
| | | | Stem | BA (cm²) | Stem | BA (cm²) |
| 1 | Ươi | *Scaphium macropodum* | 36 | 5746 | 27 | 4952 |
| 2 | Trắc | *Dalbergia cochinchinensis* | 13 | 9187 | 12 | 4766 |
| 3 | Dầu con rái | *Dipterocarpus alatus* | 3 | 823 | 5 | 1458 |
| 4 | Long não | *Cinnamomum camphora* | 2 | 1510 | 2 | 1420 |
| 5 | Trâm roi | *Syzygium* | 2 | 267 | 3 | 1200 |
| 6 | Chai | *Shorea thorelii* | 1 | 1256 | 2 | 917 |
| 7 | Keo | *Acacia* | 2 | 403 | 3 | 895 |
| 8 | Kơnia | *Irvingia malayana* | 1 | 730 | 1 | 962 |
| 9 | Dẻ đỏ | *Lithocarpus ducampii* | 3 | 409 | 2 | 232 |
| 10 | Đa rừng | *Ficus sp.* | 2 | 1040 | 1 | 79 |
| 11 | Móng bò | *Bauhinia purpurea* | 1 | 491 | 1 | 804 |
| 12 | Vả | *Ficus roxburghii Wall* | 1 | 707 | 1 | 962 |
| 13 | Họ dầu | *Dipterocarp* | 2 | 319 | 2 | 319 |
| 14 | Bạch đàn | *Eucalyptus* | 1 | 87 | 3 | 502 |
| 15 | Cà phê | *Coffea arabica* | 2 | 14 | 1 | 6 |
| 16 | Quếch | *Chisocheton paniculatus* | 1 | 254 | 1 | 254 |
| 17 | Sao đen | *Hopea odorata* | 1 | 177 | 1 | 177 |
| 18 | quế | *Cinnamomum cassia* | 1 | 113 | 1 | 113 |
| 19 | Họ đậu | *Leugume* | 2 | 541 | 0 | 0 |
| 20 | Ớt rừng | *Micromelum minutum* | 1 | 7 | 1 | 7 |
| 21 | Kháo ngứa | *Phoebe cuneate Blume* | 2 | 455 | 0 | 0 |
| 22 | Mít rừng | | 1 | 254 | 0 | 0 |
| 23 | Sp11 | | 1 | 14 | 0 | 0 |
| 24 | Trắc dây | *Dalbergia rimosa* | 1 | 113 | 0 | 0 |
| 25 | Hậu phát | *Cinnamomum polyadelphum* | 1 | 10 | 0 | 0 |
| 26 | Chò chang | *Dipterocarpus turbinatus* | 0 | 0 | 1 | 380 |
| 27 | Dung giấy | *Symplocos laurina var. Acuminata* | 1 | 20 | 0 | 0 |
| 28 | Dẻ đá | *Lithocarpus dealbatus* | 1 | 113 | 0 | 0 |
| 29 | Sp1 | | 1 | 1256 | 0 | 0 |
| 30 | Duối nhám | *Streblus asper* | 0 | 0 | 1 | 189 |
| 31 | Mây | *Calamus* | 0 | 0 | 2 | 4 |
| 32 | Chiêu liêu ổi | *Terminalia corticosa* | 0 | 0 | 2 | 320 |
| 33 | Ba soi | *Macaranga denticulata* | 0 | 0 | 2 | 86 |
| 34 | Sp12 | | 0 | 0 | 0 | 0 |
| Tổng | 34 species | | 87 | 26316 | 78 | 21005 |

| Quadrat | | Total stem | Basal area (cm²) | Occ. | Den. | Fre. (%) | RD (%) | RF (%) | RBA (%) | IVI |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | |
| Stem | BA (cm²) | | | | | | | | | |
| 33 | 4344 | 96 | 15.042 | 3 | 32,0 | 100,0 | 38,7 | 3,8 | 21,4 | 63,9 |
| 13 | 8414 | 38 | 22.367 | 3 | 12,7 | 100,0 | 15,3 | 3,8 | 31,8 | 50,9 |
| 3 | 1363 | 11 | 3.643 | 3 | 3,7 | 100,0 | 4,4 | 3,8 | 5,2 | 13,4 |
| 2 | 0 | 6 | 2.930 | 3 | 2,0 | 100,0 | 2,4 | 3,8 | 4,2 | 10,3 |
| 2 | 1134 | 7 | 2.601 | 3 | 2,3 | 100,0 | 2,8 | 3,8 | 3,7 | 10,3 |
| 1 | 742 | 4 | 2.916 | 3 | 1,3 | 100,0 | 1,6 | 3,8 | 4,1 | 9,5 |
| 2 | 288 | 7 | 1.586 | 3 | 2,3 | 100,0 | 2,8 | 3,8 | 2,3 | 8,8 |
| 1 | 298 | 3 | 1.991 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 2,8 | 7,8 |
| 2 | 78 | 7 | 720 | 3 | 2,3 | 100,0 | 2,8 | 3,8 | 1,0 | 7,6 |
| 2 | 159 | 5 | 1.278 | 3 | 1,7 | 100,0 | 2,0 | 3,8 | 1,8 | 7,6 |
| 1 | 488 | 3 | 1.783 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 2,5 | 7,5 |
| 1 | 0 | 3 | 1.669 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 2,4 | 7,3 |
| 2 | 13 | 6 | 651 | 3 | 2,0 | 100,0 | 2,4 | 3,8 | 0,9 | 7,1 |
| 1 | 102 | 5 | 691 | 3 | 1,7 | 100,0 | 2,0 | 3,8 | 1,0 | 6,7 |
| 2 | 241 | 5 | 261 | 3 | 1,7 | 100,0 | 2,0 | 3,8 | 0,4 | 6,1 |
| 1 | 0 | 3 | 509 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 0,7 | 5,7 |
| 1 | 0 | 3 | 353 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 0,5 | 5,5 |
| 1 | 18 | 3 | 244 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 0,3 | 5,3 |
| 2 | 102 | 4 | 643 | 2 | 1,3 | 66,7 | 1,6 | 2,5 | 0,9 | 5,0 |
| 1 | 9 | 3 | 23 | 3 | 1,0 | 100,0 | 1,2 | 3,8 | 0,0 | 5,0 |
| 2 | 6 | 4 | 462 | 2 | 1,3 | 66,7 | 1,6 | 2,5 | 0,7 | 4,8 |
| 1 | 443 | 2 | 697 | 2 | 0,7 | 66,7 | 0,8 | 2,5 | 1,0 | 4,3 |
| 1 | 659 | 2 | 673 | 2 | 0,7 | 66,7 | 0,8 | 2,5 | 1,0 | 4,3 |
| 1 | 364 | 2 | 477 | 2 | 0,7 | 66,7 | 0,8 | 2,5 | 0,7 | 4,0 |
| 1 | 411 | 2 | 421 | 2 | 0,7 | 66,7 | 0,8 | 2,5 | 0,6 | 3,9 |
| 0 | 1134 | 1 | 1.514 | 1 | 0,3 | 33,3 | 0,4 | 1,3 | 2,2 | 3,8 |
| 1 | 230 | 2 | 249 | 2 | 0,7 | 66,7 | 0,8 | 2,5 | 0,4 | 3,7 |
| 1 | 102 | 2 | 215 | 2 | 0,7 | 66,7 | 0,8 | 2,5 | 0,3 | 3,6 |
| 0 | 0 | 1 | 1.256 | 1 | 0,3 | 33,3 | 0,4 | 1,3 | 1,8 | 3,4 |
| 0 | 939 | 1 | 1.127 | 1 | 0,3 | 33,3 | 0,4 | 1,3 | 1,6 | 3,3 |
| 0 | 638 | 2 | 641 | 1 | 0,7 | 33,3 | 0,8 | 1,3 | 0,9 | 3,0 |
| 0 | 12 | 2 | 332 | 1 | 0,7 | 33,3 | 0,8 | 1,3 | 0,5 | 2,5 |
| 0 | 230 | 2 | 316 | 1 | 0,7 | 33,3 | 0,8 | 1,3 | 0,4 | 2,5 |
| 1 | 0 | 1 | 0 | 1 | 0,3 | 33,3 | 0,4 | 1,3 | 0,0 | 1,7 |
| 83 | 22960 | 248 | 70280 | | 82,7 | 2666,7 | 100,0 | 100,0 | 100,0 | 300,0 |

## **Annex 3:** Importance Value Index (IVI) of woody tree species in M'drak *site*

| No. | Species | | Quadrat | | | |
|---|---|---|---|---|---|---|
| | Local name | Scientific Name | 1 | | 2 | |
| | | | Stem | BA (cm²) | Stem | BA (cm²) |
| 1 | Chai | *Shorea thorelii* | 9 | 12920 | 2 | 2955 |
| 2 | Lồ ô | *Bambusa procera* | 57 | 351 | 3 | 517 |
| 3 | Ươi | *Scaphium macropodum* | 9 | 3297 | 5 | 652 |
| 4 | Trâm roi | *Syzygium* | 3 | 5493 | 2 | 2246 |
| 5 | Họ dầu | *Dipterocarpacea sp.* | 0 | 0 | 4 | 2989 |
| 6 | Táu | *Vatica odorata* | 0 | 0 | 4 | 801 |
| 7 | Dẻ đá | *Lithocarpus dealbatus* | 0 | 0 | 3 | 1293 |
| 8 | Kháo ngứa | *Phoebe cuneate Blume* | 3 | 1546 | 0 | 0 |
| 9 | Ngái | *Ficus hispida* | 0 | 0 | 3 | 17 |
| 10 | Dầu rái | *Dipterocarpus alatus* | 0 | 0 | 2 | 679 |
| 11 | Giổi | *Manglietia sp* | 1 | 1195 | 0 | 0 |
| 12 | Sp9 | | 3 | 2332 | 0 | 0 |
| 13 | Dầu lông | *Dipterocarpus intricatus* | 0 | 0 | 1 | 346 |
| 14 | Bông gòn | *Ceiba pentandra* | 1 | 57 | 0 | 0 |
| 15 | Thanh thất | *Ailanthus triphysa* | 0 | 0 | 1 | 269 |
| 16 | Máu chó | *Knema pierrei* | 0 | 0 | 1 | 52 |
| 17 | Sòi | *Sapium sebiferum* | 0 | 0 | 1 | 29 |
| 18 | Ba soi | *Macaranga denticulata* | 0 | 0 | 1 | 16 |
| 19 | Bưởi bung | *Acronychia pedunculata* | 0 | 0 | 1 | 10 |
| 20 | sp3 | | 1 | 1590 | 0 | 0 |
| 21 | Họ đậu | *Leuguminocea sp.* | 2 | 1006 | 0 | 0 |
| 22 | Sp8 | | 2 | 982 | 0 | 0 |
| 23 | Cẩm lai | *Dalbergia oliveri* | 2 | 368 | 0 | 0 |
| 24 | Sp10 | | 1 | 64 | 0 | 0 |
| 25 | Dung dẻ | | 1 | 7 | 0 | 0 |
| Total 25 species | | | 95,0 | 31.207 | 34,0 | 12.871 |

| Quadrat | | Total stem | Basal area (cm²) | Occ. | Den. | Fre. (%) | RD (%) | RF (%) | RBA (%) | IVI |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | |
| Stem | BA (cm²) | | | | | | | | | |
| 6 | 5367 | 17 | 21.242 | 3 | 5,7 | 100,0 | 10,4 | 6,5 | 35,5 | 52,4 |
| 0 | 0 | 60 | 868 | 2 | 20,0 | 66,7 | 36,6 | 4,3 | 1,5 | 42,4 |
| 6 | 2570 | 20 | 6.518 | 3 | 6,7 | 100,0 | 12,2 | 6,5 | 10,9 | 29,6 |
| 2 | 1478 | 7 | 9.218 | 3 | 2,3 | 100,0 | 4,3 | 6,5 | 15,4 | 26,2 |
| 2 | 1396 | 6 | 4.385 | 2 | 2,0 | 66,7 | 3,7 | 4,3 | 7,3 | 15,3 |
| 4 | 835 | 8 | 1.636 | 2 | 2,7 | 66,7 | 4,9 | 4,3 | 2,7 | 12,0 |
| 2 | 1072 | 5 | 2.365 | 2 | 1,7 | 66,7 | 3,0 | 4,3 | 4,0 | 11,4 |
| 1 | 241 | 4 | 1.787 | 2 | 1,3 | 66,7 | 2,4 | 4,3 | 3,0 | 9,8 |
| 3 | 143 | 6 | 159 | 2 | 2,0 | 66,7 | 3,7 | 4,3 | 0,3 | 8,3 |
| 1 | 452 | 3 | 1.132 | 2 | 1,0 | 66,7 | 1,8 | 4,3 | 1,9 | 8,1 |
| 1 | 227 | 2 | 1.422 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 2,4 | 7,9 |
| 0 | 0 | 3 | 2.332 | 1 | 1,0 | 33,3 | 1,8 | 2,2 | 3,9 | 7,9 |
| 1 | 755 | 2 | 1.101 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 1,8 | 7,4 |
| 1 | 661 | 2 | 717 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 1,2 | 6,8 |
| 1 | 227 | 2 | 496 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 0,8 | 6,4 |
| 1 | 133 | 2 | 184 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 0,3 | 5,9 |
| 1 | 74 | 2 | 103 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 0,2 | 5,7 |
| 1 | 74 | 2 | 90 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 0,2 | 5,7 |
| 1 | 38 | 2 | 48 | 2 | 0,7 | 66,7 | 1,2 | 4,3 | 0,1 | 5,6 |
| 0 | 0 | 1 | 1.590 | 1 | 0,3 | 33,3 | 0,6 | 2,2 | 2,7 | 5,4 |
| 0 | 0 | 2 | 1.006 | 1 | 0,7 | 33,3 | 1,2 | 2,2 | 1,7 | 5,1 |
| 0 | 0 | 2 | 982 | 1 | 0,7 | 33,3 | 1,2 | 2,2 | 1,6 | 5,0 |
| 0 | 0 | 2 | 368 | 1 | 0,7 | 33,3 | 1,2 | 2,2 | 0,6 | 4,0 |
| 0 | 0 | 1 | 64 | 1 | 0,3 | 33,3 | 0,6 | 2,2 | 0,1 | 2,9 |
| 0 | 0 | 1 | 7 | 1 | 0,3 | 33,3 | 0,6 | 2,2 | 0,0 | 2,8 |
| 35,0 | 15.741 | 164,0 | 59.819 | | 55 | 1.533 | 100 | 100 | 100 | 300 |

## **Annex 4:** Importance Value Index (IVI) of woody tree species in Bachma *site*

| No. | Species | | Quadrat | | | |
|---|---|---|---|---|---|---|
| | Local name | Scientific Name | 1 | | 2 | |
| | | | Stem | BA ($cm^2$) | Stem | BA ($cm^2$) |
| 1 | Đào | | 10 | 12240 | 26 | 133,1 |
| 2 | Tam lang | | 24 | 8728 | 20 | 1890,0 |
| 3 | Ươi | *Scaphium macropodum* | 11 | 2816 | 5 | 6166,9 |
| 4 | Trâm đỏ | | 7 | 4122 | 36 | 581,5 |
| 5 | Sơn | *Sophora subprostrata* | 14 | 73 | 19 | 3194,9 |
| 6 | Nấm lửa | | 30 | 1401 | 24 | 258,5 |
| 7 | Bách bệnh | *Eurycoma longifolia* | 21 | 569 | 31 | 207,3 |
| 8 | Ngát | *Gironniera subacqualis* | 2 | 141 | 17 | 1558,2 |
| 9 | Trám chủa | | 7 | 61 | 17 | 956,0 |
| 10 | Trâm chủy | | 12 | 514 | 14 | 914,8 |
| 11 | Dẻ sạn | | 11 | 4855 | 0 | 0,0 |
| 12 | Lim xanh | *Erythrophloeum fordii Oliv.* | 0 | | 15 | 1149,6 |
| 13 | Cơi | *Pterocarya tonkinensis* | 13 | 5320 | 0 | 0,0 |
| 14 | Cồn | | 18 | 1898 | 5 | 35,2 |
| 15 | Cau rừng | *Areca catechu* | 3 | 21 | 17 | 34,9 |
| 16 | Máu chó | *Knema globularia* | 9 | 76 | 14 | 84,0 |
| 17 | Trường đại | | 4 | 20 | 15 | 65,5 |
| 18 | Vè ve | | 11 | 2307 | 3 | 50,5 |
| 19 | Trâm vối | *Syzygium cuminii (L.) Skeel* | 1 | 491 | 5 | 775,4 |
| 20 | Mía tượng | | 3 | 123 | 10 | 254,1 |
| 21 | Trám trắng | *Canarium album* | 7 | 1079 | 6 | 60,3 |
| 22 | Bứa | *Garcinia oblongifolia* | 7 | 582 | 7 | 44,8 |
| 23 | Mít nai | *Artocarpus rigidus* | 7 | 999 | 2 | 293,2 |
| 24 | Bạn | | 1 | 7,1 | 16 | 1809,2 |
| 25 | Bời lời nhớt | *Litsea glutinosa (Lour.) C.B. Rob.* | 0 | | 6 | 338,3 |
| 26 | Huỷnh | *Tarrietia javanica Blume* | 2 | 2828 | 0 | 0,0 |
| 27 | Bù hòn | *Nephelium chryseum* | 0 | | 15 | 64,3 |
| 28 | Trâm bầu | *Combretum parviforum* | 3 | 12 | 5 | 38,8 |
| 29 | Trâm bói (Sâm bồn bồn) | | 1 | 133 | 7 | 81,7 |
| 30 | Trường ngân | *Amesiodendron chinense* | 4 | 749 | 2 | 55,2 |
| 31 | sp15 | *sp15* | 4 | 1120 | 0 | 0,0 |
| 32 | Dẻ bộp | *Lithocarpus fissus (Champ.ex Benth.) A. Camus; Castanopsis fissa (Champ. ex Benth.) Rehd & Wils* | 4 | 1071 | 0 | 0,0 |
| 33 | Trám đen | *Canarium littorale* | 1 | 154 | 0 | 0,0 |
| 34 | Trường đen | | 1 | 1257 | 0 | 0,0 |

| Quadrat | | Total stem | Basal area ($cm^2$) | Occ. | Den. | Fre. (%) | RD (%) | RF (%) | RBA (%) | IVI |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | |
| Stem | BA ($cm^2$) | | | | | | | | | |
| 27 | 3456,0 | 63 | 15829,4 | 3 | 21,0 | 100,0 | 5,6 | 2,4 | 14,8 | 22,8 |
| 17 | 3102,0 | 61 | 13720,0 | 3 | 20,3 | 100,0 | 5,5 | 2,4 | 12,8 | 20,7 |
| 9 | 4727,0 | 25 | 13709,9 | 3 | 8,3 | 100,0 | 2,2 | 2,4 | 12,8 | 17,5 |
| 32 | 602,7 | 75 | 5306,4 | 3 | 25,0 | 100,0 | 6,7 | 2,4 | 5,0 | 14,1 |
| 17 | 1975,0 | 50 | 5242,8 | 3 | 16,7 | 100,0 | 4,5 | 2,4 | 4,9 | 11,8 |
| 25 | 497,3 | 79 | 2156,7 | 3 | 26,3 | 100,0 | 7,1 | 2,4 | 2,0 | 11,5 |
| 27 | 189,3 | 79 | 966,0 | 3 | 26,3 | 100,0 | 7,1 | 2,4 | 0,9 | 10,4 |
| 22 | 1873,0 | 41 | 3572,6 | 3 | 13,7 | 100,0 | 3,7 | 2,4 | 3,3 | 9,4 |
| 27 | 1257,0 | 51 | 2274,5 | 3 | 17,0 | 100,0 | 4,6 | 2,4 | 2,1 | 9,1 |
| 11 | 798,0 | 37 | 2226,9 | 3 | 12,3 | 100,0 | 3,3 | 2,4 | 2,1 | 7,8 |
| 5 | 19,7 | 16 | 4874,3 | 2 | 5,3 | 66,7 | 1,4 | 1,6 | 4,6 | 7,6 |
| 17 | 1650,0 | 32 | 2799,6 | 2 | 10,7 | 66,7 | 2,9 | 1,6 | 2,6 | 7,1 |
| 0 | 0,0 | 13 | 5319,9 | 1 | 4,3 | 33,3 | 1,2 | 0,8 | 5,0 | 6,9 |
| 7 | 47,0 | 30 | 1979,8 | 3 | 10,0 | 100,0 | 2,7 | 2,4 | 1,9 | 6,9 |
| 27 | 109,0 | 47 | 165,1 | 3 | 15,7 | 100,0 | 4,2 | 2,4 | 0,2 | 6,8 |
| 21 | 189,0 | 44 | 348,7 | 3 | 14,7 | 100,0 | 3,9 | 2,4 | 0,3 | 6,7 |
| 25 | 165,0 | 44 | 250,9 | 3 | 14,7 | 100,0 | 3,9 | 2,4 | 0,2 | 6,6 |
| 3 | 79,0 | 17 | 2436,8 | 3 | 5,7 | 100,0 | 1,5 | 2,4 | 2,3 | 6,2 |
| 7 | 875,0 | 13 | 2141,3 | 3 | 4,3 | 100,0 | 1,2 | 2,4 | 2,0 | 5,6 |
| 15 | 287,0 | 28 | 663,8 | 3 | 9,3 | 100,0 | 2,5 | 2,4 | 0,6 | 5,5 |
| 7 | 270,0 | 20 | 1409,0 | 3 | 6,7 | 100,0 | 1,8 | 2,4 | 1,3 | 5,5 |
| 7 | 44,8 | 21 | 671,8 | 3 | 7,0 | 100,0 | 1,9 | 2,4 | 0,6 | 4,9 |
| 2 | 293,0 | 11 | 1585,1 | 3 | 3,7 | 100,0 | 1,0 | 2,4 | 1,5 | 4,9 |
| 0 | 0,0 | 17 | 1816,3 | 2 | 5,7 | 66,7 | 1,5 | 1,6 | 1,7 | 4,8 |
| 16 | 977,0 | 22 | 1315,3 | 2 | 7,3 | 66,7 | 2,0 | 1,6 | 1,2 | 4,8 |
| 1 | 48,0 | 3 | 2875,8 | 2 | 1,0 | 66,7 | 0,3 | 1,6 | 2,7 | 4,6 |
| 12 | 67,0 | 27 | 131,3 | 2 | 9,0 | 66,7 | 2,4 | 1,6 | 0,1 | 4,1 |
| 9 | 96,0 | 17 | 147,0 | 3 | 5,7 | 100,0 | 1,5 | 2,4 | 0,1 | 4,1 |
| 5 | 201,0 | 13 | 415,4 | 3 | 4,3 | 100,0 | 1,2 | 2,4 | 0,4 | 4,0 |
| 1 | 34,0 | 7 | 838,6 | 3 | 2,3 | 100,0 | 0,6 | 2,4 | 0,8 | 3,8 |
| 1 | 357,0 | 5 | 1477,2 | 2 | 1,7 | 66,7 | 0,4 | 1,6 | 1,4 | 3,4 |
| 2 | 252,0 | 6 | 1323,5 | 2 | 2,0 | 66,7 | 0,5 | 1,6 | 1,2 | 3,4 |
| 5 | 1056,0 | 6 | 1209,9 | 2 | 2,0 | 66,7 | 0,5 | 1,6 | 1,1 | 3,3 |
| 1 | 299,0 | 2 | 1555,6 | 2 | 0,7 | 66,7 | 0,2 | 1,6 | 1,5 | 3,2 |

## **Annex 4:** Importance Value Index (IVI) of woody tree species in Bachma *site (cont.)*

| No. | Species | | Quadrat | | | |
|---|---|---|---|---|---|---|
| | Local name | Scientific Name | 1 | | 2 | |
| | | | Stem | BA (cm²) | Stem | BA (cm²) |
| 35 | Chuồng | | 8 | 379 | 3 | 41,0 |
| 36 | Trò nâu | *Dipterocarpus retusus* | 0 | | 1 | 490,9 |
| 37 | Dẻ | *Lithocarpus* | 2 | 28 | 0 | 0,0 |
| 38 | Kiền kiền | *Hopea pierrei* | 2 | 81 | 0 | 0,0 |
| 39 | Giang | | 14 | 138 | 0 | 0,0 |
| 40 | Sến mật | *Madhuca pasquieri* | 0 | | 2 | 20,8 |
| 41 | Dâu rừng | *Baceaurea sapida* | 4 | 17 | 1 | 28,3 |
| 42 | Gõ đỏ | *Afzelia xylocarpa* | 1 | 133 | 0 | 0,0 |
| 43 | Nhãn | *Dimocapus longan* | 0 | | 3 | 45,7 |
| 44 | Chai | *Shoera thoreli* | 0 | | 1 | 33,2 |
| 45 | Chay | *Artocarpus tonkinensis A* | 0 | | 1 | 0,4 |
| 46 | Quế rừng | *Cinnamomum cassia (L.) J.Presl.* | 2 | 27 | 1 | 4,9 |
| 47 | Xoài rừng | *Mangifera minitifolia* | 1 | 113 | 1 | 3,1 |
| 48 | Trôm hôi | *Sterculia foetida* | 0 | | 1 | 33,2 |
| 49 | sp13 | *sp13* | 5 | 446 | 0 | 0,0 |
| 50 | sp14 | *sp14* | 6 | 312 | 0 | 0,0 |
| 51 | sp17 | *sp17* | 3 | 325 | 0 | 0,0 |
| 52 | Trường ớt | | 0 | | 5 | 39,6 |
| 53 | sp16 | *sp16* | 2 | 183 | 0 | 0,0 |
| 54 | Nạp ná | | 1 | 201 | 0 | 0,0 |
| 55 | Chôm Chôm | *Nephelium lappaceum L* | 0 | | 2 | 2,6 |
| 56 | sp18 | *sp18* | 1 | 33 | 0 | 0,0 |
| Total | 56 species | | 305 | 58184 | 381 | 21840 |

| Quadrat | | Total stem | Basal area (cm²) | Occ. | Den. | Fre. (%) | RD (%) | RF (%) | RBA (%) | IVI |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | |
| Stem | BA (cm²) | | | | | | | | | |
| 0 | 0,0 | 11 | 419,8 | 2 | 3,7 | 66,7 | 1,0 | 1,6 | 0,4 | 3,0 |
| 2 | 396,7 | 3 | 887,6 | 2 | 1,0 | 66,7 | 0,3 | 1,6 | 0,8 | 2,7 |
| 5 | 207,0 | 7 | 234,6 | 2 | 2,3 | 66,7 | 0,6 | 1,6 | 0,2 | 2,4 |
| 5 | 57,0 | 7 | 138,1 | 2 | 2,3 | 66,7 | 0,6 | 1,6 | 0,1 | 2,4 |
| 0 | 0,0 | 14 | 137,6 | 1 | 4,7 | 33,3 | 1,3 | 0,8 | 0,1 | 2,2 |
| 3 | 54,0 | 5 | 74,8 | 2 | 1,7 | 66,7 | 0,4 | 1,6 | 0,1 | 2,1 |
| 0 | 0,0 | 5 | 45,0 | 2 | 1,7 | 66,7 | 0,4 | 1,6 | 0,0 | 2,1 |
| 2 | 75,0 | 3 | 207,7 | 2 | 1,0 | 66,7 | 0,3 | 1,6 | 0,2 | 2,1 |
| 1 | 66,0 | 4 | 111,7 | 2 | 1,3 | 66,7 | 0,4 | 1,6 | 0,1 | 2,1 |
| 2 | 47,0 | 3 | 80,2 | 2 | 1,0 | 66,7 | 0,3 | 1,6 | 0,1 | 1,9 |
| 2 | 32,0 | 3 | 32,4 | 2 | 1,0 | 66,7 | 0,3 | 1,6 | 0,0 | 1,9 |
| 0 | 0,0 | 3 | 31,6 | 2 | 1,0 | 66,7 | 0,3 | 1,6 | 0,0 | 1,9 |
| 0 | 0,0 | 2 | 116,2 | 2 | 0,7 | 66,7 | 0,2 | 1,6 | 0,1 | 1,9 |
| 1 | 33,2 | 2 | 66,4 | 2 | 0,7 | 66,7 | 0,2 | 1,6 | 0,1 | 1,8 |
| 0 | 0,0 | 5 | 446,3 | 1 | 1,7 | 33,3 | 0,4 | 0,8 | 0,4 | 1,7 |
| 0 | 0,0 | 6 | 312,2 | 1 | 2,0 | 33,3 | 0,5 | 0,8 | 0,3 | 1,6 |
| 0 | 0,0 | 3 | 325,2 | 1 | 1,0 | 33,3 | 0,3 | 0,8 | 0,3 | 1,4 |
| 0 | 0,0 | 5 | 39,6 | 1 | 1,7 | 33,3 | 0,4 | 0,8 | 0,0 | 1,3 |
| 0 | 0,0 | 2 | 182,9 | 1 | 0,7 | 33,3 | 0,2 | 0,8 | 0,2 | 1,1 |
| 0 | 0,0 | 1 | 201,1 | 1 | 0,3 | 33,3 | 0,1 | 0,8 | 0,2 | 1,1 |
| 0 | 0,0 | 2 | 2,6 | 1 | 0,7 | 33,3 | 0,2 | 0,8 | 0,0 | 1,0 |
| 0 | 0,0 | 1 | 33,2 | 1 | 0,3 | 33,3 | 0,1 | 0,8 | 0,0 | 0,9 |
| 433 | 26861 | 1119 | 106884 | | 373,0 | 4166,7 | 100 | 100 | 100 | 300 |

Hard working at study site in Cattien (July 2009)

Working team at *S. macropodum* site in Dakuy (July 2009)

# Chapter 3
# Population dynamics of *Scaphium macropodum* in three Vietnamese forests with different extraction practices

*With P.A. Zuidema, M.J.A. Werger and R.G.A. Boot. Submitted*

## Abstract

1. As populations of *Scaphium macropodum* decline in the field due to disturbances by man, studies on the biology of this species increase in importance. Knowledge on its population biology and sustainability still is scant, however. We conducted a 3-year demographic study to evaluate population dynamics of the species in response to current harvesting disturbances. The study was conducted in three Vietnamese forest sites: Cattien, with high disturbance level, Bachma with medium disturbance, and Dakuy, with low disturbance. We analyzed the population dynamics at these sites using matrix modeling.

2. Almost all vital rates significantly differed between Cattien on the one hand and Dakuy and Bachma on the other, but most of them did not significantly differ between Dakuy and Bachma. Lowest seedling survival and reproductive fractions of *S. macropodum* were found in Cattien.
3. Among study sites, population growth rate (*λ*) was lowest at Cattien (0.981) but its 95 % confidence limits include the value of 1, so that we cannot demonstrate a statistically significant decline of that population. Population growth rates at Bachma (1.022) and Dakuy (1.017) are higher, their 95 % confidence limits include the value 1, so their populations appear to be stable or growing. Cattien's *λ* is significantly lower than that of Bachma, but not lower than that of Dakuy. Lamda values of Backma and Dakuy are not statistically different.
4. Vital rate elasticity analysis showed that the survival in all categories (б) was most important for λ at the three sites, followed by fecundity (f) from category 9 onward. Growth was least important.
5. Life Table Response Experiment (LTRE) analysis of the vital rates showed that site differences caused strong variation in *λ*. The mean value of site effect α(m) was 0.0471, highest α(m) was found in Cattien (absolute value of -0.0771), followed by Dakuy with α(m) =0.0455, and Bachma had the least effect on the variation in *λ*, with α(m) only 0.0209. The differences in fecundity between populations explained 74 % of the difference in *λ*; variation in survival explained 23%, while growth contributed just 3% to variation in *λ*.
6. The fruit harvesting pattern by cutting branches in Cattien had negative effects on the height growth of seedlings, on tree DBH and on seedling survival of *S. macropodum*, and as a result negative impact on its population dynamics.
7. Our analysis found that the natural regeneration and future prospect of *S. macropodum* was worrisome in Cattien, rather good in Dakuy, and good in Bachma. It is suggested that for sustainable management of these Scaphium sites first of all we should improve the harvesting practice in a sustainable way, which means collection of fruits from the ground, perhaps combined with a low intensity of branch cutting, as in the case of Bachma. Furthermore, we encourage local authorities and farmers for a joint management in which local farmers would own certain *S. macropodum* trees and sustainably manage those prudence and a high sense of responsibility. This approach would be extended to other *Scaphium* forests.

**Key words:** *Scaphium macropodum*, population dynamics, vital rate, matrix transition model, population growth rate (*λ*), elasticity, life table response experiment (LTRE), sustainable harvesting.

## Introduction

Non-timber and multipurpose forest species are important components of the tropical forests. In most tropical countries, non-timber forest products (NTFPs) play important roles in the livelihoods of hundreds of millions of rural and urban peoples across the globe (Emanuel et al. 2005, Gaoue and Ticktin 2007, 2008). Over 4,000 NTFP species are used for commercial purposes and thousands more are utilized for subsistence use (Ticktin and Nantel 2004, Endress et al. 2006).

NTFP extraction is considered to be less damaging to forest ecosystems than timber harvest and therefore more compatible with sustainable forest management and species conservation (Salick et al. 1995, Neumann and Hirsch 2000, Ros-Tonen 2000, Sinha and Brault 2005, Gaoue and Ticktin 2008). However, the process of extraction of NTFPs can result in over harvesting leading to declines in yields and degradation of the biota (Neumann and Hirsch 2000, Gaoue and Ticktin 2007, 2008). And if the NTFP extraction is done unsustainably, it would lead to the ecological consequence of altering the rates of survival, growth and reproduction of harvested individuals. These changes can in turn affect the structure and dynamics of harvested populations (Peres et al. 2003, Ticktin and Nantel 2004). Understanding harvesting patterns of multipurpose NTFP species and their impacts are essential for designing plans for their sustainable management (Ticktin and Nantel 2004, Gaoue and Ticktin 2010); but these are still limited (Gaoue and Ticktin 2010).

*Scaphium macropodum* is an important multipurpose timber species in tropical rain forests in Vietnam as well as other Southeast Asian countries. It is utilized for beverages, medicines and timber. In Vietnam this species was once abundant in natural forests and local farmers significantly benefited from its valuable fruit product (one-seed fruit) (Duong 1995, Hy 2005, Huy et al. 2010a). Unfortunately, the trees have been seriously damaged by drastically cutting down either their stems or branches for fruit harvesting, which led to a serious decline (Huy et al. 2010a) and endangerment of the species (MoST 2007). This kind of harvesting is unsustainable. Thus, studies on the population dynamical response to current harvesting disturbances are important in order to develop sustainable harvesting methods. So far, studies on this species were field inventories for baseline data (Duong 1995, Hy 2005), investigations on morphology and spatial distribution (Yamada and Suzuki 1996, 1997, 1999, Yamada et al. 2000), and on recruitment and regeneration (Yamada and Suzuki 1997). Some of them focused on mixed and enrichment planting, either under plantations of densely growing species or under secondary poor, young forests (Duong 1995, McNamara et al. 2006, Kuijk 2008, Huy et al. 2010a) and only few studies addressed stand structure and population dynamics in response to differently disturbed forest sites (Yarwudhi et al. 1994, Huy et al. 2010b).

In this paper, we present a study on the population dynamics of *Scaphium macropodum* in three study sites which differ strongly in levels of human disturbance related to fruit harvesting activities. We addressed the following research questions (*i*) What are the demographic characteristics of *Scaphium macropodum* in the three studies sites, with particular attention to their natural regeneration? To answer this question, we carried out population studies for three years, constructed and analyzed their respective matrix models, assessed seedling recruitment and survival as well as reproductive status (*ii*) Which factors importantly affect the population growth rate ($\lambda$) and do fruit harvesting practices have any impact on the population growth rate? To answer these, we performed elasticity analysis to determine the importance of vital rates (survival, growth and reproduction) on the population growth rate of *Scaphium* (Kroon et al. 2000, Caswell 2001, Zuidema and Franco 2001), and Life table response experiment (LTRE) analysis to quantify the contribution of the three vital rates to the variation of $\lambda$ in response to site differences (Caswell 1989, Cooch et al. 2001, Oli et al. 2001, Jongejans and de Kroon 2005, Yamada et al. 2007, Caswell 2010, Jongejans et al. 2010). We also correlated crown damage and growth (height growth for seedlings and diameter growth for trees), as well as site disturbance indices and seedling survival to determine impacts of harvesting by cutting off branches, (*iii*) What are the future prospects of *S. macropodum* and implications for sustainable management in the three study sites? To this end we analyzed matrix models for population growth rate ($\lambda$), and projected the regeneration status of *Scaphium macropodum* in the study sites.

## Method

### *Study species*

*Scaphium macropodum* (*Sterculiacae*) is a valuable multipurpose forest tree species, utilized for beverages, medicines and timber. Its natural range of distribution comprises the tropical rain forests in Myanmar, Laos, Cambodia, Thailand, Indonesia and Vietnam. It is a timber tree that can reach 30-40 m in height and 0.8-1.0 m in diameter (Kostermans 1953, Yamada and Suzuki 1999, MoST 2007).

*S. macropodum* is considered as a common shade-tolerant species (Yamada and Suzuki 1997). It is deciduous and flowers on bare twigs during the leafless period (Kostermans 1953). The tree produces wind-dispersed fruits with a boat-shaped wing derived from a dehiscing follicle. All fruits are one-seed (Yamada and Suzuki 1996).

*S. macropodum* is native to Vietnam. Its fruiting occurs unevenly, normally with 4 to 5 year intervals. Each year only about 10 to 20 % of the mature population bears fruits, and many mature trees apparently never bear any fruit (Huy et al. 2010a). It flowers from February and disperses its fruits from April to July varying between different locations (Hy 2005, Huy et al. 2010a).

***Study site***

We selected three forest sites with natural populations of *S. macropodum*. These sites differed in fruit harvesting practices, and consequently in site disturbance levels. The site in Cattien National Park (Dinh Quan district, Dong Nai province) suffered strong branch cutting for fruit harvesting and, as a result, high disturbance. In the site in Dakuy special use forest (Dakuy district, Kontum province) harvesting was done by collecting fruits from the ground, so that disturbance was slight. In the site in Bachma National Park (Namdong district, Thua Thien Hue province) harvesting was practised by fruit collection from the ground combined with scattered branch cutting; there was medium disturbance.


*Figure 1. Study site*

***1. Cattien National Park***

The site is located at 11° 22' 12" NL and 107° 15' 18" EL, on the edge of Cattien National Park (Dinh Quan, Dong Nai province). Mean annual temperature of the area is 25.4°C, mean maximum and minimum temperature is 30.8 °C and 21.3°C respectively. Annual rainfall in the area is 2,185 mm and mean annual relative humidity 83.6 %. The study site slopes gently with gradients of less than 10°, the altitude is less than 150 m. It is a protected area, but it is easy to access.

All *S. macropodum* trees of the site have been allocated to local farmers for joint management, an approach also suggested by Gaoue et al. (2011b) to reduce pressure on foliage harvesting of *Khaya senegalensis*.

Nevertheless, the whole area has been highly disturbed by man harvesting *S. macropodum* fruits by branch cutting and bamboo cutting.

### *2. Dakuy Special Use Forest (SUF)*

This site is located at 14° 33' 15" NL and 107° 54' 65" EL (Dakuy district, Kontum province), at altitudes of 640-662 m. It is rather flat and is easy to access. Mean annual temperature of the area is 23.4°C, mean maximum and minimum temperatures are 29.7°C and 18.7°C, respectively. Its annual rainfall is 1,804 mm, and most rain comes in June to October; the mean annual relative humidity is 78 %.

The whole studied site w is within the strictly protected area of Dakuy SUF. In this area local farmers can only collect fruits of *S. macropodum* from the ground (natural collection), they are not allowed to cut trees or branches for fruit collection. Disturbance in this site is low.

### *3. Bachma National Park*

The site of the Bachma National park is located in Nam Dong district, Thua Thien Hue province (16° 7.9' 66" NL, 107° 46' 77" EL), at altitudes of 500- 700 m. Mean annual temperature is 25.3°C, mean maximum and minimum temperatures are 29.1°C and 22.1°C, respectively. The mean annual relative humidity is 81 %. Mean annual rainfall in the area is 4,000 mm. This study site is a steep slope (20-25 degree), strongly divided by valleys and streams. It is rather difficult to access. Here also local farmers can collect fruits of *S. macropodum* from the ground, and sometimes cut branches for fruit harvesting. The *S. macropodum* trees at the site have been recently allocated to local farmers for management.

### *Data collection*

In our study sites, permanent plots were established in 2007. Three 1.5 ha permanent plots were established in Cattien, and three 1.0 ha permanent plots in both Dakuy and Bachma. Measurements were conducted yearly from 2007 to 2009. At the first measurement, all juvenile and adult trees (diameter at breast height, DBH > 5 cm) of the study species in the plots were searched, roughly mapped, tagged and measured. Measured parameters were DBH, total height, height to the first branch and crown damage estimation of the trees. We used calipers to measure diameters for stems with DBH < 5 cm, for bigger DBH stems first girth (at breast height) was measured by measuring tape and then converted to DBH. Mortality and reproductive status of individuals were recorded. The measurements were repeated in 2008 and 2009. Crown damage was determined by estimating the proportion of crown volume lost due to branch cutting.

Within each permanent plot 4-5 subplots (20 m x 20 m) were randomly established to study seedlings and saplings of the study species (< 5 cm DBH). At first measurement in 2007, all seedlings and saplings of the study species in the subplots were searched, roughly mapped, tagged and measured. Measured parameters were total height and diameter at stem base or DBH (for stems with height>1.30 m). Mortality and recruitment of seedlings and saplings were also recorded. Same measurements were repeated in 2008 and 2009.

Light conditions around each individual were assessed using the crown illumination index (CII) developed by Dawkins (1 = no direct light; 2 = some lateral direct light; 3 = partial overhead light; 4 = almost direct overhead light; and 5 = emergent crown with direct light from all directions) (Clark and Clark 1992, Poorter et al. 2005).

***Data analysis***

We tested the demographic data of all plots in each site (ANOVA), on significant differences, and when this was not the case, pooled the data and constructed transition matrices. We analyzed vital rates of survival, growth and reproduction based on regressions and constructed transition matrix models. Correlations between survival rate to height and diameter and correlations between reproductive rate to diameter were analyzed fitting binary logistic regressions. The regression curves of reproduction were based on three years of observations, whereas reproductive fractions were calculated per year.

We related height growth of seedlings and seedling height, using polynomial regressions, we related diameter growth to DBH fitting the Hossfeld IV model (Zeide 1993):

$$\Delta DBH = \frac{b * c * DBH^{(c-1)}}{[b + (DBH^{c})/a]^{2}}$$

where $\Delta DBH$ is DBH growth rate (cm $y^{-1}$), and a, b and c are fitted parameters.

We tested the significant difference of all vital rates (survival, height growth, and diameter growth and reproduction) among study sites by applying analysis of variance (ANOVA) followed by post hoc Tukey multiple comparisons.

The correlation between the CII and height was fitted by a multinomial logistic to analyze the light exposure as dependent on height.

Saplings that showed clear signs of stem breakage, or had a large height decrease (which is likely to be caused by damage or measurement error), were excluded from the growth analysis (Zuidema and Boot 2002, Poorter et al. 2005)

We also examined the correlations between seedling survival and site disturbance index (SDI), DBH growth to crown damage, and the T-test to determine differences in height growth between damaged and undamaged seedling groups in Cattien.

***Construction of transition matrices***

The studied populations were divided into 13 size categories: the three smallest based on plant height and the remaining on DBH. Categorisation was based on biological characteristics of the plant species that maximise differences in vital rates among categories.

The stage-classified projection matrix model (Caswell 2001) was used. In matrix models of the form $n(n+1) = \mathbf{A}n(t)$, A is a square matrix, and n, a vector, that gives the numbers of individuals in each size class at time t or t + 1. In this study t was one year. The dominant eigenvalue ($\lambda$) of the matrix model equals the population growth rate and the stable stage distribution is equivalent to the right eigenvector. Elements $a_{ij}$ of matrix **A**, (denoting the $i^{th}$ row and $j^{th}$ column) can be grouped into those representing growth G (the probability that one survived individual grows from current size class j to the next i), stasis P (the probability that one individual remains in current category j, the value in the diagonal of the matrix), and fecundity F (the number of sexual offspring produced by an individual in category j, value in upper row)

The growth elements (G) of category i were calculated as $G_i = б_i \times \gamma_i$ where $\gamma_i$ is the probability that a surviving individual in category i moves to i+1, $б_i$ is the survival probability in category i. The value of $\gamma_i$ was calculated as $g_i/c_i$, in which gi is the height or DBH growth rate for category i (in m or cm $yr^{-1}$) and $c_i$ the category width (m in height or cm in DBH). Stasis P was calculated as $P_i = б_i - G_i$. Fecundity F was calculated as $F_i = б_i \times Pr\{f\}_i \times f_i$, where $Pr\{f\}_i$ is the probability that an individual in category i is reproductive and fi the number of seedlings produced by a reproductive individual in category i. The value of fi was calculated by dividing the number of new seedlings/category i/year (based on the fruit yield of category i and number of seedling/kg fruit (also so-called seed in this study) by the number of adult trees in category i. The number of newly emerged seedlings was recorded in the subplots. The fruit production for the study plots was determined by counting all fruits harvested by famers for each fruiting tree and adding the number of fruits that remained after the harvest. Vital rate parameters used for transition matrix construction were all obtained from regression-based analysis from observed population data.

Three separate transition matrices were constructed for three different study sites.

***Analysis of transition matrices***

Similarity index (PS) between the stable stage distribution (SSD) from matrix models and the observed population structures was analyzed, following Horvitz and Schemske (1995): PS = $\sum\{min\ [ops_i,\ ssd_i]\ x\ 100\}$, where opsi is the value of observed population structures, and ssdi is the value of SDD; these values were scaled to sum to one. A high value of the similarity index indicates that the matrix model is a good simulation of the observed population. We followed Cochran & Ellner (1992) to calculate survivorship values up to mature size classes for the study species in the three sites.

We calculated population growth rate (*λ*) for three matrix models (Caswell 2001) to compare population growth rates of *S. macropodum* in the three sites studied. If *λ>1*, the population is projected to grow, if *λ<1*, the population is projected to decline.

To check whether the population growth rates (*λ*) of the three sites significantly differed from 1 and among each others, we calculated 95 % confidence limits for *λ* by applying the series approximation approach (Caswell 1989, 2000, Yamada et al. 2007). The variance of *λ* was calculated using the following equation:

$$V(\lambda) = \sum_{ij} V(a_{ij})\ (б\lambda/бa_{ij})^2,$$

where *V(λ)* is the variance of lamda, $V(a_{ij})$ is the variance of vital rate, and $б\lambda/бa_{ij}$ is the sensitivity of the vital rate. The 95 % confidence limits of λ were calculated by multiplying the square root of *V(λ)* by a *t* value obtained from a table of *t.*

We analyzed vital rate elasticity to estimate the weighted importance of vital rates (survival, growth and reproduction) on the population growth rate of *S. macropodum* in the study sites. Elasticities of survival (Eб), growth (Eγ) and reproduction (Ef) were calculated following the approach of Caswell (2001) and Zuidema and Franco (2001). The elasticity of vital rates to $\lambda$ is the proportional change in $\lambda$ due to a proportional change in a vital rate (Kroon et al. 2000), and that indicates the importance of the vital rates to $\lambda$. The vital rate elasticities may be negative (if an increase in a certain vital rate leads to a reduction in $\lambda$) and they do not need to sum to one (Caswell 2001).

Life table response experiment (LTRE) analysis was performed for vital rates to quantify the contribution of the three vital rates on the observed change of the population growth rate ($\lambda$) among sites in response to site differences (Caswell 1989, Cooch et al. 2001, Oli et al. 2001, Jongejans and de Kroon 2005, Yamada et al. 2007, Caswell 2010, Jongejans et al. 2010). Fixed-design LTRE was applied as this allowed to quantify the effects of habitat (Jongejans and de Kroon 2005). The LTRE model with site factor site is:

$$\lambda^{(m)} = \lambda^{(\cdot\cdot)} + \alpha^{(m)}$$

in which a given $\lambda$ for site m, $\lambda^{(m)}$, is written as the sum of the dominant eigenvalue of the mean of all matrices, $\lambda^{(\cdot\cdot)}$ and the main effect of site m, $\alpha^{(m)}$.

To show the magnitude and direction (positive or negative) of the contribution of each vital rate, the effect was decomposed into contribution per vital rate, (Caswell 2001):

$$\alpha^{(m)} = \sum (x_j^{(m\cdot)} - x_j^{(\cdot\cdot)}) \delta\lambda/\delta x_j |_{1/2(A^{(m\cdot)} + A^{(\cdot\cdot)})}$$

in which differences between the value of vital rate $x_j^{(m\cdot)}$ of the matrix site m, $A^{(m\cdot)}$ and the mean vital rate $x_j^{(\cdot\cdot)}$ of the mean matrix $A^{(\cdot\cdot)}$ are multiplied by the sensitivity of that vital rate of the matrix midway between the matrix of interest and the mean matrix.

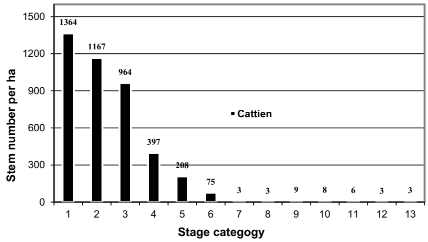
## Results

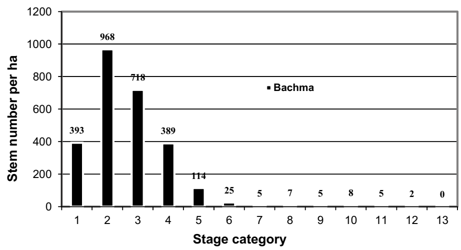
### *Size distribution and natural regeneration*

**Table 1. Observed parameters of *S. macropodum* of three studied populations**

| Observed parameters | Cattien | Dakuy | Bachma |
|---|---|---|---|
| Fruit harvesting practice | Branch cutting | Ground fruit collection | Ground fruit collection with some branch cutting |
| Site disturbance index (SDI) | 0.68-0.78 | 0.25-0.32 | 0.40-0.48 |
| Area (ha) | 4.5 | 3.0 | 3.0 |
| Sample size (n) | 1661 | 992 | 829 |
| Survival rate | 0.54-1.00 | 0.73-1.00 | 0.81-1.00 |
| Maximum Height (m) | 36.0 | 34.0 | 37.0 |
| Maximum DBH (cm) | 95.9 | 55.4 | 65.9 |
| Seedling height growth (m/yr) | 0.10-0.16 | 0.14-0.26 | 0.11-0.16 |
| DBH growth (cm/yr) | 0.19-0.67 | 0.16-0.43 | 0.23-0.73 |
| Repro. fraction per yr | 0.02-0.24 | 0.04-0.33 | 0.03-0.33 |
| Kg of fruit/ha/yr | 62 | 56 | 118 |
| Recruitment (new seedlings/ ha/yr) | 427 | 62 | 289 |

Maximum DBH of *S. macropodum* was considerably different among the three sites. The largest DBH was found in Cattien, followed by Bachma and Dakuy (95.9 cm, 65.9 cm and 55.4 cm, respectively). The largest size category 13 (DBH>60 cm) was absent in Dakuy. Unlike the DBH, the maximum estimated height of the plants did not differ considerably between sites: Bachma (37 m), Cattien (36 m), Dakuy ( 34 m) (Table 1).



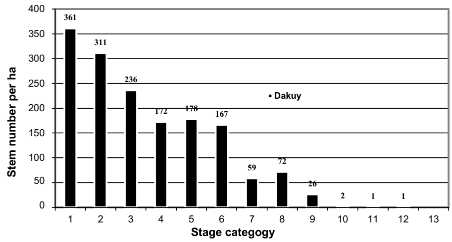




*Figure 2. Population structure of S. macropodum as observed in 3 studied sites in Vietnam. The first three categories were clasified as seedling based on their height (height <1.35m) and the remaining categories were clasified as sapling, pole and mature trees based on their DBH (cm). Details on stage category are presented in Annex 1 to Annex 3*

The size distribution of *S. macropodum* in the three study sites showed inverse “J” shaped patterns and strongly declined in abundance when shifting from their smallest seedling stages (category 1, 2 and 2) to the lager sapling stages, except in the case of Bachma, where the abundance of the smallest category was lower than that of larger seedling sizes. In all three populations, high proportions of plants in the population belonged to the three smallest categories (seedling 1, 2 and 3): 83.0 % in Cattien, 57.3 % in Dakuy and 78.7 % in Bachma, whereas small proportions belonged to the four largest categories 9 to 13 (matured categories), with 0.69 % in Cattien, 1.85 % in Dakuy and 0.77 % in Bachma (*Fig. 2*).

Natural regeneration of the species depends mostly on seeds. Fruit yield (kg/ha/year) was recorded at the sites in Cattien, Dakuy and Bachma as 62 kg, 56 kg and 118 kg, respectively, while the number of new seedlings recorded at these sites was 427, 62 and 289 seedling/ha/year, respectively.

### *Vital rates*

Vital rates were tested (post hoc tests) for significant difference among the three study sites. Detailed results of the test presented in Annex 4 showed that, survival significantly differed from Cattien to Dakuy and Bachma ($p<0.001$), and did not significantly differ between Dakuy and Bachma. Diameter growth showed the same pattern as survival ($p<0.01$); and height growth was significantly different between all sites ($p<0.05$). Reproduction was significantly different between Cattien and Bachma ($P<0.05$) as well as Bachma and Dakuy ($p<0.01$), but non-significantly different between Cattien and Dakuy.

In Cattien, harvesting by branch cutting had damaged crowns and stems of a number of *S. macropodum* seedlings. At this site damaged and undamaged seedlings were significantly different in height growth (t-test, p<0.001).

Crown damage (in percentage), as a result of harvesting by branch cutting, and DBH growth of *S. macropodum* trees in Cattien proved negatively correlated (see Fig. 3 for details).

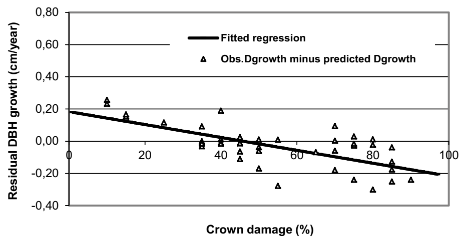



*Figure 3. Relationship between tree DBH growth and crown damage of S. macropodum in Cattien. Shown is the fitted linear regression (Y= -0.004X + 0.183, p<0.001, $R^2$ = 0.46) and dots are different values between observed DBH growth and Hossfeld predicted DBH growth.*

## *Survival*

Across the three study sites, survival rate of the species varied from 0.54 to 1.00 in Cattien, 0.73 to 1.00 in Dakuy and 0.81 to 1.00 in Bachma. The lowest survival rate was recorded in Cattien, especially for new seedlings (0.54), followed by Dakuy; Bachma recorded the highest survival rate in new seedlings (0.81).
Across size categories, at each site the lowest survival rate was recorded in the smallest category (category 1) and higher survivals were found in larger categories (Table 1 and Annex 1, 2, 3).

The relationships between the survival rate on the one hand, and height and DBH on the other, were fitted by binary logistic regression. Details of the fitted logistic analysis are presented in Figure 4 and Figure 5.

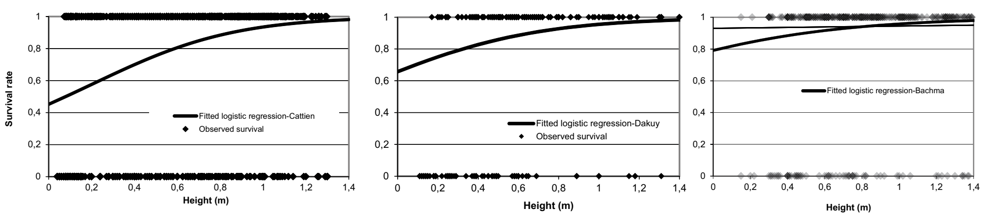



*Figure 4. Relation between survival rate and the height of Scaphium macropodum at the three studied sites in Vietnam. Dots are observed values for survival rate and lines are fitted logistic regression: Y = 1/(1+Exp(-(a*Height + b))). Fitted parameters a, b and $R^2$ (Nagelkerke): Cattien 3.29, -1.36 and 0.32 respectively; Dakuy 2.62, -0.27 and 0.17 respectively; Bachma 1.91, 0.52 and 0.09 respectively.*

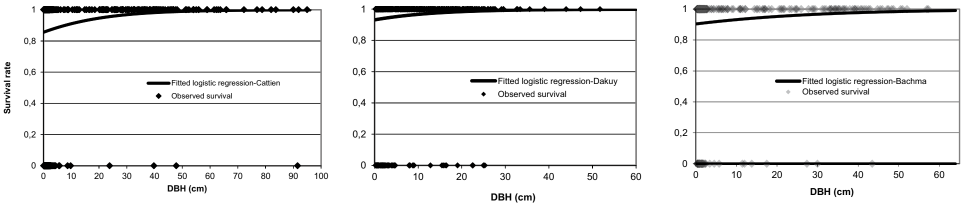
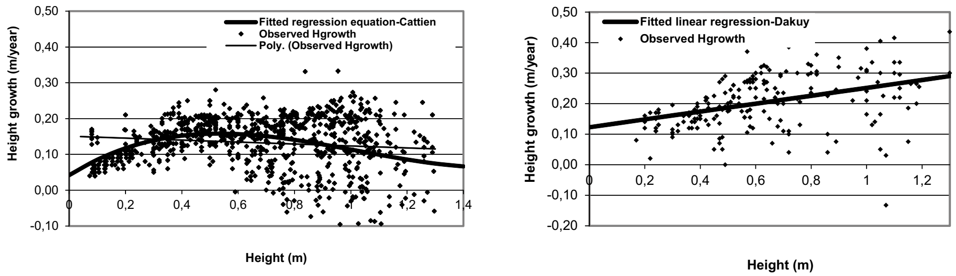



*Figure 5. Relation between survival rate and the DBH of S. macropodum at the three studied sites in Vietnam. Dots are observed values for survival rate and lines are fitted logistic regression: Y = 1/(1+Exp(-(a*DBH + b))). Fitted parameters a, b and R2 (Nagelkerke): Cattien 0.06, 1.01 and 0.12 respectively; Dakuy 1.88, 0.08 and 0.04 respectively; Bachma 0.04, 1.50 and 0.05 respectively.*

## Growth

Height growth of *S. macropodum* seedling was highly variable within seedling size categories at each particular site and considerably different among studied sites (Figure 6). Across the three sites, maximum height growth was recorded in Dakuy, followed by Bachma and Cattien. In Dakuy, height growth of the seedlings was from 0.14 to 0.26 m per year, while the height growth in Cattien and Bachma was from 0.10 to 0.16 and 0.11 to 0.16 m per year, respectively. Correlation between height growth and initial height was fitted by polynomial regression. Details of the fitted model analysis are presented in Figure 6 Unusual data of seedling height which seemed to result from measurement error were excluded from this analysis.



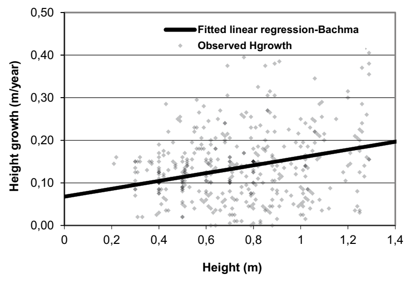




*Figure 6. Size-dependent pattern in seedling height growth of S. macropodum for size categories 1, 2 and 3 in the three studied sites in Vietnam. Lines are fitted regression and dots are observed values. Fitted models: Cattien $\Delta_H = 0.204H^3 - 0.626H^2 + 0.493H + 0.042$ ($R^2 = 0.08$); Dakuy $\Delta H = 0.129H + 0.123$ ($R^2 = 0.21$) and Bachma $\Delta H = 0.092H + 0.068$ ($R^2 = 0.15$).*

Logistic regression analysis for correlation between height and the crown illumination index (CII) showed that, in Cattien most individual *S.*

*macropodum* stems occurring at a low CII level ranging from 1.0 to 3.0 belonged to the height range of less than 10 m; more than 90 % of the plants at CII 4.0 were of the height class from 10 to 25 m, and more than 95 % of individual stems at CII 5.0 were of the height class higher than 25 m. In Dakuy, however, the situation was considerably different. There only about 70 % of the plant stems at CII level from 1.0 to 3.0 belonged to the height class of less than 10 m, and more than 95 % of individual stems at CII level 4.0 to 5.0 were in the height class 10 to 30 m. In Bachma more than 90 % of individual stems at CII level from 1.0 to 3.0 was of the height class less than 10 m and most plant stems distributed at CII level 4.0 to 5.0 were of the height class higher than 15 m.

DBH growth was correlated to DBH by fitting non-linear Hossfeld IV equations. Details of the fitted model analysis are presented in Figure 7. DBH growth rate also showed considerable variation, both among and within size categories as well as among studied sites. Highest growth in DBH was recorded in Bachma and the lowest was found in Dakuy. All three sites showed similar patterns in their DBH growth, increasing from low values from small stems to higher trees, peaking at a medium DBH trees, then gradually declining in the higher DBH trees. In Cattien, DBH growth peaked at the DBH class from 40 to 50 cm, while in Dakuy it peaked in the DBH range from 25 to 30 cm, and in Bachma it peaked at the DBH range from 30 to 40 cm (Figure 7).

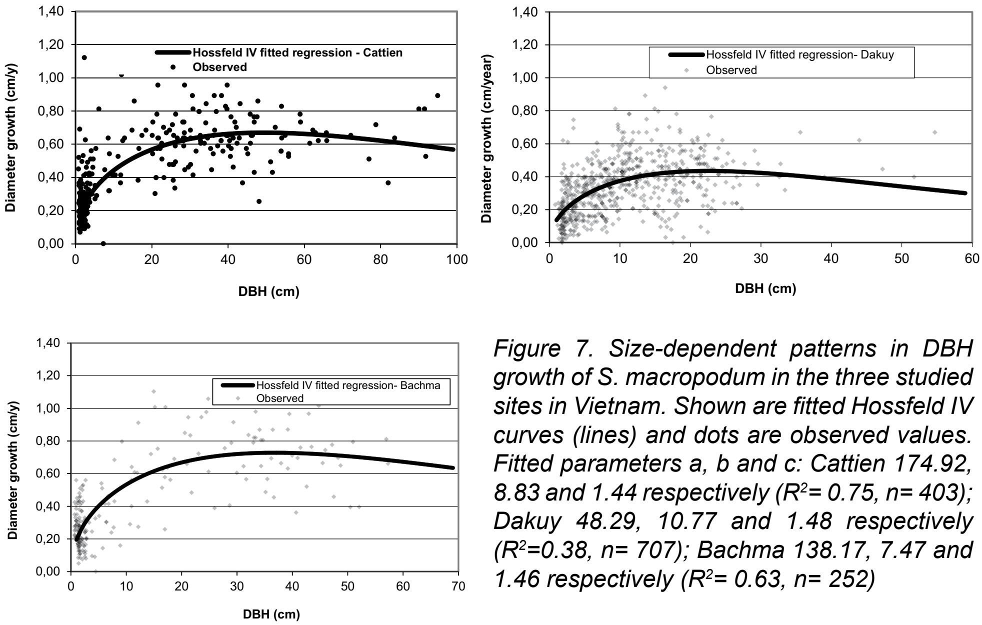
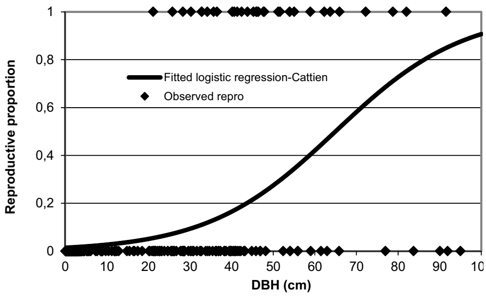


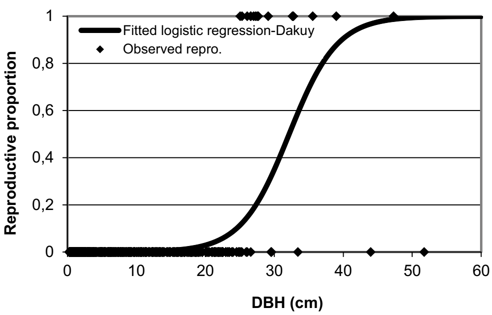

*Figure 7. Size-dependent patterns in DBH growth of S. macropodum in the three studied sites in Vietnam. Shown are fitted Hossfeld IV curves (lines) and dots are observed values. Fitted parameters a, b and c: Cattien 174.92, 8.83 and 1.44 respectively ($R^2$= 0.75, n= 403); Dakuy 48.29, 10.77 and 1.48 respectively ($R^2$=0.38, n= 707); Bachma 138.17, 7.47 and 1.46 respectively ($R^2$= 0.63, n= 252)*

### *Reproduction*

The reproductive fraction of *S. macropodum* was low and highly varied among matured size categories (category 9 onward) at each site as well as among the three sites (from 0.02 to 0.33) (Table 1). At all three sites, reproductive fractions showed a similar pattern as they increased continuously from the smallest mature size (category 9) up to the larger mature sizes and did not increase from DBH size of 45 cm onward. At Cattien, the reproductive fraction was lowest and increased up to the DBH size of 95 cm. Across the three sites, *S. macropodum* trees all started their reproduction at size category 9 (DBH 20 cm and larger). No mature tree reproduced twice during the study period and many mature trees remained un-reproductive during the 3 years of observation. The lowest reproductive fraction was recorded in Cattien, ranging from 0.02 to 0.24 in its mature sizes (categories 9 to 13). Higher reproductive rates were recorded at Bachma and Dakuy, ranging from 0.03 to 0.33 in the mature size categories.

The relationships between reproductive fraction and the DBH was fitted using binary logistic regressions for the data of three years of observation (Figure 8).



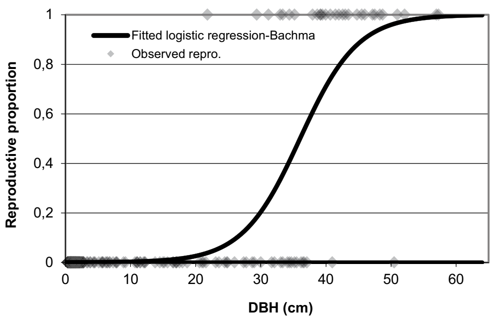




*Figure 8. Relation between reproductive fraction and DBH of S. macropodum at the three studied sites in Vietnam. Dots are observed values of reproductive rate and lines are fitted logistic regression: Y = 1/(1+Exp(-(a*DBH + b))). Fitted parameters a, b and $R^2$ (Nagelkerke): Cattien 0.07, -4.22 and 0.36; Dakuy 0.29, -9.26 and 0.55; Bachma 0.23, -8.14 and 0.77, respectively*

## Transition matrix output

### Similarity between the observed population and stable stage structure

In this study, the population structures observed in the three sites and those predicted by the model (w, stable stage structure) were not significantly different, respectively (Kolmogornov-Smirnov test, $P > 0.05$), and the values of similarity index (PS) between these were all high (78.3 in Cattien; 75.1 in Dakuy and 68.8 in Bachma), which indicates that our model realistically describes the dynamics of observed population structure, in spite of limited data on some of its parameters.

### Population growth rate

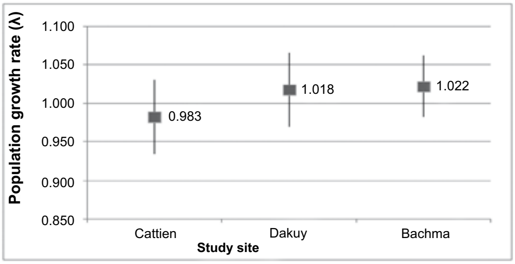



*Figure 9. Population growth rate (λ) of S. macropodum in the three studied sites in Vietnam. The vertical bars show 95 % confidence limits of λ (CLλ). The CLλ in Bachma significantly differ from that of Cattien (no overlap at 0.983 value), whereas it does not significantly differ between Dakuy and Cattien as well as Dakuy and Bachma.*

The population growth rate (λ) of *S. macropodum* in Cattien was lower than 1 (0.983), suggesting that the population is declining, and the 50-year projection of the population also showed a similar result: its abundance will decline steeply from 4207 down to 301 individuals after 50 years of growth (Figure 10). However 95 % confidence limits of the λ included the value of 1 (Figure 9), so that we cannot demonstrate a statistically significant decline of this population.

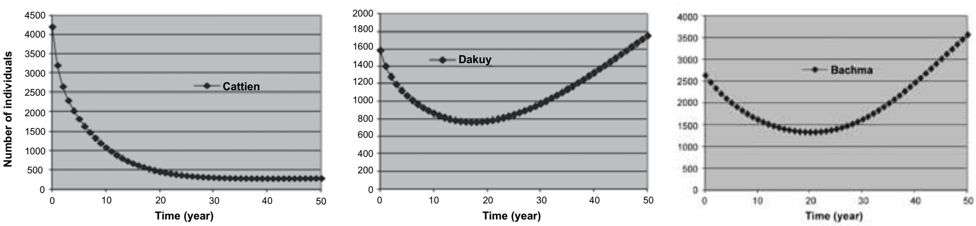
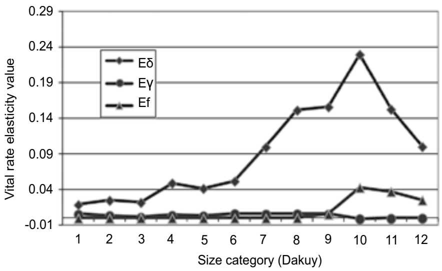
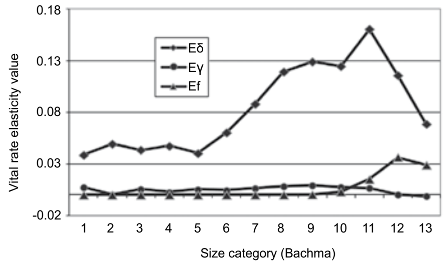



*Figure 10. 50-year population projection of S. macropodum in the three sites as obtained from the transition matrix model.*

The *λ* of *S. macropodum* populations in Dakuy and Bachma were slightly higher than 1 (1.018 and 1.022 respectively), indicating that these populations are stable to slightly growing in size. Their 50-year projection obtained from the matrix models also showed that. The *Scaphium* population in Dakuy slightly increases in abundance from 1585 to 1753, though it initially decreases up to year 15, then increases again. This pattern of initial decline is mainly caused by the difference between the observed population structure and stable stage distributions and result from an initial decrease in the abundances of seedlings and saplings due to mortality. Similarly, *S. macropodum* in Bachma increases in abundance from 2640 to 3572, with an initial decrease up to year 20 (Figure 10).

### *Vital rate elasticity*



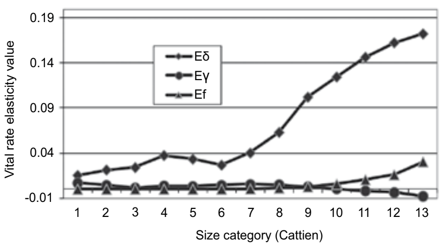
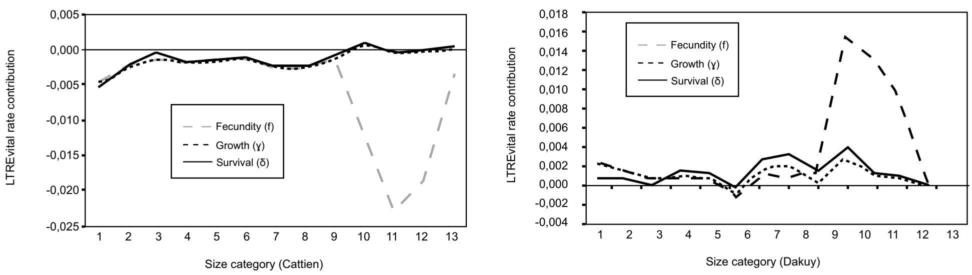




*Figure 11. Vital rate elasticity for S. macropodum at the three studied sites in Vietnam. Shown are elasticities for survival (б), growth (γ) and fecundity (f), denoting their respective weighted-importance on the population growth rate (λ), proportional changes in λ due to proportional changes in the vital rates.*

Elasticity analysis of *S. macropodum* vital rates showed that the survival (б) was most important for the population growth rate, in all categogies and at all three sites, followed by fecundity (f) from category 9 onward. This is due to the plants maturing and starting to reproduce at size categogy 9. Growth showed to be least important for *λ* (Fig. 11). In all three study sites, the elasticity analysis showed negative values for tree growth in large size trees (category 11 onward) (Fig. 11). This would indicate that increased growth in large trees leads to a reduced population growth rate.

### *Life table response experiment (LTRE)*

We analyzed the vital rate LTRE to quantify the contribution of different vital rates (growth, fecundity and survival) to the change in population growth rate (λ) of *S. macropodum* in response to site differences. The results of the analysis are presented in Figure 12.



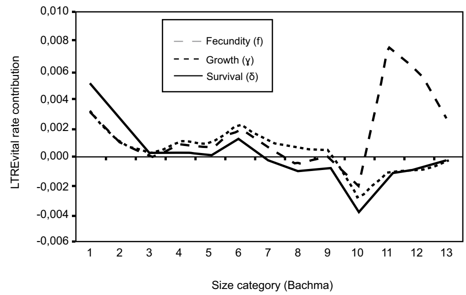




*Figure 12. Results of Life Table Response Experiments (LTRE) analysis for S. macropodum in the three study sites in Vietnam. Shown are the contributions of vital rates to the variation in population growth rate (λ) across the three studied sites of Cattien, Dakuy and Bachma.*

Our LTRE analyses showed that site differences caused strong variation in *λ*. The mean value of site effect $\alpha^{(m)}$ was 0.0471, of which Cattien had the highest effect on the variation in *λ* with a value of $\alpha^{(m)}$ = -0.0771 (negative contribution), followed by the effect at Dakuy with $\alpha^{(m)}$ =0.0455, and Bachma had the least effect on the variation in λ, with $\alpha^{(m)}$ value only 0.0209 (Table 3).

**Table 3. Magnitudes of the site effect on variation in population growth rate of *S. macropodum* in Life Table Response Experiment (LTRE). The mean and standard deviation (SD) of the absolute values of α(m) are given.**

| | Cattien | Dakuy | Bachma | Mean | ± SD of \| $\alpha^{(m)}$\| |
|---|---|---|---|---|---|
| $\lambda^{(..)}$ | 1.0087 | 1.0087 | 1.0087 | | |
| $\alpha^{(m)}$ | -0.0771 | 0.0455 | 0.0209 | 0.0471 | ± 0.0185 |
| $\lambda^{(m)}$ | 0.9316 | 1.0542 | 1.0296 | | |
| $\lambda$ | 0.9825 | 1.0177 | 1.0220 | | |
| Difference | -0.0510 | 0.0366 | 0.0076 | | |
| Accuracy (%) | 94.81 | 103.59 | 100.74 | 99.72 | ± 3.27 |

Differences in fecundity between populations explained 74 % of the difference in λ; variation in survival explained 23%, while growth contributed just 3% to the variation in *λ*.

The results in Figure 12 and Table 3 showed that, at Cattien, where α(m) was negative, all its vital rates contributed negatively to the change in *λ*; its population growth rate (*λ*) was lower the $\lambda^{(\cdot\cdot)}$ of the mean matrix. In Bachma and Dakuy, which both showed positive effects of $\alpha^{(m)}$, almost all of vital rates contributed positively to the change in λ, excepting for growth in Dakuy with negative contribution, due to λ being higher than $\lambda^{(\cdot\cdot)}$ of the mean matrix (Fig. 12).

Accuracy of the approximation between the predicted values of $\lambda^{(m)}$ and the actual *λ* was 99.72 % (Table 3), indicating that LTRE provided good estimates for the contribution of vital rates to the variation in population growth rate (*λ*) in response to site differences.

## Discussion

### *Do the fruit harvesting practices have impacts on population growth?*

In recent years, the number of studies on demographic impacts of NTFP harvesting have increased as a result of unsustainable potentials of the harvests. However our understanding of how plant demography responses to harvest is still limited (Gaoue and Ticktin 2010, Schmidt et al. 2011). In this light we discuss the three following results of our study.

Firstly, fruit harvesting by branch cutting in Cattien has damaged the crowns and stems of a considerable number of *S. macropodu*m seedlings and this negatively impacted the height growth of these seedlings. We showed that the height growth of damaged seedlings was significantly lower than that of the un-damaged seedling group (p<0.001).

Secondly, fruit harvesting by branch cutting in Cattien also caused serious crown damages in bear-fruit trees of *S. macropodum*, and had negative impact on DBH growth of these trees (Figure 3). Undoubtedly, crown damage of mature trees also must have negatively affected the fruit production of those trees. But due to the fact that none of the trees reproduced twice during the few years of our observations, we cannot estimate the size of this negative effect. However our results showed that, in Cattien where harvesting by branch cutting commonly occurred, the reproductive rate of *S. macropodum* was lowest among sites, even though here the adult trees were much larger in DBH size as compared to those of the other sites (Table 1).

Thirdly, fruit harvesting by branch cutting causes strong site disturbance, and makes up 55 % of the value of the Site Disturbance Index (SDI) (see Tables 2 and 3 of Chapter 2). The SDI was estimated in each 1000 $m^2$ sampling plot, four plots per study site and then 400 $m^2$ sampling plots were set up accordingly for new seedling observations of *Scaphium macropodum* in subsequent years and used to examine correlations between them (Table 1). We showed that, across the three study sites, seedling survival of *S. macropodum* was negatively and linearly correlated to the SDI (Figure 13).

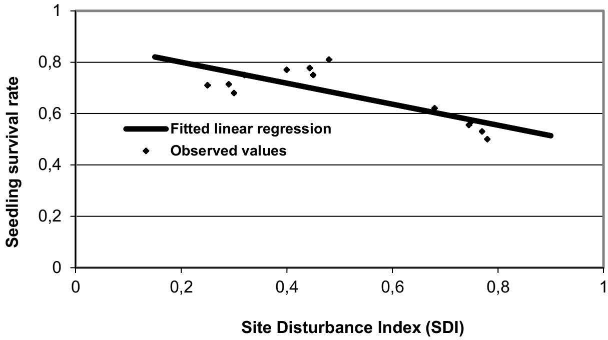



*Figure 13. Relationship between seedling survival of Scaphium macropodum and site disturbance index (SDI) in the three study sites. Fitted linear regression (Y= -0.41 SDI + 0.88, $R^2$ = 0.64) and dots of observed values.*

In fact, the practice of harvesting by branch cutting harvests all fruits on the branch at once, including unripe fruits. Large numbers of fruits, ripe and unripe ones, remained hidden under the thick leaf and branch residues that the farmers left under the trees (Huy et al. 2010a). The mature fruits that were overlooked mostly germinate in dense, small patches. In Cattien we later found these in our plots and counted them as new seedlings. But often the quality of these seedlings was low due to low seed quality. A similar result was also found in populations of *Khaya senegalensis* harvested for leaves (Gaoue and Ticktin 2007, 2008). Often the thick residue layer remaining on the forest floor caused the death of most of these low-quality seedlings. Yamada and Suzuki (1997) showed this for *S. macropodum* growing in natural forest in Kalimantan. They found that a thick litter layer, mainly produced by the parent trees, often physically prevented the seedlings' roots to reach the soil layer below the litter and that caused them to die.

In conclusion, even though we do not exclude the effects of site factors, it seems clear that the fruit harvesting practice of branch cutting in Cattien has negative effects on height growth of *S. macropodum* seedlings, on tree DBH and on the survival rate of new seedlings, and thus it has a negative impact on the population dynamics of *S, macropodum*. In this negative impact our results correspond to those of Gaoue et al. (2011a) and Gaoue and Ticktin (2010) who reported that populations of *Khaya senegalensis* declined due to a high intensity of foliage harvesting.

### *Natural regeneration*

Natural regeneration is an important measure for forest rehabilitation and highly supports the approach of a close-to-nature forest management and biodiversity conservation (Kuchelmeister and Huy 2005). Natural regeneration of *S. macropodum* in the study sites depends on three major factors: (*i*) The status of the existing population and site disturbance, (*ii*) the reproductive status (reproductive rate, seed source quantity and quality), and (*iii*) the seedling survival rate. All three factors are linked in this study, so we consider each in relation to others.

Firstly, the status of the populations and the sites studied was considerably different. The size distribution of the *S. macropodum* populations in the three sites resembled the inverse "J" pattern, typical of natural rainforests (Davis et al. 1987, Richards 1996) (Fig. 2). This pattern suggests a continuous regeneration and development of the uneven aged populations at my sites. Chien (2006) also found this pattern for some endangered timber species in natural tropical forests in Vietnam. At the Bachma site, however, the abundance of the smallest seedling size was lower as compared to that of the next larger seedling category. This unusual abundance might result from uneven fruiting of the species over time at this site.

The Site disturbance index (SDI) was also clearly different between the study sites: it had a high value in Cattien, medium in Bachma and low in Dakuy (Table 1). The survival rate of *S. macropodum* seedlings was negatively correlated to the SDI, and value of this index was largely determined by the prevailing harvesting practice. This importantly contributes to explain why the number of new seedlings found in Cattien was high, but their survival rate was low (Table 1) as the harvesting by branch cutting at Cattien resulted in low quality seeds and a thick remaining residue layer that increased seedling mortality.

Secondly, the reproductive status was also largely different between the studied sites, and thus had different impact on the natural regeneration. Cattien showed a very low reproductive rate and fruit yield, but, as said above, a high number of new seedlings per ha and also a high seedling mortality. Bachma had a much higher reproductive rate and fruit yield, but less new seedlings per ha and a much lower seedling mortality (Table 1). Thus suggests that under high pressure of fruit extraction, the high amount of fruit yield recorded at a site does not necessary mean that a high number of seedlings will also be found, and a high number of new seedlings found at a site does not necessary mean that they all will be recruited in the natural regeneration of the site.

Thirdly, seedling survival importantly determines the fraction of new seedlings recruited for natural regeneration (Ishuzuka et al. 2010). In our study, the survival rate of new seedlings in Cattien was lowest among the study sites, due to their low quality and high SDI, and thus recruitment for natural regeneration was low. This is also shown in the 50-years projection for Cattien. This result is highly consistent with that reported by Fashing et al. (2004), who found that trees at a high SDI site showed extremely poor recruitment into the small size classes, a condition that can probably be attributed to human harvesting activities. The higher survival rates of new seedlings found in Dakuy and Bachma led to higher fractions to be recruited to the next stages of natural regeneration. Fashing et al. (2004) also found that, the low SDI site was best for seedling recruitment.

To assess whether at the study sites, under high pressure of fruit extraction, *S. macropodum* has the opportunity to regenerate naturally or not, we calculated two seedling factors: “producing and demanding”. Seedlings factually produced by an adult tree can be calculated based on the observed data, and seedlings that need to be produced to offset mortality for its entire reproductive life can be calculated based on survival rates up to mature size (Chien 2006, Chien et al. 2008). If the balance between “producing” and “demanding” numbers is positive, i.e. when “producing” is higher, it indicates a positive regeneration status (+), and if “demanding” is higher, it indicates a negative regeneration status (-). For example, at Cattien, survival to the adult size amounted to 0.03% (Table 4 and Annex **1**), implying that against one plant growing into an adult tree, already 3332 other plants have died off before reaching the adult size, so a tree needs to produce 3332 seedlings to offset mortality. But at Cattien the actually produced number of seedlings per mature tree in its entire reproductive life as calculated from observed data was 155.

**Table 4. Regeneration status of *S. macropodum* in the study sites**

| Site | Survival to matured size (%) | No. of seedling need to be produced by an adult | No. of seedling factually produced by an adult | Regeneration status |
|---|---|---|---|---|
| Cattien | 0.03 | 3332 | 155 | --- |
| Dakuy | 1.56 | 63 | 196 | + |
| Bachma | 0.97 | 102 | 472 | ++ |

*Note: the number of “+”/”-“ indicates the level of sufficiency or insufficiency*

From this analysis we can conclude that, under high pressure of fruit extraction, the regeneration status of *S. macropodum* was highly negative in Cattien, slightly positive in Dakuy, and positive in Bachma.

***Future prospect and implication for sustainable management***

To estimate the future prospects of *S. macropodum* in the three study sites, we calculated and combined three measures from their transition matrix models, namely population growth rate ($\lambda$), abundance in 50-year population projection and regeneration status.

According to this approach, the *S. macropodum* population at Cattien appears to have a worrisome future as almost all of its measures showed below-threshold values. It is therefore suggested that the site will be made subject to appropriate interventions for sustainable growth and management. The populations at Dakuy and Bachma, however, showed good future prospects as their $\lambda$ are higher than 1, their abundances in the 50-year projection increased, and their natural regeneration appeared rather good.

Future prospect estimations that are based on measures from a short-term demographic study are of uncertain value, however, and should be supported by other applied studies and necessary interventions for sustainable management of the populations. Conclusions on the future prospects are therefore subject to change (Keith 2000, van Mantgem and Stephenson 2005, Chien 2006). Further long-term research on tree population dynamics of this species in the study sites will be critical to improve our understanding.

Most remaining populations of *S. macropodum* are small, scattered and managed in an unsustainable way (Huy et al. 2010a, Huy et al. 2010b). They decline and their prospects look bad. In order to obtain a sustainable management of *S. macropodum*, it is strongly suggested that the fruit harvesting practice is drastically improved. This implies that the current practice of harvesting by branch cutting should stop and be replaced by other sustainable ways, that site disturbance should be strongly reduced in order to decrease seedling mortality and improve reproductive status. By this approach a trade-off between productivity (fruit harvesting) and species conservation would be obtained (Jobidon et al. 2004). An important aspect of this approach is that, as the populations of *S. macropodum* increase and improve, their reproduction and fruit yield will improve, and this will give local people a chance to profit from this valuable resource and to improve their income. This social aspect is important for sustainable management.

It is also suggested that while we have no harvesting solution yet that is better than those practised in Dakuy and Bachma, we should promote their application. That means to simply just collect fruits from the ground, and perhaps this can be combined with a low intensity of cutting branches, as that might improve the light conditions in dense stands of Scaphium-bearing forest. We should also encourage local authorities and farmers to adopt a joint management in which local farmers would own certain *S. macropodum* trees and sustainably manage those with prudence and a high sense of responsibility. This approach seems a contribution to the sustainable management of *S. macropodum*.

## Acknowledgements

The study, especially its field work would not be done without the supports and assistances from my friends, colleagues and teachers. We would like to thank Le Thanh Cong, Tran Thi Thu Ha, Nguyen The Manh, Nguyen Van Thang, Nguyen Thu Huong, Nguyen Van Duong for their active and helpful participation in the field work. We highly express our sincere thanks to the leaders and their staff of the three protected areas viz. Cattien national park, Dakuy special use forest and Bachma national park for their kind support and help to our study. We sincerely thank Pieter Zuidema, Marinus Werger, Rene Boot and Heinjo During for their very valuable discussions and comments on the study. We also would like to thank Tropenbos International and Forest Science Institute of Vietnam, Ministry of Agriculture and Rural Development for their financial grant to this study.

*Figure 12. New seedling of S. macropodum on thick residue layer remaining from branch cutting for fruit harvesting in Cattien (June 2007 and May 2008)*

## Annexes

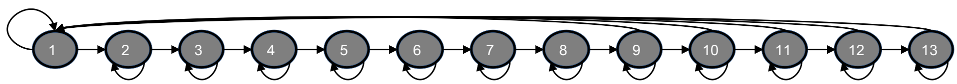
## Annex 1:

Size category definition and vital rate values used for transition matrix construction of *S. macropodum* in Cattien. Categories 1-3 are based on seedling height, 4-13 on DBH. Shown are estimates for vital rates obtained from regression analyses: survival probability (*δ*), growth rate (g, in height for seedlings, and in DBH for trees), reproductive rate (*f*), and sample size per ha. Seedling height growth was related to height as fitted polynomial regression (Fig. 5). Diameter growth was fitted by nonlinear Hossfeld IV curve (see Fig 6). Seedling survival rate and reproductive rate were fitted by the binary logistic equation *Y= 1/(1 + EXP((c +d*X)))* (see Fig 3, 4 and 7).

| # | Category name | Class | | Sample size (n) | Survival (δ) | Growth rate (g) | | Rep (f) |
|---|---|---|---|---|---|---|---|---|
| | | H class (m) | DBH Classes (cm) | | | Dia (cm/y) | Height (m/y) | |
| 1 | Seedling 1 | 0 - 0.29 | | 1364 | 0.541 | | 0.10 | 0.0 |
| 2 | Seedling 2 | 0.3-0.79 | | 1167 | 0.779 | | 0.16 | 0.0 |
| 3 | Seedling 3 | 0.8-1.3 | | 964 | 0.944 | | 0.11 | 0.0 |
| 4 | Sapling 1 | | 1.0-1.9 | 397 | 0.865 | 0.19 | | 0.0 |
| 5 | Sapling 2 | | 2.0-2.9 | 208 | 0.871 | 0.24 | | 0.0 |
| 6 | Sapling 3 | | 3.0-4.9 | 75 | 0.877 | 0.28 | | 0.0 |
| 7 | Pole 1 | | 5.0-9.9 | 3 | 0.899 | 0.39 | | 0.0 |
| 8 | Pole 2 | | 10.0-19.9 | 3 | 0.930 | 0.52 | | 0.0 |
| 9 | Mature 1 | | 20.0-29.9 | 9 | 0.959 | 0.61 | | 0.02 |
| 10 | Mature 2 | | 30.0-39.9 | 8 | 0.976 | 0.65 | | 0.04 |
| 11 | Mature 3 | | 40.0-49.9 | 6 | 0.986 | 0.67 | | 0.07 |
| 12 | Mature 4 | | 50.0-59.9 | 3 | 0.992 | 0.67 | | 0.11 |
| 13 | Matrue 5 | | ≥60.0 | 3 | 0.998 | 0.62 | | 0.24 |

Transition matrix model of *S. macropodum* in Cattien

| | CATEGORY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Seedling1 | **0,353** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,0** | **0,1** | **0,6** | **1,7** | **2,7** | **4,9** |
| 2 | Seedling2 | **0,188** | **0,528** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 3 | Seedling3 | 0,000 | **0,251** | **0,744** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 4 | Sapling 1 | 0,000 | 0,000 | **0,199** | **0,680** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 5 | Sapling 2 | 0,000 | 0,000 | 0,000 | **0,186** | **0,636** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 6 | Sapling 3 | 0,000 | 0,000 | 0,000 | 0,000 | **0,236** | **0,747** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 7 | Pole 1 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,131** | **0,827** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 8 | Pole 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,072** | **0,882** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 9 | Mature 1 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,048** | **0,900** | 0,000 | 0,000 | 0,000 | 0,000 |
| 10 | Mature 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,059** | **0,912** | 0,000 | 0,000 | 0,000 |
| 11 | Mature 3 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,064** | **0,920** | 0,000 | 0,000 |
| 12 | Mature 4 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,067** | **0,925** | 0,000 |
| 13 | Mature 5 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,067** | **0,936** |




Life cycle of *S. macropodum* population in Cattien

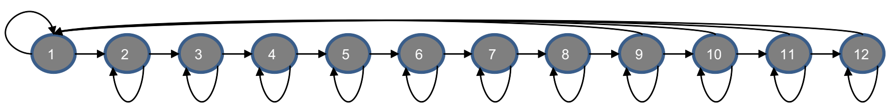
## Annex 2:

Size category definition and vital rate values used for transition matrix construction of *S. macropodum* in Dakuy. Categories 1-3 are based on seedling height, 4-12 on DBH. Shown are estimates for vital rates obtained from regression analyses: survival probability *(δ)*, growth rate (*g*, in height for seedlings, and in DBH for trees), reproductive rate *(f)*, and sample size per ha. Seedling height growth related to height as fitted polynomial regression (*Fig. 5*). Diameter growth was fitted by nonlinear Hossfeld IV curve (see *Fig 6*). Seedling survival rate and reproductive rate were fitted by the binary logistic equation *Y= 1/(1 + EXP((c +d*X)))* (see *Fig 3, 4* and *7*)

| # | Category name | Class | | Sample size *(n)* | Survival *(δ)* | Growth rate *(g)* | | Rep *(f)* |
|---|---|---|---|---|---|---|---|---|
| | | H class (m) | DBH Classes (cm) | | | Dia (cm/y) | Height (m/y) | |
| 1 | Seedling1 | 0 - 0.29 | | 361 | 0.727 | | 0.14 | 0.00 |
| 2 | Seedling2 | 0.3-0.79 | | 311 | 0.873 | | 0.19 | 0.00 |
| 3 | Seedling3 | 0.8-1.3 | | 236 | 0.961 | | 0.26 | 0.00 |
| 4 | Sapling 1 | | 1.0-1.9 | 172 | 0.938 | 0.16 | | 0.00 |
| 5 | Sapling 2 | | 2.0-2.9 | 178 | 0.943 | 0.21 | | 0.00 |
| 6 | Sapling 3 | | 3.0-4.9 | 167 | 0.896 | 0.25 | | 0.00 |
| 7 | Pole 1 | | 5.0-9.9 | 59 | 0.960 | 0.34 | | 0.00 |
| 8 | Pole 2 | | 10.0-19.9 | 72 | 0.977 | 0.42 | | 0.00 |
| 9 | Mature 1 | | 20.0-29.9 | 26 | 0.979 | 0.43 | | 0.04 |
| 10 | Mature 2 | | 30.0-39.9 | 2 | 0.995 | 0.41 | | 0.23 |
| 11 | Mature 3 | | 40.0-49.9 | 1 | 0.995 | 0.36 | | 0.33 |
| 12 | Mature 4 | | 50.0-59.9 | 1 | 0.999 | 0.32 | | 0.33 |

Transition matrix model of *S. macropodum* in Dakuy

| | **CATEGORY** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | Seedling1 | **0,372** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,0** | **0,1** | **2,2** | **1,8** | **3,4** |
| **2** | Seedling2 | **0,355** | **0,528** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **3** | Sapling 1 | 0,000 | **0,344** | **0,464** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **4** | Sapling 2 | 0,000 | 0,000 | **0,497** | **0,767** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **5** | Sapling 3 | 0,000 | 0,000 | 0,000 | **0,171** | **0,723** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **6** | Pole 1 | 0,000 | 0,000 | 0,000 | 0,000 | **0,220** | **0,780** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **7** | Pole 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,116** | **0,894** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **8** | Mature 1 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,066** | **0,936** | 0,000 | 0,000 | 0,000 | 0,000 |
| **9** | Mature 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,041** | **0,936** | 0,000 | 0,000 | 0,000 |
| **10** | Mature 3 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,043** | **0,954** | 0,000 | 0,000 |
| **11** | Mature 4 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,041** | **0,959** | 0,000 |
| **12** | Mature 5 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,037** | **0,967** |




Life cycle of *S. macropodum* population in Dakuy

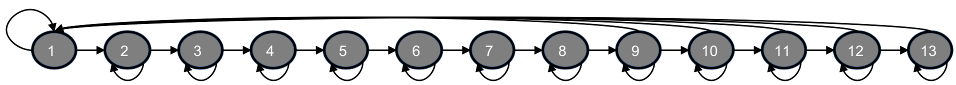
## Annex 3:

Size category definition and vital rate values used for transition (Yamada and Suzuki 1996) matrix construction of *S. macropodum* in Bachma. Categories 1-3 are based on seedling height, 4-13 on DBH. Shown are estimates for vital rates obtained from regression analyses: survival probability *(δ)*, growth rate (*g*, in height for seedlings, and in DBH for trees), reproductive rate *(f)*, and sample size per ha. Seedling height growth related to height as fitted polynomial regression (*Fig. 5*). Diameter growth was fitted by nonlinear Hossfeld IV curve (see *Fig 6*). Seedling survival rate and reproductive rate were fitted by the binary logistic equation Y= *1/(1 + EXP((c +d*X)))* (see *Fig 3, 4* and *7*)

| # | Category name | Class | | Sample size *(n)* | Survival *(δ)* | Growth rate *(g)* | | Rep *(f)* |
|---|---|---|---|---|---|---|---|---|
| | | H class (m) | DBH Classes (cm) | | | Dia (cm/y) | Height (m/y) | |
| 1 | Seedling1 | 0 - 0.29 | | 393 | 0.810 | | 0.08 | 0.00 |
| 2 | Seedling2 | 0.3-0.79 | | 968 | 0.909 | | 0.12 | 0.00 |
| 3 | Seedling3 | 0.8-1.3 | | 718 | 0.962 | | 0.16 | 0.00 |
| 4 | Sapling 1 | | 1.0-1.9 | 389 | 0.909 | 0.23 | | 0.00 |
| 5 | Sapling 2 | | 2.0-2.9 | 114 | 0.912 | 0.29 | | 0.00 |
| 6 | Sapling 3 | | 3.0-4.9 | 25 | 0.915 | 0.34 | | 0.00 |
| 7 | Pole 1 | | 5.0-9.9 | 5 | 0.926 | 0.48 | | 0.00 |
| 8 | Pole 2 | | 10.0-19.9 | 7 | 0.943 | 0.62 | | 0.00 |
| 9 | Mature 1 | | 20.0-29.9 | 5 | 0.960 | 0.70 | | 0.03 |
| 10 | Mature 2 | | 30.0-39.9 | 8 | 0.946 | 0.73 | | 0.15 |
| 11 | Mature 3 | | 40.0-49.9 | 5 | 0.981 | 0.72 | | 0.29 |
| 12 | Mature 4 | | 50.0-59.9 | 2 | 0.987 | 0.69 | | 0.33 |
| 13 | Matrue 5 | | ≥60.0 | 0 | 0.991 | 0.65 | | 0.33 |

Transition matrix model of *S. macropodum* in Bachma

| | CATEGORY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Seedling1 | **0,597** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,0** | **0,1** | **1,6** | **7,4** | **9,4** | **14,92** |
| 2 | Seedling2 | **0,233** | **0,690** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 3 | Seedling3 | 0,000 | **0,219** | **0,645** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 4 | Sapling 1 | 0,000 | 0,000 | **0,317** | **0,675** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 5 | Sapling 2 | 0,000 | 0,000 | 0,000 | **0,234** | **0,614** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 6 | Sapling 3 | 0,000 | 0,000 | 0,000 | 0,000 | **0,297** | **0,750** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 7 | Pole 1 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,165** | **0,836** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 8 | Pole 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,090** | **0,884** | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 9 | Mature 1 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,059** | **0,892** | 0,000 | 0,000 | 0,000 | 0,000 |
| 10 | Mature 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,068** | **0,876** | 0,000 | 0,000 | 0,000 |
| 11 | Mature 3 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,070** | **0,910** | 0,000 | 0,000 |
| 12 | Mature 4 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,072** | **0,918** | 0,000 |
| 13 | Mature 5 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | **0,000** | **0,069** | **0,926** |




Life cycle of *S. macropodum* population in Bachma

# Annex 4:

ANOVA- POST HOC TEST: Multiple Comparisons for significant differences of vital rates of *S. macropodum* among study sites

| Dependent Variable | (I) Catg. | (J) Catg. | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| Survival | 1 | 2 | -.234* | .017 | .000 | -.27 | -.19 |
| | | 3 | -.219* | .018 | .000 | -.26 | -.18 |
| | 2 | 1 | .234* | .017 | .000 | .19 | .27 |
| | | 3 | .015 | .020 | .731 | -.03 | .06 |
| | 3 | di 1 | .219* | .018 | .000 | .18 | .26 |
| | | 2 | -.015 | .020 | .731 | -.06 | .03 |
| D Growth | 1 | 2 | -.03685* | .00741 | .000 | -.0542 | -.0195 |
| | | 3 | -.02566* | .00826 | .005 | -.0450 | -.0063 |
| | 2 | 1 | .03685* | .00741 | .000 | .0195 | .0542 |
| | | 3 | .01119 | .00867 | .400 | -.0091 | .0315 |
| | 3 | 1 | .02566* | .00826 | .005 | .0063 | .0450 |
| | | 2 | -.01119 | .00867 | .400 | -.0315 | .0091 |
| H growth | 1 | 2 | -.27135* | .01101 | .000 | -.2972 | -.2455 |
| | | 3 | -.03126* | .01232 | .030 | -.0601 | -.0024 |
| | 2 | 1 | .27135* | .01101 | .000 | .2455 | .2972 |
| | | 3 | .24009* | .01290 | .000 | .2098 | .2703 |
| | 3 | 1 | .03126* | .01232 | .030 | .0024 | .0601 |
| | | 2 | -.24009* | .01290 | .000 | -.2703 | -.2098 |
| Fecundity | 1 | 2 | .004 | .006 | .736 | -.01 | .02 |
| | | 3 | -.018* | .006 | .011 | -.03 | .00 |
| | 2 | 1 | -.004 | .006 | .736 | -.02 | .01 |
| | | 3 | -.022* | .007 | .003 | -.04 | -.01 |
| | 3 | 1 | .018* | .006 | .011 | .00 | .03 |
| | | 2 | .022* | .007 | .003 | .01 | .04 |

***Note*** * *The mean difference is significant at the 0.05 level.*

*1 denotes site of Cattien, 2 denotes site of Dakuy and 3 denotes Bachma site.*

# Chapter 4
# Effect of light availability and top breakage on growth of *Scaphium macropodum* seedlings in a greenhouse

*With M.J.A. Werger and R.G.A. Boot. Submitted*


## Abstract

1. Understanding seedling growth responses to different light regimes and top breakage disturbances is important for the seedling production by farmers, and also for our understanding of the regeneration dynamics of forests. We conducted greenhouse experiments (2008-2010) with seedlings of *Scaphium macropodum*, a broadleaved tree species in tropical forests of Vietnam, to study the effects of light availability on their growths and their response to top breakage.
2. The effects of light availability on height and diameter growth of *S. macropodum* seedlings showed two clearly different stages: during the first stage from month 1 to 8 of the experiment, height growth was strongest at 25% irradiance and lowest at full irradiance. In

the second stage (as from month 8) the pattern reverses and the strongest height growth is at the higher light level. Photo-inhibition still seems to play a role, as height growth and photosynthetic rates are strongest at 50 % irradiance. Diameter growth was strongest at full sunlight and lowest at the lowest light level (12.5 %) but and this difference was significant only in the second stage.

3. *S. macropodum* grew strongly in height from April to October, then slowed down particularly in the period from November to February. This is mirrored in the actual seasonal planting practice of local farmers in the *S. macropodum* regions.
4. Across the light levels, Relative Growth Rate (RGR) was maximal at 50 % sunlight (0.199) and a just a bit lower at full irradiance 100 % (0.198), Net Assimilation Rate (NAR) increased (from 1.105 to 3.789) with increase of light levels, while Leaf Area Ratio (LAR) and Specific Leaf Area (SLA) both decreased with the increase in light level. The RGR positively and linearly correlated with NAR, and correlated negatively with LAR, LWR and SLA.
5. After 19 months of growth, the plants had allocated most of their biomass to the stem, ranging from 38.2 % (50 % light) to 43.8 % (12.5 % light); least was allocated to roots, ranging from 18.0 % to 27.6 %. Proportional biomass allocation to roots increased with increasing light availability, while allocation into leaves showed the reversed pattern.
6. No significant difference was found in height between topped-off and control plants at low light availability (12.5 %), but at 50 % light topped-off plants remained significantly lower than in the control as from month 4 onward, whereas at full light, they were significantly lower only for a period in the middle of the experiment. As expected, the effect of the top breakage on diameter growth was not significant.
7. Low light treatment itself seems to affect mortality; increased mortality after topping-off was found only at low irradiance (12.5 %). Apparently top breakage usually does not significantly affect the rate of survival. *S. macropodum* juveniles exhibited their excellent capacity to recover from top breakage. All topped off plants that survived at all light levels grew at least one new shoot; about one fifth and less than one tenth grew with two new shoots at 50 % and full light, respectively.

**Key words**: *Scaphium macropodum*, seedlings, greenhouse experiment, light availability, top breakage, relative growth rate (RGR), biomass allocation

## Introduction

*Scaphium macropodum* is a valuable multipurpose forest tree species, utilized for beverages, medicines and timber. It is a common shade-tolerant plant species in tropical rain forests in South East Asia (Yamada and Suzuki 1997). Its natural range of distribution comprises the tropical rain forests in Myanmar, Laos, Cambodia, Thailand, Indonesia and Vietnam. It is a timber tree that can reach 40 m in height and 1 m in diameter (Kostermans 1953, Yamada and Suzuki 1999).

In Vietnam, *S. macropodum* occurs naturally from Bach Ma National Park (Thua Thien Hue) southwards to Cattien National Park in Dong Nai province. A good tree of *S. macropodum* in a fruiting year, produces 40-60 kg of fruit (Ho Hy 2005), currently bringing an income of about 160-180 $US, (3-5 $US/1kg). Under favorable conditions, annually about 20 % of *S. macropodum* trees are fruiting (equal to 4-5 trees/ha). Harvesting their fruits they would provide local farmers with an annual income of about 12-16 million VND (about 600-800 $ US). This species was once abundant in natural forests and local communities significantly benefited from its valuable products. Unfortunately, due to improper harvesting practices, the species is now endangered (MoST 2007). Large areas of *S. macropodum* have been cut down for only a single harvesting of its fruits. This bad situation is being continued at some places and has brought about a serious decline of this species in terms of forest area supporting this species, number of populations, individuals, and their quality of growth. Most remaining populations of *S. macropodum* are small, scattered and occur only in protected areas in natural reserves and in very remote natural forest stands where local people either are not be allowed to cut them down for fruit harvesting or cannot easily reach the trees (Huy et al. 2010a).

With this status an appropriate programs for conservation and rehabilitation of *S. macropodum* plant resources is now a prerequisite. However, there is no scientific basis for such a program and research is needed. Most research studies done so far on *S. macropodum* were field inventories for baseline data (Duong 1995, Hy 2005), for population dynamics and recruitment (Yarwudhi et al. 1994, Huy et al. 2010b) and for some field planting establishment (Duong 1995, McNamara et al. 2006, Huy et al. 2010a). Also research in the field of experimental ecophysiology is necessary in order to develop appropriate measures for the conservation and rehabilitation of *S. macropodum*.

Light is one of the most important environmental factors, providing plants with both a source of energy and informational signals that control their growth and development (Markesteijn et al. 2007, Lambers et al. 2008). Research on the effects of different irradiance levels on growth and development of *S. macropodum* is essential as young seedlings appear to need other light conditions than adult trees. However there have been only a few studies conducted. Duong (1995) found that 3 month old seedlings of *S. macropodum* need a shading 50 % of the full sunlight for their development. But this finding only refers to the very young seedlings, while according to the production experience of local farmers, *S. macropodum* seedlings in nursery requires at least 12 to 24 months of growth, depending upon specific ecological conditions, before they can be successfully planted outside. There is currently no scientifically based method for producing *S. macropodum* seedlings. Farmers tend to produce them based on their own experience. In this way most farmers apply shade levels of 50 – 60 % of full light at the very early stage, and then, gradually reduce the shade as seedlings grow older (Kuchelmeister and Huy 2004).

Yamada and Suzuki (1997) stated that *S. macropodum* is hypothesized to require a gap for seedling growth and successful regeneration, whereas it can germinate and persist under closed canopies as suppressed seedlings or saplings. Sapling growth increased with increasing light levels around the saplings. It is suggested that higher light levels are essential for rapid vertical growth of juveniles of S. *macropodum*, and therefore for growing into an adult tree.

Patterns in biomass allocation of plants across different light environments have been studied relatively well, but not for *S. macropodum*. Previous studies found that in species that inherently exhibit strong degrees of branching, plant biomass is closely related to the total number of leaves, whereas in plants with less branched above-ground architecture, biomass is related to stem size (Bazzaz and Harper 1977, Harper 1989, Schmid and Bazzaz 1994, Menalled and Kelty 2001). Kuppers (1985) stated that the proportion of biomass allocated into leaves tends to be similar in all plant species belonging to a specific growth form. He mentioned that in mature woody plants, about 10% of total biomass is allocated to leaves. However, Menalled and Kelty (2001) found, in some woody plants, about 3-fold higher values than Kuppers (1985).

It is also commonly found that, biomass allocation to leaf tissue (LAR and LWR) decreases with increasing light availability. In order to acquire much light in a stand, a plant does not just need a large leaf area, but also has to position its leaves high in the canopy. Such plants must invest a large fraction of their biomass in support tissues such as stems (Werger et al. 2002, Werger and Hirose 2008). Even so each species appears to have a unique pattern of biomass allocation across light environments (Montgomery 2004). For *S. macropodum* this type of research has not been carried out yet.

In nature, plants are often subjected to disturbances, either from biotic or abiotic factors such as predation (Ishuzuka et al. 2010), cutting, fires, hurricanes, landslides and so on (Moravec 1990, Bellingham et al. 1994, Sakai et al. 1995, Yamada et al. 2001). The ability of plants to mitigate the damage imposed by such disturbances and subsequently recover may thus play an important role in determining the survival of a seedling or juvenile (Bellingham et al. 1994, Sakai et al. 1995). In the case of *S. macropodum*, re-growth that induces branching would be very useful for farmers. Unfortunately, we so far have very little knowledge on this *S. macropodum*. Yamada, Kumagawa and Suzuki (2001) did some explorative research on the vegetative sprouting of decumbent juveniles of *S. macropodum* in the field. They reported that *S. macropodum* juveniles re-sprout from such decumbent shoots. Furthermore, it was found that, after natural predation of seedlings (in case of Fagus crenata and Fagus japonica), there was a high rate of mortality of the predated plants and only 15% and 36 %, respectively, re-grew and survived (Ishizuka, Goto and Kaji, 2010).

The current study we thus designed with the following specific objectives:

i. To examine the growth response of *S. macropodum* (up to a seedling age of 22 months) to different irradiance levels in a greenhouse,
ii. To analyze biomass allocation pattern of *S. macropodum* plants across the different light environments of the experiment (up to 22 months old),
iii. To explore the re-growth of *S. macropodum* seedlings after topping off the shoot at a very early stage under different levels of irradiance in the greenhouse.

## Materials and method

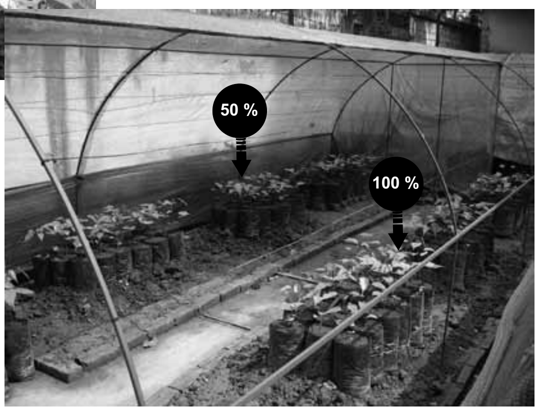
### *Plant materials*

Seeds and new seedlings of *S. macropodum* were collected from the forest ground at a *S. macropodum* site in Bach Ma National Park, Thua Thien Hue (Nam Dong district) in May and June, 2008. The seeds were then either germinated on moist sand or stored in cool conditions for later use. The seedlings were potted in black polyethylene bags and kept under 50 % irradiance in a nursery of Forest Science Institute of Vietnam (FSIV) in Hanoi for 2 months until used for experiment.

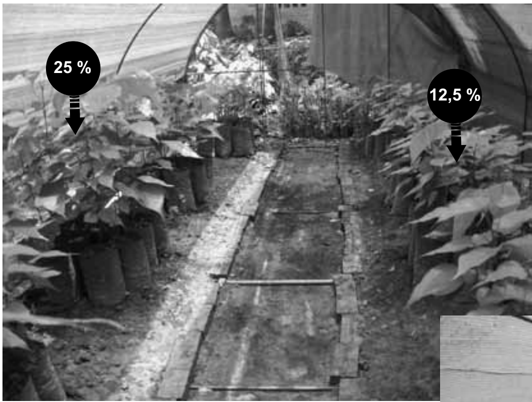
Homogenous seedlings of *S. macropodum* (as regards height, diameter, leaf number) were selected from the potted seedlings kept under 50 % irradiance and transferred to bigger poly bags (25 cm x 35 cm) and used as plant material for the experiments. We used a mixture of 83 % forest soil, 15 % compost and 2 % phosphorus as potting medium for the experimental plants.

***Experiment 1: effects of different light availabilities on seedling growth and biomass allocation of S. macropodum***

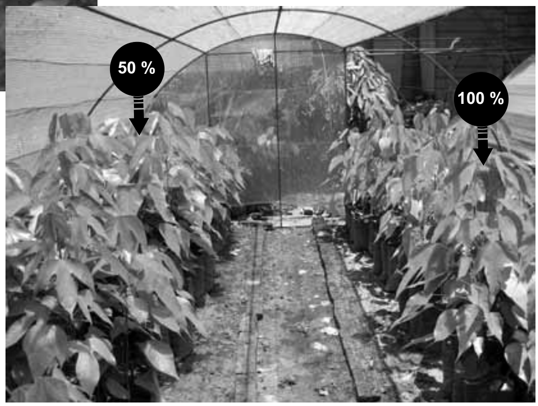
**Experimental design:** the experiments lasted from August 2008 until February 2010 (19 months). Tunnel-shaped greenhouses of 6.0 m x 2.5 m x 1.8 m were constructed and used for the experiments. Green-color nets with different density were used to set different levels of sunlight irradiance (treatments), viz. 12.5 %, 25.0 %, 50.0 % and 100 % of full sunlight. For each treatment, initially we set up 54 seedlings in 3 replicated blocks (18 seedlings per block). Seedling spacing within a block was 10 cm and block spacing in each treatment was 100 cm. After one month, we harvested 8 seedlings of each replicated block in all treatments for growth and biomass measurements (so-called T1). The 10 remaining seedlings were measured monthly for standard growth analyses and final biomass harvesting after 18 months of growing (so-called T19) (Poorter et al. 2005).


*S. macropodum seedlings at initial lay-out in the greenhouse experiment at FSIV, Chem, Hanoi (started in August 2008)*




*S. macropodum seedlings after one year in the same greenhouse. Chem, Hanoi. (August, 2009)*




**Observations and measurements:** Monthly measures for total height (H), basal diameter (D), number of branches, leaves and mortality were made until the end of the experiments.

One month after the start of the experiments, T1 biomass measures were done individually for 8 seedlings of each replicated block: dried biomass of leaves, stems and roots, number of leaves and leaf area. Individual seedlings were harvested and separated into root, shoot and leaf components. Both coarse and fine roots per seedling were collected for root mass measurement. Petioles were included in leaf mass. Leaf area was measured using the CI-340 photosynthesis system, (CID, InC.USA).

All plant parts were chopped or clipped in pieces, then put in paper bags for oven-drying at 70°C for about 2-3 days until their weight was stable, and then weighed. Correlations between total biomass and stem diameter and number of leaves were determined.

The same biomass measurements as at T1 were done at T19 (final harvesting) at the end of the experiment in February, 2010. Data from these biomass measures were used for analyses of growth and biomass allocation (Menalled and Kelty 2001, Hunt et al. 2002, Hegazy et al. 2004, Selaya et al. 2007, Selaya et al. 2008)

Additional we analyzed chlorophyll a, b contents and photosynthesis rates (Pn). Chlorophyll analysis was done from leaf extracts in October 2009 using the spectrometer method following Hall & Rao (1998). Photosynthesis (Pn) measurement was done at the same time using the CI-340 Photosynthesis system (CID, InC.USA).

*Measurement of photosynthesis rate (Pn) and leaf area of S. macropodum seedlings*

***Experiment 2: effects of top breakage on the growth of S. macropodum seedlings at different irradiance levels***

**Experimental design:** the experiment lasted for one year, from January 2009 until January 2010. It was carried out in the same tunnel-shape greenhouses under three levels of sunlight, viz. 12.5 %, 50.0 % and 100 % of full irradiance. The main shoot of each seedlings was topped off one month after transplanting the seedlings for this experiment (topped), using intact *S. macropodum* seedlings as a control. This experiment was laid out in three blocks at three light levels. As in experiment 1, we planted 18 seedlings per block, harvested 8 seedlings of per block one month after planting for growth and biomass measures (so-called T1), while 10 remaining seedlings continued growing and were measured monthly, and were finally harvested after 12 months for growth analyses (so-called T12) (Poorter et al. 2005) as in experiment 1.

***Data analyses***

***Plant growth analysis of S. macropodum following Hunt et al. 2002:***

We conducted a growth analysis following Hunt et al. (2002) to determine growth related traits:

- Relative growth rate (RGR; biomass growth per unit plant biomass, in mg $mg^{-1}$ $month^{-1}$): RGR = $(\ln W_2 - \ln W_1)/(t_2 - t_1)$,
  where $W_1$ and $W_2$ are total plant mass at time $t_1$ and time $t_2$.
- Net assimilation rate (NAR; biomass growth per unit leaf area, in mg $cm^{-2}$ $month^{-1}$): NAR = $[(W_2 - W_1) \times (\ln A_2 - \ln A_1)] / [(A_2 - A_1) \times (t_2 - t_1)]$,
  with $A_1$ and $A_2$ are leaf area at time $t_1$ and time $t_2$.
- Leaf area ratio (LAR; leaf area/total plant mass, in $cm^2$ $mg^{-1}$):
  LAR = $[(A_2 - A_1) \times (\ln W_2 - \ln W_1)] / [(\ln A_2 - \ln A_1) \times (W_2 - W_1)]$,

- Leaf weight ratio (LWR; leaf mass/total plant mass, in mg $mg^{-1}$ ) was calculated as LWR = $[(LW_2-LW_1) \times (lnW_2-lnW_1)] / [(lnLW_2- lnLW_1) \times (W_2-W_1)]$,
  in which $LW_1$ and $LW_2$ are leaf mass at time $t_1$ and time $t_2$, $W_1$ and $W_2$ are same as above
- Specific leaf area (SLA; leaf area/ leaf mass, in $cm^2$ $mg^{-1}$): SLA = LAR/ LWR,
- Root-shoot ratio (total root weight/total shoot weight).
- RGR = NAR x SLA x LWR (in direct RGR)

### *Statistical analyses*

We used regression analysis to examine the relations of RGR with the other growth parameters NAR, LAR, LWR, SLA and R-S ratio and between total biomass and different stem and leaf parameters.

We used analyses of variance (ANOVA) followed by post hoc Tukey pairwise multiple comparisons in SPSS 18 to test for significant differences among and between mean values of plant height (H), diameter (D) and biomass across light treatments (at significance level α=0.05), and Independent T-tests for significant differences in (mean values) of height (H), diameter (D), number of regrown shoots and survival rate of the *S. macropodum* seedlings in the top breakage experiment.

## Results

### *Effects of light availability on growth of S. macropodum seedlings*

### *Effect on height (H) growth of S. macropodum*

**Table 1. Height growth (cm) of *S. macropodum* under different irradiance levels in the greenhouse (experiment started with 3 months old seedlings)**

| Light level | Time of experiment (months) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 4 | 7 | 10 | 13 | 16 | 19 |
| 12.5% | 12.1 | 14.1$^a$ | 15.6$^a$ | 18.9$^a$ | 20.9$^b$ | 26.7$^c$ | 33.6$^d$ | 35.4$^d$ | 37.2$^d$ |
| 25.0% | 12.1 | 14.0$^a$ | 15.4$^a$ | 19.8$^a$ | 22.9$^a$ | 35.5$^b$ | 51.4$^c$ | 56.5$^c$ | 61.1$^c$ |
| 50.0% | 12.2 | 13.5$^b$ | 15.2$^b$ | 17.8$^a$ | 21.0$^{ba}$ | 41.5$^a$ | 72.1$^a$ | 81.5$^a$ | 91.2$^a$ |
| 100% | 12.1 | 13.4$^b$ | 15.2$^b$ | 17.4$^a$ | 20.1$^b$ | 36.4$^b$ | 64.4$^b$ | 74.1$^b$ | 86.4$^b$ |

*Anova Post Hoc Multiple Comparison Test: different "letters"per column indicate significant difference, at α=0.05*

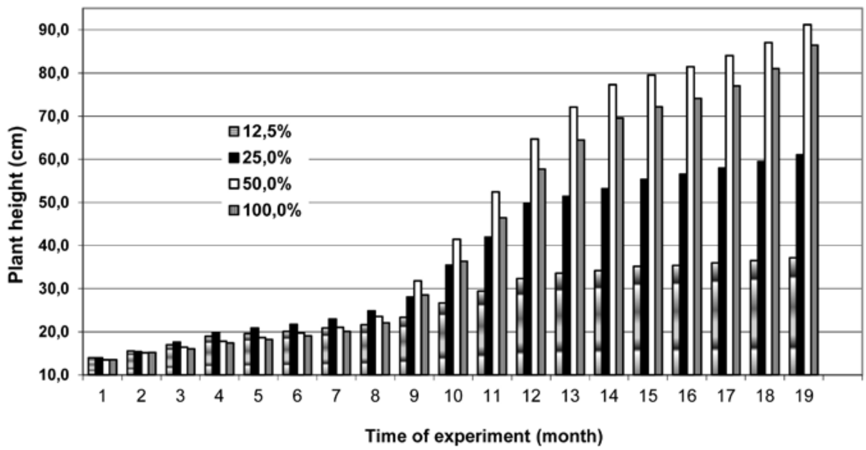



*Figure 1. Effect of different irradiances on height growth of S. macropodum in greenhouse experiments*

The results of the experiments presented in Table 1 and Fig. 1 show that, the height growth of *S. macropodum* seedlings responding to different levels of irradiance can be divided by two different stages:

In the first stage, from month 1 to month 8 of the experiment, *S. macropodum* seedlings at 25 % of full irradiance were highest (with a mean height of 25.0 cm at month 8), and those at 50 % of full irradiance were second (with a mean height of 23.0 cm at month 8); smallest were the seedlings at full sunlight (mean height of 21.1 cm). Height differences were only significant between the 12.5 % and 25 % treatments and the 25 % to 100 % treatments (Post Hoc multiple comparison test at α=0.05).

In the next stage, from month 10 up to month 19, the seedlings at 50 % of full sunlight grew highest (with 91.2 cm in month 19), followed by those at full irradiance (with 86.4 cm in month 19); lowest were those at 12.5 % (with 37.2 cm in month 19, which is roughly one-third of the height at 50 % of full sunlight). For this stage differences in height growth were statistically significant (Post Hoc multiple comparison test at α=0.05).

Across different levels of the irradiance we found that height growth rates were low from September (2008) to February (2009) with less than 2.0 cm/month, and increasingly higher as from March (2009) to a maximum in June - July (2009), ranging from 2.5 cm/month at 12.5 % of sunlight to 12.0 cm/month at 50 % sunlight. Thereafter the rate drastically decreased from mid-July until November (2009 Across the treatments, highest height growth rates of *S. macropodum* seedlings was found at 50 % sunlight, followed by that at 100 % sunlight, and lowest was at 12.5 % of full sunlight (Fig 2).

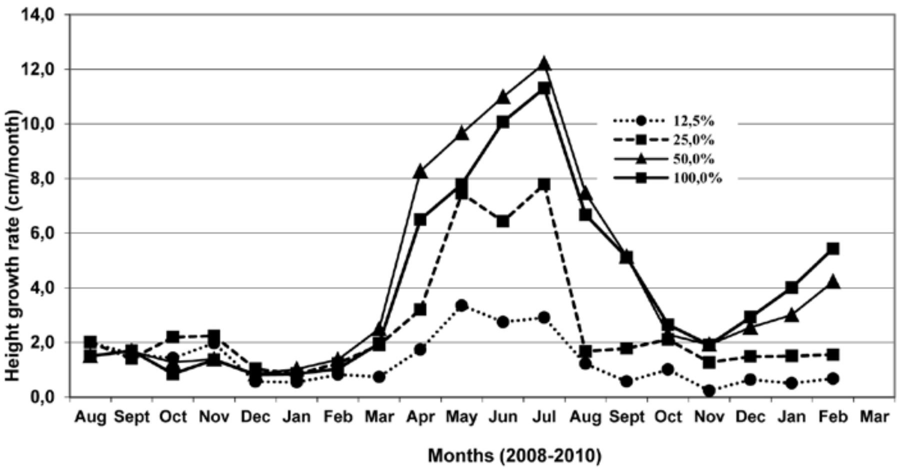



*Figure 2. Height growth rate of S. macropodum across irradiance levels in the greenhouse (monthly data collected from August 2008 to Feb. 2010)*

### *Effect on diameter (D) growth of S. macropodum*

Diameter growth of the *S. macropodum* seedlings also can be divided into two different stages:

In the early stage from month 1 to month 7 of the experiment, the *S. macropodum* seedlings responded rather equally to the different levels of irradiance regarding their diameter growth. Differentiation of the diameter growth was found only starting in month 7 with a slower diameter growth at 12.5 % (Table 2).

In the later stage, until month 19, diameter growth developed significant differences between treatments, with the stronger diameter growth as light levels increased, and the highest mean value reaching 1.32 cm at full sunlight and lowest of only 0.65 cm at 12.5 %.

**Table 2. Diameter growth (cm) of *S. macropodum* under different sunlight availabilities at greenhouse (starting with 3 months old seedlings)**

| Light level | Time of experiment (months) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 4 | 7 | 10 | 13 | 16 | 19 |
| 12.5% | 0.15 | 0.19 a | 0.27 a | 0.34 a | 0.40 b | 0.48 c | 0.54 c | 0.60 c | 0.65 d |
| 25.0% | 0.16 | 0.19 a | 0.26a | 0.35 a | 0.44 ab | 0.58 b | 0.71 b | 0.80 b | 0.89 c |
| 50.0% | 0.16 | 0.20 a | 0.27 a | 0.36 a | 0.47 a | 0.69 a | 0.93 a | 1.11 a | 1.27 b |
| 100% | 0.15 | 0.19 a | 0.27 a | 0.38 a | 0.48 a | 0.68 a | 0.99 a | 1.17 a | 1.32 a |

*Anova Post Hoc Multiple Comparison Test: different "letters" per column indicate significant difference, at α=0.05.*

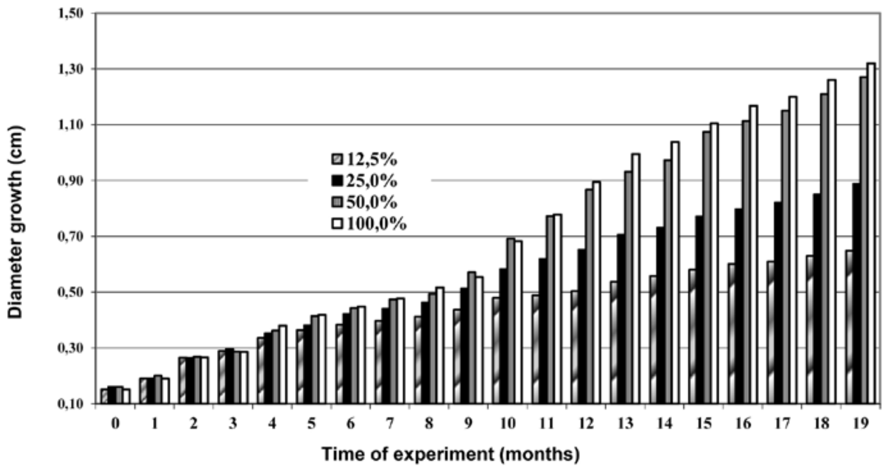



*Figure 3. Effect of different irradiance on diameter growth of S. macropodum in greenhouse experiments*

### *Effect on chlorophyll a,b and photosynthesis (Pn) of S. macropodum seedling*

**Table 3. Effect of irradiance on chlorophyll a,b ; photosynthetic rate (Pn) Oct. 2009**

| Sunlight (%) | Chlorophyll a+b (mg/g leaves) | Chlorophyll a/b | Fv/Fm | Pn ($\mu mCO_2/m^2/s$) |
|---|---|---|---|---|
| 12.5 | 5.78 | 1.49 | 0.78 | 0.53 |
| 25.0 | 5.36 | 2.26 | 0.76 | 1.27 |
| 50.0 | 4.34 | 2.53 | 0.75 | 2.30 |
| 100.0 | 3.29 | 2.59 | 0.63 | 1.87 |

The results presented in Table 3 show that, total contents of chlorophyll a and b (a+b) decrease from 5.78 mg/g in leaves at 12.5 % light treatment to 3.29 mg/g in leaves at full sunlight. Chlorophyll a/b ratios increased from 1.49 at 12.5 % sunlight to 2.59 at full sunlight. Chlorophyll fluorescence Fv/Fm decreased from 0.78 at 12.5 % sunlight to 0.63 at full sunlight, a value that indicated a low effectiveness of the photosynthesis process. Photosynthetic rates (Pn) were highest at 50 % sunlight, and lowest at 12.5 % sunlight.

### *Growth related traits*

**Table 4: Plant Growth ratios of *S. macropodum* in the greenhouse experiment**

| Light treatment | 12.5% | 25% | 50% | 100% |
|---|---|---|---|---|
| RGR (mg/mg/month) | 0.098 | 0.129 | 0.199 | 0.198 |
| NAR (mg/cm$^2$/month) | 1.105 | 1.648 | 3.399 | 3.789 |
| LAR (cm$^2$/mg) | 0.108 | 0.085 | 0.082 | 0.074 |
| LWR (leaf weight fraction) | 0.433 | 0.444 | 0.400 | 0.413 |
| SLA (cm$^2$/mg) | 0.268 | 0.218 | 0.202 | 0.175 |
| Root-Shoot ratio | 1.023 | 1.124 | 1.019 | 1.169 |
| Indirect RGR (= NAR x LWR x SLA): | 0.128 | 0.160 | 0.275 | 0.275 |

Plant growth ratios (Hunt et al. 2001) across the irradiance levels differed. Maximum RGR was found at 50 % sunlight and stayed about the same at full sunlight, and this is about twice the lowest RGR at 12.5 %. A similar pattern was found for NAR, though values differed here more than 3-fold and was highest at full sunlight. As expected, LAR decreased with increasing light level, as did SLA. LWR appeared somewhat higher at the lower light levels and Root-Shoot ratios did not show a clear pattern.

### *Correlation between RGR and other growth parameters*

**Table 5. Regressed correlations between relative growth rate (RGR) and other growth parameters (NAR, LAR, LWR, SLA; NAR to SLA and LAR to SLA) of *S. macropodum* seedlings across different irradiance environments in the greenhouse.**

| # | Correlation | Model | $r^2$ | p | n | Fig. |
|---|---|---|---|---|---|---|
| 1 | RGR to NAR | RGR = 0.061+ 0.038*NAR | 0.98 | 0.011 | 4 | 4.1 |
| 2 | RGR to LAR | RGR = 0.418 – 3.008*LAR | 0.76 | 0.032 | 4 | 4.2 |
| 3 | RGR to LWR | Not correlated | | >0.05 | 4 | 4.3 |
| 4 | RGR to SLA | RGR = 0.413 – 1.191*SLA | 0.83 | 0.039 | 4 | 4.4 |
| 5 | NAR to SLA | NAR = 9.13 – 30.18*SLA | 0.83 | 0.002 | 4 | 4.5 |
| 6 | LAR to SLA | LAR = 0.37*SLA | 0.98 | 0.012 | 4 | 4.6 |
| 7 | RGR to R-S ratio | Not correlated | | >0.05 | | |

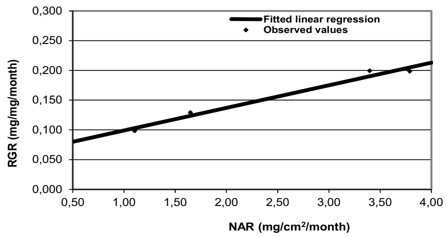



*Fig. 4.1: Correlation between RGR and NAR*

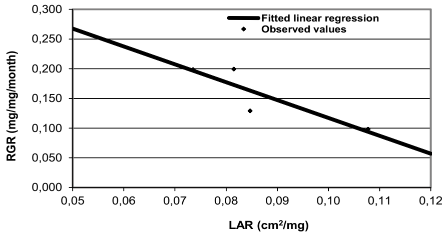



*Fig. 4.2: RGR and LAR*

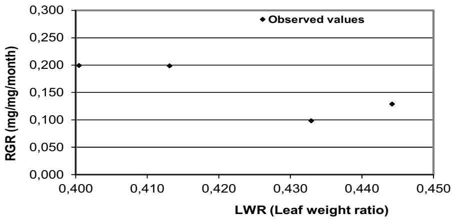



*Fig. 4.3: RGR and LWR*

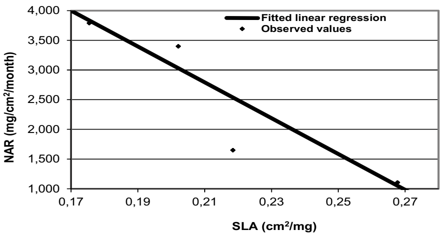



*Fig. 4.4: RGR and SLA*

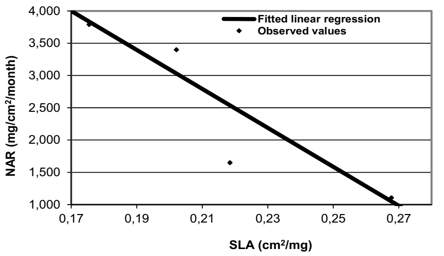



*Fig. 4.5: NAR and SLA*

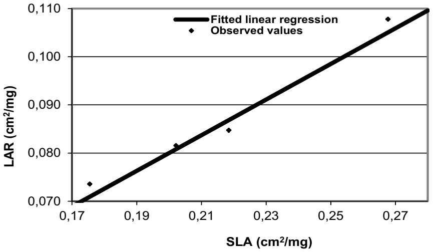



*Fig. 4.6: LAR and SLA*

*Figure 4. Relationship between RGR and different growth parameters of S. macropodum seedlings across different irradiance environments in the greenhouse*

Across light levels RGR positively and linearly correlated with NAR and negatively with LAR and SLA. NAR and SLA correlated negatively, LAR and SLA positively, and RGR did not correlate with the Leaf Weight Ratio and Root-Shoot Ratio (Table 5).

### *Biomass allocation pattern of S. macropodum seedlings across light levels*

The biomass analysis results presented in table 6 and 7 and figure 5 show that, after 19 months in the experiment and across light levels, the plants allocated most of their biomass to the stem, ranging from 38.2 % (50 % light) to 43.8 % (12.5 % light); least was allocated to roots, ranging from 18.0 % (12.5 % light) to 27.6 % (at full sunlight) (Table 5). Proportional biomass allocation to roots increased with increasing light availability, while allocation into leaves tended to decrease somewhat with increasing light availability.

**Table 6. Mean values of total biomass, biomass allocation to different plant parts, leaf area, stem diameter and stem height. Sample size is 24 plants per light treatment.**

| | Light level | | | |
|---|---|---|---|---|
| | 12.5% | 25% | 50% | 100% |
| **Total dry biomass (g)** | **6.4** | **14.2** | **41.2** | **42.2** |
| Allocation of total biomass in roots (%) | 18.0 | 23.5 | 24.2 | 27.6 |
| Allocation of total biomass in stems (%) | 43.8 | 37.5 | 38.2 | 38.7 |
| Allocation of total biomass in leaves (%) | 38.1 | 39.0 | 37.6 | 33.7 |
| Leaf area ($cm^2$) | 439.9 | 977.3 | 1841.6 | 1716.9 |
| Stem diameter-D (cm) | 0.65 | 0.89 | 1.27 | 1.32 |
| Stem height –H (cm) | 37.2 | 61.1 | 91.2 | 86.4 |

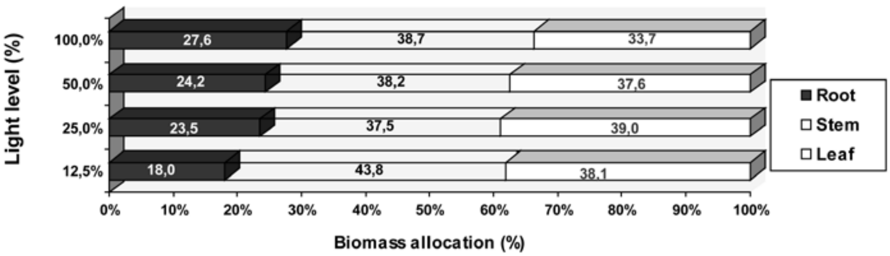



*Figure 5: Allocation of dry biomass to different plant parts of S. macropodum across light levels in the greenhouse.*

After 19 months biomass allocation showed significant differences between two groups of light treatments: group 1 (12.5 % and 25.0 %

sunlight) had lower biomass values than group 2 (50 % and 100 % sunlight) higher (Table 7).

**Table 7. Mean value of biomass allocation (in gram) to different parts of *S. macropodum* seedlings after 19 months under different light treatment levels.**

| | Root | Stem | Leaf |
|---|---|---|---|
| 12.5% | 1.2 [b] | 2.8 [b] | 2.4 [b] |
| 25.0% | 3.3 [b] | 5.3 [b] | 5.6 [b] |
| 50.0% | 10.0 [a] | 15.7 [a] | 15.7 [a] |
| 100.0% | 11.7 [a] | 16.3 [a] | 14.2 [a] |

*Anova Post Hoc Multiple Comparison Test: different "letters" per column indicate significant difference, at α=0.05*

Regression analysis (Table 8, Figure 6) showed that across light levels, total dry biomass of the *S. macropodum* seedlings was linearly related to both stem diameter and total leaf number. Total biomass was also closely related to leaf area, and weakly stem height.

**Table 8. Regression correlation between total dry biomass (TM) to stem and leaf parameters.**

| Correlation | Model | $r^2$ | p | n | Fig. |
|---|---|---|---|---|---|
| TM to stem diameter (D) | TM = -25.39 + 55.65*D | 0.63 | 0.000 | 96 | 6.1 |
| TM to stem height (H) | TM = -14.10 + 0.64*H | 0.50 | 0.000 | 96 | |
| TM to leaf number (LN) | TM = -15.12 + 2.14*LN | 0.68 | 0.000 | 96 | 6.3 |
| TM to leaf area (LA) | TM = -7.17 + 0.03*LA | 0.81 | 0.000 | 96 | 6.4 |

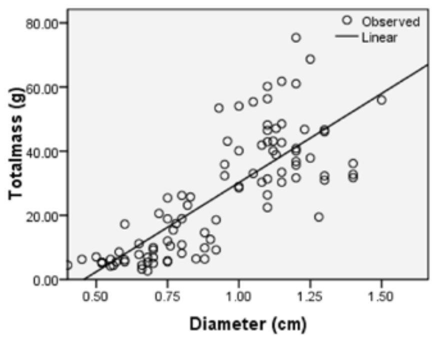



*Fig. 6.1: Total mass and Diameter*

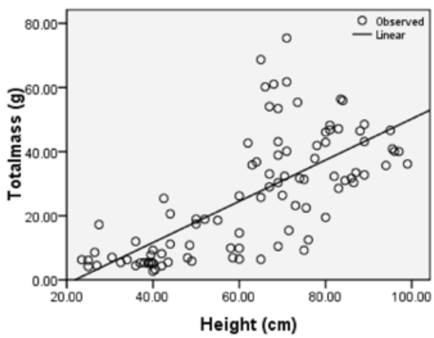



*Fig. 6.2: Total mass and Height*

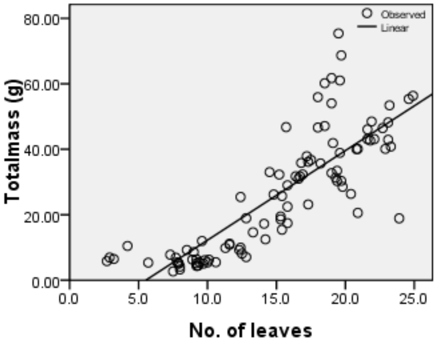



Fig. 6.3: *Total mass and Leaf number*

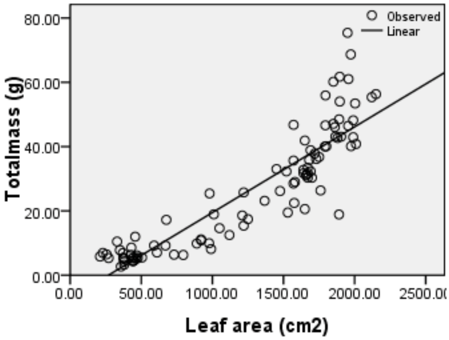



*Fig. 6.4: Total mass and Leaf area*

*Figure 6. Relationship between total dry biomass (TM) to different stem and leaf parameters (stem diameter, stem height, leaf number and leaf area)*

## *Growth response of S. macropodum seedlings to top breakage across light levels in the greenhouse*

## *Height (H) growth response of S. macropodum seedlings*

**Table 9. Height growth of *S. macropodum* under top breakage across light levels in the greenhouse**

| Light level | Treat. | Height (H) in cm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan-09 | Feb | Mar | Apr | May | Jun | Aug | Oct | Nov | Dec | Jan-10 |
| 12.5 % | Topped | 12.6 | 12.9 | 13.1 | 13.7 | 15.1 | 17.1 | 22.3 | 23.2 | 25.1 | 28.0 | 28.8 |
| | Cont. | 13.5 | 13.7 | 14.0 | 14.6 | 16.4 | 18.4 | 23.5 | 24.5 | 25.5 | 27.8 | 28.7 |
| 50 % | Topped | 12.6 | 13.0 | 13.4 | 15.4(*) | 19.2** | 27.7(*) | 44.7** | 47.5** | 50.3** | 53.1* | 56.0* |
| | Cont. | 12.4 | 12.6 | 14.9 | 17.9 | 25.1 | 32.8 | 58.9 | 62.6 | 66.4 | 70.1 | 73.9 |
| 100 % | Topped | 12.3 | 12.9 | 13.5** | 14.2** | 18.0*** | 25.5** | 44.8(*) | 48.9(*) | 53.1 | 57.2 | 61.3 |
| | Cont | 13.5 | 14.3 | 16.3 | 18.3 | 24.8 | 33.1 | 54.4 | 58.2 | 61.9 | 65.6 | 69.3 |

*t-test for significance levels: ***p<0.001, **p<0.01, *p≤0.05, (*)0.05<p≤0.1*

Height growth did not significantly differ between topped off plants and non-topped plants at 12.5 % irradiance, but plants at 50% irradiance were significantly lower than non-topped ones from the 4th month onwards, and at full sunlight the topped off plants were smaller than the non-topped ones, but this was statistically significant only for a short period in the middle of the experiment (Table 9).

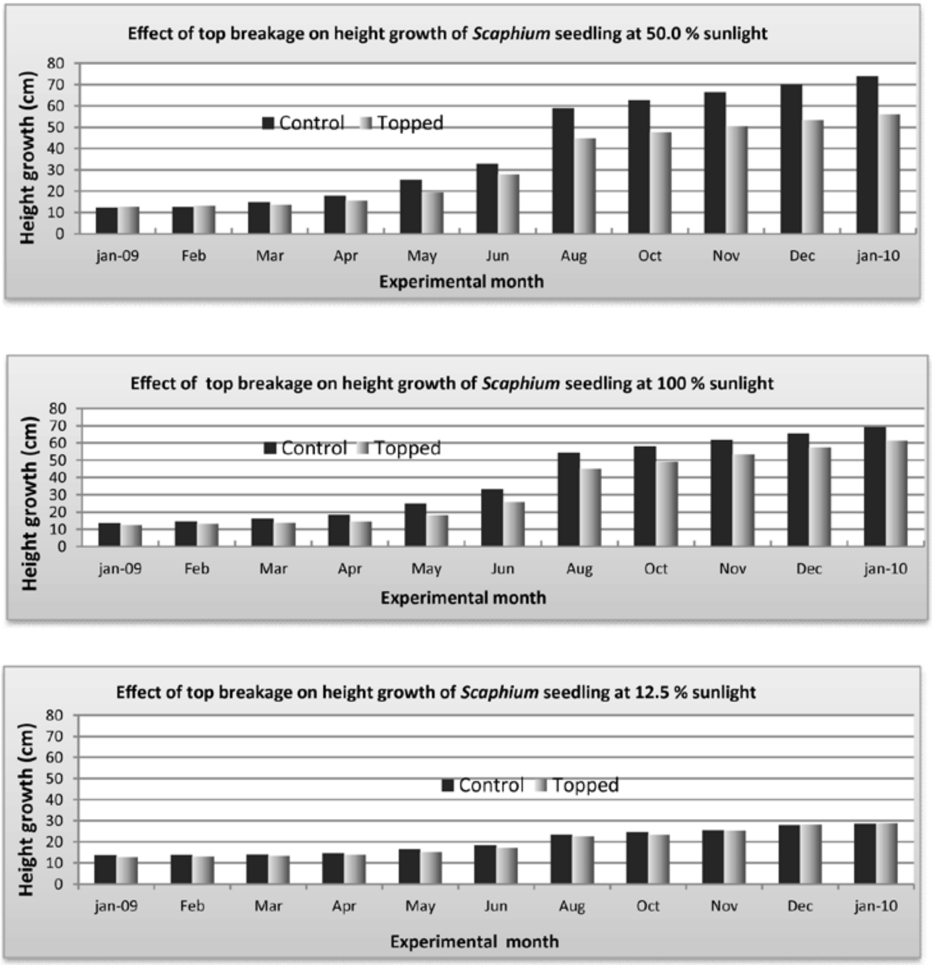



*Figure 7. Height growth of S. macropodum under top breakage across light levels in greenhouse*

## *Diameter (D) growth response of S. macropodum seedlings*

**Table 10. Diameter growth of *S. macropodum* under top breakage across light levels in greenhouse**

| Light level | Treat. | Diameter (D) in cm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan-09 | Feb | Mar | Apr | May | Jun | Aug | Oct | Nov | Dec | Jan-10 |
| 12.5 % | Topped | 0.32 | 0.32* | 0.33* | 0.34 | 0.36 | 0.37 | 0.39 | 0.42 | 0.46 | 0.51 | 0.55 |
| | Cont. | 0.32 | 0.34 | 0.35 | 0.35 | 0.36 | 0.38 | 0.40 | 0.44 | 0.47 | 0.52 | 0.56 |
| 50 % | Topped | 0.32 | 0.34 | 0.36 | 0.38 | 0.42(*) | 0.48(*) | 0.60* | 0.65* | 0.70(*) | 0.74(*) | 0.79 |
| | Cont. | 0.32 | 0.34 | 0.37 | 0.41 | 0.46 | 0.54 | 0.72 | 0.78 | 0.84 | 0.88 | 0.93 |
| 100 % | Topped | 0.33 | 0.35 | 0.37 | 0.39 | 0.44(*) | 0.51 | 0.65 | 0.71 | 0.77 | 0.81 | 0.86 |
| | Cont | 0.32 | 0.35 | 0.37 | 0.41 | 0.48 | 0.55 | 0.74 | 0.81 | 0.88 | 0.93 | 0.98 |

*t-test for significance levels: ***p<0.001, **p<0.01, *p≤0.05, (*)0.05<p≤0.1*

At any of the light levels there was no significant difference in diameter growth between topped off plants and non-topped ones, though at the 50 % light level there appeared a tendency to smaller diameters in topped off plants (Table 10).

### *Effect of top breakage on survival rate of S. macropodum*

**Table 11. Survival rate of *S. macropodum* under top breakage across light levels in greenhouse**

| Light level | Treat. | Survival rate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan-09 | Feb | Mar | Apr | May | Jun | Aug | Oct | Nov | Dec | Jan-10 |
| 12.5 % | Topped | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.94[a] | 1.00 | 1.00 | 0.87* [a] | 0.77 [b] | 1.00 |
| | Cont. | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.86 | 1.00 |
| 50 % | Topped | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00[a] | 1.00 | 1.00 | 1.00a | 1.00 [a] | 1.00 |
| | Cont. | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 100 % | Topped | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00[a] | 1.00 | 1.00 | 1.00 [a] | 1.00[a] | 1.00 |
| | Cont | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*T-test for significance levels:* ***p<0.001, **p<0.01, *p≤0.05, (*)0.05<p≤0.1
*Anova Post Hoc Multiple Comparison Test:* *different "letters" per column indicate significant difference, at α=0.05*

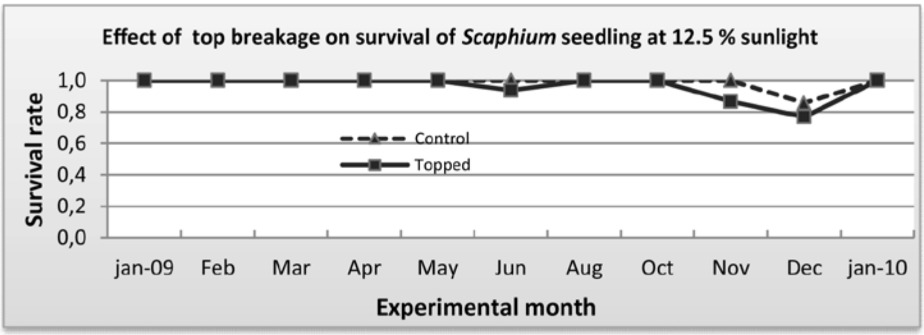



*Figure 8. Survival rate of S. macropodum under top breakage in the greenhouse.*

Mortality was only significantly higher in topped off plants as compared to control at low irradiance (12.5 %) in November, and significantly higher as compared to plants at higher light levels in December; June and November mortality data also were higher but non-significant. At this low level of irradiance, the accumulated rate of the mortality of the topped off plants for the whole period of the experiment was as high as 37.5 % and the control also showed 14 % mortality in December (Table 11).

### *Effect of top breakage on new shoot re-growth of S. macropodum*

**Table 12. Average number of re-grown shoots of *S. macropodum* after top breakage in the greenhouse.**

| Light level | Treat. | New shoot regrowth rate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan-09 | Feb | Mar | Apr | May | Jun | Aug | Oct | Nov | Dec | Jan-10 |
| 12.5 % | Topped | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Control | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 50 % | Topped | 1.00 | 0.00 | 1.00 | 1.19(*) | 1.19(*) | 1.19(*) | 1.19(*) | 1.19(*) | 1.19(*) | 1.19(*) | 1.19(*) |
| | Control | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 100 % | Topped | 1.00 | 0.00 | 1.00 | 1.25 | 1.13 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| | Control | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*t-test for significance levels: ***p<0.001, **p<0.01, *p≤0.05, (*)0.05<p≤0.1*

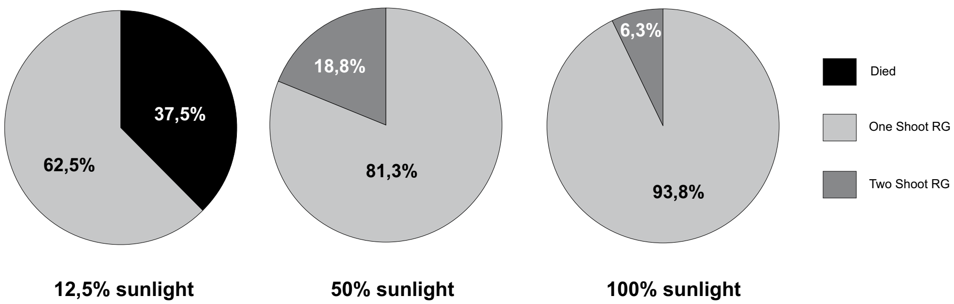



*Figure 9. Responses of S. macropodum plants to topped off shoots under different light levels*

At 12.5 % irradiance all topped off *S. macropodum* seedlings responded with growing only one new shoot (Fig. 9). At 50 %, 18.8 % of the topped off plants grew two new shoots and 81.3 % only one new shoot. At full irradiance, the topped off plants initially responded with either one, two or three new shoots but finally, only 6.3 % of the plants grew with two new shoots and 93.8 % with only one new shoot (Table 12 and Fig. 9).

### *Effect on growth ratios of S. macropodum under different light levels in the greenhouse*

**Table 13. Growth ratio analysis of *S. macropodum* under top breakage in greenhouse**

| Sunlight | Treatments | Growth Parameters | | | | | |
|---|---|---|---|---|---|---|---|
| | | RGR | NAR | LAR | LWR | SLA | R-S ratio |
| 12.5 % | Topped | 0.120 | 1.020 | 0.107 | 0.429 | 0.268 | 0.980 |
| | Control | 0.108 | 1.284 | 0.090 | 0.507 | 0.185 | 1.232 |
| 50 % | Topped | 0.227 | 2.946 | 0.083 | 0.435 | 0.202 | 0.684 |
| | Control | 0.255 | 4.427 | 0.075 | 0.463 | 0.164 | 0.779 |
| 100 % | Topped | 0.257 | 3.719 | 0.086 | 0.429 | 0.201 | 0.724 |
| | Control | 0.271 | 5.962 | 0.066 | 0.437 | 0.152 | 0.855 |

*Relative growth rate (RGR): mg $mg^{-1}month^{-1}$*
*Net assimilation rate (NAR): mg $cm^{-2}month^{-1}$*
*Leaf area ratio (LAR): $cm^2$ $mg^{-1}$ dry mass*
*Leaf weight ratio (LWR): mg $mg^{-1}$*
*Specific leaf area (SLA): $cm^2$ $mg^{-1}$ dry mass*
*Root - shoot ratio (R-S ratio): mg $mg^{-1}$*

At 50 % and 100 % irradiance the topped off *S. macropodum* plants showed lower RGR values than those of the control (t-test, significant level of $0.05<p\leq0.1$), but at 12.5% irradiance, the topped off plants had higher RGR values as compared to the control ($0.05<p\leq0.1$).

Topped off plants at all irradiance levels showed lower NAR values as compared to control ($p<0.05$), while both their LAR and SLA values were higher than in the control, and the LWR were lower ($0.05<p\leq0.1$).

## Discussion

### *Effects of different irradiance levels on growth of S. macropodum seedlings in the Greenhouse*

#### *Height (H) and diameter (D) growth*

The effects of different levels of irradiance on height (H) and diameter (D) growth of *S. macropodum* seedlings in the greenhouse experiment showed two clearly different stages during the experiment:

During the first stage, height growth was strongest at 25% irradiance and lowest at full irradiance. This is possibly due to photo-inhibition at high irradiance, as chlorophyll a/b ratios suggest, in the early growth stage of the seedlings. But this pattern may also result from etiolation at the lower light treatments (see also Lambers et al. 2008). *S. macropodum* is considered a common shade-tolerant, but later emergent, tree species in tropical rainforests (Yamada and Suzuki 1996). In such species, etiolation promotes the height growth of the young plants, but as the young plants also have to be adapted to low light availability, at higher light levels photo-inhibition may easily occur.

In the second stage (as from month 8) the pattern reverses and strongest height growth is at the higher light levels. The reason for this reverse in pattern seems caused by the fact that initial strong height growth at low light levels depends on etiolation but these plants do not acquire a high amount of carbohydrates at these low light levels. Thus, finally their height growth has to slowdown. The plants at higher light levels, however, acquire steadily more carbohydrates and use these, amongst other, for height growth. Photo-inhibition still seems to play a role, as height growth is strongest at 50 % irradiance, and photosynthetic rates there are also highest. This result seems consistent with the experience that *S. macropodum* seedlings of up to 3 months old in a nursery need shading of 50 % for sustaining their normal growth (Duong 1995).

Diameter growth was somewhat similar to height growth: strongest diameter growth was found at full and 50 % light levels and lowest at the lowest light level (12.5 %) but and this difference was significant only in the second stage. Again here this can be explained by the plants at higher light levels acquiring more carbohydrates and using these to construct thicker stems which they need, because their height and leaf mass also are larger and this requires stronger stems (Niklas 1992).

In the forest, Suzuki (1997) found that the *S. macropodum* can survive under closed canopies as suppressed seedlings, but it requires a gap for growth and successful regeneration. Seedling growth increased with increasing light levels in the forest, Higher light levels are essential for rapid vertical growth.

My results are also supported by the practical experiences in nursery production of this species by local farmers in Vietnam. Local farmers produce their *S. macropodum* seedlings just based on their own experience with regard to light availability. In order to produce good *S. macropodum* seedlings, they apply a shading of 50-60 % irradiance at the very early stage of the seedlings; then as the seedlings grow up, they gradually reduce the shade and give more light (Kuchelmeister and Huy 2004).

We found that in *S. macropodum* the season with strong height growth was from April to October. After that, from November to February, its growth rate is very low and plants partly shed their leaves. This is mirrored in the actual seasonal planting practice of local farmers in the *S. macropodum* regions. The farmers do their *S. macropodum* planting in the field in December, at the time of its lowest growth rate, and the planted seedlings can start new rooting and shooting with the new growing season in March, April (Kuchelmeister and Huy 2004, Huy et al. 2010a).

***Effects on chlorophyll a,b and photosynthesis intensity (Pn)***

Contents of chlorophyll a and b (a+b) of *S. macropodum* leaves were found highest at the lowest light level (12.5 %) and lowest at high irradiance. This is in accordance with other studies that found that shade tolerant plants have increased leaf thickness and higher chlorophyll concentrations per unit leaf area and therefore their leaves have dark-green colors (Lambers et al. 2008); whereas at higher to full irradiance, their SLA decreased, but their chlorophyll tended to disintegrate at such high irradiance levels (Kramer and Kozlowski 1979), leading to lower chlorophyll concentrations and their leaves did not look dark-green but lighter.

The photosynthetic rate (Pn) showed highest values at 50 % irradiance, and was much higher as compared to that at full irradiance. This would indicate that photo-inhibition seems to occur at the full light level.

***Growth ratios and their correlations***

Across the light levels, the RGR was maximal at 50 % sunlight (0.199) and a just a little bit lower at full irradiance 100 % (0.198). This suggests that both treatments are near light saturation.

NAR is closely correlated with the photosynthetic capacity of plants (Poorter and van der Werf 1998). In my study NAR increased (from 1.105 to 3.789) with increase of light levels. LAR and SLA were both high (0.108 and 0.268 respectively) at the lowest light level (12.5 %), and much less (0.074 and 0.175 respectively) at full light. These results are consistent with those reported previously (Villar et al. 1998, Montgomery 2004, Poorter et al. 2005, Lambers et al. 2008).

Across the light levels, the RGR positively and linearly correlated with NAR, whereas, it negatively correlated with LAR and SLA. Again these results are consistent with those previously reported by Villar et al. (1998) and Lambers et al. (2008); however Poorter and van der Werf (1998) argued that RGR is always highly correlated to LAR, but usually not correlated to NAR.

In this study, NAR negatively correlated with SLA, and both RGR and NAR increased with increasing light availability, whereas LAR and SLA both decreased with the increase in light level (Table 4). Again these results are consistent with those of Villar et al. (1998) and Montgomery (2004). It is evident that the *S. macropodum* seedlings in my growth experiment across light levels showed the expected growth responses, as have been found for many other species in various experiments.

***Biomass allocation pattern of S. macropodum seedlings***

In my study, biomass allocation to the leaves ranged from 33.7 % to 38.1 % (Table 6). This is comparable to values that Menalled and Kelty (2001) reported as normal and much higher than the 10 % that Küppers (1985) states as normal. Obviously, investment in leaves also responds to light levels (cf Montgomery 2004): in the low light treatments investment in leaves was somewhat higher that under better illumination.

Several authors argued that woody plants with inherently different intensities of branching show different grow patterns: in inherently strongly branched plants biomass is reported to be closely related to the total number of leaves, while in less branched plants biomass is related to stem size (Bazzaz and Harper 1977, Harper 1989, Schmid and Bazzaz 1994, Menalled and Kelty 2001). *S. macropodum* is not a strongly branched tree (Kostermans 1953, Yamada and Suzuki 1999, Huy et al. 2010a) and across different light levels, total dry biomass of the *S. macropodum* seedlings was linearly correlated to both their stem diameter and to leaf numbers (Table 8). It is possible that this result is an effect of the growth pattern at the seedling stage, and that at the adult stage of *S. macropodum* another pattern might emerge.

***Effect of top breakage on S. macropodum growth in greenhouse***

The seedlings of *S. macropodum* grow up, over several years in tropical forest. During their seedling and also their juvenile stages they are subject to disturbance caused by falling debris and branches from the taller trees around. This often causes the tops of the seedling or juvenile to break off. In order to analyze the resulting effects of top breakage we performed the top breakage experiment in the greenhouse.

***Effect on height (H) and diameter (D) growth***

At low light availability (12.5 %), no significance difference in H between topped-off and control plants was found, but at 50 % light availability topped-off plants remained significantly lower than in the control as from month 4 onward, whereas at full light level they were significantly lower only for a period in the middle of the experiment (Table 9). Thus, topped-off plants under high light availability manage to quickly recover the lost height growth (Halle et al. 1978, Moravec 1990, Bellingham et al. 1994, Sakai et al. 1995, Yamada et al. 2001).

As expected, the effects of the top breakage on diameter growth was not significant. Breaking the top off does hardly affect the weight balance of the stem, and thus no effect on diameter growth is to be expected.

***Effect on survival rate***

Low light treatment itself seems to affect mortality, independent of breakage, as the December data and mortality accumulated at 12.5 % light suggest. Increased mortality after topping-off was found only at low irradiance (12.5 %). Apparently top breakage usually does not significantly affect the rate of survival; only for November we found an exception to this. In a field study on the re-growth of seedlings of *Fagus crenata* and *F. japonica* after having been topped-off by grazing deer it was found that 37.6 % and 60 %, respectively, of the seedlings died, whereas 25 % of the seedlings first re-grew shoots but subsequently still died, and only 15% and 36 % respectively re-grew and survived (Ishuzuka et al. 2010).

***Effect on new shoot re-growth***

All topped off plants that survived at 12.5 % light availability grew with only one new shoot (Table 12 and Fig. 9). At 50 % one fifth grew with two new shoots, and at full light topped off plants initially often responded with growing two or three new shoots, but later self-pruned some of the new shoots, so that most of the plants re-grew with one new shoot (Table 12 and Fig. 9). This shows that *S. macropodum* juveniles have an excellent capacity to recover from top breakage, which is an important feature for young plants growing up in forest understorey where damage by falling debris is common. It also is an advantage to re-grow with a single new branch instead of several, as a stronger height growth can be realized by a single shoot, and thus the better illuminated environment higher in the forest canopy can be reached sooner. My results complement those of a field research on the sprouting of decumbent juveniles of *S. macropodum*: 43 % of the decumbent juveniles on the forest floor grew up by sprouting a new shoot (Yamada and Suzuki 1996, Yamada et al. 2001). On the other hand, re-sprouting more new shoots may be advantageous for farmers growing *S. macropodum*, provided that these regenerating plants reach the better illuminated parts of the canopy, because more shoots imply more fruits to be harvested.

## Acknowledgements

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# Annexes

## **Annex 1**. *S. macropodum* dried biomass of light experiment in greenhouse measured at T1 and T19

**Scaphium dried biomass of light ex. in greenhouse**

Date of Ex.: Aug 2008 to Feb 2010 Location: Nursery Greenhouse at FSIV, Chem, Hanoi

Date of measure: T1: 26 Sept 2008; T2: 27 Jan 2010

Plant age: 21 months at harvesting time

**Dried biomass measured at T2: 20-27 Jan 2010**

| Light treat-ment | Plant | R1 | | | | R2 | | | | R3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Leaf | Stem | Root | Leaf area | Leaf | Stem | Root | Leaf area | Leaf | Stem | Root | Leaf area |
| 12,5% | 1 | 4,31 | 3,15 | 1,78 | 590,0 | 2,22 | 1,47 | 0,79 | 446,0 | 2,89 | 1,63 | 0,90 | 476,0 |
| | 2 | 1,94 | 3,58 | 1,35 | 370,0 | 2,69 | 1,60 | 0,95 | 440,0 | 2,43 | 1,22 | 0,81 | 442,0 |
| | 3 | 0,48 | 3,10 | 1,78 | 270,0 | 2,26 | 1,85 | 1,11 | 379,0 | 1,98 | 2,14 | 1,34 | 375,0 |
| | 4 | 1,14 | 5,20 | 1,45 | 350,0 | 0,62 | 1,28 | 0,79 | 357,0 | 3,74 | 2,18 | 1,13 | 610,0 |
| | 5 | 5,53 | 9,82 | 1,89 | 676,0 | 1,40 | 2,46 | 1,23 | 465,0 | 1,69 | 1,67 | 0,81 | 380,0 |
| | 6 | 2,60 | 2,46 | 1,23 | 427,0 | 1,26 | 1,40 | 0,60 | 380,0 | 2,00 | 1,46 | 0,91 | 440,0 |
| | 7 | 3,50 | 7,51 | 0,98 | 457,0 | 2,56 | 1,30 | 1,16 | 376,0 | 2,27 | 2,04 | 1,20 | 447,0 |
| | 8 | 2,78 | 4,10 | 1,70 | 430,0 | 2,96 | 2,23 | 0,95 | 470,0 | 2,88 | 1,97 | 0,65 | 505,0 |
| **Mean** | | **2,79** | **4,87** | **1,52** | **446,3** | **2,00** | **1,70** | **0,95** | **414,1** | **2,49** | **1,79** | **0,97** | **459,4** |
| 25,0% | 1 | 1,14 | 5,87 | 3,46 | 330,0 | 6,28 | 7,09 | 5,57 | 1010,0 | 4,00 | 13,01 | 8,41 | 980,0 |
| | 2 | 10,60 | 8,84 | 3,72 | 1367,0 | 12,26 | 3,39 | 3,25 | 1890,0 | 3,42 | 3,75 | 2,68 | 890,0 |
| | 3 | 13,17 | 9,96 | 5,40 | 1570,0 | 6,30 | 5,29 | 3,03 | 1050,0 | 6,27 | 7,49 | 3,67 | 1250,0 |
| | 4 | 7,49 | 4,65 | 3,28 | 1220,0 | 0,59 | 3,56 | 1,68 | 210,0 | 3,98 | 4,00 | 2,84 | 920,0 |
| | 5 | 0,65 | 2,86 | 2,96 | 256,0 | 6,67 | 1,30 | 4,52 | 1120,0 | 0,30 | 3,95 | 2,67 | 230,0 |
| | 6 | 4,60 | 2,25 | 1,30 | 990,0 | 10,56 | 5,70 | 4,32 | 1650,0 | 3,76 | 5,02 | 2,38 | 920,0 |
| | 7 | 3,30 | 1,90 | 1,09 | 795,0 | 3,44 | 3,50 | 2,30 | 670,0 | 2,56 | 2,26 | 1,58 | 730,0 |
| | 8 | 4,36 | 3,96 | 1,63 | 977,0 | 9,50 | 11,28 | 4,95 | 1220,0 | 7,96 | 7,21 | 3,41 | 1210,0 |
| **Mean** | | **5,66** | **5,04** | **2,86** | **938,1** | **6,95** | **5,14** | **3,70** | **1102,5** | **4,03** | **5,84** | **3,46** | **891,3** |
| 50,0% | 1 | 16,78 | 16,82 | 9,06 | 1880,0 | 23,50 | 20,12 | 11,75 | 2120,1 | 8,10 | 12,22 | 10,00 | 1700,1 |
| | 2 | 16,82 | 15,95 | 10,34 | 1865,0 | 9,00 | 13,64 | 8,69 | 1660,7 | 16,29 | 21,15 | 8,62 | 1860,5 |
| | 3 | 19,07 | 19,99 | 9,43 | 1890,7 | 12,99 | 14,40 | 12,65 | 1790,6 | 16,02 | 14,03 | 13,05 | 1905,2 |
| | 4 | 20,07 | 18,79 | 9,33 | 1990,0 | 12,89 | 14,00 | 12,00 | 1690,3 | 14,47 | 13,32 | 12,31 | 1800,3 |
| | 5 | 10,62 | 14,66 | 8,15 | 1670,0 | 8,26 | 12,89 | 9,16 | 1670,2 | 13,06 | 8,39 | 4,90 | 1760,7 |
| | 6 | 19,85 | 12,72 | 7,54 | 1975,0 | 17,01 | 18,02 | 11,43 | 1955,3 | 25,49 | 21,00 | 9,84 | 2150,0 |
| | 7 | 19,85 | 13,80 | 7,17 | 2010,0 | 17,30 | 14,11 | 11,50 | 1990,2 | 21,67 | 20,93 | 10,83 | 2003,2 |
| | 8 | 10,07 | 16,74 | 15,08 | 1650,0 | 8,91 | 15,28 | 8,55 | 1640,0 | 13,00 | 14,81 | 7,86 | 1570,2 |
| **Mean** | | **16,64** | **16,18** | **9,51** | **1866,3** | **13,73** | **15,31** | **10,72** | **1814,7** | **16,01** | **15,73** | **9,68** | **1843,8** |
| 100% | 1 | 10,43 | 14,72 | 6,54 | 1670,2 | 24,93 | 26,21 | 17,54 | 1972,7 | 29,23 | 28,36 | 17,80 | 1950,3 |
| | 2 | 18,77 | 22,56 | 20,42 | 1895,1 | 19,58 | 14,30 | 13,22 | 1850,5 | 18,30 | 23,24 | 12,49 | 1895,5 |
| | 3 | 19,59 | 27,15 | 14,28 | 1957,0 | 17,12 | 21,61 | 17,20 | 1795,2 | 8,79 | 12,95 | 9,99 | 1640,7 |
| | 4 | 15,23 | 18,32 | 13,08 | 1794,1 | 14,44 | 12,98 | 10,44 | 1720,1 | 9,60 | 10,95 | 10,44 | 1660,3 |
| | 5 | 11,55 | 13,70 | 10,90 | 1730,0 | 13,23 | 11,17 | 7,88 | 1520,7 | 14,72 | 13,94 | 8,11 | 1750,2 |
| | 6 | 6,99 | 8,64 | 3,85 | 1530,0 | 11,91 | 11,55 | 5,55 | 1580,4 | 13,19 | 12,54 | 10,12 | 1680,3 |
| | 7 | 8,46 | 7,89 | 6,11 | 1575,2 | 9,49 | 15,44 | 8,09 | 1450,7 | 16,80 | 22,69 | 20,68 | 1850,7 |
| | 8 | 5,89 | 12,87 | 7,42 | 1475,5 | 10,78 | 11,75 | 9,80 | 1690,2 | 12,34 | 16,45 | 17,98 | 1570,7 |
| **Mean** | | **12,11** | **15,73** | **10,33** | **1703,4** | **15,19** | **15,63** | **11,22** | **1697,6** | **15,37** | **17,64** | **13,45** | **1749,8** |

## **Annex 1**. *S. macropodum* dried biomass of light experiment in greenhouse measured at T1 and T19 (cont.)

**Scaphium dried biomass of light ex. in greenhouse**

Date of Ex.: Aug 2008 to Feb 2010 | Location: Nursery Greenhouse at FSIV, Chem, Hanoi

Date of measure: T1: 26 Sept 2008; T2: 27 Jan 2010

Plant age: 21 months at harvesting time

**Dried biomass measured at T1: 20-26 Sept 2008**

| Light treat-ment | Plant | R1 | | | | R2 | | | | R3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Leaf | Stem | Root | Leaf area | Leaf | Stem | Root | Leaf area | Leaf | Stem | Root | Leaf area |
| 12,5% | 1 | 0,13 | 0,26 | 0,33 | 135,0 | 0,27 | 0,33 | 0,56 | 147,0 | 0,27 | 0,52 | 0,71 | 167,0 |
| | 2 | 0,22 | 0,35 | 0,67 | 148,0 | 0,18 | 0,29 | 0,55 | 152,0 | 0,15 | 0,69 | 1,09 | 185,0 |
| | 3 | 0,16 | 0,30 | 0,30 | 121,0 | 0,24 | 0,53 | 0,36 | 135,0 | 0,17 | 0,31 | 0,38 | 138,0 |
| | 4 | 0,45 | 0,63 | 1,42 | 182,0 | 0,10 | 0,40 | 0,39 | 143,0 | 0,21 | 0,30 | 0,30 | 137,0 |
| | 5 | 0,19 | 0,39 | 0,52 | 151,0 | 0,18 | 0,30 | 0,66 | 158,0 | 0,19 | 0,43 | 0,79 | 169,0 |
| | 6 | 0,13 | 0,66 | 0,75 | 165,0 | 0,25 | 0,22 | 0,38 | 138,0 | 0,20 | 0,41 | 0,40 | 147,0 |
| | 7 | 0,12 | 0,31 | 0,47 | 125,0 | 0,15 | 0,38 | 0,44 | 148,0 | 0,17 | 0,45 | 0,60 | 156,0 |
| | 8 | 0,37 | 0,53 | 0,78 | 157,0 | 0,23 | 0,37 | 0,34 | 130,0 | 0,21 | 0,33 | 0,32 | 135,0 |
| **Mean** | | **0,22** | **0,43** | **0,66** | **148,0** | **0,20** | **0,35** | **0,46** | **143,9** | **0,20** | **0,43** | **0,57** | **154,3** |
| 25,0% | 1 | 0,34 | 0,63 | 0,96 | 151,0 | 0,18 | 0,43 | 0,72 | 147,0 | 0,16 | 0,33 | 0,44 | 112,0 |
| | 2 | 0,37 | 0,57 | 0,85 | 136,0 | 0,31 | 0,51 | 0,77 | 160,0 | 0,29 | 0,46 | 0,83 | 174,0 |
| | 3 | 0,23 | 0,39 | 0,87 | 140,0 | 0,16 | 0,44 | 0,52 | 122,0 | 0,19 | 0,40 | 0,80 | 176,0 |
| | 4 | 0,37 | 0,53 | 0,81 | 134,0 | 0,26 | 0,40 | 0,65 | 136,0 | 0,17 | 0,34 | 0,38 | 67,0 |
| | 5 | 0,23 | 0,42 | 0,89 | 151,0 | 0,31 | 0,47 | 0,76 | 159,0 | 0,35 | 0,48 | 0,65 | 145,0 |
| | 6 | 0,43 | 0,72 | 1,04 | 171,0 | 0,32 | 0,60 | 0,60 | 130,0 | 0,23 | 0,32 | 0,38 | 85,0 |
| | 7 | 0,30 | 0,62 | 0,75 | 125,0 | 0,37 | 0,58 | 0,78 | 157,0 | 0,44 | 0,61 | 0,74 | 165,0 |
| | 8 | 0,21 | 0,32 | 0,40 | 75,0 | 0,15 | 0,33 | 0,53 | 115,0 | 0,32 | 0,46 | 0,80 | 154,0 |
| **Mean** | | **0,31** | **0,53** | **0,82** | **135,4** | **0,26** | **0,47** | **0,67** | **140,8** | **0,27** | **0,43** | **0,63** | **134,8** |
| 50,0% | 1 | 0,38 | 0,60 | 0,57 | 158,2 | 0,20 | 0,39 | 0,62 | 165,0 | 0,20 | 0,30 | 0,53 | 158,5 |
| | 2 | 0,38 | 0,61 | 0,71 | 165,3 | 0,40 | 0,42 | 0,65 | 161,3 | 0,21 | 0,32 | 0,53 | 160,1 |
| | 3 | 0,51 | 0,63 | 0,72 | 167,1 | 0,21 | 0,32 | 0,53 | 160,1 | 0,51 | 0,82 | 0,43 | 145,7 |
| | 4 | 0,36 | 0,41 | 0,63 | 137,7 | 0,25 | 0,50 | 0,53 | 160,7 | 0,21 | 0,33 | 0,43 | 147,1 |
| | 5 | 0,40 | 0,66 | 0,75 | 162,5 | 0,32 | 0,47 | 0,61 | 165,3 | 0,25 | 0,50 | 0,52 | 161,5 |
| | 6 | 0,32 | 0,64 | 0,68 | 162,1 | 0,21 | 0,32 | 0,53 | 160,1 | 0,29 | 0,40 | 0,50 | 150,4 |
| | 7 | 0,39 | 0,34 | 0,57 | 140,6 | 0,40 | 0,45 | 0,70 | 163,4 | 0,38 | 0,60 | 0,51 | 157,2 |
| | 8 | 0,40 | 0,45 | 0,70 | 163,4 | 0,30 | 0,45 | 0,42 | 140,5 | 0,41 | 0,45 | 0,70 | 163,4 |
| **Mean** | | **0,39** | **0,54** | **0,67** | **157,1** | **0,29** | **0,42** | **0,57** | **159,6** | **0,31** | **0,47** | **0,52** | **155,5** |
| 100% | 1 | 0,29 | 0,70 | 1,10 | 143,2 | 0,22 | 0,32 | 0,42 | 128,6 | 0,33 | 0,39 | 0,62 | 134,6 |
| | 2 | 0,13 | 0,45 | 0,70 | 137,7 | 0,24 | 0,48 | 0,65 | 141,2 | 0,29 | 0,57 | 0,99 | 147,6 |
| | 3 | 0,25 | 0,53 | 0,58 | 125,8 | 0,22 | 0,31 | 0,40 | 129,5 | 0,12 | 0,47 | 0,83 | 144,7 |
| | 4 | 0,21 | 0,69 | 1,11 | 147,2 | 0,18 | 0,62 | 0,82 | 143,5 | 0,18 | 0,56 | 0,68 | 135,3 |
| | 5 | 0,25 | 0,66 | 1,03 | 149,2 | 0,26 | 0,38 | 0,47 | 127,6 | 0,15 | 0,35 | 0,39 | 127,4 |
| | 6 | 0,23 | 0,35 | 0,57 | 128,6 | 0,52 | 0,45 | 0,70 | 141,2 | 0,23 | 0,46 | 0,68 | 138,9 |
| | 7 | 0,32 | 0,49 | 0,88 | 130,2 | 0,40 | 0,37 | 0,61 | 143,5 | 0,28 | 0,37 | 0,61 | 130,2 |
| | 8 | 0,27 | 0,30 | 0,41 | 125,7 | 0,25 | 0,43 | 0,59 | 134,9 | 0,18 | 0,35 | 0,66 | 135,7 |
| **Mean** | | **0,24** | **0,52** | **0,80** | **136,0** | **0,29** | **0,42** | **0,58** | **136,3** | **0,22** | **0,44** | **0,68** | **136,8** |

**Annex 2**. Different growth parameters of *S. macropodum* plants at biomass measurement T19

| Dried biomass measured at T19: 20-27 Jan 2010 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Light treat.** | **Plant** | **D (cm)** | **H (cm)** | **Leaf (g)** | **Stem (g)** | **Root (g)** | **Leaf area ($cm^2$)** | **Total mass (g)** | **No. of leaves** |
| 12.5% | 1 | 0.70 | 40.0 | 4.31 | 3.15 | 1.78 | 590.0 | 9.2 | 12.3 |
| | 2 | 0.68 | 48.0 | 1.94 | 3.58 | 1.35 | 370.0 | 6.9 | 7.7 |
| | 3 | 0.68 | 38.0 | 0.48 | 3.10 | 1.78 | 270.0 | 5.4 | 5.7 |
| | 4 | 0.65 | 39.5 | 1.14 | 5.20 | 1.45 | 350.0 | 7.8 | 7.3 |
| | 5 | 0.60 | 27.5 | 5.53 | 9.82 | 1.89 | 676.0 | 17.2 | 14.1 |
| | 6 | 0.45 | 23.5 | 2.60 | 2.46 | 1.23 | 427.0 | 6.3 | 8.9 |
| | 7 | 0.75 | 36.0 | 3.50 | 7.51 | 0.98 | 457.0 | 12.0 | 9.6 |
| | 8 | 0.58 | 26.5 | 2.78 | 4.10 | 1.70 | 430.0 | 8.6 | 9.0 |
| | 9 | 0.40 | 27.0 | 2.22 | 1.47 | 0.79 | 446.0 | 4.5 | 9.3 |
| | 10 | 0.52 | 37.0 | 2.69 | 1.60 | 0.95 | 440.0 | 5.2 | 9.2 |
| | 11 | 0.52 | 40.0 | 2.26 | 1.85 | 1.11 | 379.0 | 5.2 | 7.9 |
| | 12 | 0.68 | 40.0 | 0.62 | 1.28 | 0.79 | 357.0 | 2.7 | 7.5 |
| | 13 | 0.52 | 39.0 | 1.40 | 2.46 | 1.23 | 465.0 | 5.1 | 9.7 |
| | 14 | 0.66 | 40.5 | 1.26 | 1.40 | 0.60 | 380.0 | 3.3 | 8.0 |
| | 15 | 0.70 | 40.0 | 2.56 | 1.30 | 1.16 | 376.0 | 5.0 | 7.9 |
| | 16 | 0.60 | 25.0 | 2.96 | 2.23 | 0.95 | 470.0 | 6.1 | 9.8 |
| | 17 | 0.52 | 32.5 | 2.89 | 1.63 | 0.90 | 476.0 | 5.4 | 10.0 |
| | 18 | 0.66 | 36.0 | 2.43 | 1.22 | 0.81 | 442.0 | 4.5 | 9.3 |
| | 19 | 0.57 | 39.5 | 1.98 | 2.14 | 1.34 | 375.0 | 5.5 | 7.8 |
| | 20 | 0.50 | 30.5 | 3.74 | 2.18 | 1.13 | 610.0 | 7.1 | 12.8 |
| | 21 | 0.55 | 25.0 | 1.69 | 1.67 | 0.81 | 380.0 | 4.2 | 8.0 |
| | 22 | 0.56 | 42.0 | 2.00 | 1.46 | 0.91 | 440.0 | 4.4 | 9.2 |
| | 23 | 0.75 | 43.5 | 2.27 | 2.04 | 1.20 | 447.0 | 5.5 | 9.4 |
| | 24 | 0.60 | 39.0 | 2.88 | 1.97 | 0.65 | 505.0 | 5.5 | 10.6 |

**Annex 2**. Different growth parameters of *S. macropodum* plants at biomass measurement T19 (cont.)

| Dried biomass measured at T19: 20-27 Jan 2010 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Light treat. | Plant | D (cm) | H (cm) | Leaf (g) | Stem (g) | Root (g) | Leaf area ($cm^2$) | Total mass (g) | No. of leaves |
| 25.0% | 25 | 0.76 | 69.0 | 1.14 | 5.87 | 3.46 | 330.0 | 10.5 | 4.2 |
| | 26 | 0.82 | 73.0 | 10.60 | 8.84 | 3.72 | 1367.0 | 23.2 | 17.3 |
| | 27 | 1.00 | 83.0 | 13.17 | 9.96 | 5.40 | 1570.0 | 28.5 | 19.8 |
| | 28 | 0.77 | 71.5 | 7.49 | 4.65 | 3.28 | 1220.0 | 15.4 | 15.4 |
| | 29 | 0.85 | 60.0 | 0.65 | 2.86 | 2.96 | 256.0 | 6.5 | 3.2 |
| | 30 | 0.80 | 42.0 | 4.60 | 2.25 | 1.30 | 990.0 | 8.2 | 12.5 |
| | 31 | 0.55 | 34.0 | 3.30 | 1.90 | 1.09 | 795.0 | 6.3 | 10.1 |
| | 32 | 0.70 | 58.0 | 4.36 | 3.96 | 1.63 | 977.0 | 10.0 | 12.4 |
| | 33 | 0.80 | 50.0 | 6.28 | 7.09 | 5.57 | 1010.0 | 18.9 | 12.8 |
| | 34 | 0.75 | 52.0 | 12.26 | 3.39 | 3.25 | 1890.0 | 18.9 | 23.9 |
| | 35 | 0.88 | 60.0 | 6.30 | 5.29 | 3.03 | 1050.0 | 14.6 | 13.3 |
| | 36 | 0.75 | 49.0 | 0.59 | 3.56 | 1.68 | 210.0 | 5.8 | 2.7 |
| | 37 | 0.90 | 76.0 | 6.67 | 1.30 | 4.52 | 1120.0 | 12.5 | 14.2 |
| | 38 | 0.72 | 44.0 | 10.56 | 5.70 | 4.32 | 1650.0 | 20.6 | 20.9 |
| | 39 | 0.92 | 75.0 | 3.44 | 3.50 | 2.30 | 670.0 | 9.2 | 8.5 |
| | 40 | 0.83 | 65.0 | 9.50 | 11.28 | 4.95 | 1220.0 | 25.7 | 15.4 |
| | 41 | 0.75 | 42.5 | 4.00 | 13.01 | 8.41 | 980.0 | 25.4 | 12.4 |
| | 42 | 0.88 | 60.0 | 3.42 | 3.75 | 2.68 | 890.0 | 9.9 | 11.3 |
| | 43 | 0.78 | 50.0 | 6.27 | 7.49 | 3.67 | 1250.0 | 17.4 | 15.8 |
| | 44 | 0.80 | 48.5 | 3.98 | 4.00 | 2.84 | 920.0 | 10.8 | 11.6 |
| | 45 | 0.70 | 58.5 | 0.30 | 3.95 | 2.67 | 230.0 | 6.9 | 2.9 |
| | 46 | 0.65 | 44.0 | 3.76 | 5.02 | 2.38 | 920.0 | 11.2 | 11.6 |
| | 47 | 0.88 | 65.0 | 2.56 | 2.26 | 1.58 | 730.0 | 6.4 | 9.2 |
| | 48 | 0.92 | 55.0 | 7.96 | 7.21 | 3.41 | 1210.0 | 18.6 | 15.3 |

**Annex 2**. Different growth parameters of *S. macropodum* plants at biomass measurement T19 (cont.)

| Dried biomass measured at T19: 20-27 Jan 2010 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Light treat. | Plant | D (cm) | H (cm) | Leaf (g) | Stem (g) | Root (g) | Leaf area ($cm^2$) | Total mass (g) | No. of leaves |
| 50.0% | 49 | 1.15 | 62.0 | 16.78 | 16.82 | 9.06 | 1880.0 | 42.7 | 21.8 |
| | 50 | 1.12 | 89.0 | 16.82 | 15.95 | 10.34 | 1865.0 | 43.1 | 21.6 |
| | 51 | 1.15 | 89.0 | 19.07 | 19.99 | 9.43 | 1890.7 | 48.5 | 21.9 |
| | 52 | 1.10 | 81.0 | 20.07 | 18.79 | 9.33 | 1990.0 | 48.2 | 23.1 |
| | 53 | 1.15 | 87.0 | 10.62 | 14.66 | 8.15 | 1670.0 | 33.4 | 19.4 |
| | 54 | 1.00 | 71.0 | 19.85 | 12.72 | 7.54 | 1975.0 | 40.1 | 22.9 |
| | 55 | 1.20 | 95.5 | 19.85 | 13.80 | 7.17 | 2010.0 | 40.8 | 23.3 |
| | 56 | 1.08 | 78.0 | 10.07 | 16.74 | 15.08 | 1650.0 | 41.9 | 19.1 |
| | 57 | 1.05 | 73.5 | 23.50 | 20.12 | 11.75 | 2120.1 | 55.4 | 24.6 |
| | 58 | 1.10 | 75.0 | 9.00 | 13.64 | 8.69 | 1660.7 | 31.3 | 19.3 |
| | 59 | 1.20 | 97.0 | 12.99 | 14.40 | 12.65 | 1790.6 | 40.0 | 20.8 |
| | 60 | 1.13 | 69.0 | 12.89 | 14.00 | 12.00 | 1690.3 | 38.9 | 19.6 |
| | 61 | 1.15 | 69.0 | 8.26 | 12.89 | 9.16 | 1670.2 | 30.3 | 19.4 |
| | 62 | 1.10 | 88.0 | 17.01 | 18.02 | 11.43 | 1955.3 | 46.5 | 22.7 |
| | 63 | 1.10 | 80.0 | 17.30 | 14.11 | 11.50 | 1990.2 | 42.9 | 23.1 |
| | 64 | 1.40 | 89.0 | 8.91 | 15.28 | 8.55 | 1640.0 | 32.7 | 19.0 |
| | 65 | 1.08 | 86.5 | 8.10 | 12.22 | 10.00 | 1700.1 | 30.3 | 19.7 |
| | 66 | 1.30 | 80.0 | 16.29 | 21.15 | 8.62 | 1860.5 | 46.1 | 21.6 |
| | 67 | 0.96 | 69.0 | 16.02 | 14.03 | 13.05 | 1905.2 | 43.1 | 22.1 |
| | 68 | 1.12 | 96.0 | 14.47 | 13.32 | 12.31 | 1800.3 | 40.1 | 20.9 |
| | 69 | 1.10 | 70.0 | 13.06 | 8.39 | 4.90 | 1760.7 | 26.4 | 20.4 |
| | 70 | 1.10 | 83.5 | 25.49 | 21.00 | 9.84 | 2150.0 | 56.3 | 24.9 |
| | 71 | 0.93 | 69.0 | 21.67 | 20.93 | 10.83 | 2003.2 | 53.4 | 23.2 |
| | 72 | 1.20 | 94.0 | 13.00 | 14.81 | 7.86 | 1570.2 | 35.7 | 18.2 |

**Annex 2.** Different growth parameters of *S. macropodum* plants at biomass measurement T19 (cont.)

| Dried biomass measured at T19: 20-27 Jan 2010 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Light treat.** | **Plant** | **D (cm)** | **H (cm)** | **Leaf (g)** | **Stem (g)** | **Root (g)** | **Leaf area ($cm^2$)** | **Total mass (g)** | **No. of leaves** |
| | 73 | 1.20 | 74.0 | 10.43 | 14.72 | 6.54 | 1670.2 | 31.7 | 16.7 |
| | 74 | 1.15 | 71.0 | 18.77 | 22.56 | 20.42 | 1895.1 | 61.8 | 19.0 |
| | 75 | 1.20 | 68.0 | 19.59 | 27.15 | 14.28 | 1957.0 | 61.0 | 19.6 |
| | 76 | 1.30 | 95.0 | 15.23 | 18.32 | 13.08 | 1794.1 | 46.6 | 18.0 |
| | 77 | 1.40 | 99.0 | 11.55 | 13.70 | 10.90 | 1730.0 | 36.2 | 17.3 |
| | 78 | 1.28 | 80.0 | 6.99 | 8.64 | 3.85 | 1530.0 | 19.5 | 15.3 |
| | 79 | 1.10 | 75.5 | 8.46 | 7.89 | 6.11 | 1575.2 | 22.5 | 15.8 |
| | 80 | 0.80 | 60.0 | 5.89 | 12.87 | 7.42 | 1475.5 | 26.2 | 14.8 |
| | 81 | 1.25 | 65.0 | 24.93 | 26.21 | 17.54 | 1972.7 | 68.7 | 19.7 |
| | 82 | 1.13 | 83.0 | 19.58 | 14.30 | 13.22 | 1850.5 | 47.1 | 18.5 |
| | 83 | 1.50 | 84.0 | 17.12 | 21.61 | 17.20 | 1795.2 | 55.9 | 18.0 |
| 100.0% | 84 | 1.25 | 77.5 | 14.44 | 12.98 | 10.44 | 1720.1 | 37.9 | 17.2 |
| | 85 | 1.30 | 82.0 | 13.23 | 11.17 | 7.88 | 1520.7 | 32.3 | 15.2 |
| | 86 | 1.00 | 67.0 | 11.91 | 11.55 | 5.55 | 1580.4 | 29.0 | 15.8 |
| | 87 | 1.05 | 67.0 | 9.49 | 15.44 | 8.09 | 1450.7 | 33.0 | 14.5 |
| | 88 | 0.95 | 70.5 | 10.78 | 11.75 | 9.80 | 1690.2 | 32.3 | 16.9 |
| | 89 | 1.20 | 71.0 | 29.23 | 28.36 | 17.80 | 1950.3 | 75.4 | 19.5 |
| | 90 | 1.00 | 67.0 | 18.30 | 23.24 | 12.49 | 1895.5 | 54.0 | 19.0 |
| | 91 | 1.40 | 86.0 | 8.79 | 12.95 | 9.99 | 1640.7 | 31.7 | 16.4 |
| | 92 | 1.30 | 84.5 | 9.60 | 10.95 | 10.44 | 1660.3 | 31.0 | 16.6 |
| | 93 | 1.20 | 64.0 | 14.72 | 13.94 | 8.11 | 1750.2 | 36.8 | 17.5 |
| | 94 | 0.95 | 63.0 | 13.19 | 12.54 | 10.12 | 1680.3 | 35.9 | 16.8 |
| | 95 | 1.10 | 66.0 | 16.80 | 22.69 | 20.68 | 1850.7 | 60.2 | 18.5 |
| | 96 | 1.23 | 81.0 | 12.34 | 16.45 | 17.98 | 1570.7 | 46.8 | 15.7 |

# Chapter 5
# Growth analysis of *Scaphium macropodum* in an enrichment planting experiment

*With M.J.A. Werger and R.G.A. Boot*


## Abstract

1. Enrichment planting is one of the important measures for forest establishment either to enrich economical and ecological values of secondary poor forest or to convert monoculture plantation into a mixed species forest for long-term objectives and permanent forest cover. We established an enrichment planting trial with *Scaphium macropodum* planted in belts cut at different widths and thus providing different light availabilities in a secondary poor forest (Km 9, Bachma National Park of Vietnam). We monitored this trial for three years,
2. The light environment had clear and significant effects on the survival of the *Scaphium macropodum* plants at the early stage of establishment. A low light environment of around 25 % and lower significantly reduced

the survival rate. This result was not fully expected, given the fact that *Scaphium macropodum* is considered shade-tolerant.

3. Among treatments, strongest growth of height and diameter was obtained at the widest cut belt treatment (3 m with a mean light availability of 42.5 %) and significantly different from those of the control and the 2 m wide belt treatment, except for height growth in the control.
4. Relative Growth Rate (RGR) of *Scaphium macropodum* plants at the enrichment trial increased over the trajectory from 20 to 50 % light availability, but at further increase of the light availability the RGR decreased.
5. We extrapolated and transposed our results of 3 regression relations between RGR to light availability (eqn.3); belt width to light availability (eqn.6) and establishment cost to belt width (eqn.5). We concluded from the cross point of the curves, that at about 50 % light availability, which is created with a belt width of a bit more than 4 m (and at a cost of US $ 579.7 per ha), RGR of *S. macropodum* will be highest.

**Key words**: *Scaphium macropodum*, enrichment planting, cut-belt width, light availability, relative growth rate (RGR)

## Introduction

Forest policy in Vietnam has undergone several significant changes over the last decades in an attempt to overcome its problem of forest declining in both area and quality (McNamara et al. 2006) viz. the National Forestry Action Plan developed in the early 1990s, Vietnam Forestry Development Strategy (FDS) for the period 2006 – 2020 (Vietnam FDS 2006 – 2020, Decision No. 18/2007/QD-TTg, dated 5 February 2007, by the Prime Minister) and the implementation of the “Five Million Hectares Rehabilitation Program (5MHRP)” (MARD 2001, Ohlsson et al. 2005). Through these policies and programs, Vietnam has so far significantly increased forest cover to 39.5 % as recently reported (MARD 2011). However, most of the forests in Vietnam are either secondary, poor forests or plantation forests, that might need further appropriate silviculture interventions to mature into permanent forest, for forest function diversification and for sustainable management.

Enrichment planting is one of the important measures for forest establishment, on the one hand to establish and increase the economical value of the forest with valuable forest plant species, and on the other hand to sustain biodiversity of the forest resources. The ultimate objective of enrichment planting is to establish a permanent forest estate resembling natural forest with a broad mixture of species, products and services. The permanent forest estate is able to fulfill economic requirements and other forest functions, such as watershed protection, erosion control, biodiversity, etc. Furthermore, it is particularly suited to smallholder forest management on small area units (Kuchelmeister and Huy 2004).

Enrichment planting in Vietnam could be approached by additional planting of native broad-leaved species under either the canopy of natural poor forests, in belts or in gaps (Doan 1996, d'Oliveira 2000, Kuchelmeister and Huy 2004) or under plantation canopies (Hai 2001, McNamara et al. 2006), e.g. Acacia spp. after relevant thinning. Understanding the importance of enrichment planting measures, since 1993 the Ministry of Forestry in Vietnam has distributed technical procedure QPN14-92, which contains one chapter for enrichment planting with native broad-leaved forest species (Ministry of Forestry 1993). For improvement of the enrichment planting in Vietnam, initiatives on this field have been initially taken for specific target native species viz. *Hopea odorata*, *Dipterocapus alatus*, *Parashorea chinensis*, *Tarrietia javanica*, *Parashorea stellata*, *Peltophorum tonkinensis* (Doan 1996, McNamara et al. 2006), and also for other native forest species.

*S. macropodum*, a common shade-tolerant emergent tree (Yamada and Suzuki 1996) is an important multipurpose timber species in tropical rain forests of Vietnam. It was once abundant in natural forests and local farmers significantly benefited from its valuable fruit product (Duong 1995, Hy 2005, Huy et al. 2010a). However the species has now seriously declined due to overharvesting: many large trees have been cut down for only a single harvesting of its fruits. As an effort to rehabilitate this tree species in the forests, enrichment planting has been considered as a potential measure. However few studies so far focused on this field, and therefore the achievement on forest rehabilitation through this measure is still very limited. Initial results was achieved in a trial planting of *S. macropodum* in a 2.5 m wide open belt under secondary forest (Kuijk 2008). In another trial, enrichment planting with *S. macropodum* and other native species was done in Haivan pass in Vietnam under the canopy of a 8-year-old plantation of *Acacia auriculiformis* with a basal area of 9-13 m2/ha, after several thinnings. Here *S. macropodum* did not grow as well as the other native species (McNamara et al. 2006), and *S. macropodum* planted under very light shading of Acacia spp. on a hill site also had a mortality (>50 %) (Hai 2001).

Here we report of another enrichment planting of *S. macropodum* in Bachma National Park. We address the following question: what are the effects of the light environment on the growth parameters of *S. macropodum* planted in secondary poor and young forest, We analyzed this in a set-up in which *S. macropodum* was planted in cleared belts of three different widths, taking three years of growth measurements and analyze for differences among treatments. We used the results to establish recommendations for enrichment planting of this species with regard to the width of the cut-belt, the light environment, and the costs needed to clear the belts and maintain them.

## Method

### *Study site*

We surveyed and selected the study site for the enrichment planting of *S. macropodum* at Km 9, in Bachma National Park, Thua Thien Hue (16°12’93” NL; 107o51’66” EL). This was a site of poor, young secondary forest. Tree density was from 500 to 800 stems per ha (all stems ≥ 1 m in height), and all stems were less than 20 cm in diameter at breast height (DBH). Land use history included logging, slash and burn for shifting cultivation, and other.

The main physical characteristics of the study site are presented in Table 1.

**Table 1. Main characteristics of study site.**

| Site | Km 9, Bachma National Park |
|---|---|
| Elevation | 500-600 m |
| Facing | North-West |
| Slope | 15-20o |
| Forest tree composition and density (stems per ha) | |
| *Castanopsis* ssp. (Dẻ) | 215 |
| *Cinnamomum* ssp. (Re) | 136 |
| *Endospermum chinense* (Vạng trứng) | 21 |
| *Camellia japonica* (Sơn trà) | 25 |
| *Illicium ssp.* (Hồi lá nhỏ) | 25 |
| *S. macropodum* (Ươi) | 35 |
| Other species | 106 |
| ***Total*** | ***563 stems/ha (Height ≥ 1 m)*** |
| Soil type | Ferralite |
| Soil depth | Medium (≤ 50cm) |
| Soil color | Yellow or grey yellow |
| Mother rock | Sandy rock (Fs) |

*cont. Table 1. Main characteristics of study site.*

| Site | Km 9, Bachma National Park | |
|---|---|---|
| Soil chemistry | 0-20 cm depth | 20-40 cm depth |
| Humus (%) | 3.02 | 1.28 |
| Total N (%) | 0.12 | 0.06 |
| $P_2O_5$ (mg/100g) | 15.0 | 2.51 |
| $K_2O$ (mg/100g) | 38.0 | 26.6 |
| $pH_{KCl}$ | 4.44 | 4.56 |

***Study species and planting material***

*S. macropodum* was the study species for this enrichment planting experiment.

We prepared seedlings of *S. macropodum* for the planting from seeds. They were collected from *S. macropodum* forest in Bach Ma National Park, Thua Thien Hue (Nam Dong district) in June, 2007. The seedlings were potted in black polyethylene bags of 15 cm diameter and 20 cm deep and kept under 50 % light condition in a nursery in Bachma National Park for one year before transplanting out in the field for the experiment. We used a mixture of 83 % forest soil, 15 % compost and 2 % phosphorus as potting medium for the experimental plants. Homogenous seedlings of *S. macropodum* (as regards height, diameter, leaf number) were selected from the potted seedlings and used for the enrichment planting (about 35- 40 cm in height, 0.7-1.0 cm in collar diameter).

***Experimental design for enrichment planting***

The enrichment planting experiment was designed in three blocks at different heights on a hill site. The distance between blocks was 35 m. In each block we made three parallel belts following the contours: one with a belt width of 3 m, another with a belt width of 2 m, and a control.

In each belt, about 11-12 seedlings of *S. macropodum* were planted in one line in the middle of the belt with a spacing of 5 m between plants within one belt, and 6 m between rows in different belts (333 plants per ha).

***Site preparation and planting***

***Belt cutting***

In the 3 and 2 m belts all shrubs and climbers were removed, but threes with a height of > 1 m were left. These trees belonged to the species listed in Table 1.

In the control belt no vegetation was cut.

### Pit digging

Pits of 40x40x40 cm were dug along a line in the middle of each belt, with about 5 m spacing between pits on the same line, and 6 m between two pits in adjacent belts. The distance between pits on a belt varied slightly in order to avoid damaging the existing trees in the belts.

### Planting and maintenance

The enrichment planting was done in November 2008, the right planting season in the region with favorable conditions of sufficient moisture in the soil.

All treatments were tended similarly: fertilizer was applied once a year, new growth inside the belt was cleared twice a year, as well as in-growth from both sides of the belts.

### Data collecting

Data collecting was done annually for three years, from 2009 to 2011. The first measurement was conducted in July 2009. Before the first measurement, all individuals of the planted *S. macropodum* were tagged and numbered.

We measured the following variables:

- Light availability was measured in 2009 and 2011 in four directions (East, South, West and North) near each planted *S. macropodum* at 1 m high above the ground, using a spherical densiometer (model C). Light availability for each individual was calculated as the average of the four readings, and the light availability in each belt was averaged over all individuals in the belt.
- Height of the stems (H stem) was measured from ground level along their main shoot. Total height (H total) was measured a H stem plus the height of leaves above the growth point.
- Diameters (D) of stems were measured by calipers at 10% and 50 % of the total stem height of each plant.
- Number of leaves were counted per plant, and width and length of representative leaves of each plant were measured to calculate leaf area.
- Crown width in the direction of the belt and crown width perpendicular to the belt were measured.
- Mortality of plants was counted per belt and treatment.

The second and the third measurements were conducted in July 2010 and in May 2011, respectively.

***Data analyses***

All analyses of the enrichment planting experiment were based on three years of measurements.

The light environment of each belt and of each individual plant was taken as the mean values of the light measurements in July 2009 and in May 2011.

Survival rates were calculated over the 3-year period. Height and diameter growth was calculated over the three year period, and expressed as growth rate per year. Leaf area of each plant was calculated from width and length measurements of each representative leaf multiplied by the number of leaves per plants.

Relative growth rates (RGR) of stem mass was calculated for each plant following the modified equation of Yamada and Suzuki (1997):

$$RGR = (\log SMi - \log SMf)/T, \quad \text{(Eqn.1)}$$

Where SMi, SMf and T are the initial stem mass, final stem mass, and time interval (year), respectively.

The SM was calculated from stem cubic volume (SV), by dividing the SV by 2 as the wood density of *S. macropodum* was about 0.5 g/cm$^3$ (Choo et al. 1999). Stem cubic volume (SV) was calculated as:

$$SV = \pi \times (D_{50}/2)^2 \times H_{stem} \quad \text{(Eqn.2)}$$

Where $\pi$=3.1416, $D^{50}$ and $H_{stem}$ are diameter at 50 % stem height, and the height of the stem, respectively (Philip 1994, Poorter and Werger 1999).

Growth analysis of *S. macropodum* in this enrichment planting was analyzed with two different approaches. In the first approach, we analyzed growth parameters related to the different belt treatments (McNamara et al. 2006, Huy et al. 2010a), and in the second approach, we analyzed growth parameters of individual plants in response to their respective light environment (Yamada and Suzuki 1997, Huy et al. 2010a).

We also analyzed the costs of each planting treatment for two years based on the factual expenditure.

### *Statistical analyses*

We used analysis of variance (ANOVA) followed by post hoc Tukey multiple comparisons in SPSS 18 to test for significant differences of all growth parameters measured viz. survival rate, height growth, diameter growth, leaf area and RGR as affected by different treatments (at significance level α=0.05).

We examined the relation between the RGR of each individual plant and its light environment by fitting a polynomial regression. The survival of *S. macropodum* was correlated to its light environment by fitting a binary logistic regression.

We noted the factual costs of establishing the belts for enrichment planting and maintain these for a few years, and calculated it on a hectare basis and against a US $ exchange rate of May 2011. We related these data to the RGR and light availability data of the planted tree juveniles in order to estimate a cost-effective belt clearance for optimal growth of *S. macropodum* juveniles.

## Results

### *Growth responses to different belt treatments*

**Table 2. Effects of belt treatments on growth parameters of *S. macropodum* in enrichment planting experiments at the Km 9 site, Bachma National park, Thua Thien Hue, Vietnam; 3 years of measurements (2009-2011)**

| Belt treatment | Light environment (%) | Survival rate | Leaf area ($cm^2$) | H growth (cm/year) | D growth (cm/year) | RGR (g/g/year) |
|---|---|---|---|---|---|---|
| 3 m belt cut | 42.4$^a$ | 0.97$^a$ | 2354.1$^a$ | 10.8$^a$ | 0.16$^a$ | 0.251$^a$ |
| 2 m belt cut | 35.5$^b$ | 0.95$^a$ | 1357.1$^b$ | 5.1$^b$ | 0.11$^b$ | 0.166$^b$ |
| Control | 25.1$^c$ | 0.52$^b$ | 722.9$^b$ | 7.0ab | 0.11$^b$ | 0.099$^b$ |

*Anova Post Hoc Multiple Comparison Test: different “letters” per column indicate significant difference at α=0.05.*

The belt that was cut at a width of 3 m had on average 42.4 % of the full sun light. This was the highest value, as the 2 m wide belt had 35.5 % and the control 25.1 %. The light value of the 2 m wide belt was also significantly different from that of the control.

Survival rates of *S. macropodum* in the enrichment planting was significantly different between control and both belt width treatments, but it was non-significant between the 2 m and 3 m belt treatments. Lowest survival rate was found in control (0.52) (Table 2).

Plants of *S. macropodum* in the enrichment planting showed strongest height growth in the 3 m belt and this differed significantly from that in the 2 m belt, but not from the control. Height growth of *S. macropodum* in the 2 m belt did not differ significantly from the control.

Strongest diameter growth of *S. macropodum* was also found in the 3 m belt (0.16 cm/yr), and it was significantly different from those in the 2 m belt and the control. Diameter growth in the 2 m belt did not significantly differ from that in the control. Results for leaf area showed the same pattern (Table 2).

Similar to the diameter growth and leaf area, the highest RGR of *S. macropodum* was recorded in the 3 m belt (0.251), which was significantly different from that in the 2 m belt and the control, and the RGRs in the latter two treatments did not significantly differ (Table 2).

### *Effects of light availability on growth and survival of individual plants*

We calculated RGRs for each *S. macropodum* plant individually and correlated that with their light values fitting a polynomial regression (Figure. 1). RGR initially increased with increasing light availability, peaked at value of 0.25 g/g/year at about 50 % light availability, and then declined.

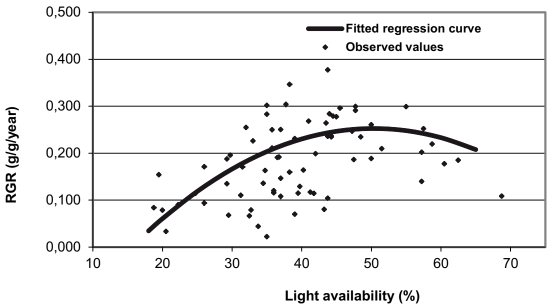


*Figure 1. Relationship between RGR and light availability of S. macropodum in enrichment planting experiments at the Km9 site, Bachma National Park, Thua Thien Hue, Vietnam. The fitted regression curve ($Y= 0.0002X^2 + 0.021X – 0.276$, $R^2 = 0.36$) (**Eqn.3**), and dots are observed values based on 3 year of measurements (2009-2011).*

It appears that the *S. macropodum* plants in the enrichment trial were planted in a light environment range from 17 to 70 %, and most plants were in the range from 20 to 50 % (Figure 2). The survival rate of *S. macropodum* in the enrichment trial correlated positively with the light environment of the plants, especially for the light range from 20 to 40 %, after which they attained a survival rate of approximately 1. Below a light environment of 25 % plant mortality increased drastically (Figure 2).

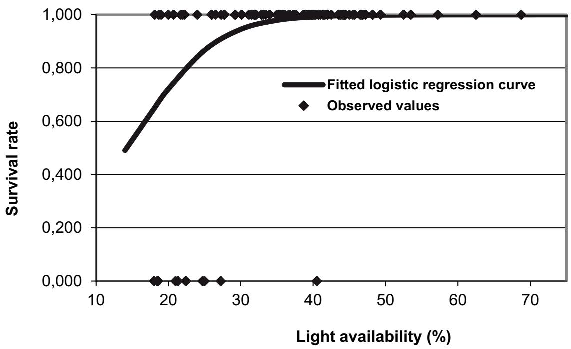


*Figure 2. Relationship between survival rate and light environment of S. macropodum at an enrichment planting experiment at the Km9 site, Bachma National Park, Thua Thien Hue, Vietnam. Dots are observed values for survival rate and line is fitted logistic regression: Y = 1/(1+Exp(-(a*Height + b))) (**Eqn.4**). Fitted parameters a = 0.205, b = -4.017 and* $R^2$ *= 0.40*

### *Cost analysis for establishing an enrichment planting*

**Table 3. Cost of enrichment planting with *S. macropodum* (333 seedlings per ha; pit size of 40x40x40 cm)**

| Items | Cost per ha (US $) | | |
|---|---|---|---|
| | No cut (25.1% light) | 2 m belt cut (35.5% light) | 3 m belt cut (42.4 % light) |
| Belt cutting | 0 | 100 | 150 |
| Pit digging | 66.6 | 66.6 | 66.6 |
| Seedling | 133.2 | 133.2 | 133.2 |
| Fertilizer | 49.95 | 49.95 | 49.95 |
| Maintenance | 80 | 100 | 120 |
| **Total** | **349.75** | **449.75** | **519.75** |

The establishment cost of the enrichment planting was calculated for different planting trials with different widths of the planting belts, based on the factual cost expenditure of the implementation. Details of the cost calculation presented in Table 3 show that, the wider the cut belt, the higher the cost of establishment, due to cutting and maintaining the belts.

Regression analysis showed that establishment cost of the enrichment planting positively correlated to width of the cut belt (Y = 62.9X + 328.3 ($R^2$ = 0.998) (**Eqn.5**); where Y is the establishment cost, and X is the cut belt width), and the cut belt width also linearly and positively correlated to light availability (Y = 0.18X – 4.34, ($R^2$ = 0.995), (**Eqn.6**); where Y is the cut belt width and X is the light availability).

## Discussion

### *Light environment and growth of S. macropodum in enrichment planting*

The light environment is found to be one of the most important factors determining plant growth (Markesteijn et al. 2007, Lambers et al. 2008). *S. macropodum* commonly is defined as a shade-tolerant emergent tree species in tropical rain forests (Yamada and Suzuki 1996).

In our enrichment planting trial, the light environment had clear and significant effects on the survival rate of the *S. macropodum* plants at the early stage of establishment. Low light environment of around 25 % and lower significantly reduced the survival rate (Table 1, Fig, 2). This result was not fully expected, given the fact that *S. macropodum* is considered shade-tolerant. In another study, however, in which S. macropodum was planted under very light shading of *Acacia* spp. on slope, its mortality was also high (>50 %) (Hai 2001). It is possible that in this slope experiment another factor than light affected mortality. Our results clearly show, however, that enrichment of the forest stand by planting *S. macropodum* juveniles can be successful when they grow at light regimes of 40 to 50 % of ambient.

While our experiment only provided two cut belts and a control belt, we could test the RGR – light availability relation because we determined the light availability around every plant in the transects.

Light environment also had significant effects on height and diameter growth of *S. macropodum* plants in the enrichment planting, and therefore significantly affected their RGR. With increasing width of the planting belt, creating more light, the RGR increased over the trajectory from 20 to 50 % light availability, but at further increase of the light availability, RGR decreased (Fig. 1). This result is consistent with the results of our growth experiment at different light conditions in a greenhouse, as reported in chapter 4. But the RGR of seedlings and saplings in the field is much lower than that of those in a greenhouse (Poorter et al. 2005). We will return to this point in the General Discussion. Our results on height growth are consistent with those reported by Yamada and Suzuki (1997) measuring sapling height growth of *S. macropodum* in dipterocarp forest in Kalimantan: height growth was severely suppressed under severe shade conditions in the forest, and it increased as light conditions in the forest increased somewhat.

### *Cost of enrichment planting and optimal growth*

The wider a belt for enrichment planting is cut, the higher are the costs for cutting and keeping the belt clean of undesired regrowth. But the wider the belt, the more light is available in that belt.

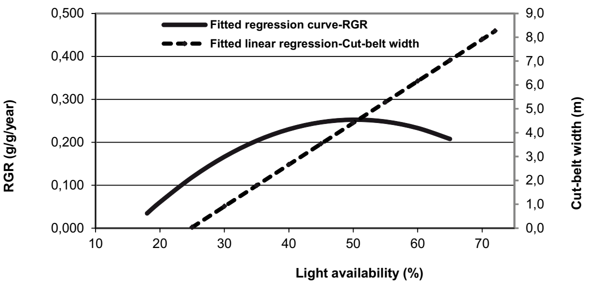


*Figure 3. Transposed graph for Light availability and belt width and light availability and RGR of S. macropodum.*

If we extrapolate from our field data the light availability in belts cut wider than 3 m (Eqn.6), and transpose this relation on the RGR – light availability relationship (Eqn.3), fixing the light availability points measured for the 2 and 3 m wide belts (Fig. 3), the two curves cross at about 50 % light availability and a belt width at just above 4 m. This ‘cross point’ can be considered as a kind of trade-off point, determining the optimal belt width for a maximum RGR of *S. macropodum* juveniles in enrichment plantings. Based on the factual costs made in our enrichment planting trial, cutting and maintaining such a belt of just over 4 m would cost US $ 579.7 per ha for a total of 2 years (Epn.5). Further increasing the belt width decreases the growth of *S. macropodum*.

## Acknowledgements

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*Figure 4. Measurement of S. macropodum in enrichment planting at the Km9 site, Bachma National Park, Thua Thien Hue, Vietnam (July 2009)*

*Figure 5. S. macropodum in the enrichment planting in August 2010*

**Annex 1.** Survival and growth variables of *S. macropodum* in the enrichment planting experiment at the Km 9 site, Bachma National park, Thua Thien Hue, Vietnam; 3 year data measurements (2009-2011) in the **3 m wide belt**

| Individual plant | | Survival rate | Leaf area ($cm^2$) | H growth (cm/year) | D growth (cm/year) | Stem mass (g) | | RGR (g/g/year) |
|---|---|---|---|---|---|---|---|---|
| # | Code | | | | | Year 1 | Year 3 | |
| 1 | 2.1/241 | 1 | 2783.7 | 7.50 | 0.14 | 2.45 | 7.63 | 0.247 |
| 2 | 2.2/231 | 1 | 731.6 | 1.75 | 0.04 | 1.73 | 2.48 | 0.078 |
| 3 | 2.3/234 | 1 | 1129.0 | 7.00 | 0.09 | 0.99 | 3.34 | 0.264 |
| 4 | 2.4/235 | 1 | 772.5 | 1.50 | 0.18 | 1.56 | 4.61 | 0.236 |
| 5 | 2.5/236 | 1 | 391.5 | 4.00 | 0.08 | 1.35 | 2.86 | 0.164 |
| 6 | 2.6/237 | 1 | 1676.4 | 7.75 | 0.10 | 2.67 | 7.92 | 0.236 |
| 7 | 2.7/240 | 0 | | | | 2.15 | 0.00 | |
| 8 | 2.8/243 | 1 | 7576.8 | 11.50 | 0.11 | 7.45 | 12.28 | 0.108 |
| 9 | 2.9/244 | 1 | 6267.0 | 21.50 | 0.25 | 3.37 | 26.67 | 0.449 |
| 10 | 2.10/238 | 1 | 1260.1 | 6.50 | 0.13 | 1.73 | 5.58 | 0.254 |
| 11 | 2.11/239 | 1 | 3749.9 | 15.50 | 0.19 | 2.97 | 14.62 | 0.346 |
| 12 | 2.12/246 | 1 | 770.0 | 12.00 | 0.15 | 3.23 | 10.32 | 0.252 |
| 13 | 2.13/248 | 1 | | 3.50 | 0.16 | 5.34 | 12.70 | 0.188 |
| 14 | 2.14/247 | 1 | | 11.00 | 0.10 | 3.39 | 10.74 | 0.250 |
| 15 | 2.15/251 | 1 | | 15.75 | 0.17 | 5.09 | 20.20 | 0.299 |
| 16 | 2.16/263 | 1 | 1044.3 | 7.00 | 0.13 | 1.22 | 4.06 | 0.260 |
| 17 | 2.17/245 | 1 | 755.0 | 6.50 | 0.09 | 1.21 | 2.83 | 0.185 |
| 18 | 2.18/257 | 1 | 463.4 | 7.50 | 0.09 | 0.68 | 2.32 | 0.268 |
| 19 | 2.19/249 | 1 | | 32.25 | 0.33 | 0.51 | 11.45 | 0.676 |
| 20 | 7/292 | 1 | 2957.3 | 9.00 | 0.12 | 2.97 | 6.19 | 0.159 |
| 21 | 8/58 | 1 | 2229.8 | 8.50 | 0.15 | 2.12 | 5.99 | 0.226 |
| 22 | 9/204 | 1 | 1767.2 | 9.25 | 0.13 | 3.96 | 9.33 | 0.186 |
| 23 | 10/200 | 1 | 2831.4 | 14.50 | 0.13 | 3.17 | 10.89 | 0.268 |
| 24 | 11/202 | 1 | 788.5 | 1.00 | 0.12 | 1.66 | 4.81 | 0.231 |
| 25 | 12/203 | 1 | 1664.5 | 20.00 | 0.18 | 7.74 | 19.60 | 0.202 |
| 26 | 13/207 | 1 | 2343.2 | 13.50 | 0.23 | 4.37 | 15.78 | 0.279 |
| 27 | 14/178 | 1 | 2223.1 | 19.50 | 0.21 | 2.09 | 15.10 | 0.429 |
| 28 | 15/55 | 1 | 2721.7 | 14.00 | 0.16 | 2.99 | 11.03 | 0.284 |
| 29 | 16/208 | 1 | 2242.3 | 4.50 | 0.19 | 3.88 | 9.19 | 0.187 |
| 30 | 17/57 | 1 | 2177.1 | 10.50 | 0.29 | 4.09 | 15.97 | 0.296 |
| 31 | 18/59 | 1 | 5805.7 | 33.00 | 0.36 | 7.86 | 56.16 | 0.427 |
| 32 | 19/294 | 1 | 3490.3 | 7.00 | 0.12 | 3.96 | 10.46 | 0.211 |
| 33 | 20/56 | 1 | 3238.2 | 18.50 | 0.19 | 4.09 | 16.43 | 0.302 |
| 34 | 21/51 | 1 | 1972.9 | 2.00 | 0.24 | 9.51 | 14.62 | 0.093 |
| 35 | 22/52 | 1 | 3864.7 | 12.00 | 0.19 | 6.95 | 15.26 | 0.171 |
| 36 | 23/53 | 1 | 1289.2 | 2.00 | 0.08 | 5.65 | 8.55 | 0.090 |
| **Mean** | | **0.97** | **2354.1** | **10.82** | **0.16** | **3.504** | **11.333** | **0.251** |

**Annex 2.** Survival and growth variables of *S. macropodum* in enrichment planting experiment at km 9 site, Bachma National park, Thua Thien Hue, Vietnam; 3 year data measurements (2009-2011) of **2 m cut-belt treatment**

| Individual plant | | Survival rate | Leaf area (cm$^2$) | H growth (cm/year) | D growth (cm/year) | Stem mass (g) | | RGR (g/g/year) |
|---|---|---|---|---|---|---|---|---|
| # | Code | | | | | Year 1 | Year 3 | |
| 1 | 1.1/291 | 1 | 846.3 | 2.75 | 0.14 | 4.02 | 10.54 | 0.209 |
| 2 | 1.2/231 | 1 | 270.2 | 2.50 | 0.15 | 3.27 | 5.60 | 0.117 |
| 3 | 1.3/176 | 1 | 524.6 | 3.60 | 0.08 | 4.02 | 6.99 | 0.120 |
| 4 | 1.4/296 | 1 | 228.3 | 3.60 | 0.07 | 1.19 | 3.28 | 0.219 |
| 5 | 1.5/209 | 1 | 673.9 | 6.25 | 0.08 | 2.83 | 6.83 | 0.192 |
| 6 | 1.6/172 | 0 | 140.6 | | | 2.93 | 0.00 | |
| 7 | 1.7/200 | 1 | 1952.8 | 10.00 | 0.25 | 4.25 | 16.84 | 0.299 |
| 8 | 1.8/295 | 1 | 157.8 | 2.00 | 0.10 | 1.89 | 3.20 | 0.115 |
| 9 | 1.9/213 | 1 | 142.9 | 5.50 | 0.15 | 8.20 | 11.31 | 0.070 |
| 10 | 1.10/297 | 1 | 1683.9 | 5.65 | 0.15 | 3.95 | 9.56 | 0.192 |
| 11 | 1.11/230 | 1 | 396.6 | 2.40 | 0.03 | 4.74 | 9.63 | 0.154 |
| 12 | 1.12/293 | 1 | 2250.2 | 9.00 | 0.18 | 3.33 | 12.70 | 0.291 |
| 13 | 1.13/180 | 1 | 452.5 | 10.75 | 0.11 | 3.01 | 8.85 | 0.235 |
| 14 | 1.14/171 | 1 | 1310.6 | 2.75 | 0.09 | 5.25 | 7.54 | 0.079 |
| 15 | 1.15/174 | 1 | 434.3 | 2.00 | 0.07 | 4.16 | 5.09 | 0.044 |
| 16 | 1.16/54 | 1 | 397.6 | 1.55 | 0.03 | 3.40 | 8.50 | 0.199 |
| 17 | 1.17/232 | 1 | 29.5 | 2.00 | 0.05 | 2.39 | 2.64 | 0.022 |
| 18 | 1.18/189 | 1 | 573.3 | 4.75 | 0.07 | 3.31 | 6.16 | 0.135 |
| 19 | 1.19/185 | 1 | 1645.1 | 2.50 | 0.15 | 6.48 | 10.95 | 0.114 |
| 20 | 1/181 | 1 | 591.0 | 5.00 | 0.02 | 1.88 | 3.58 | 0.140 |
| 21 | 2/211 | 1 | 3768.4 | 1.50 | 0.12 | 8.33 | 15.08 | 0.129 |
| 22 | 3/60 | 1 | 918.0 | 5.00 | 0.08 | 2.45 | 4.81 | 0.146 |
| 23 | 4/198 | 1 | 2955.6 | 9.50 | 0.14 | 3.71 | 15.01 | 0.304 |
| 24 | 5/240 | 1 | 549.2 | 8.50 | 0.08 | 0.95 | 3.02 | 0.250 |
| 25 | 6/88 | 1 | 2318.5 | 12.75 | 0.08 | 2.70 | 9.68 | 0.277 |
| 26 | 7/183 | 1 | 1675.3 | 5.00 | 0.10 | 0.92 | 2.51 | 0.217 |
| 27 | 8/196 | 1 | 810.5 | 1.50 | 0.07 | 3.02 | 5.01 | 0.110 |
| 28 | 9/206 | 1 | 603.6 | 1.50 | 0.04 | 1.56 | 3.74 | 0.190 |
| 29 | 10/173 | 1 | 2041.6 | 1.50 | 0.08 | 3.56 | 8.06 | 0.177 |
| 30 | 11/179 | 1 | 4262.5 | 15.00 | 0.23 | 3.67 | 20.86 | 0.377 |
| 31 | 12/210 | 1 | 455.7 | 2.00 | 0.03 | 1.97 | 3.33 | 0.114 |
| 32 | 13/232 | 1 | 1000.6 | 10.00 | 0.18 | 4.08 | 12.02 | 0.234 |
| 33 | 1/201 | 1 | 2222.4 | 6.75 | 0.15 | 6.48 | 8.85 | 0.068 |
| 34 | 2/235 | 1 | 1777.6 | 6.50 | 0.13 | 3.59 | 8.84 | 0.195 |
| 35 | 3/186 | 1 | 810.5 | -10.00 | 0.03 | 6.90 | 4.42 | -0.097 |
| 36 | 4/54 | 1 | 1648.9 | 3.00 | 0.04 | 3.76 | 6.19 | 0.108 |
| 37 | 5/205 | 1 | 2909.9 | 1.00 | 0.15 | 4.02 | 6.48 | 0.104 |
| 38 | 6/212 | 1 | 6137.4 | 23.50 | 0.31 | 10.46 | 38.49 | 0.283 |
| **Mean** | | **0.95** | **1357.1** | **5.11** | **0.11** | **3.86** | **8.58** | **0.166** |

**Annex 3.** Survival and growth variables of *S. macropodum* in enrichment planting experiment at km 9 site, Bachma National park, Thua Thien Hue, Vietnam; 3 year data measurements (2009-2011) of **Control (no cut treatment)**

| Individual plant | | Survival rate | Leaf area ($cm^2$) | H growth (cm/year) | D growth (cm/year) | Stem mass (g) | | RGR (g/g/year) |
|---|---|---|---|---|---|---|---|---|
| # | Code | | | | | Year 1 | Year 3 | |
| 1 | 1/250 | 0 | | 16.00 | 0.10 | 3.04 | 0.00 | |
| 2 | 2/253 | 0 | | 8.00 | 0.25 | 1.65 | 0.00 | |
| 3 | 3/262 | 0 | | 10.00 | 0.15 | 2.87 | 0.00 | |
| 4 | 4/255 | 1 | 1082.3 | 2.50 | 0.10 | 4.14 | 6.09 | 0.084 |
| 5 | 5/260 | 0 | | 12.00 | 0.20 | 3.63 | 0.00 | |
| 6 | 6/261 | 1 | 777.5 | 4.50 | 0.09 | 2.89 | 5.40 | 0.136 |
| 7 | 7/252 | 1 | 431.6 | 0.50 | 0.02 | 1.24 | 1.44 | 0.033 |
| 8 | 8/256 | 0 | | 13.00 | 0.04 | 1.85 | 0.00 | |
| 9 | 9/264 | 1 | 155.2 | 2.00 | 0.16 | 1.78 | 2.58 | 0.080 |
| 10 | 10/259 | 1 | 1162.4 | 5.00 | 0.06 | 2.67 | 4.53 | 0.115 |
| 11 | 11/258 | 1 | 527.2 | 4.50 | 0.14 | 1.66 | 3.52 | 0.163 |
| 12 | 12 | 0 | | 9.00 | 0.10 | 2.93 | 0.00 | |
| 13 | 13 | 1 | 637.0 | 4.00 | 0.12 | 2.44 | 3.52 | 0.079 |
| 14 | 14 | 1 | | 2.00 | 0.02 | 1.25 | 1.44 | 0.031 |
| 15 | 15 | 0 | | 7.00 | 0.20 | 1.91 | 0.00 | |
| 16 | 16 | 0 | | 9.00 | 0.05 | 3.39 | 0.00 | |
| 17 | 17 | 1 | 630.5 | 4.00 | 0.10 | 4.49 | 6.09 | 0.066 |
| 18 | 18 | 0 | | 12.00 | 0.15 | 4.37 | 0.00 | |
| 19 | 19 | 1 | | 4.00 | 0.08 | 2.95 | 5.40 | 0.131 |
| 20 | 20 | 0 | | 11.00 | 0.06 | 2.18 | 0.00 | |
| 21 | 21 | 1 | 1102.0 | 7.00 | 0.07 | 2.07 | 4.53 | 0.170 |
| **Mean** | | **0.52** | **722.9** | **7.00** | **0.11** | **2.64** | **2.12** | **0.099** |

**Annex 4.** ANOVA - Post Hoc Test: Multiple Comparisons of mean growth parameter values of *S. macropodum* in the enrichment planting experiment.

| Dependent Variable | (I) Treatment | (J) Treatment | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| Leaf area (cm$^2$) | 0 | 2 | -667.6927 | 640.8487 | .553 | -2201.323 | 865.938 |
| | | 3 | -1664.7662* | 650.6403 | .033 | -3221.829 | -107.703 |
| | 2 | 0 | 667.6927 | 640.8487 | .553 | -865.938 | 2201.323 |
| | | 3 | -997.0734* | 353.0600 | .017 | -1841.990 | -152.157 |
| | 3 | 0 | 1664.7662* | 650.6403 | .033 | 107.703 | 3221.829 |
| | | 2 | 997.0734* | 353.0600 | .017 | 152.157 | 1841.990 |
| Survival rate | 0 | 2 | -.450* | .076 | .000 | -.63 | -.27 |
| | | 3 | -.448* | .077 | .000 | -.63 | -.27 |
| | 2 | 0 | .450* | .076 | .000 | .27 | .63 |
| | | 3 | .001 | .065 | 1.000 | -.15 | .16 |
| | 3 | 0 | .448* | .077 | .000 | .27 | .63 |
| | | 2 | -.001 | .065 | 1.000 | -.16 | .15 |
| Height growth (cm/year) | 0 | 2 | 1.89054 | 1.68481 | .503 | -2.1245 | 5.9056 |
| | | 3 | -3.82143 | 1.70215 | .069 | -7.8778 | .2350 |
| | 2 | 0 | -1.89054 | 1.68481 | .503 | -5.9056 | 2.1245 |
| | | 3 | -5.71197* | 1.45405 | .000 | -9.1771 | -2.2468 |
| | 3 | 0 | 3.82143 | 1.70215 | .069 | -.2350 | 7.8778 |
| | | 2 | 5.71197* | 1.45405 | .000 | 2.2468 | 9.1771 |
| Diameter growth (cm/ year) | 0 | 2 | .00086 | .01839 | .999 | -.0430 | .0447 |
| | | 3 | -.05205* | .01858 | .017 | -.0963 | -.0078 |
| | 2 | 0 | -.00086 | .01839 | .999 | -.0447 | .0430 |
| | | 3 | -.05290* | .01588 | .004 | -.0907 | -.0151 |
| | 3 | 0 | .05205* | .01858 | .017 | .0078 | .0963 |
| | | 2 | .05290* | .01588 | .004 | .0151 | .0907 |
| RGR (g/g/year) | 0 | 2 | -.074119 | .032592 | .065 | -.15197 | .00373 |
| | | 3 | -.152548* | .032701 | .000 | -.23066 | -.07444 |
| | 2 | 0 | .074119 | .032592 | .065 | -.00373 | .15197 |
| | | 3 | -.078429* | .022457 | .002 | -.13207 | -.02479 |
| | 3 | 0 | .152548* | .032701 | .000 | .07444 | .23066 |
| | | 2 | .078429* | .022457 | .002 | .02479 | .13207 |

***Note **** *The mean difference is significant at the 0.05 level.*
*0 denotes Control, 2 denotes 2 m cut-belt treatment and 3 denotes 3 m cut-belt*

# Chapter 6
# General discussion and summary

*Scaphium macropodum*, a common shade-tolerant tree (Yamada and Suzuki 1996), is an important multipurpose timber species in tropical rain forests of Vietnam. It was once abundant in natural forest and local farmers significantly benefited from its valuable fruits (Hy 2005, Huy et al. 2010a). However it is now facing serious decline due to over-harvesting of its fruits (Huy et al. 2010a). Ecological research on this species, including research on the plant's growth and population biology would, provides knowledge about how to develop and manage this plant resource in a sustainable way.

## *Plant species diversity and population growth rate of Scaphium macropodum in relation to site disturbance*

The environmental conditions of sites which carry populations of *Scaphium macropodum* strongly depend on the disturbances caused by the various practices of harvesting the fruits of this species. We assessed the disturbances as the Site Disturbance Index (SDI), and showed that fruit harvesting by cutting branches in *Scaphium macropodum*-sites may account for up to 55 % of the local SDI value (Chapter 2). The SDI is strongly related to plant species biodiversity (Naveh and Whittaker 1979, During and Willems 1984, Acharya 1999, Bongers et al. 2009), and it was also found to be negatively correlated to seedling survival, and thus may negatively affect population growth. This also applies to *S. macropodum* populations in Vietnam (Chapter 3).

We quantified plant species diversity of *S. macropodum* forests (Chapter 2) and population dynamics of *S. macropodum* (Chapter 3) at four sites: Cattien, with high disturbance due to fruit harvesting, bamboo invasion, and forest encroachment, Bachma and M'drak with medium to high disturbances, and Dakuy, with least disturbance (Table 1).

**Table 1. Site disturbance, Species diversity (SR & H') and population growth rate of *S. macropodum* in different study sites.**

| Site | SDI | SR | H' | λ |
|---|---|---|---|---|
| Cattien | 0.68-0.78 | 11-30 | 1.19-3.32 | 0.981 |
| Dakuy | 0.25-0.32 | 24-34 | 3.01-3.64 | 1.017 |
| Bachma | 0.40-0.48 | 39-56 | 4.69-5.08 | 1.022 |
| M'drak | 0.50-0.75 | 14-25 | 2.26-3.71 | --- |

***Note**: SDI- Site disturbance index, SR-Species richness, H'-Shannon diversity index, λ-Population growth rate;* ***Sources**: Chapter 2 and Chapter 3.*

Across these sites, the Shannon diversity index (H') ranged from 1.19 to 5.08 and the population growth rate (λ) ranged from 0.981 to 1.022. The highest values of H' were found at Bachma, the medium disturbance site, where *S. macropodum* seems to thrive best and which shows the highest λ value. The lowest values of H' were found at Cattien, the high disturbance site, where the population growth rate of *S. macropodum* was found lowest (Table 1). H' correlated negatively with relative importance of *S. macropodum* in the stand and H' peaked at moderately disturbance (SDI of 0.45) in our study sites.

We had hoped to be able to demonstrate a trade-off between economic production of stands of *S. macropodum* and biodiversity conservation of the site. That would allow, e.g. managing the proportion of stem number or basal area of *S. macropodum* to the total stem number or basal area of the forest stand in such a way that both a high species diversity of the stand and a good productivity of *S. macropodum* fruits, guaranteeing a proper income for the farmers, could be achieved (Jobidon et al. 2004). However, we did not find the trade-off in this study (Chapter 2).

Actually, we noticed two trends in the management of *S. macropodum*. On the one hand, in natural forests, when *S. macropodum* is fruiting, local farmers try to harvest as much as possible and cut all *S. macropodum* trees with fruits, which finally causes its decline. On the other hand, once the plant resources have seriously declined, they try to plant *S. macropodum* in the forest, usually in belts in secondary poor forests by clearing everything inside the planting belts, and planting only *S. macropodum* as dense as possible. Both trends are clearly not good for the establishment and population growth of *S. macropodum*, and for the stand diversity. The first trend will seriously reduce the *S. macropodum* population, and the plant biodiversity of the stand, and the latter will also damage and reduce the plant biodiversity.

***Matrix modeling for analyses of population dynamics and sustainable management of S. macropodum***

Demographic research combining elasticity and Life Table Response Experiments (LTRE), usually obtained from their matrix models, is a new potential and valuable method to evaluate the sustainability of management in general and harvesting practice in particular (Sinha and Brault 2005, Zuidema et al. 2007, Schmidt et al. 2011).

We conducted a 3 year demographic study on *S. macropdum* to evaluate the population dynamics in response to current harvesting disturbances in 3 sites in Vietnam, viz. Cattien, with high disturbance, Bachma with medium disturbance, and Dakuy, with least disturbance (Chapter 3). We wanted to use our results on the demography of this species in the 3 sites in trying to formulate a sustainable management for those sites. For this objective, we analyzed the respective matrix models for population growth rate, population projection and their future prospect.

We found in Cattien, the highly disturbed site, that fruit harvesting practice by cutting branches had negative impacts on the vital rates of plant growth, seedling survival, and reproduction (leading to unstable and lowest fruit yield). Although our results on the population growth of *S. macropodum* at Cattien, showed a λ value below 1, its 95 % confidence limits included the value 1, so that we could not demonstrate a statistically significant decline of that population on the basis of our data. The 50 year population projection showed that its abundance will seriously decline in the future and we assessed the future prospect of this species at Cattien highly pessimistic (Chapter 3). As mentioned above, the strong site disturbance at Cattien also largely caused its lowest biodiversity index (H’) among our study sites (Table 1, also Chapter 2). All together we conclude that the *S. macropodum* population at Cattien is under unsustainable management and harvesting practice and faces decline while its future prospect is bad.

Whereas in Dakuy and Bachma, the low to medium disturbed sites, fruit extraction of *S. macropodum* practiced by ground collecting considerably reduced seed availability, this did not negatively impact the vital rates, and their λ values were both higher than 1. Both populations seem to have have good future prospects, especially at Bachma, which was also found to have the highest biodiversity index (H') among study sites (Table 1, also Chapter 2). The site is considered to be under sustainable management and harvesting practice.

For a sustainable management of all *S. macropodum* sites, we first of all suggest to improve the harvesting practice in such a way that it promotes the population growth of *S. macropodum* and preserves plant biodiversity, and secondly, we also encourage local farmers to own certain *S. macropodum* trees for joint and sustainable management with their full responsibility for a good, steady fruit yield. This approach to sustainability (Gaoue and Ticktin 2010, Schmidt et al. 2011) can be extended to other *S. macropodum* forests.

***Growth of S. macropodum in greenhouse and field trials under different environmental conditions***

Quality of the seedlings in one of the most important factors determining the success of establishment after field planting as well as the regeneration of natural forests (Kuchelmeister and Huy 2004, Ishuzuka et al. 2010). Growth of seedlings differs strongly under the managed conditions in the nursery as compared to the natural conditions in the field (Poorter et al. 2005). Understanding growth responses to different environmental conditions and disturbances would help to improve the seedling production of farmers, and also the regeneration management in forests.

We conducted greenhouse experiments (2008-2010) with seedlings of *S. macropodum* to study the effects of light availability on their growths and their response to top breakage that might result from falling debris in the forest (Chapter 4). We also established an enrichment planting trial with *S. macropodum* juveniles planted in belts cut at different widths and thus providing different light availabilities in a secondary poor forest at Km 9, Bachma National Park, Vietnam (Chapter 5).

In Chapter 4, we found that light availability affects height and diameter growth of *S. macropodum* seedlings differently in two different stages. From month 1 to month 8 increased light availability (as from 25 %) negatively effected height, but positively effected diameter growth, while from month 9 onward it positively affected both height and diameter growth. For the entire experimental period and across all light levels, height and diameter growth, photosynthetic rates and Relative Growth Rate (RGR) of *S. macropodum* seedlings were highest at 50 % irradiance.

From these results we may infer that 50 % irradiance would be considered as the optimum light intensity for growth of *S. macorpodum* seedlings at a stage up to 19 months old, an approach also taken by Dai et al. (2009) and (Poorter and Rose 2005) for other rain forest species. However, since the growth response to light availability changes over time, it would be more accurate and useful to analyze growth data in response to different light availabilities in order to determine optimum light intensity for maximal growth as a function of time along the different stages in the growth trajectory of seedlings.

In Chapter 5, we found that the RGR of *S. macropodum* plants at the field enrichment trial was low compared to that in the greenhouse. And again it was maximal at 50 % light availability, after which it slowed down with further increase of the light availability. We concluded that a belt cut at a width of about 4 m would create a light availability of 50 % and there the RGR of *S. macropodum* will be highest.

In our study, with optimum growing conditions, seedlings of *S. macropodum* growing in the greenhouse showed a four times higher height growth than those in the natural forests (Chapter 3 and Chapter 4), and they also exhibited a RGR ten times higher as compared to those in the field enrichment trial in their first two years (Chapter 3 and Chapter 5). In the field enrichment trial, mortality of *S. macropodum* juveniles was 48 % in the control (Chapter 5), and this is about 10 % higher than that at 12.5 % light availability in the greenhouse experiment (Chapter 4).

The lower growth and higher mortality of *S. macropodum* in the field trials as compared to those in the greenhouse must be due to the harder growing conditions in the field, resulting from soil characteristics, drought (water availability), plant competition, insect herbivory, and pests and diseases (Huy et al. 2010a).

From our results on optimum light intensity for growth and the large differences in growth of seedlings growing conditions in the greenhouse or in a field trial, we draw the following important suggestions for seedling production by farmers:

i. To improve seedling quality of *S. macropodum*, young seedlings should be shaded at an appropriate level; 50 % shading should be proper for a good production;
ii. Before transplanting the seedlings into the field, they should be undergoing a period of hardening to acclimate to the hard conditions of the field, for example by stopping watering, fertilizing, and so on. This technical approach is useful to reduce mortality after planting in the field and will increase establishment in the field.
iii. For field enrichment establishment, a belt cut at 4 m width would be cost-effective and suitable for the field planting of *S. macropodum*, as it creates sufficient light availability to obtain highest RGRs.

***Proposed sustainable management of S.macropodum forest based on the actual practice at the Bachma site***

A real sustainable management of a *S. macropodum* forest should be base on three important factors: (i) It preserves or improves biodiversity and ecological conservation, (ii) It produces steady fruit yields and therefore income, and (iii) It is a join management of the forest from which farmers can benefit (Figure 1).

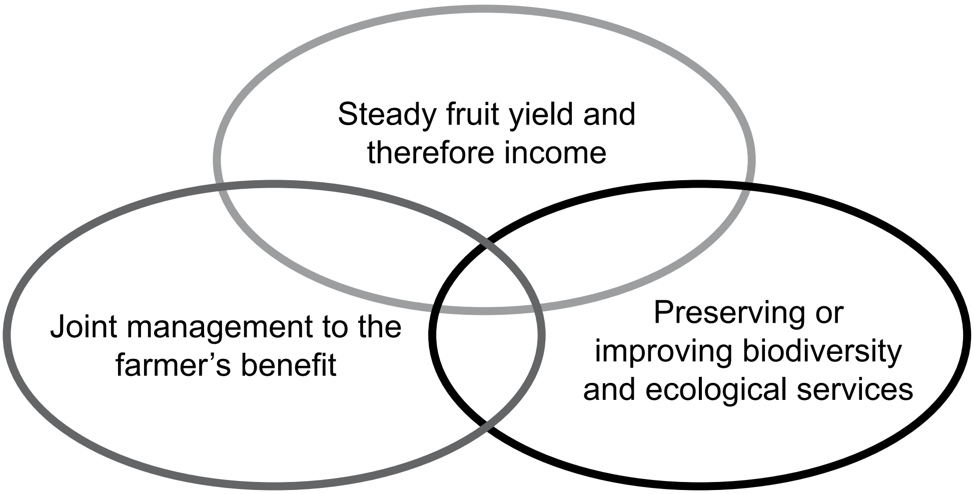


*Figure 1. Three factors for sustainable management of S. macropodum forest*

The management of the *S. macropodum* forest at the Bachma site has been found sustainable and all the three important factors were sufficiently developed and functioned properly in the forest system.

Firstly, as discussed above, the *S. macropodum* forest at Bachma showed the highest plant species diversity (H') among the study sites, and the site had a stable, medium SDI (Table 1). Secondly, the *S. macropodum* population at Bachma had the highest population growth rate (λ), the highest reproductive probability and also the highest fruit yield, and that generates a good income for the local community, who strongly depends on the forest for survival. Thirdly, the *S. macropodum* forest at Bachma has been allocated to farmer households for joint management of the forest, and therefore, farmers have played an important role as main, responsible actors in the system. This responsible exploitation of the forest ecosystem brought them significant benefits.

To evaluate income generated by the Bachma farmers from fruit production of *S. macropodum*, we conducted a Cost – Benefit Analysis (CBA) (Huy 2005a) based on 3 years data gathering from 2007-2010:

- No. of *S. macropodum* trees per ha with DBH >5 cm: 33
- No. of matured *S. macropodum* trees per ha: 20
- Fruiting fraction of the matured trees: 0.23
- Average fruit yield (kg/tree/year): 25.7
- Fruit price at site ($US/kg): 5.0
- Labor cost ($US/man-day): 10.0

**Table 2. Cost - Benefit Analysis of *Scaphium macropodum* at the Bachma site**

| Cost- Benefit Analysis | | | | |
|---|---|---|---|---|
| | Unit | Quantity | Price | Amount |
| **Total income ($US/ha/year)** | | | | **592** |
| *S. macropodum* fruits (/ha/year) | kg | 118 | 5.0 | 592 |
| Other | | | | |
| **Total cost ($US/ha/year)** | | | | **170** |
| Clearing bushes below fruiting trees | Man-day | 2.0 | 10.0 | 20.0 |
| Fruit collection from the ground | Man-day | 10.0 | 10.0 | 100.0 |
| Maintenance and protection of the *S. macropodum* site | Man-day | 5.0 | 10.0 | 50.0 |
| **Benefit ($US/ha/year)** | | | | **422** |

The CBA (Table 2) shows that *S. macropodum* in the Bachma forest site produced a steady, annual income of 592 $US per ha from 20 mature trees. From this income should be subtracted all costs for necessary activities in this sustainable approach of management and harvesting, amounting to 170 $US per ha per year. The net benefit was 422 $US per ha per year. The income and profit are expected to increase due to the increase of the fruit yield in years to come. And this income is besides other important values of the forest, like timber, other Non-Timber Forest Products (NTFP), biodiversity and ecological services.

Our study suggests that a sustainable and productive management of the *S. macropodum* stands in our study sites is possible, and this management can also be applied at other, similar sites of this species in Vietnam. Farmers in the regions with *S. macropodum* that produce seedlings should be aware that optimal growth of *S. macropodum* seedlings occurs at 50 % light availability, and that this light level is achieved when juveniles are planted in cut belts of about 4 m wide. Farmers also should be aware that sustainable harvesting regimes of *S. macropodum* fruits are possible, and they should completely abandon harvesting by cutting branches or even entire fruit-bearing trees, as this will rapidly lead to a catastrophic decline of the *S. macropodum* population, and to the end of them harvesting its fruits.

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# Samenvatting

Scaphium macropodum is een schaduwtolerante boomsoort in de tropische regenwouden van Vietnam. Deze soort levert timmerhout en, veel belangrijker nog, vruchten, die door de boeren verzameld worden en momenteel een hoge marktwaarde hebben. De soort was vroeger algemeen, maar als gevolg van zware over-exploitatie is de soort sterk in aantal afgenomen. Ecologisch onderzoek naar de groei en de populatiebiologie van deze boomsoort lijkt van nut voor het ontwikkelen van een duurzaam beheerssysteem ervoor.

Mijn onderzoek heb ik uitgevoerd op vier verschillende lokaties in Vietnam, waar S. macropodum voorkomt. Die lokaties verschillen in de graad van verstoring (de zogenaamde Site Disturbance Index, SDI). Op deze standplaatsen heb ik de lokale diversiteit, in termen van soortenrijkdom (SR) en Shannon's Diversity Index (H'), onderzocht en de groeisnelheid van de populatie (λ) bepaald (Tabel 1).

**Tabel 1. Graad van verstoring (SDI), soortenrijkdom (SR), Shannon's Index (H') en populatiegroeisnelheid (λ) op vier verschillende lokaties met *S. macropodum.***

| Lokatie | SDI | SR | H' | λ |
|---|---|---|---|---|
| Cattien | 0.68-0.78 | 11-30 | 1.19-3.32 | 0.981 |
| Dakuy | 0.25-0.32 | 24-34 | 3.01-3.64 | 1.017 |
| Bachma | 0.40-0.48 | 39-56 | 4.69-5.08 | 1.022 |
| M'drak | 0.50-0.75 | 14-25 | 2.26-3.71 | --- |

In Cattien is er sprake van sterke verstoring als gevolg van het af- of omhakken van takken en bomen om de vruchten te oogsten en ook vanwege de invasie van bamboe in het bos; in M'drak is de verstoring iets minder; in Bachma is ze middelmatig en in Dakuy het minst.

Uit ons onderzoek bleek, dat het oogsten van de vruchten van *S. macropodum* door takken af te hakken, of zelfs de hele boom om te hakken, tot wel 55 % aan de lokale verstoringsindex (SDI) kan bijdragen. En een hoge verstoringsindex blijkt samen te gaan met relatief lage diversiteitsindices, waarbij die voor Bachma (middelmatige graad van verstoring) overigens het hoogst zijn. In Bachma is ook λ het hoogst, gevolgd door Dakuy (Tabel 1).

Ik hoopte, dat mijn onderzoek een 'trade-off' tussen de economische opbrengst van een bos met S. macropodum en haar biodiversiteit zou aantonen, omdat men op grond daarvan dan een management systeem zou kunnen formuleren, waarbij het aantal stammen of de stam oppervlakte ('basal area') van *S. macropodum* ten opzichte van het totale aantal stammen (of de 'basal area') in het bos zodanig op peil wordt gehouden, dat het bos zowel een goede productie van *Scaphium*-vruchten zou leveren, alsook een hoge biodiversiteit zou bewaren. Maar dat heb ik niet aan kunnen tonen.

In feite zag ik twee benaderingen in het management van *S. macropodum*: In natuurlijke bossen met *S. macropodum* probeerden de boeren zoveel mogelijk vruchten te oogsten door gewoon de vruchtdragende bomen om te kappen of er grote takken af te hakken en dat leidde dus tot een flinke afname van deze soort. Maar als het aantal *S. macropodum*-bomen sterk was verminderd, plantten ze jonge boompjes van deze soort in het verarmde bos, gewoonlijk in strippen, die eerst werden schoon gehakt, waarna er dan zoveel mogelijk *S. macropodum*-juvenielen in werden geplant. Beide behandelingen bleken niet goed voor de vestiging en populatiegroei van S. macropodum, en ook niet voor de biodiversiteit van het bos.

Een drie-jarige census van de demografie van *S. macropodum* op drie onderzoekslokaties (Cattien, Bachma en Dakuy) liet zien, dat in Cattien (met de sterkste verstoring) het af- of omhakken negatieve effekten op de populatiegroei, de overleving van kiemplanten en op de reproduktie van *S. macropodum* had, hetgeen tot een onstabiele en lage vruchtenoogst leidde. In Cattien was de populatiegroeisnelheid λ minder dan 1, maar de waarde 1 viel binnen het 95 % betrouwbaarheidsinterval, zodat ik, op basis van mijn data, statistisch gesproken geen significante achteruitgang van de populatie kon aantonen. Een populatieprojektie voor de komende 50 jaar liet wel een ernstige achteruitgang van deze populatie zien, en ik schat de toekomst van deze soort in Cattien, bij ongewijzigd management, somber in. Daarmee ziet het er ook slecht uit wat betreft de toekomstige oogstopbrengsten van Scaphium-vruchten in Cattien.

In de weinig tot matig verstoorde lokaties Dakuy en Bachma lieten de boeren de vruchten van *S. macropodum* aan de boom rijpen en er afvallen en ze raapten deze dan van de grond op. Daardoor waren er weliswaar minder zaden voor kieming en vestiging beschikbaar, maar dit had geen negatief effect op de populatiegroeisnelheid; op beide lokaties was $\lambda > 1$. Op beide lokaties lijken de toekomstige ontwikkelingen van de *S. macropodum*-populaties ook goed, en vooral in Bachma, dat ook het soortenrijkst is, lijkt de populatie goed en duurzaam te worden beheerd.

Het belangrijkst voor een goed en duurzaam beheer van alle *S. macropodum*-populaties is, dat de oogstpraktijken zodanig verbeteren dat de populatie blijft groeien en de biodiversiteit van de lokaties op peil blijft. Maar ik beveel ook aan, dat individuele *S. macropodum*-bomen als eigendom aan lokale boeren worden toegewezen en zij verantwoordelijk worden gemaakt voor een duurzaam beheer ervan, gericht op een goede en van jaar tot jaar stabiele oogst.

Van 2008 – 2010 heb ik in plastic kassen groei-experimenten met juvenielen van S. macropodum onder verschillende lichtbeschikbaarheden uitgevoerd. Ook heb ik hun groei bestudeerd nadat ik de top eruit gebroken had, als simulatie van overeenkomstige beschadiging van juvenielen in het bos door het vallen van takken uit het kronendak.
In de kassen bleek de hoogtegroei van de juvenielen gedurende de eerste 8 maanden geringer als de lichtbeschikbaarheid meer dan 25 % van het volle zonlicht bedroeg, terwijl de diametergroei van de stam juist toenam. Maar vanaf de negende tot de achttiende maand namen zowel hoogte- als diametergroei van de juvenielen toe bij hogere lichtbeschikbaarheid. Groei was het snelst bij 50 % lichtbeschikbaarheid.

In Bachma heb ik ook de groei van juvenielen van *S. macropodum*, die in opengehakte strippen van verschillende breedte in het bos waren ingeplant, bestudeerd. Ook hier bleek de groei het snelst bij 50 % lichtbeschikbaarheid, en die werd gerealiseerd bij een stripbreedte van 4 m. Maar de hoogtegroei van de juvenielen in de kas was ongeveer 4 keer zo snel als in de strippen in het veld en de relatieve groeisnelheid (RGR) zelfs tien keer zoveel. In de strippen was de mortaliteit van de juvenielen ook veel hoger dan in de kas.

Op grond van mijn resultaten beveel ik voor wat betreft de produktie van juvenielen om in het bos in te planten het volgende aan:

i. Voor het verkrijgen van juvenielen van goede kwaliteit moet men ze bij een lichtbeschikbaarheid van 50 % opkweken;
ii. Voordat de juvenielen in het veld worden ingeplant moeten ze een periode van acclimatisatie aan de veldomstandigheden ondergaan

door ze bijvoorbeeld een tijdje geen water of kunstmest te geven. De mortaliteit na inplanting in het veld zal hierdoor afnemen;

iii. Voor succesrijke vestiging in het veld is een stripbreedte van 4 m het best en kosten-effectiefst.

Duurzaam beheer van S. macropodum-bossen moet op het behoud van de biodiversiteit van het bos gebaseerd zijn, constante oogsten en dus stabiele inkomsten opleveren en het zou onder de gezamenlijke verantwoordelijkheid van de lokale boeren moeten vallen. In Bachma bleek het beheer duurzaam en die lokatie voldeed aan alle drie voorwaarden. De Bachma-lokatie was niet al te erg verstoord, had de hoogste diversiteitswaarden, had de hoogste waarde voor de populatiegroeisnelheid, de beste reproduktie, en de grootste oogst. Dat genereerde een goed inkomen voor de lokale gemeenschap, die sterk van de opbrengsten van het bos afhankelijk is. In Bachma is het S. macropodum-bos aan de boeren toegewezen om het gezamenlijk te beheren en de boeren zijn hier dus verantwoordelijk voor het funktioneren van het systeem. Een dergelijk beheer levert de boeren belangrijke voordelen.

Uit een kosten-baten analyse van de produktie van S. macropodum-vruchten in Bachma over de jaren 2007 – 2010 bleek dat het bos een gelijkmatig inkomen van US $ 592 per hectare per jaar opleverde, waarbij er per hectare 20 volwassen S. macropodum-bomen staan. Het duurzaam beheer en het oogsten kostten tezamen US $ 170 per hectare per jaar, zodat de netto opbrengst dus US $ 422 per hectare per jaar was.

Uit mijn onderzoek blijkt, dat een duurzaam en produktief beheer van S. macropodum-bossen in Vietnam mogelijk is. De lokale boeren moeten weten dat juvenielen optimaal groeien bij 50 % lichtbeschikbaarheid en dat dit bereikt kan worden in opengekapte strippen van 4 m breed. De boeren moeten ook weten dat duurzame oogst van S. macropodum-vruchten mogelijk is, en dat ze volledig op moet houden met het oogsten van de vruchten door takken en hele bomen af en om te hakken. Als ze daar niet mee ophouden komt er gauw een eind aan hun oogsten.

# Tóm tắt các kết quả nghiên cứu

Ươi (Scaphium macropodum) là một loài cây chịu bóng (Yamada and Suzuki 1996), đa tác dụng quan trọng trong các rừng mưa nhiệt đới của Việt Nam. Chúng phân bố từ Quảng Trị vào đến Đồng Nai, Đông Nam Bộ. Trước đây, cây ươi rất phổ biến trong các rừng tự nhiên và người dân địa phương hưởng lợi tốt từ việc thu hoạch quả ươi (Hy 2005, Huy et al. 2010a). Tuy nhiên cây ươi hiện tại đang bị tàn phá, suy thoái nghiêm trọng do khai thác "triệt" để thu lấy quả (Huy et al. 2010a). Nghiên cứu đặc tính sinh thái cây ươi, bao gồm các nghiên cứu về sinh trưởng cá thể, sinh học và động thái quần thể sẽ cung cấp cho chúng ta những kiến thức làm cơ sở cho quản lý phát triển bền vững tài nguyên thực vật quan trọng này.

Trong nghiên cứu này, chúng tôi có các mục tiêu nghiên cứu cụ thể như sau:

- Nhằm đánh giá định lượng đa dạng sinh học thực vật các lâm phần cây ươi nghiên cứu tại các địa điểm khác nhau với 3 mức tác động hiện trường SDI (Site disturbance index): cao, trung bình và thấp;
- Phân tích động thái quần thể cây ươi (S. macropodum) tại các địa điểm nghiên cứu dưới các tác động động hiện trường và phương thức khai thác quả khác nhau;
- Nhằm xác định được nhu cầu và ảnh hưởng của chế độ ánh sáng đến sinh trưởng toàn diện của cây ươi giai đoạn dưới 2 năm tuổi và phản ứng sinh trưởng khi bị gãy mất ngọn chính;
- Phân tích đánh giá sinh trưởng cây ươi trồng làm giàu rừng trong các băng chặt khác nhau tại hiện trường rừng nghèo tái sinh Km 9, vườn quốc gia Bạch Mã.

Nội dung và kết quả nghiên cứu của luận án được trình bày trong 6 chương. Chương 1 là phần giới thiệu chung. Chương 2 trình bày kết quả đánh giá định lượng đa dạng sinh học thực vật các lâm phần cây ươi nghiên cứu tại các địa điểm khác nhau. Chương 3 trình bày kết quả phân tích động thái quần thể cây ươi (S. macropodum) tại các địa điểm nghiên cứu dưới các tác động động hiện trường và phương thức khai thác quả khác nhau. Chương 4 là kết quả phân tích định lượng sinh trưởng cây ươi trong các thí nghiệm ánh sáng và gãy ngọn trong nhà lưới. Chương 5 là kết quả phân tích định lượng sinh trưởng cây ươi trồng làm giàu rừng trong các băng chặt khác nhau tại hiện trường Km 9, Bạch Mã, và Chương 6: phân tích tổng hợp và thảo luận những vấn đề cơ bản của tất cả các chương nghiên cứu và tóm lược lại kết quả.

Dưới đây là phân tích tổng hợp và thảo luận những vấn đề cơ bản của tất cả các chương nghiên cứu và tóm lược những kết quả của toàn bộ Luận án:

## Đa dạng sinh học loài của lâm phần và tốc độ tăng trưởng quần thể của cây ươi (S. macropodum) dưới các mức độ tác động hiện trường khác nhau

Điều kiện môi trường của hiện trường nghiên cứu cây ươi phụ thuộc nhiều vào những tác động của các phương thức khai thác quả ươi. Chúng tôi đánh giá bằng chỉ số tác động hiện trường SDI (Site Disturbance Index), và thấy rằng trên một hiện trường nghiên cứu, phương pháp thu hoạch quả ươi bằng cách chặt cành có thể quyết định tới 55 % tổng giá trị SDI (Chương 2). Chỉ số SDI có tương quan chặt chẽ với chỉ số đa dạng sinh học loài thực vật (Naveh and Whittaker 1979, During and Willems 1984, Acharya 1999, Bongers et al. 2009), và tương quan tỷ lệ nghịch với tỷ lệ sống của cây con và do vậy ảnh hưởng âm tính tới tốc độ tăng trưởng quần thể. Vấn đề này cũng được nghiên cứu phát hiện với các quần thể ươi nghiên cứu tại Việt Nam (Chương 3).

Chúng tôi đánh giá định lượng đa dạng sinh học thực vật của các lâm phần ươi nghiên cứu (Chương 2) và động thái quần thể của cây ươi (Chương 3) tại 4 hiện trường bao gồm: Nam Cát Tiên, hiện trường bị tác động mạnh bởi hoạt động khai thác quả ươi, sự xâm lấn của tre lồ ô, và sự xâm canh; Bạch Mã và M'drak, các hiện trường với những tác động từ trung bình đến cao, và Đăk Uy với tác động hiện trường nhỏ nhất (Bảng 1).

**Bảng 1. Chỉ số SDI, Đa dạng sinh học loài (SR & H') và Tốc độ tăng trưởng quần thể (λ) của cây ươi (*S. macropodum*) tại các hiện trường nghiên cứu khác nhau**

| Site | SDI | SR | H' | λ |
|---|---|---|---|---|
| Cattien | 0.68-0.78 | 11-30 | 1.19-3.32 | 0.981 |
| Dakuy | 0.25-0.32 | 24-34 | 3.01-3.64 | 1.017 |
| Bachma | 0.40-0.48 | 39-56 | 4.69-5.08 | 1.022 |
| M'drak | 0.50-0.75 | 14-25 | 2.26-3.71 | --- |

***Ghi chú:*** *SDI- Chỉ số tác động hiện trường, SR-Độ phong phú loài, H'-Chỉ số đa dạng loài Shannon , λ- Tốc độ tăng trưởng quần thể; Nguồn: Chương 2 và Chương 3.*

Trong các hiện trường nghiên cứu, Chỉ số Đa dạng Shannon (H’) giao động mạnh từ 1.19 đến 5.08 và tốc độ tăng trưởng quần thể (λ) giao động từ 0.981 đến 1.022. Trong đó, hiện trường Bạch Mã có giá trị H’ cao nhất, nơi có SDI trung bình và ở đó cây ươi có sinh trưởng tốt nhất, với giá trị λ cao nhất. Giá trị H’ thấp nhất tại Nam Cát Tiên, nơi có chỉ số tác động hiện trường SDI cao nhất và tốc độ tăng trưởng λ của cây ươi đạt được thấp nhất (Bảng 1). Trong các hiện trường nghiên cứu của chúng tôi, chỉ số đa dạng sinh học H’ tương quan tỷ lệ nghịch với giá trị quan trong tương đối của cây ươi trong lâm phần và chỉ số H’ cũng tương quan với chỉ số tác động hiện trường SDI theo một đường cong xác định (H’ = -1.381 + 25.095 SDI – 27.441SDI2, r2= 0.76, p<0.001), trong đó H’ tăng dần và đạt giá trị cực đại tại giá trị SDI tương ứng là 0,45 (giá trị trung bình).

Chúng tôi hy vọng có thể tìm thấy một “điểm cân bằng” (trade-off) cho quản lý giữa chức năng sản xuất của cây ươi với vấn đề bảo tồn đa dạng sinh học trong các lâm phần. “Điểm cân bằng” này là sự duy trì ổn định một tỷ lệ giữa số lượng cây ươi (hoặc tiết diện ngang) trên tổng số cá thể (cây) của tất cả các loài trong lâm phần (hoặc tổng tiết diện ngang), tại đó cả giá trị đa dạng sinh học H’ của lâm phần và sản lượng năng suất quả của cây ươi đạt được cao (Jobidon et al. 2004) và do vậy đảm bảo được nguồn thu nhập ổn định đáng kể cho người dân liên quan. Tuy nhiên chúng tôi không tìm thấy được “điểm cân bằng” (trade-off) trong nghiên cứu này (Chương 2).

Thực tế chúng tôi thấy có hai xu hướng xảy ra trong quản lý phát triển tài nguyên cây ươi (S. macropodum). Một mặt, tại các lâm phần tự nhiên khi cây ươi có quả, người dân địa phương tìm mọi cách để khai khác quả được nhiều nhất bằng cách chặt cả cây hoặc chặt cành, điều này tất yếu dẫn đến sự suy thoái nghiêm trọng. Mặt khác, khi các lâm phần ươi đã bị suy thoái, người dân cố gắng trồng phục hồi, và thường trồng theo băng trong các rừng nghèo, tái sinh, các băng được phát dọn sạch, và trồng ươi với mật độ cao. Cả hai xu hướng này rõ ràng đều không phù hợp cho thiết lập và sinh trưởng của lâm phần ươi gây trồng, và không hỗ trợ cho đa dạng sinh học của lâm phần. Xu hướng 1 tất yếu sẽ làm suy thoái nghiêm trọng quần thể cây ươi và đa dạng sinh học của lâm phần, trong khi đó, xu hướng 2 cũng sẽ làm tổn thương và suy giảm đa dạng sinh học thực vật.

## Mô hình Ma trận cho phân tích động thái quần thể và quản lý bền vững tài nguyên cây ươi (*S. macropodum*)

Sự kết hợp phân tích tính đàn hồi linh hoạt (elasticity) và LTRE (Life Table Response Experiments) trong các nghiên cứu động thái quần thể, thường được thực hiện thông qua mô hình ma trận là một phương pháp tiếp cận mới quan trọng, tiềm năng cho đánh giá tính bền vững của quản lý nói chung và các phương thức khai thác nói riêng (Sinha and Brault 2005, Zuidema et al. 2007, Schmidt et al. 2011).

Chúng tôi tiến hành nghiên cứu động thái quần thể cây ươi trong 3 năm (2007-2010) tại 3 địa điểm khác nhau tại Việt Nam với các tác động khác nhau từ các hoạt động khai thác quả khác nhau, trong đó, hiện trường Nam Cát Tiên chịu tác động cao nhất do khai thác quả ươi, hiện trường Bạch Mã chịu tác động trung bình và Đăk Uy chịu tác động nhỏ nhất (Chương 3). Chúng tôi mong muốn sẽ sử dụng các kết quả nghiên cứu động thái này làm cơ sở cho đề xuất xây dựng biện pháp quản lý bền vững các lâm phần ươi tại các khu vực nghiên cứu. Với mục tiêu như vậy, chúng tôi lập các mô hình ma trận riêng rẽ cho phân tích động thái quần thể cây ươi tại các khu vực nghiên cứu, phân tích tốc độ tăng trưởng quần thể, phân tích dự báo động thái phát triển quần thể và triển vọng phát triển của chúng trong tương lai.

Kết quả nghiên cứu cho thấy, tại Cát Tiên, hiện trường bị tác động mạnh do hoạt động khai thác quả ươi, phương pháp chặt cành khai thác quả ươi đã tác động xấu rõ rệt tới các chỉ số tốc độ sinh trưởng quần thể, tỷ lệ sống cây con, và sức sinh sản (hoa, quả) của ươi (điều này dẫn đến năng suất, sản lượng quả thấp và không ổn định). Kết quả nghiên cứu của chúng tôi cho thấy tốc độ tăng trưởng quần thể λ của cây ươi tại Nam Cát Tiên nhỏ hơn 1 (λ<1), có nghĩa rằng quần thể đang bị suy thoái, tuy nhiên khoảng giới hạn 95 % độ tin cậy của λ này lại bao gồm cả giá trị 1 (unity), do vậy về mặt thống kê và với số liệu điều tra nghiên cứu 3 năm chúng ta không thể biểu thị được sự suy thoái rõ rệt của quần thể này. Phân tích dự báo động thái quẩn thể ươi tại Nam Cát Tiên trong 50 năm cho thấy rằng kích cỡ quần thể sẽ bị suy thoái nghiêm trọng, và triển vọng phát triển quần thể của cây ươi tại Nam Cát Tiên trong tương lai là rất đáng lo ngại (Chương 3). Như đã đề cập đến trong phần trên là chỉ số tác động hiện trường cao tại Nam Cát Tiên cũng là nguyên nhân chính làm giảm chỉ số đa dạng sinh học H', thấp nhất trong số các hiện trường nghiên cứu (Bảng 1, và xem Chương 2). Từ đó chúng tôi có thể kết luận như sau: quẩn thể cây ươi tại Nam Cát Tiên đang được quản lý, khai thác quả không bền vững, và do đó đang bị suy thoái nghiêm trọng, triển vọng của chúng trong tương lai rất đáng lo ngại.

Trong khi đó tại Đak Uy và Bạch Mã, hiện trường nghiên cứu được đánh giá là chịu tác động trung bình và thấp, quả ươi được thu hái truyền thống theo phương pháp thu lượm tự nhiên. Phương thức này làm giảm đáng kể nguồn hạt gieo giống, tuy nhiên không tác động xấu tới các chỉ số quần thể, tốc độ tăng trưởng quần thể λ của cả Đak Uy và Bạch Mã đều lớn hơn 1 (λ>1), cho thấy rằng quần thể đang ổn định phát triển. Kết quả phân tích cho thấy, cả hai quần thể ươi tại Đak Uy và Bạch Mã đều có triển vọng phát triển khá tốt trong tương tương lai, đặc biệt là tại Bạch Mã, nơi có chỉ số đa dạng sinh học H' cao nhất (Bảng 1, và xem Chương 2). Quần thể cây ươi tại hiện trường Bạch Mã được đánh giá là có phương thức quản lý và khai thác quả khá bền vững.

Để quản lý bền vững các lâm phần cây ươi tự nhiên còn lại, điều quan trọng trước tiên chúng tôi đề xuất là cần phải thay đổi cải tiến phương thức khai thác quả theo cách bền vững, không làm ảnh xấu tới tốc độ tăng trưởng quẩn thể λ, và bảo vệ được đa dạng sinh học của lâm phần; thứ 2, chúng tôi cũng đề xuất khuyến khích sự tham gia tích cực của ngươi dân địa phương và thực hiện "chương trình đồng quản lý bền vững", trong đó người dân địa phương được giao nhận một số lượng cây ươi cụ thể và quản lý sử dụng bền vững với tinh thần trách nhiệm cao nhất nhằm đảm bảo đạt được năng suất quả cao và ổn định. Cách tiếp cận bền vững này (Gaoue and Ticktin 2010, Schmidt et al. 2011) cũng có thể được áp dụng nhân rộng cho các lâm phần cây ươi còn xót lại ở các khu vực khác không thuộc địa bàn nghiên cứu.

## Sinh trưởng của cây ươi (S. macropodum) trong thí nghiệm nhà lưới và trồng làm giàu rừng dưới các điều kiện khác nhau

Chất lượng cây con là một trong các yếu tố quan trọng nhất quyết định sự thành công của gây trồng rừng và tái sinh tự nhiên (Kuchelmeister and Huy 2004, Ishuzuka et al. 2010). Sinh trưởng của cây con thí nghiệm trong nhà lưới với các điều kiện được kiểm soát khác nhiều so với sinh trưởng của chúng trong điều kiện thí nghiệm ngoài hiện trường (Poorter et al. 2005). Hiểu rõ được phản ứng sinh trưởng thực vật với các điều kiện môi trường và tác động hiện trường khác nhau sẽ giúp cải thiện đáng kể quá trình sản xuất cây con của người dân và đồng thời hoạch định quản lý tốt quá trình tái sinh tự nhiên của rừng.

Chúng tôi tiến hành thí nghiệm cây con ươi trong nhà lưới (2008-2010) nhằm nghiên cứu ảnh hưởng của các chế độ ánh sáng khác nhau tới các chỉ tiêu sinh trưởng thực vật cây ươi và phản ứng sinh trưởng của chúng tới tác động "gãy mất ngọn chính" (top breakage disturbance), điều thường xuyên xảy ra với các cây ươi con trong rừng dưới tác động của các hoạt động khai thác (Chương 4). Chúng tôi cũng tiến hành một thí nghiệm trồng làm giàu rừng bằng cây ươi tại hiện trường rừng nghèo tái sinh, Km 9, Vườn quốc gia Bạch Mã, Việt Nam. Tại đây, cây ươi con được trồng theo phương thức làm giàu trong các băng chặt chiều rộng là 0 m (đối chứng), 2 m và 3 m, và do đó chế độ ánh sáng trong các băng chặt cũng sẽ khác nhau (Chương 5).

Kết quả trong Chương 4 cho thấy rằng, chế độ ánh sáng tác động ảnh hưởng tới sinh trưởng chiều cao và đường kính của cây ươi thí nghiệm 2 giai đoạn khác nhau. Giai đoạn 1 từ tháng thí nghiệm 1 đến tháng thứ 8, chế độ ánh sáng tăng (bắt đầu từ 25 %) làm giảm sinh trưởng chiều cao, nhưng lại tác dụng làm tăng sinh trưởng đường kính của cây ươi, trong khi đó từ tháng thí nghiệm thứ 9 trở đi (giai đoạn 2), khi tăng chế độ ánh sáng thì tác dụng làm tăng cả sinh trưởng chiều cao và đường kính của cây ươi. Tổng hợp kết quả của toàn bộ quá trình thí nghiệm và của tất cả các công thức chế độ ánh sáng, chúng tôi nhận thấy rằng với công thức chế độ ánh sáng là 50 % sinh trưởng chiều cao, đường kính, cường độ quang hợp và tốc độ tăng trưởng tương đối RGR (Relative Growth Rate) của cây ươi thí nghiệm đạt được trị số cao nhất.

Từ kết quả thí nghiệm này, chúng tôi nhận định rằng cường độ ánh sáng 50% có thể được coi là tối ưu cho sinh trưởng cây ươi giai đoạn dưới 20 tháng tuổi. Với phương pháp tiếp cận tương tự, Dai et al. (2009) và Poorter và Rose (2005) đã xác định được chế độ ánh sáng tối ưu cho sinh trưởng của một số loài cây rừng nhiệt đới. Tuy nhiên, phản ứng sinh trưởng với ánh sáng thường thay đổi theo thời gian, tùy thuộc vào các giai đoạn sinh trưởng khác nhau, do vậy để chính xác và hiệu quả hơn, chúng ta nên phân tích đầy đủ các số liệu sinh trưởng cho mỗi công thức chế độ sáng khác nhau theo chức năng thời gian để xác định được cường độ ánh sáng tối ưu  cho sinh trưởng của cây ươi cho từng giai đoạn sinh trưởng cụ thể. Kết quả trong Chương 5 cho chúng ta thấy rằng tốc độ tăng trưởng tương đối RGR của cây ươi trồng thí nghiệm làm giàu rừng tại hiện trường Km 9, vườn quốc gia Bạch Mã thấp hơn rất nhiều so với RGR của cây ươi thí nghiệm trong điều kiện nhà lưới. Và tại hiện trường thí nghiệm trồng làm giàu rừng này, một lần nữa cây ươi lại được đánh giá là có sinh trưởng tốt nhất, giá trị RGR cao nhất tại chế độ ánh sáng 50 %; khi cường độ ánh sáng tiếp tục tăng, RGR không tăng và thận chí giảm đi. Từ kết quả thí nghiệm thu được, chúng tôi kết luận như sau: băng chặt với chiều rộng 4 m (chừa lại các cây mục đích) sẽ tạo được chế độ ánh sáng tương đương 50 % và cây ươi trồng làm giàu rừng trong băng này đạt được tốc độ tăng trưởng tương đối RGR cao nhất.

Trong nghiên cứu của chúng tôi, cây ươi con thí nghiệm trong nhà lưới có sinh trưởng chiều cao cao hơn 4 lần so với sinh trưởng chiều cao của cây ươi con ngoài rừng tự nhiên (Chương 3 và Chương 4), và có trị số RGR cao gấp 10 lần so với RGR của cây ươi trồng thí nghiệm làm giàu rừng ngoài hiện trường trong 2 năm đầu tiên (Chương 3 và Chương 5), với chế độ ánh sáng tương đương. Trong thí nghiệm trồng làm giàu rừng, tỷ lệ chết của cây ươi trong lô đối chứng (ánh sáng là 18-20%) là 48 % l (Chương 5), cao hơn khoảng 10 % so với tỷ lệ chết của cây ươi thí nghiệm trong nhà lưới với ánh sáng 12,5 % (Chương 4).

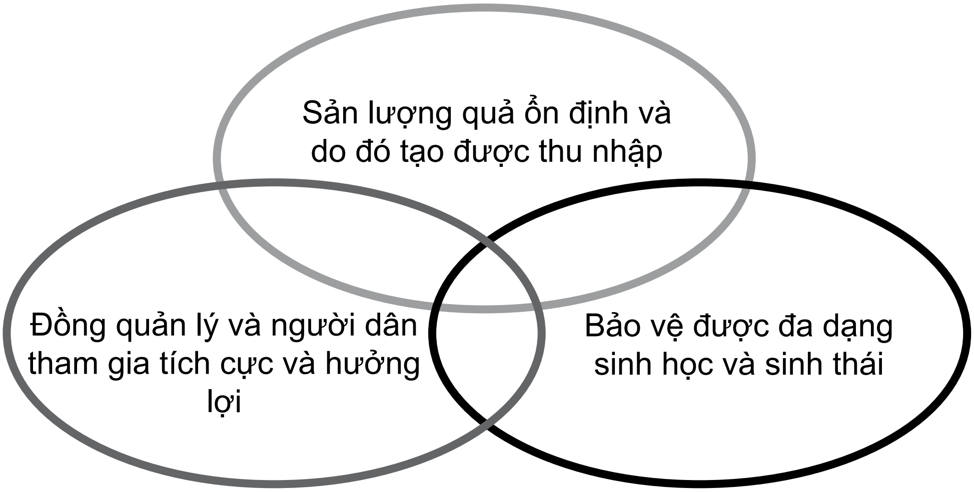
Tốc độ sinh trưởng thấp hơn và tỷ lệ chết cao hơn của cây ươi trồng thí nghiệm ngoài hiện trường so với cây ươi thí nghiệm trong nhà lưới được lý giải là do điều kiện gây trồng khắc nghiệt, khó khăn của hiện trường liên quan đến đất đai, điều kiện khô hạn, cạnh tranh thực vật, sâu bệnh và côn trùng ăn lá (Huy et al. 2010a).

Trên cơ sở những kết quả nghiên cứu của chúng tôi về chế độ ánh sáng tối ưu cho sinh trưởng cây ươi và sự khác biệt sinh trưởng lớn của cây ươi trong điều kiện thí nghiệm vườn ươm nhà lưới và điều kiện hiện trường, chúng tôi đề xuất một số điểm kỹ thuật quan trọng cho sản xuất cây con vườn ươm trồng rừng của người dân như sau:

- **i.** Nhằm tăng cường cải thiện chất lượng cây con vườn ươm, cây con ươi cần phải được che bóng phù hợp từ đầu tại vườn ươm; độ che sáng 50 % là thích hợp nhằm đảm bảo cho sản xuất cây con ươi chất lượng.
- **ii.** Trước khi được đem đi trồng rừng ngoài hiện trường, cây con ươi trong vườn ươm cần phải được trải qua giai đoạn "huấn luyện" làm cứng cây, nhằm tác dụng làm quen dần với các điều kiện khắc nghiệt ngoài hiện trường trồng rừng. Trong giai đoạn "huấn luyện" này cây con ươi sẽ bị hạn chế tối đa tưới nước, bón phân, dinh dưỡng và các chăm sóc khác. Kỹ thuật này hiệu quả và có thể làm giảm đáng kể tỷ lệ cây chết sau trồng, làm tăng khả năng thành rừng về sau.
- **iii.** Đối với kỹ thuật trồng làm giàu rừng ngoài hiện trường, băng chặt với chiều rộng 4 m (chừa lại các cây mục đích) được đánh giá là phù hợp cho trồng làm giàu rừng bằng cây ươi tại hiện trường rừng tái sinh nghèo Km 9, vườn quốc gia Bạch Mã, cả về khía cạnh chi phí, chế độ ánh sáng và sinh trưởng; kỹ thuật băng chặt này sẽ tạo được chế độ ánh sáng tương đương 50 % và cây ươi trồng làm giàu rừng trong băng chặt này đạt được tốc độ tăng trưởng tương đối RGR cao nhất.

## Đề xuất quản lý bền vững các lâm phần cây ươi (*S. macropodum*) trên cơ sở kinh nghiệm thực tế về cây ươi tại Nam Đông, vườn quốc gia Bạch Mã

Quản lý bền vững hiệu quả các lâm phần cây ươi tại Việt Nam có thể đạt được phải trên cơ sở của 3 yếu tố quan trọng, đó là (i) phải bảo vệ, bảo tồn được đa dạng sinh học và sinh thái, (ii) phải có năng suất và sản lượng quả ươi ổn định, và do đó tạo được thu nhập, và (iii) được tiếp cận theo đồng quản lý các lâm phần ươi, trong đó người dân có vai trò quan trọng và được hưởng lợi (Figure 1).




*Hình 1. Ba yếu tố cho quản lý bền vững các lâm phần cây ươi tại Việt Nam*

Tại Nam Đông, vườn quốc gia Bạch Mã, các lâm phần cây ươi được tiếp cận quản lý theo cách khá bền vững, trong đó tất cả ba yếu tố trên đều đã hình thành và áp dụng tốt cho việc quản lý các lâm phần cây ươi.

Thứ nhất, như đã trình bày trong phần trên các lâm phần ươi tại hiện trường Nam Đông, vườn quốc gia Bạch Mã có đa dạng sinh học loài H' cao nhất trong số các hiện trường nghiên cứu, và hiện trường này có chỉ số tác động hiện trường SDI trung bình và ổn định (Bảng 1). Thứ hai, quần thể ươi nghiên cứu tại đây có tốc độ tăng trưởng quần thể λ cao nhất, tỷ lệ cây ra quả và sản lượng quả cao nhất, và do đó tạo được thu nhập ổn định tốt cho người dân địa phương, những người đang gắn bó cuộc sống với rừng và bảo vệ các khu rừng này. Thứ ba, các lâm phần cây ươi tại Nam Đông, vườn quốc gia Bạch Mã đã được giao quản lý bởi cộng đồng người dân địa phương theo phương pháp cùng tham gia, và do vậy người dân có vai trò quan trọng, họ rất tích cực và trách nhiệm cao. Điều quan trọng nữa là người dân sẽ được hưởng lợi tương xứng với những tham gia đóng góp tích cực trong hệ thống đồng quản lý các lâm phần cây ươi tại đây.

Để đánh giá thực tế thu nhập của người dân tại Nam Đông, Bạch Mã từ việc thu hoạch quả ươi hàng năm tại đây, chúng tôi tiến hành một phân tích Chi phí- Lợi nhuận CBA (Cost –Benefit Analysis) (Huy 2005a) trên cơ sở số liệu thực tế thu được trong 3 năm, từ 2007 đến 2010 như sau:

- Số lượng cây ươi (S. macropodum) có DBH >5 cm (/ha): 33
- Số lượng cây ươi thành thục (/ha): 20
- Tỷ lệ cây thành thục có quả: 0.23
- Sản lượng quả trung bình (kg/cây/năm): 25.7
- Giá quả ươi tại khu vực ($US/kg): 5.0
- Chi phí nhân công ($US/công): 10.0

**Bảng 2. Phân tích Chi phí- Lợi nhuận thu hoạch quả ươi tại Nam Đông, Bạch Mã**

| **Phân tích Chi phí – Lợi nhuận** | | | | |
|---|---|---|---|---|
| | **Đơn vị** | **Số lượng** | **Giá** | **Thành tiền** |
| **Tổng thu nhập ($US/ha/năm)** | | | | **592** |
| Quả ươi (/ha/năm) | kg | 118 | 5.0 | 592 |
| Khác | | | | |
| **Tổng chi phí ($US/ha/năm)** | | | | **170** |
| Công phát dọn sạch thực bì cây bụi quanh gốc cây ươi | công | 2.0 | 10.0 | 20.0 |
| Công thu lượm quả ươi chín rụng | công | 10.0 | 10.0 | 100.0 |
| Bảo trì và bảo vệ lâm phần ươi | công | 5.0 | 10.0 | 50.0 |
| **Lợi nhuận ($US/ha/năm)** | | | | **422** |

Kết quả phân tích chi phí và lợi nhuận CBA (Bảng 2) cho thấy, từ việc thu hoạch quả, các cây trưởng thành của lâm phần ươi tại Nam Đông, Bạch Mã tạo ra được một thu nhập khá tốt, ổn định hàng năm cho người dân, cụ thể là thu nhập 592 $US trên ha (từ 20 cây ươi trưởng thành). Với khoản thu nhập này, sau khi trừ đi tất cả các khoản chi phí cần thiết cho các hoạt động quản lý và khai thác tiếp cận theo hướng quản lý bền vững và cùng tham gia tại đây (170 $US/ha/năm), thì khoản lợi nhuận người dân có được là 422 $US/ha/năm. Thu nhập và lợi nhuận này từ cây ươi dự kiến sẽ tăng trong những năm tới do cách tiếp cận quản lý bền vững, và năng suất và sản lượng quả ươi sẽ tăng trong các năm tiếp theo. Và đây mới chỉ là giá trị thu nhập tính ra bằng tiền của sản phẩm quả ươi, bên cạnh đó còn nhiều giá trị của các sản phẩm và dịch vụ quan trọng khác chưa được phân tích tính toán (gỗ, lâm sản phi gỗ, đa dạng sinh học, dịch vụ môi trường, vv…).

Từ kết quả nghiên cứu, chúng tôi đề xuất là chúng ta có thể áp dụng một tiếp cận quản lý bền vững và hiệu quả như trên cho các lâm phần cây ươi nghiên cứu, đặc biệt là vấn đề khai thác quả, và phương pháp tiếp cận này cũng có thể được áp dụng cho các lâm phần cây ươi khác chưa được nghiên cứu tại Việt Nam, nhưng có các điều kiện tự nhiên và kinh tế xã hội tương tự. Người dân địa phương liên quan đến sản xuất và quản lý cây ươi cần được chú ý là 50 % ánh sáng là điều kiện tối ưu cho cây ươi sinh trưởng phát triển gia đoạn dưới 2 năm tuổi, và khi tiến hành trồng làm giàu rừng cây ươi (nghiên cứu tại hiện trương Km 9, vườn quốc gia Bạch mã), băng chặt chiều rộng 4 m sẽ tạo được một chế độ ánh sáng tương 50 % cho cây ươi con sinh trưởng. Một vấn đề quan trọng cần phải được hiểu sâu rộng đó là chúng ta có thể nghiên cứu áp dụng được những phương thức khai thác quả bền vững cho các lâm phần cây ươi, và cần phải dừng ngay các hình thức khai thác quả ươi bằng chặt cành, đốn hạ cây, đây là các hình thức khai thác triệt hạ và tàn phá, và tất yếu sẽ dẫn đến sự suy thoái và diệt vong của loại cây gỗ, cho thu hoạch quả rất có giá trị này.

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# Curriculum vitae

Le Quoc Huy was born on 10 October 1962 in Phu Tho, Vietnam. In 1983, he started his B.Sc. study in biology at Hanoi National University and graduated in December 1988. After graduation, he continued his study at the Hanoi Agricultural University for an apprenticeship in Tree Crop Improvement for more than one year. From 1990 to 1994 he worked at the National Institute for technology, Hanoi, Vietnam. In February 1995 he joined the Research Center for Forest Ecology and Environment under the Forest Science Institute of Vietnam (SFIV) as a researcher. He participated in several research projects on plant ecology and forest resource management. In April 2001 he was appointed as deputy director of the Research Center for Forest Ecology and Environment. From August 2002 to August 2004, he studied and obtained his M.Sc. in plant ecology and biodiversity from the College of Forestry, University of Horticulture and Forestry, Solan (HP.), India. From 2004 onward, he conducted a number of research projects as project manager in the fields of plant ecology and sustainable management and sustainable biofuel development in Vietnam. In the meanwhile, he also acquired vast experiences in working as an expert with a number of international projects dealing with forest rehabilitation and sustainable management in Vietnam like KfW projects and feasibility studies, GTZ project, UNDP, JBIC watershed project, sustainable biofuel development project. Since September 2007, he has been admitted as a Ph.D. student to the Ecology and Biodiversity group, Faculty of Science, Utrecht University, the Netherlands. His Ph.D. study on “Growth, demography and stand structure of *Scaphium macropodum* in differently managed forests in Vietnam” has been conducted under the framework of the Tropenbos International (TBI) Vietnam Program with the title “Capacity Development and institutional support to the Forest Science Institute of Vietnam (FSIV) through Ph.D. and Post-Doc research”. After completion of his Ph.D. in May 2012, he returns to Vietnam to continue doing research in this field.

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