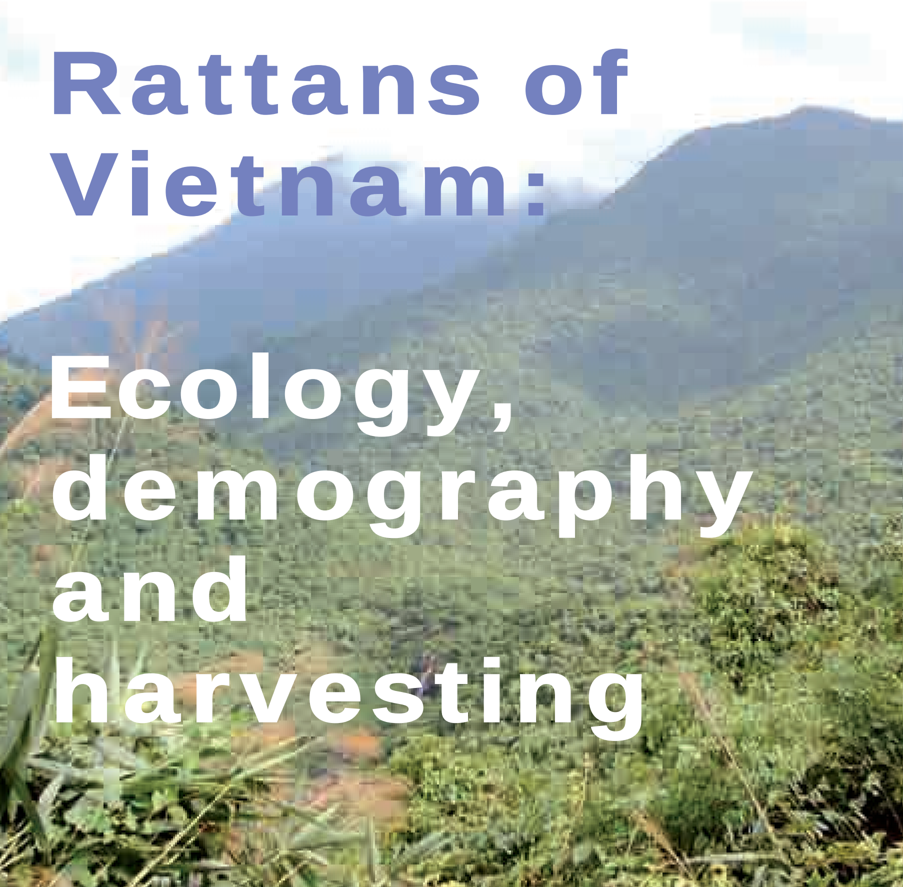

Rattans of Vietnam:

Ecology, demography and harvesting

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ISBN: 978-90-393-5157-4

Back: Rattan stems are sun-dried for a couple of days

Printed by Ponsen & Looijen of GVO printers & designers B.V.
Designed by Kooldesign Utrecht

Rattans of Vietnam:
Ecology, demography and harvesting

Vietnamese rotans: ecologie, demografie en oogst

(met een samenvatting in het Nederlands)

Song Việt Nam: sinh thái, quần thể học và khai thác

(phần tóm tắt bằng tiếng Việt)

Proefschrift

ter verkrijging van de graad van doctor
aan de Universiteit Utrecht
op gezag van de rector magnificus, prof. dr. J.C. Stoof,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen
op woensdag 14 oktober 2009 des middags te 2.30 uur

door

Bui My Binh

geboren op 17 februari 1973 te Thai Nguyen, Vietnam

Promotor: Prof.dr. M.J.A. Werger
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Universiteit Utrecht

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Bernhard
Chair

TROPENBOS INTERNATIONAL

This study was financially supported by the Tropenbos International and the Netherlands Fellowship Programme (Nuffic).

To Tũn and Bông

Contents

Daemonorops cf. poilanei

Chapter 1

General introduction

Sustainable forest management

The conversion of tropical forests to agricultural fields, pastures and plantations is considered a serious threat to these ecosystems and their biodiversity since the 1970s (Myers 1984, Wilson 1988). An estimated 11 million hectares of tropical forest are destroyed annually (FAO 2001). Tropical forests offer a habitat for large numbers of plant and animal species, yield many useful products but are also important in regulating the global climate. For these reasons, the conservation and sustainable use of tropical forests has become an important goal for conservation organizations as well as timber organizations (ITTO 1990, 1993, IUCN 1992, Putz 1994, Sist 2000). Over the last decades, various sets of guidelines have been produced for sustainable forest management, both for timber products and non-timber products obtained from these forests. Although the need for sustainable forest management is now internationally recognized, it is hard to put in practice (de Beer and McDermott 1989, Peters 1996, Wilkie et al. 2003). Potential causes for the lack of sustainable management include insufficient financial incentives and high returns from forest conversion to agriculture or unsustainable forest use (Pearce et al. 1999). The new climate agreement that is to be signed in Copenhagen in December 2009 may provide additional financial incentives to keep tropical forests standing and improve their management, through the REDD mechanism of Reducing Emissions from Deforestation and forest Degradation (Gullison et al. 2007, Putz et al. 2008).

Non-timber forest products as a conservation and development strategy

The concern about tropical deforestation and biodiversity loss in 1980s led to a growing recognition of the importance of non-timber forest products (NTFP) from tropical forests (Myers 1984, de Beer and McDermott 1989, Peters et al. 1989). In most tropical countries, NTFP play an important role in the daily lives and well being of the local population, in particular rural and poor people. According to de Beer and McDermott (1989) 29 million forest dwellers in Southeast Asia depend on NTFP for their food security, health care and cash income. In addition to local consumption, NTFP are also important traded commodities on the local, regional, national as well as the international market (FAO 2002). It is increasingly acknowledged that the exploitation of NTFP can play an important role in the conservation and development of tropical rain forest areas (Nepstad and Schwartzman 1992, Wegge 1993).

An exploitation system of NTFP is sustainable when it is ecologically sustainable, economically feasible and socially acceptable (Ros-Tonen et al. 1995). In this thesis, the focus is on ecological sustainability of NTFP use, in particular at the level of the population.

Rattan in Vietnam

Rattans are climbing palms belonging to the Arecaceae family. There are about 558 species of rattans in the world and they are widely distributed in the Old World tropics (Dransfield et al. 2008). In Vietnam, rattan is one of the most important NTFP after timber and bamboo. Rattan has been used by the Vietnamese people for a long time as raw material for weaving and making home appliances for domestic use and for sale (Dzung 2000, Nghia et al. 2000). As the demand for rattan products is increasing, there is a high pressure on the natural populations of rattan. The gap between demand and raw material supply is the greatest challenges facing Vietnam's rattan production. Meanwhile, rich and medium forests with many species of rattan are being seriously depleted. According to Dzung (2000), the supplies of raw rattan will disappear within 10-20 years if no extensive rattan plantation and management plan is implemented. Some economic species which still were abundant two decades ago now become rare in many areas of the country (e.g. *Calamus poilanei)*.

There are clear needs to conserve rattan resources, but there is also a need to use these resources for economic development. The sustainable use of rattan provides one way to combine these two needs. It is this sustainable rattan management that was the main aim of this study.

Context of this study

This research project formed part of the Tropenbos International-Vietnam Programme in cooperation with Utrecht University, the Institute of Ecology and Biological Resources and the Forest Science Institute of Vietnam.

Tropenbos International (TBI) is a non-governmental organization funded by the Dutch Government. The main objective of TBI is to improve the conservation status and sustainable use of tropical rain forests by generating and developing applicable methodologies and making these locally available. TBI has carried out multi-disciplinary research programs in cooperation with research institutions, government agencies and other stakeholders in tropical countries, e.g. Colombia, Indonesia, Ghana, Guyana, Suriname, and Vietnam (for details see the website: www.tropenbos.org).

Tropenbos International Vietnam (TBI – Vietnam) was established in 2001 with its main research site in Central Vietnam. TBI - Vietnam aims to contribute to implementing the National Forest Strategy and to support the formulation of the National Forest Research Strategy of Vietnam. It also supports counterparts to carry out research projects on conservation and sustainable utilisation of forest resources in Vietnam. The results thereof are subsequently supported to be transferred into policy and practical forest management. In addition, TBI - Vietnam supports to build research capacity in the forestry sector by providing short and long training programs, both in the country and overseas (for details see the website: www.tropenbos.org).

The Institute of Ecology and Biological Resources (IEBR) is the main research institution on ecology and biological resources of Vietnam. Its main tasks are to carry out surveys and inventories of biological resources in different ecosystems of Vietnam, and to implement research on the biology of both flora and fauna. The results of fundamental research in the Institute provide a basis for important publications as “Fauna and Flora of Vietnam”, “Plant Resources of Vietnam”, and the “Red Data Book of Vietnam”. IEBR is also responsible for education and training in ecology and biological resources at the post-graduate level (for details see the website: www.iebr.ac.vn).

The Forest Science Institute of Vietnam (FSIV) is the main research institution on forestry of Vietnam. Its main tasks are to organize and implement research on forestry ranging from ecology, silviculture, forest industry, forest economics to forestry organization and management. It is also responsible for post-graduate training and international research cooperation on forestry (for details see the website: www.fsiv.org.vn).

In 2004, within the framework of the TBI – Vietnam activities, the Department of Plant Ecology and Biodiversity, Utrecht University, the Institute of Ecology and

Biological Resources and the Forest Science Institute of Vietnam started intensive cooperation on a research project, named: "Conservation and sustainable utilization of rattans in Thua Thien Hue province, Vietnam". The project started running with the funding partly supported by TBI – Vietnam and the Non-timber forest products project (phase 2) under the Forest Science Institute of Vietnam. This dissertation is one of the results of this cooperation project which received additional financial support from the Netherlands Fellowship Programme (Nuffic).

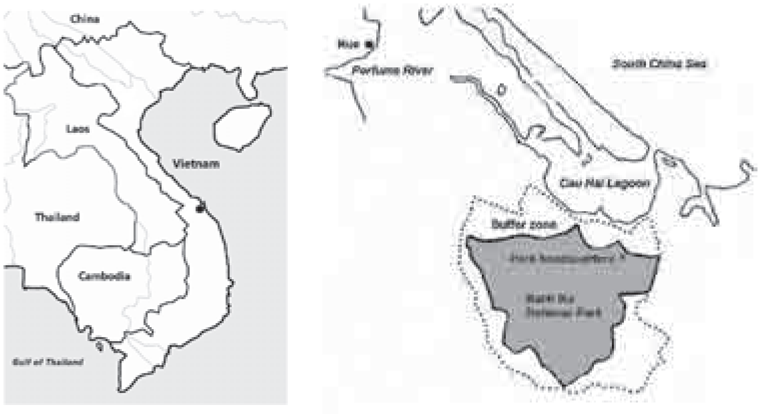


Figure 1. Study location in Bach Ma National Park, Thua Thien Hue Province, Central Vietnam.

This dissertation contains the results of a study on the ecology, demography and harvesting of three valuable rattan species. The study species *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei* are common in Vietnam and are exploited there. The field study was carried out in Bach Ma National Park, Thua Thien Hue province, Vietnam (Figure 1). Species characteristics, status and distribution of the three species are presented in Chapter 3.

Objectives of this study

The overall objectives of the study are to contribute basic knowledge on the ecology, demography and harvesting for three economic rattan species in Vietnam.

The specific objectives of the study are:

1. to describe and explain patterns of growth, survival and reproduction of rattan stems for the three study species;
2. to analyse the demography of the three study species, with special emphasis on the relative importance of sexual and vegetative reproduction modes and clonal growth for of the study species;
3. to study the effects of harvesting on rattan growth, survival and reproduction, and their consequences for population growth and future rattan availability.

Outline of the thesis

This thesis consists of six chapters, the contents of which are briefly presented below:

Chapter 2 describes the general setting, presenting short descriptions of the geography, climate, and soil types in Vietnam. Also, the forest status, biodiversity and ecosystems are described, pointing out the importance of non-timber forest products for conservation and development. In addition, the taxonomy, diversity, economic importance, and management of rattan resources in Vietnam are discussed.

Chapter 3 presents the results of a study on patterns of growth, survival and reproduction of the three study species. Determinants of growth, survival and reproduction are evaluated. The importance of clonal support to shoots and stems are quantified, and some implications for management are suggested.

Chapter 4 analyses the demography of three clustered rattan species in Vietnam, using ramet-within-genet population models. Matrix models are applied, in which the dynamics of ramets (stems) depend on its own size and that of the genet (clump) to which it belongs. Based on the population matrix model, the contribution of sexual and vegetative reproduction and clonal support to the populations are evaluated.

Chapter 5 analyses the impact of rattan harvesting on the growth, survival and reproduction of remaining stems, using results from a harvest experiment. In this chapter, the ramet-within-genet model is extended to include the effect of stem cutting on the population dynamics of two species. Subsequently, matrix population models are used with 4 different harvest scenarios to determine the future rattan populations and their rattan resources for the coming 30 years.

Chapter 6 summarizes the main results of the thesis and provides a general discussion and recommendations for further research.

Acknowledgements

I would like to thank Marinus Werger and Pieter Zuidema for valuable comments on a draft version of this chapter.

View at the summit of Bach Ma National Park (1400 m)

View of the valley in Bach Ma (8 km pole)

Chapter 2

Vietnam: forest ecology and distribution of rattan species

With Marinus J. A. Werger, Ha Chu Chu and Trieu Van Hung

Introduction

Tropical forests are located largely between the latitudes 23.5°N and S. About 61% of these forests are in Latin America, 23% in Asia and 16% in Africa (Leslie et al. 1996). Public interest is increasingly focusing on the world's tropical forests (Lamprecht 1989). Over the past ten years or so several new slogans related to the sustainable management of tropic forests have entered the popular lexicon. "Rainforest harvest", "green marketing" and "use or lose it" all refer to the essential principle that the best way to ensure the maintenance of tropical forests and their biodiversity is to make them economically relevant to nearby residents (Neumann and Hirsch 2000). It is increasingly acknowledged that the exploitation of non-timber forest products (NTFP) can play an important role in the conservation and development of tropical rain forest areas (Wegge 1993, Van Valkenburg 1997). Nothing, however, can make up for the loss of forest that causes an increase in the severity of natural disasters and even affects global climate (Lamprecht 1989). Each year about 11 million hectares of tropical forest are destroyed (FAO 2001).

In this chapter, we give an outline of the natural conditions of Vietnam, its forest situation, biodiversity of its forests, forest resources including NTFP, and rattan species in particular. The overall contribution of NTFP and rattan towards the economic growth in the country, employment of the people, development and conservation of the rattan resources and other aspects will also be discussed.

Geographic and topographic characteristics

Vietnam is a tropical country, situated on the eastern coast of the Indochinese Peninsula in Southeast Asia, sharing borders with China (1,400 km) to the north, Laos (2,067 km) and Cambodia (1,080 km) to the west and the Eastern sea to the east and south. Vietnam, stretching over 3,260 km along the coast of the Eastern Sea and at outer and southern edge of Southeast Asia, lies between the latitudes of 8°02' and 23°23' N, and between the longitudes of 102°08' and 109°28' E (SRVN 2003, FOMIS 2008). Its northernmost point is located in the north of Cao Bang province, next to the tropic of Cancer, and its southernmost point is the Ca Mau Cape. The total land area of Vietnam is 331,688 square km, including 327,480 square km of land and over 4,200 square km of inland waters, with about 4,000 islands (FOMIS 2008).

The topography is diversified with mountains, hills, deltas, coastlines and a continental shelf. Three quarters of the country is composed of hills and mountains with the highest peaks reaching over 3,000 meters above sea level. The country is S-shaped in outline. It has two wide deltas, one in the South, on the Mekong River and another in the North, on the Red River. Central Vietnam is occupied by the Truong Son Range, which makes the country narrow and the terrain either coastal or mountainous. At its narrowest point in the central section (Thao 1998, Lap 1999, Chien 2006), the country is only 50 km across, while at its widest in the North, it is about 600 km. The elevation decreases from the northwest to the southeast, as illustrated by the flow of the big rivers. There are in the whole country 55 big rivers over 100 km long, 150 medium sized rivers of 50-100 km long and 2,151 rivers shorter than 50 km (FOMIS 2008).

Climate

Climate is a factor that has determining effects on the formation of forest cover in Vietnam. Generally, the basic elements constituting a climatic regime are temperature, rainfall, atmospheric humidity, and solar radiation. However, in Vietnam monsoons have determining impacts on the climate and should be considered a constituting element as well. Besides, topographic features of the territory have a significant influence on the local climate, creating different bioclimatic zones. This affects the distribution pattern of the vegetation.

In general, according to the climatic conditions Vietnam can be divided into two zones:

- A monsoon tropical climate with a hot and rainy season from May to October and a cold and drizzling-prone season, from November to April, prevailing in the Northern part of the country.
- A hot monsoon climate with strong winds and heavy rains in summer and dry weather in winter prevailing in the southern part of the country especially on the High Plateau (Tay Nguyen).

Solar radiation

In general, Vietnam receives a great amount of sunshine, decreasing from the South to the North. The total of sunny hours in the North (from Thua Thien Hue to Ha Giang province) is about 1,400 to 2,000 hours while in the South (from Da Nang to Ca Mau) it is around 2,000 to 3,000 hours. Due to the influences of topographic conditions, the solar radiation differs per area. The intensity of the solar radiation also declines from the South to the North. The South annually receives in average of 140-160 kcal cm^{-2} yr^{-1} with the highest values on the High Plateau (Central Highlands) and the Mekong Delta. The North receives around 110-140 kcal cm^{-2} yr^{-1} annually (Toan 1998, Lap 1999, Chien 2006).

Monsoons

In winter, from September to April, the north wind (northeast monsoon), originating from Siberia, blows over the Chinese continent and carries cold and dry air to Vietnam, causing cold and dry weather in the northern part of the country. In summer the southwest Pacific monsoon blows over the country via Cambodia and Laos. Where the southwest wind, saturated with water, is hindered by the Truong Son Range, it causes a lot of rainfall on the west flank of the range, but a dry and hot climate in the east, particularly from June to August. Some provinces of Central Vietnam are strongly affected by the hot and dry weather. In contrast, the southeast monsoon from the Eastern sea brings a lot of rainfall to the northern part of the country (Toan 1998, Lap 1999, Chien 2006).

Apart from these three monsoons, the country is frequently affected by tropical low pressure cells and typhoons originating over the Eastern sea from July to November (Trung 1998).

Temperature

The long north-south extension of the territory over 15 degrees of latitude results in a difference in temperature between the northern and southern parts. Temperature is rather high during most of the year in the southern part from Da Nang to Ca Mau, while the northern part experiences a cold winter season due to northeast monsoons originated from Siberia (Lap 1999). Affected by high radiation loads, a seasonally monsoonal weather pattern and complicated topographical conditions, the temperature varies with seasons, latitudes and altitudes. The existence of 4 months of cold winter weather north of the Ngang Pass (18^{o}N latitude) signifies the difference in climate between the South and the North.

Table 1. Monthly mean temperature for areas throughout the country in 2006 (°C) (NCHMF 2007).

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Lang Son	14.8	14.9	17.8	23.4	24.8	26.8	27.1	26.0	24.8	24.5	20.2	14.2
Ha Noi	18.3	18.4	20.3	25.4	27.3	30.2	30.0	28.1	28.2	27.4	24.7	18.3
Vinh	18.3	19.3	20.5	26.0	28.2	31.0	30.3	28.2	27.3	26.2	25.2	19.3
Dong Hoi	19.1	20.4	21.1	25.9	27.1	31.1	30.0	28.3	26.9	26.2	25.3	20.6
Hue	19.9	21.6	22.7	26.4	27.3	30.1	29.8	27.8	26.5	26.1	25.1	21.6
Da Nang	21.6	23.3	24.0	26.9	27.6	30.2	30.1	28.3	27.3	26.7	26.2	23.4
Quy Nhon	23.1	24.7	25.4	27.1	29.5	30.3	30.3	30.0	28.3	28.1	26.8	24.9
Phan Thiet	25.5	26.5	27.1	29.0	29.1	28.2	26.9	26.9	27.4	27.4	27.3	26.5
HCM City	27.2	28.2	28.6	29.5	29.2	28.4	27.9	27.6	27.6	27.7	28.9	27.3
Ca Mau	26.0	27.4	27.9	29.0	28.4	27.9	27.4	27.2	27.2	27.5	28.1	26.8

The decrease in temperature with an increase in altitude (0.5-0.6°C/100 m) creates climate belts along isotherms in mountainous regions (Lap 1999). In the tropical submontane and montane zones (from 1,000 to 1,800 m in the South or from 700 to 1,600 m in the North) the average annual temperature ranges from 15°C to 20°C. At altitudes from 1,600 to 2,600 m in the South and from 1,600 to 2,400 m in the North the annual temperature ranges from 10°C to 15°C (Lap 1999, Chien 2006). At these altitudes the minimal mean temperature of the coldest month can be below 0°C. On the top of some northern mountains, such as Fan Xi Pan, Mau Son, Sa Pa it is cold throughout the year, and there is sometimes snow in winter (Trung 1998, Chien 2006).

The coldest month is January and the hottest one is July. As an example, the monthly mean temperature in 2006 for different areas is given in Table 1.

Rainfall

The rainfall regime is also complex. The precipitation is not evenly distributed throughout the year and varies between years (Table 2). Varying with latitude and the seasons, linking with the effects of monsoons, under the influences of geographic and topographic conditions, the rainfall is the main factor creating regional climates.

The average annual precipitation is between 1,500 and 2,000 mm in a large area of the country (FOMIS 2008). However, in montane regions, where the monsoons confront high mountains, such as Sa Pa (Hoang Lien Son) and Hon Ba (Truong Son), the annual rainfall can reach 3,000-3,750 mm yr^{-1} (Lap 1999, Chien 2006). In some particular localities like Bach Ma (Truong Son) the annual rainfall is extremely high, over 8,000 mm yr^{-1} (Keo 2003, Chien 2006). In contrast, in the areas behind mountains the rainfall may be little, for instance, it is only 653 mm yr^{-1} at Phan Rang (southern Truong Son) and 643 mm yr^{-1} at Ky Son (northern Truong Son) (Lap 1999, Chien 2006).

The rainfall is concentrated in a rainy season that comprises about 70 to 80% of the rainfall of the year as a whole (Lap 1999). The rainy season lasts from May to October in the North, on the High Plateau and the South, and from August to February in Central Vietnam. On the High Plateau and in Central Vietnam rains fall heavily, often causing flooding, but during the dry season large parts of these regions experience droughts during 6 months.

Table 2. Average monthly rainfall and number of rainy days in areas throughout the country *(mm/rainy days)* (NCHMF 2007).

Month / Places	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Lang Son	18/5	15/15	37/16	23/6	125/16	130/16	358/17	210/19	45/6	25/8	34/7	2/3
Ha Noi	1/1	16/10	34/19	18/6	140/19	97/10	247/16	365/19	183/8	28/9	116/5	1/1
Quang Binh	105/11	53/18	64/14	50/14	84/9	4/1	37/9	207/17	371/8	362/17	47/10	137/16
Hue	179/14	144/20	19/9	52/11	61/11	13/4	54/7	467/15	510/14	406/15	239/6	382/23
Quy Nhon	57/14	54/16	166/5	42/3	106/6	28/4	70/8	47/11	218/17	195/22	137/12	193/18
Nha Trang	9/9	38/6	168/3	4/3	24/5	5/3	7/7	68/14	158/15	179/18	61/8	98/11
Vung Tau	0/0	0/0	22/2	72/3	202/16	249/22	219/22	190/23	169/15	252/16	19/2	120/1
HCM city	10/2	73/6	9/3	212/9	299/19	139/24	169/24	349/22	248/20	256/21	16/2	29/4
CanTho	10/3	11/3	99/3	116/15	208/19	139/23	176/22	141/20	307/18	295/20	61/5	72/4

Humidity

The air humidity is high in the country as a whole. However, in the North it is often more humid than in the South. The average annual humidity is around 80% to 85% in the North and about 78% to 83% in the South (Trung 1998, Chien

2006). In the northern part of the country the highest humidity can reach over 90%, prevailing from March to April. The humidity is generally reduced down to 75%-80% with the presence of the northeast wind, prevailing from November to February. In the South, the humidity is rather high (82% - 88%) during the rainy season (May to October), and dry (70% - 80%) in the remainder of the year (November to April). The air humidity in Central Vietnam is relatively low (73% - 82%) from May to July, but exceedingly high (86% - 91%) from August to April (Trung 1998, Lap 1999, Chien 2006).

Climatic and bioclimatic zones

The temperatures, rainfall, air humidity and monsoons in combination with geographic and topographic conditions create the climatic patterns of Vietnam. As said earlier, there are two typical climatic zones (Lap 1999):

- A monsoon tropical climate with a hot and rainy summer and a cold and drizzling-prone winter prevailing in the northeastern part of the North and the Red River Delta.
- A hot monsoon tropical climate with heavy rains in summer and dry weather in winter prevailing on the High Plateau and in the South (from Binh Thuan to Ca Mau provinces).

Nevertheless, besides the two main climatic zones there are the local climatic patterns modified by the monsoons with different intensity, such as the climate with an influence of a strong southwest monsoon in summer, when the temperature may reach 40^{o}C (northwest region of the North and some provinces of northern Central Vietnam: Nghe An, Ha Tinh, Quang Binh, Quang Tri). The northeast and southwest monsoons bring heavy rains in the coastal areas of Central Vietnam, causing flooding every year. These areas, especially Thua Thien Hue province, are frequently attacked by typhoons and tropical low pressure systems.

The climatic, geographic and topographic conditions have a determining impact on the formation and distribution of forest cover. Therefore, from the view point of forestry, a bioclimatic study is very important. According to Lap (1999), there are 6 bioclimatic types:

1. Monsoon tropical climate with cold winters and summer rains
2. Monsoon tropical climate with cool winters and summer-autumn-winter rains
3. Monsoon tropical climate with summer rains

4. Monsoon tropical climate with autumn-winter rains
5. Monsoon sub-equatorial climate with summer rains
6. Monsoon tropical climate associated with mountains

These six bioclimates cover all localities in Vietnam. The locality in focus for our study is the Thua Thien Hue region, which falls under bioclimatic type No 2, i.e. Monsoon tropical climate with cool winters and summer-autumn-winter rains.

Land and soils

Terrain

Topographically the terrain of Vietnam is divided into 5 main terrain types: hills and mountains, karsts landscapes, valleys and hollows, alluvial plains and coastal areas. These terrain types are distributed as follows (Lap 1999, Chien 2006):

- *Northwestern zone:* The northwestern zone comprises 4 provinces, Lai Chau, Dien Bien, Son La and Hoa Binh. This zone belongs geomorphologically to the folded system of great mountains running typically in a northwest-southeast direction, characterized by the Hoang Lien Son Range, stretching for 400 km from the northern frontier to the bend of the Black River (Lap 1999). The peak of the tallest mountain, Phan Xi Pan, reaches 3,143 m, 14% of the terrain of this zone lies at an elevation of over 1,000 m and 65% at 200 m above sea level. The northwestern zone represents the highest part of the country. The topography is very complicated because the terrain of much of these mountains is badly broken with steep slopes (Lap 1999). More than 50% of upland area has slopes above 20 degrees (Trung 1998).

- *Northeastern zone:* This is the largest zone, encompassing 11 provinces: Lao Cai, Yen Bai, Ha Giang, Tuyen Quang, Phu Tho, Cao Bang, Bac Can, Thai Nguyen, Quang Ninh, Lang Son and Bac Giang (Lap 1999, Chien 2006). Sharing boundaries with the Hoang Lien Son Range and the Red River delta, the northwestern zone has a bow-shaped structure of low mountains and hills alternating with valleys and plains. The altitude of the zone decreases gradually from the northwest to the southeast. The mountains and hills are distributed from the border (Vietnam-China) converging towards Tam Dao with average altitudes of 1,000 m-1,200 m (Dong Van Plateau contains a highest peak of 1,600 m). These mountains increase the effects of the winter monsoon from China (SSA 1996).

- *Red River and Mekong River deltas:* These deltas were filled up by quaternary sediments from the Red and Mekong Rivers. The terrain of these regions is generally low and flat. There are several depressions, such as Nam Ha, Ninh Binh (in the North), Dong Thap Muoi and U Minh (in the South), and also several higher tongues of land made up by alluvial deposits (Lap 1999).

- *Northern Truong Son zone:* from the Ca River to the Hai Van Pass runs the northern Truong Son Range in Central Vietnam. The range includes high mountains with steep slopes in the east, and gentle slopes in the west. There are also narrow plains with alternating depressions and sand dunes. These plains are strongly separated from one another by mountainous spurs where the Truong Son Range reaches the sea (Lap 1999, Chien 2006).

- *Southern Truong Son zone:* Beginning at Hai Van Pass and sharing a boundary with the Central Highlands, the southern Truong Son Range extends along the coastline and then to the Eastern sea in Binh Thuan province (SSA 1996, Lap 1999, Chien 2006). The topography of the region is complex with high and steep mountains, narrow plains and sand fields, again separated by spurs of the Truong Son Mountains (SSA 1996, Chien 2006).

- *Central Highlands:* From the borders with Laos and Cambodia in the west to the southern Truong Son Range in the east, the Central Highlands comprise the Plateau of Kon Tum, Gia Lai, Dac Lac, Lam Dong and Dac Nong. The altitude of the Central Highlands ranges from 500 m above sea level (Kon Tum) to more than 2000 m (Da Lat). However, the terrain of the Central Highlands is generally flat and simple, and it slopes gently from the northeast or the north to the southwest or the south (SSA 1996, Lap 1999, Chien 2006).

Soils

Affected by a tropical monsoon climate and a complicated topography, Vietnam has a diverse system of soil types, whose names are based on the geological substrate and the basic color of the soil profile. The currently used map shows 33 soil types, assembled into 14 groups: Arenosols, Salic fluvisols, Thionic fluvisols, Fluvisols, Gleysols, Histosols, Andosols, Luvisols, Calcisols, Acrisols, Ferralsols, Alisols, Solonchaks and Leptosols. The soil types considered as most important to forestry are, the Ferralsols which are widely distributed in mountains and hills, and Luvisols dominating the Highlands (SSA 1996).

- *Plinthic Ferrasols:* Formed in a humid tropical climate, these soils occupy around 47% of the total land area of the country (Lap 1999). They occur from 8°5 N to 22°5 N latitudes and at altitudes below 600 m (in the North), 800 m (in Central) and 1,000 m (in the South). These soils are often acid, and reserved for forestry and agro-forestry production (Binh 1996, Sam and Binh 2001).

- *Rhodic Ferralsols:* These soils cover around 2,680,000 ha and occur mostly in the Central Highlands and some provinces of northern Central Vietnam, e.g. Quang Tri, Nghe An and Thanh Hoa (Lap 1999).

- *Humic Ferralsols:* These soils occur on low mountains all over the country over around 3,000,000 ha. These soils are often humid and fertile and are the habitat of the evergreen forests (Lap 1999, Chien 2006).

- *Luvisols:* These soils cover around 250,000 ha and occur in the Central Highlands, the southeast and in karstic terrains in several provinces of the North, such as Cao Bang, Hoa Binh, Son La and Lai Chau (Lap 1999, Chien 2006).

Forest Biodiversity

Vietnam is recognized as one of the richest countries in terms of biodiversity in Southeast Asia (MoF 1995). Thanks to a long coast line and wide ranges of latitude and altitude the biodiversity in terms of ecosystems, species and genetic resources is high. The World Conservation Monitoring Centre (WCMC) rated Vietnam as the 16th most biologically diverse country in the world. Along with endemic and native species, Vietnam lies on the crossroads of 3 different floral regions, being centered in China, the Himalayas and Indonesia. The greater number of endemic species is concentrated in four key regions: the high mountains of Hoang Lien Son in the North, the high mountains of Ngoc Linh in Central Vietnam, the Lam Vien High Plateau in the South and rainforests in the northern Truong Son Mountains (VACNE 2004). Among the different ecosystems in Vietnam, forest ecosystems are the most diversified in terms of species composition, both in flora and fauna.

Table 3. Components of the flora of Vietnam (IEBR 2005).

Phyla	Number of families	Number of genera	Number of species
Bryophyta	60	182	841
Psilotophyta	1	1	1
Lycopodiophyta	3	5	53
Equisetophyta	1	1	2
Polypodiophyta	25	137	691
Gymnospermae	8	23	69
Angiospermae	299	2,175	12,109
Total	397	2,524	13,766
Endemic (%)	0	3	20

Flora

According to the Forest Inventory and Planning Institute, Vietnam has more than 12,000 plant species, of which 7,000 have been described (MoF 1995). In the 3 phyla Pteridophyta, Gymnospermae and Angiospermae 11,000 species belonging to 2,500 genera were described (Ly 1993). Around 368 species of Procaryota, 2,200 species of Fungi and 2,176 species of Algae also have been described (IEBR 2005). Recently, the Institute of Ecology and Biological Resources (IEBR) reported that Vietnam has 13,766 plant species (20% of which are endemic), belonging to 2,524 genera, 397 families and 7 phyla (Table 3). Many plant families occurring in Vietnam are very rich in number of species. There are 30 families with more than 100 species (Table 4).

Table 4. Plant families with more than 100 species occurring in Vietnam (Thin 2000, Henderson 2009).

Family	Number of species in Vietnam	Family	Number of species in Vietnam
Orchidaceae	800	Arecaceae*	97
Leguminosae	470	Melastomataceae	124
Euphorbiaceae*	425	Moraceae*	118
Poaceae	400	Caesalpiniaceae*	118
Rubiaceae*	400	Asclepiadaceae	113
Asteraceae*	336	Polypodiaceae	113
Cyperaceae	303	Fagaceae*	111
Lauraceae*	246	Araliaceae	110
Acanthaceae*	175	Zingiberaceae	109
Annonaceae	173	Rutaceae*	108
Apocynaceae	170	Myrtaceae*	107
Lamiaceae	145	Theaceae	101
Myrsinaceae	139	Araceae*	100
Verbenaceae*	131	Rosaceae	100
Scrophulariaceae	128	Urticaceae*	100

* families that are very abundant in the vegetation of Vietnam.

Based on the potential use of the species, the flora of Vietnam is divided into several groups (Chuyen et al. 1987, Chu 2000):

- Group of timber species: 1,200 species in 100 genera
- Group of species producing fibers for paper production: 100 species
- Group of species producing essential oils: 485 species
- Group of species producing fat oils: 473 species
- Group of species producing tannin: 800 species
- Group of species producing dyes: 200 species
- Group of medicinal plant species: 3,000 species

Fauna

The fauna of Vietnam is not only rich in species composition but also typical and representative of the Southeast Asian region (VACNE 2004). Vietnam is reported to be home to 12,518 animal species and subspecies (Table 5). Like the flora, Vietnam's fauna contains numerous endemic taxa such as over 100 species and subspecies of birds and 78 endemic species and subspecies of mammals (Quy and Can 1994, VACNE 2004).

Table 5. Components of the fauna of Vietnam (MARD 2007).

Class	Species identified in Vietnam	Species identified in the World	Vietnam's percentage of the World (%)
Insects	7,750	750,000	1.0
Fishes	3,170	30,000	10.6
Reptiles	286	6,300	4.5
Amphibians	162	4,184	3.8
Birds	840	9,040	9.3
Mammals	310	4,000	7.7

Still, many animal species have not yet been described. Between 1992-1994, two species of large mammals were discovered in Vietnam, namely *Pseudoryx nghetinhensis* and *Muntiacus vuquangensis.* In 1997, a new large mammal species was first described: *Muntiacus truongsonensis.* Recently, new species such as *Pygathrix cinerea* and *Nesolagus temminsi* have been added. Three new species of birds discovered in the Central Highlands are *Garrulax ngoclinhensis, Actinodura sodangorum* and *Garrulax kongkakingensi* (CCSE 2003, VACNE 2004).
However, illegal hunting of, and trade in wild fauna species continues to increase and is sometimes out of control, making a variety of species rarer and bringing some species under threat of extinction (CCSE 2003, VACNE 2004). Populations of forest wildlife have been seriously reduced (MoF 1995) and animals such as *Dicerorhinus sumatraensis* and *Tapicus indicus* are no longer found in Vietnam. There are only 6-8 individuals of *Rhinoceros sundaicus annamaticus* left, not more than 100 elephants, less than 100 tigers, less than 100 yellow head langurs, about 150-170 moschus deer, and about 450 gibbons (Nhat 2001). The Vietnamese Red Data Book listed 365 animal species as under threat in different degrees of endangerment (Table 6):

Table 6. Summary of threatened animal species in Vietnam (GoVN 1994).

Class \ Threat levels	Endangered	Vulnerable	Rare	Threatened	Undetermined
Mammals	30	23	24	1	-
Birds	14	6	31	32	-
Reptiles & Amphibians	8	19	11	16	-
Fishes	6	24	29	13	3
Invertebrates	10	24	29	9	3
Total	68	96	124	71	6

Based on the IUCN Red List of threatened species, Vietnam is ranked as follows (Olivier 2003):

- 6^{th} position worldwide with the largest number of threatened reptiles
- 15^{th} position worldwide with the largest number of threatened mammals
- 18^{th} position worldwide with the largest number of threatened birds.

Forest ecosystems

The forest ecosystems of Vietnam have been identified according to their main vegetation type. The vegetation of Vietnam has been studied since a century ago and was classified by a number of authors. In 1918, the vegetation of the North was first classified into 10 main types by a French scientist, Chevalier (Chevalier 1918, Chien 2006). In 1943, Maurand divided Indochina, including Vietnam, into three main zones: the North, the South and the Intermediate Zone of Indochina and distinguished 8 main types of vegetation (Maurand 1943). In the South, the vegetation was classified later than in the North. In 1953, Maurand introduced a classification of vegetation based on previous studies, and in 1962 Schmid introduced a new vegetation classification after studying the vegetation of the Southern Central Region of the country (Schmid 1962).

After that the vegetation classifications of Vietnam have been further developed by several Vietnamese authors. In 1970, Trung introduced a new classification system for Vietnam, based on the biogeographical theory of Sukachev in which he divided the vegetation of Vietnam into 14 main types (Trung 1970). Later, Chan and Dzung classified the Vietnamese vegetation into 9 main types (Chan and Dzung 1992, GoVN 1994), while the Ministry of Forestry (1995) distinguished only 8 main types. The result of all these studies was a range of vegetation classifications for Vietnam with several overlapping and/or similar forest types. Based on this, the following main forest ecosystems of Vietnam can be clearly distinguished:

Tropical evergreen broad-leaved forest ecosystem

The tropical evergreen broad-leaved forest contains highly valued wood and non-timber forest products (MoF 1995). It occurs rather widespread throughout the country at elevations below 700 m above sea level in the North and below 1,000 m in the South (Chan and Dzung 1992, Trung 1998). In the distribution area of this vegetation type the mean annual temperature ranges from 20 to 25°C. The annual precipitation is more than 1,200 mm, with 2-3 dry months (with rainfall less than 50 mm per month) (Trung 1998). This forest type is very diverse and complex in structure with a great number of tree, vine, epiphyte and shrub species. It has mainly 5 vegetation layers: a layer of emergent, the main canopy storey, the subcanopy layer, the shrub understorey and the forest floor layer. These multistoried forests are evergreen and contain trees in all age classes (MoF 1995). The emergent may reach to 25-50 m (Chan and Dzung 1992, Trung 1998) and the main species belong to the Dipterocarpaceae, Leguminoseae and Combretaceae. The main species in the subcanopy layer belong to the Fagaceae, Meliaceae, Lauraceae and Burseraceae. The shrub understorey and forest floor layers consist mainly of Rubiaceae and Melastomaceae as well as many NTFP species, such as bamboo, rattan, medicinal and herbaceous plants, resin and ornamental species. These forests harbour a rich wildlife, making this ecosystem of special value to Vietnam as it contains the highest biodiversity.

Tropical semi-deciduous broad-leaved forest ecosystem

The tropical semi-deciduous broad-leaved forest is concentrated in northern Vietnam and the Central Highlands at the same elevation as the tropical evergreen broad-leaved forest (Chan and Dzung 1992, Trung 1998, Chien 2006). Within the distribution area of this vegetation type the mean annual temperature is 20 to 25°C, with the temperature of the coldest month ranging from 15 to 20°C. Annual rainfall is high, from 1,200 to 2,500 mm, but 4-6 months are considered dry, and 1 month usually has no rain at all (Trung 1998, Chien 2006). The forest structure is also complex and diverse. About 25 to 75% of the timber trees in this forest type are deciduous (Chan and Dzung 1992, Chien 2006). Main species are *Chukrasia tabularis, Liquidambar formosana, Lagerstroemia calyculata,* *Cinnamomum camphora* and *Pometia tomentosa*. The ground vegetation is better developed, containing a greater abundance of species than the tropical evergreen broad-leaved forest (MoF 1995). Many NTFP species are found in this forest type, such as rattans, medicinal plants, resin, dyes and essential oil species.

Tropical deciduous broad-leaved forest ecosystem

This type occurs also at an elevation of less than 700 m above sea level in the North and below 1,000 m in the South but in these areas, the annual rainfall is low, about 600 mm. The dry season may last from 4 to 6 months, with at least 1 month of no rain at all (Trung 1998, Chien 2006). This kind of forest has a simple structure with 2 main layers of timber trees. The higher storey may reach to 25 m (Trung 1998) and the main species are *Pterocarpus pedatus* and *Dalbergia cochinchinensis.* The lower storey may reach up to 15-20 m and its species composition is more complex than that of the higher storey. The percentage of deciduous trees is estimated at more than 75% (Chan and Dzung 1992, Chien 2006).

Subtropical evergreen forest ecosystem

The subtropical evergreen forest occurs at altitudes above 700m above sea level in the north and above 1,000 m in the south (Chan and Dzung 1992, Chien 2006). At these elevations the climate is subtropical. The mean annual temperature ranges from 15 to 20°C. The annual rainfall is still high, fluctuating from 1,200 to 2,500 mm (Chan and Dzung 1992, Chien 2006). Like the temperate forest, the subtropical evergreen forest has a simple structure of 2 main layers of timber trees. The main species belong to the Fagaceae, Lauraceae, Ericaceae, Woodsiaceae and bamboos (MoF 1995). This forest type is favourable for the cultivation of numerous highly valued medicinal species, particularly *Euonymus cochinchinensis, Cinamomum cassia* and *Panax pseudoginseng* (MoF 1995). The overall species richness is less than in the tropical evergreen forest ecosystem (Chan and Dzung 1992, Chien 2006).

Limestone forest ecosystem

This is a unique ecosystem in Vietnam. This forest grows on limestone substrate (calcareous soil), extending over a large karst area in the north and a smaller area in the northern middle of Vietnam (GoVN 1994, Truong 1996, Chien 2006).

The area of limestone forest is estimated at about 5.4% of the total forested land (Phon et al. 2001, Chien 2006). In fact, these forests are subtypes of the closed evergreen and semi-deciduous broad-leaved forests. The flora is diverse and includes a large number of coniferous and broad-leaved species (Chan and Dzung 1992, Truong 1996, Chien 2006). Some endemic hard-wood species occur in this type of forest, such as *Cupressus torulosa, Parapentace tongkinensis, Diospyros mun* and *Burretiodendron hsienmu* (MoF 1995, Trung 1998). Growing on infertile and excessively drained soil, the forest structure is simple, with 1-2 layers of slow-growing tree species (GoVN 1994, Truong 1996, Chien 2006). The limestone forests and their numerous caves shelter vulnerable wildlife species like foxes, civet cats, antelopes, monkeys, squirrels, and large birds like pheasants and grey peacocks (MoF 1995, Trung 1998). This ecosystem contains many precious NTFP medicinal and resin species, such as *Fallopia multiflorum, Stepania glabra,* one leaf orchid, *Fibraurea tinctoria,* etc. This forest type has recently been severely degraded by random logging, wildfire and slash and burn cultivation, and needs to be protected and reserved (GoVN 1994, Phon et al. 2001).

Coniferous forest ecosystem

The coniferous forest occurs in the North and the Central Highlands, at elevations of over 1,000 m above sea level where the climate is cool in summer and cold in winter (Chan and Dzung 1992, Truong 1996, Chien 2006). These areas are comparatively dry as annual precipitation is only 600 to 1,200 mm (Chan and Dzung 1992, Chien 2006). The dry season is long, lasting from 4 to 6 months, with 1 month without any rain (Trung 1998, Chien 2006). The forest structure is often simple and the forest is dominated by 2 species, *Pinus merkusii* and *P. kesiya* (Chan and Dzung 1992, Chien 2006). In many cases, pine trees are mixed with broad-leaved species of the subtropical evergreen forests, subject to the same elevations and rainfall regimes (MoF 1995, Trung 1998). Recently, large areas of plantations of *P. merkusii, P. kesiya, P. massoniana* and *P. caribaea* have been established at lower elevations (Truong 1996, Chien 2006).

Mangrove forest ecosystem

These forests grow in tidal areas along the coast of the country, especially in estuaries (Chan and Dzung 1992, Sam et al. 2005, Chien 2006). This type of forest is most prevalent in the South, but also occurs as shorter and simpler forest in the North (GoVN 1994, Chien 2006). The structure of the forest is simple as it often has one layer (Chan and Dzung 1992, Truong 1996, Chien 2006). The typical species of mangrove forests are *Bruguiera gymnorhiza, Sonnerata alba, Rhizophora mucronata* and *Rhizophora conjugata,* often reaching a height of 10-15 m (MoF 1995). The mangrove forests offer a favourable habitat for a particularly diverse animal population, including crabs, fish, tortoises, snakes, crocodiles and many wetland birds and mammals. It is an attractive shelter for native and exotic birds migrating from Siberia during the severe winter of the North (MoF 1995). However, this type of forest has dramatically been destroyed and replaced by farming and land reclamation (GoVN 1994, Sam et al. 2005, Chien 2006).

Bamboo forest ecosystem

The bamboo forests are either pure or mixed with tree species of the evergreen rain forests or deciduous forests throughout Vietnam (MoF 1995). Bamboo forests often emerge after harvesting the primary, natural forests or after slash and burn cultivation (Chan and Dzung 1992, Chien 2006). Being wet-tolerant, preferring high light conditions and growing fast, bamboos develop steadily in flat lands and hills and along streams with short growing rotations (2-4 years). Important bamboo species in Vietnam include *Indosasa crassifolia, Bambusa procera, B. stenostachya, Dendrocalamus membranaceus, D. sericeus, D. giganteus, D. latiflorus* and *Phyllostachys pubescens.* The total area of bamboo forests in Vietnam is estimated at 1,489,000 ha, of which 1,415,500 ha are natural bamboo forests (both pure and mixture) and 73,500 ha are plantations, with main species are *Dendrocalamus membranaceus, Indosasa crassiflora, Phyllostachys pubescens* and others. The bamboo species of Vietnam are diverse and they contain about 29 genera and 140 species (Lam 2005, Chien 2006). Bamboos are NTFP species and widely used for many purposes such as paper and board industry, house construction, furniture, handicraft, weaving mats and others. Some species provide edible shoots like “special vegetable” in restaurants as *Bambusa ohlami, Dendrocalamus latiflorus, D. giganteus* and *Indosasa amabilis.* Vietnam has a very long tradition of using bamboos (MoF 1995).

Forest area and natural forest resources

Forest cover

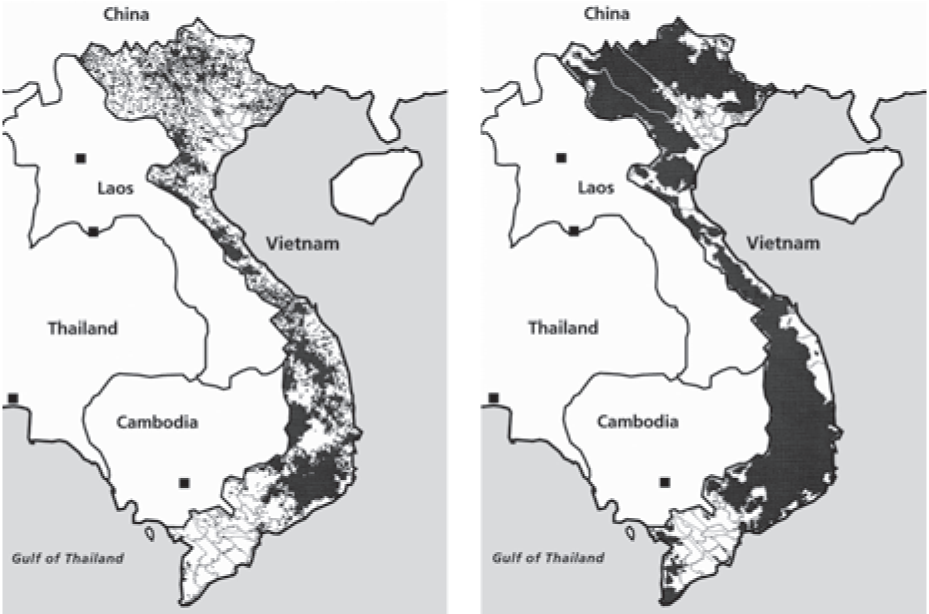


Figure 1. Forest cover of Vietnam in 2000 (a) and in 1943 (b) (Maurand 1943, Forest Department 2004).

In the past, Vietnam had a rather high forest cover, but forests deteriorated heavily over the past decades. During the period of the French colonization, the forests of Vietnam have been exploited heavily for timber and poles, and many large areas in the South were cleared for plantations of coffee, rubber, tea and other industrial crops (VACNE 2004). In the middle of the 20th century, most of forests in the Red River delta, a large part of Mekong River delta, and in low-lying land in coastal Central Vietnam were cleared for agriculture and human settlement. As a result, in 1943, the forest area was 14,272,000 ha, covering around 43% of the total land area (Figure 1) (Maurand 1943, Chien 2006). During the 30 years of war, from 1945 to 1975, the forest cover in Vietnam rapidly shrunk. Over two million hectares of tropical forests were destroyed completely by 80 million liters of herbicides, 13 million tons of bombs, creating 25 million craters, and by a huge fleet of bulldozers (Quy 1985, MoF 1995, Truong 1996, VACNE 2004, Chien 2006). By 1976, the total area of forests had been reduced to 11.2 million ha (covering

33.8% the country), of which only 10% were intact forests (Lung 2000, Nhat 2001, Chien 2006). Following this period the remaining forest areas continued to experience heavy exploitation to the meet demands of an increasing population growth, healing the war wounds and building the weak economy through timber harvesting, extension of agricultural areas and industrial zones in the post war period and because of resettlement policies (VACNE 2004). Many forest areas that have been converted in that period are now considered as depleted or as bare lands. The remaining forests in the northern mountains have been degraded, resulting in low wood reserves, or have been fragmented into dispersed, small forests. The natural forest area had declined by 2.8 million ha over 20 years, from 1975 to 1995 (Lung 2000, Forest Department 2004, Chien 2006). Recently, the situation of forest loss and illegal logging has been reduced but still continues (Forest Department 2007). The rate of forest loss accounts for about 120,000 to 150,000 ha per year while the annual planting is 200,000 ha (VACNE 2004).

Since 1990, the Vietnam Government has paid stronger attention to the development of forest resources. In 1992, Programme 327 on re-greening bare lands and denuded hills was launched (MoF 1995) and in 1998, the National Five Million ha Reforestation Program with the aim of restoring the forest cover to its pre-independence level of 43% of the total land area by the year 2010 (MARD 1998). As a result, the forest cover of the country has gradually increased. In 2006, the forested area of Vietnam was assessed at 12,873,851 ha, of which 10,410,141 ha were natural forests and 2,463,710 ha were plantation forests, resulting in a forest cover of 38% (Forest Department 2007). The changes in forest cover since 1943 are given in the Table 7.

Table 7. Changes in forested area in Vietnam (Forest Department 2007).

Unit: 1000 ha

Forest type	1943	1976	1980	1985	1990	1995	1999	2002	2006
Natural forest	14,272	11,076	10,186	9,308	8,430	8,252	9,471	9,865	10,410
Plantation	0	92	422	584	745	1,050	1,524	1,919	2,464
Total forest area	14,272	11,169	10,608	9,892	9,175	9,302	10,995	11,784	12,874
Coverage (%)	43.0	33.8	32.1	30.0	27.8	28.2	33.2	35.8	38.0

However, the quality of the forested area is still low as most of the forests are poor in timber volume and lack valuable species as a result of the long time of overexploitation and random logging (Thin 1997, Dang et al. 2001, Chien 2006). According to Forest Department (2007), at the end of 2005 rich and medium valued (in timber volume) natural forests were only 2.27 million ha (18%) while the poor and young forests comprised around 5.64 million ha (45%), the rest being fair forest. The total standing volume is around 812 million m^3 (of which 93% from natural forests) and 9 billion m^3 bamboo forest. The Central Highland, and the North and South Central regions have the highest standing volume as regards natural forests in the country (MARD 2007).

The population of Vietnam has increased quickly, and this has also a dramatic impact on the forests. At the beginning of the last century, the population of Vietnam was about 15 million. However, this number had doubled by 1940, in just 30-40 years. From 1960 onwards, the population doubled every 25 years (Dang et al. 2001, Chien 2006). In 2006, the population of Vietnam was more than 84 million people, with a density of 253 people per km^2, 5 times higher than the average density of the world (FOMIS 2008). Such a large population puts the forest under heavy pressure, not only through practices of shifting cultivation, but also by transforming forested land into agricultural production fields (Toan 1998, Nhat 2001, Chien 2006). On average, in Vietnam the forest area per capita is only 0.15 ha per person and 9.16 m^3 timber per person, much lower than the average figure for the world, being 0.97 ha per person and 75 m^3 per person (Forest Department 2007).

Forest status

At present, Vietnam's forests are still facing major challenges: rapid population increase, which leads to considerably increased demand for food, foodstuff and fuel wood; prevailing poverty; free immigration, continued shifting cultivation and moving settlements resulting in deforestation (MARD 2007). As a consequence, forest quality is degraded and this threatens the livelihood of millions of mountain inhabitants and causes many other negative impacts, such as flood, drought, soil erosion, forest biodiversity reduction, etc. (UNDP 2003, Forest Department 2007).

During the war as well as the difficult years of economic recovery (before 1990), Vietnam used to exploit forests for timber but did not pay attention to its environmental protection function. From 1986 onwards, the forests were classified into three categories based on their main purpose: production forest, protection forest and special use forest (MoF 1986, MoF 1995, Forest Department 1998, ADB 2001). The status of Vietnam's forest area according to this system of forest types in 2006 is given in Table 8.

Table 8. Area status of forest types in 2006 (Forest Department 2007).

Unit: ha

Forest type	Total area	Special use forest	Protection forest	Production forest
1. Forested area	12,873,850	2,202,888	5,268,789	5,402,172
Natural forest	10,410,141	2,086,935	4,599,900	3,723,305
- Timber forest	8,192,053	1,658,651	3,595,737	2,937,665
- Bamboo forest	695,979	75,644	211,515	408,820
- Mixed timber and bamboo forest	729,104	132,434	272,702	323,968
- Mangrove forest	64,042	15,683	37,917	10,441
- Rocky forest	728,962	204,524	482,029	42,410
Plantation forest	2,463,709	115,953	668,889	1,678,867
- Productive forest	1,059,083	66,443	311,688	680,952
- Unproductive forest	1,104,984	45,966	292,166	766,852
- Bamboo forest	81,307	106	6,438	74,763
- NTFP forest	218,336	3,438	58,597	156,300
2. Unforested area	5,608,763	746,699	2,429,012	2,433,052
3. Other land	14,490,090			

- Production forest

Production forests are earmarked for exploitation in compliance with approved management plans. They are divided into four categories: large timber production forest, small timber production forest, bamboo production forest and special products production forest (MoF 1995). Before issuing Governmental Decree 02/CP (1994), production forest was under management of only 412 State Forest Enterprises (SFE) (Forest Department 1998). After 1994, the other State businesses, stock companies, forestry cooperatives, private companies, households, communities and joint ventures became also involved in production forests. In this category the area of plantation forest has increased sharply, but its quality also is still low. In 2006, the area of production forest was 5.4 million ha (Forest Department 2007). This area will be increased to about 6.5 million ha when the five million ha reforestation programme will be completed. To increase yield from forests and plantations, many exotic and hybrid species have been imported. These species may invade native forests, and also bring new pests and diseases, that may damage indigenous species (Nhat 2001, UNDP 2003, Chien 2006). Most plantations pursue economic purposes by planting a single exotic and fast growing tree variety, such as *Pinus* spp., *Eucalyptus* spp. or *Acacia* spp. (Chien 2006). On average, the growth rate of the trees in the plantations is low (about 8-10 m^3 ha^{-1} $year^{-1}$). They mainly contain small and medium sized stems (Dang et al. 2001, Chien 2006). Improving the forest productivity and quality of production forests still is a big concern in the Vietnam forestry sector.

- Protection forest

Protection forests are designated to protect land and water resources and their exploitation is more or less severely restricted (MoF 1995). They are grouped into watershed management forest, wind and sand moving prevention forest, sea wave control and seashore encroachment forest and environmental conservation forest (MoF 1986, MoF 1995). Watershed protection forests are further distinguished as very critical, critical, and less critical protection forests (MoF 1986). In 2001, the less critical protection forest category was removed and reclassified as production forest (GoVN 2001). Harvesting from mature plantations and natural forests within the category of critical protection forest is permitted under strict control in order to maintain environmental protection (MoF 1995, GoVN 2001). In 2006, the area of protection forest was 5.3 million ha (Forest Department 2007).

- Special use forest

Special use forests are set aside for conserving nature in the national forest ecosystems with their forest fauna and flora genetic resources, and for research, preserving historic-cultural relics, spots of exceptional beauty and for recreation and tourism (MoF 1986, MoF 1995). Special use forests are divided into three groups: national park, nature conservation area and landscape or seascape area. As from the year 2003 there are 126 special use forests, covering more than 2.5 million ha (SRVN 2003, Chien 2006). Control of human activities in these areas has proved difficult due to the large number of local people relying on these forests for their living. They practice agriculture in the forest, extract timber and collect firewood, medicinal plants and other forest products (Quy 1985, Chien 2006).

Non-timber forest products

NTFP development

Non-timber forest products (NTFP) are at present receiving wide attention throughout the tropics. It is increasingly acknowledged that the exploitation of NTFP can play an important role in the conservation and development of tropical rain forest (Wegge 1993, Van Valkenburg 1997).

In Vietnam, NTFP were collected and used since a long time, especially as sources of drugs at the time we did not have western medicine yet. Plants and animals used to produce medicine have been studied and researched for thousands of years, as is evident from classical books, such as “Magic effects of Viet medicine” written by Tue Tinh (1761), “Linh Nam Manuscripts” by Hai Thuong Lan Ong (1756) (cf. FSSP 2006). When the French conquered Indochina, the colonial government issued a Decree in 1894 (article 51) regulating NTFP collection. Forest products were divided into two categories: principal forest products (timber) and secondary forest products including animals and vegetables. A large amount of NTFP was exhibited at the Paris exhibition in 1931 and was described in research documents such as “Forest wood in Indochina” written by Chevalier (1918), “Indochina plants” by Lecomte (1937) and “Forests in Indochina” by Maurand (1943). During 30 years of war, from 1945 to 1975, NTFP were collected widely for food, construction of camps, health care and also for the army. Since 1961, secondary forest products became an important resource, and were called “special forest products” (MoF 1995). Nowadays, the term non-timber forest products is commonly used in the forestry sector of Vietnam, instead of the terms special forest product or secondary forest product.

At present, adapting the FAO system, NTFP of Vietnam are divided into 6 categories (FSSP 2006, NTFP 2006, FOMIS 2008):

- Fiber products: bamboo, rattan, leaves, stems, fibrous barks and grasses
- Food products:
  - Vegetables: stems, shoots, roots, tubers, leaves, flowers, fruits, flavours, oily seeds, and edible mushrooms.
  - Products originating from wild animals: bee honey, meat, edible bird nests, eggs and insects.
- Drugs and cosmetics: vegetable-based drugs, toxic species and vegetable-based cosmetics.

- Extracted products: essential oil, fat oil, resin and oleoresin, gums, tannin and dyes.
- Animals and non-edible animal products: live animals, birds and insects, mulberry silk, hairs and feathers, skins, ivory, horns, bones and shellac.
- Others: Ornamental trees, leaves for packing and wrapping, etc.

NTFP resources and conservation

A large variety of NTFP are being produced in Vietnam. The natural forests possess rich reserves of plants suitable for food, medicine, handicrafts, fuel, fodder and others. Among the 13,766 plants species the flowing NTFP can be found (Table 9).

At the beginning of the 20th century, NTFP resources were abundant and local people just collected the things they needed for their home consumption and for sale, including food, fruit, medicinal herbs, fuel wood, animals, etc. (FSSP 2006). Forest decline, the exploitation method of "cutting and collecting" without any attention to stand improvement and regeneration and other factors are leading in many locations to overexploitation of NTFP resources (Chu 2000, FAO 2002). In addition, the population of Vietnam has increased quickly (about 4 times over the last 60 years), leading to a high demand on NTFP. As a result, NTFP resources have become scarce at the end of 20th century (FSSP 2006). Some species are at their margin of extinction, e.g. as *Panax vietnamensis, Morinda officinalis, Aquilaria crassna, Cuppressus torulosa,* orchids, *Rhinoceros sondaicus, Bos sauveli*.

Table 9. Diversity of plant NTFP species in Vietnam (Jukka et al. 1996, Chu 2000).

Type of NTFP	Number of species	Type of NTFP	Number of species
Fibers	242	Tannin	800
Aromatic resins	113	Medicine	3,000
Essential oils	485	Starch	27
Fatty oils	473	Dyes	200

Contrary to the previous national reforestation programme, the current 5 million ha reforestation programme (5 MHRP) contains a substantial NTFP component, covering more than 10% (580,000 ha) of the total planned area, as shown in Table 10 (ADB 2001, FSSP 2006). The programme has a provision for a total of 3,620 billion VND available as credits to finance the establishment of NTFP plantations (FSSP 2006).

Table 10. Planned area for NTFP in the 5MHRP (MARD 2001).

NTFP Plantation	Planned area (ha)
Cinnamomum cassia	65,000
Illicium verum	20,000
Pine (*Pinus* spp.)	140,000
Tung oil, tea oil	155,000
Bamboos (various species)	200,000

The potential of NTFP to improve the viability of forestry from the point of view of the farmers is very considerable. Because farmers will certainly be more willing to protect forests which are of direct value to them, this has an important potential to gain the farmer's support for natural forest protection and management (FSSP 2006).

The geographical distribution of the main NTFP species, which have high economic value and potentials for development in Vietnam, are given in Table 11.

Table 11. Distribution of high potential NTFP species in Vietnam (MARD 2007).

Region	NTFP species with high potentials for development
Northeast	*Pinus merkusii,* bamboo spp., rattan spp., *Illicium verum, Cinnamomum cassia, Amomum aromaticum, A. villosum, A. longiligulare, Canarium* spp., *Maclurochloa vietnamensis, Castanopsis* spp., *Fibraurea recisa, Monrinda officinalis, Panax pseudoginseng, Stephania dielsiana, Meliantha suavis*.
Northwest	Bamboo spp., *Amomum aromaticum, A. villosum, A. longiligulare,* honey*, Indosasa angustata, Morinda officinalis, Stephania dielsiana, Mallothus philippinensis.*
North central	*Pinus merkusii*, Bamboo spp., *Indosasa angustata,* rattan spp., *Cinnamomum cassia, Amomum villosum, A. longiligulare, Stephania dielsiana, Coscinium fenestratum, Fibraurea recisa, Aquilaria crassna.*
South central	*Cinnamomum cassia,* rattan spp., *Aquilaria crassna,* honey, *Panax vietnamensis, Amomum villosum, A. longiligulare, Lansium domesticum, Bambusa procera, Shorea thorelli, Dipterocarpus* spp.

Central highlands	*Pinus* spp., rattan spp., *Bambusa procera, Panax vietnamensis, Dipterocarpus* spp., *Shorea thorelli,* honey, *Amomum villosum, A. longiligulare, Aquilaria crassna.*
Southeast	*Dipterocarpus* spp., *Shorea thorelli,* rattan spp., bamboo spp., *Bambusa procera,* honey.

As said earlier, Vietnam is reported to be home to 12,518 animal species and subspecies including 310 species of mammals, 840 bird's species, 286 species of reptile and 162 species of amphibians. During last 50 years, due to illegal hunting activities for domestic consumption, illegal trade of living wildlife and deforestation serious losses to forest wildlife have been caused. In recent years, demand for wildlife meat and similar products is evidently increasing (FSSP 2006). Restaurants serving special dishes are established nationwide and wildlife trading has become more apparent. All this shows that there is strong market for wildlife for local and international consumption. According to the Biodiversity Action Plan, however, about 28% of the mammal species, 10% of the bird species and 21% of the reptiles and amphibians are facing extinction, while some 350 plant species are among the endangered species (GoVN 1994, FAO 2002).

In prehistoric times, wildlife was captured and bred and many valuable species of poultry and livestock were successfully domesticated in Vietnam. Currently, wildlife raising is developing and has become a new business attracting the involvement citizens of various classes (FSSP 2006). Species such as *Lepus sinensis, Sus scrofa, Gekko gekko* and *Varanus salvato* are raised widely in locked cages or in semi-natural breeding set-ups. The raising endangered species is strictly prohibited as Vietnam, as the country has signed the CITES Convention (FSSP 2006).

At present, both in-situ and ex-situ conservation for NTFP are applied in Vietnam. In-situ conservation is effectively applied for NTFP in protected areas, like in core zones of national parks or nature reserve areas. These protected NTFP forests in the future will be also used to provide seedlings for NTFP plantations. On-farm conservation needs to be promoted as local people collect seeds from the forests and plant them on their farms in forest gardens situated within the natural distribution areas of the species (FSSP 2006). Many NTFP species such as *Illicium verum* (Lang Son province), *Cinnamomum cassia* (Yen Bai, Thanh Hoa and Quang Nam provinces) and *Amomum aromaticum* (Lao Cai province) are maintained and developed in this way (Dzung 2000, MARD 2007). This type of in-situ conservation can both improve the living standards of local people and provide them with incentives for conserving forests (to secure their source of income), thereby integrating conservation and development purposes (FSSP 2006).

Ex-situ conservation of endangered NTFP species has also shown encouraging efforts. There are about 130 common NTFP species being conserved ex-situ (MARD 2004) which includes about 8% of the medicinal plant species (Tap 2002, FSSP 2006). Ex-situ conservation is applied mainly with species of high economic value, such as *Panax vietnamensis* in Quang Nam province, *Fokienia hodginsii* in Lao Cai province, *Pinus merkussi* and *Dendrocalamus* spp., etc. (FSSP 2006). Ex-situ conservation is also applied in the case of endangered animal species, such as *Cervus nippon* in Ha Tinh and *Python molorus* and *Crocodylus siamensis* in the Mekong Delta.

Economic status related to NTFP

NTFP are not only used for home sufficiency but also provide materials for industries and for export purposes (FSSP 2006). The importance of NTFP in subsistence economy tends to be heavily underestimated (Ros-Tonen et al. 1995).

- NTFP- raw material for industries

NTFP provide important raw materials for Vietnam's industrial sub-sectors, particularly the paper industry (Dzung 2000, FSSP 2006). The Government intends to develop one million ha of forest to supply raw material for 2-2.5 million tons of paper and pulp by 2010, of which 30% from bamboo material (Dzung 2000, FAO 2002). In addition, NTFP provide raw materials for essential oils factories, bamboo and rattan processing enterprises as well as handicrafts villages. During the past ten years, traditional craft villages have developed rapidly. There are about 1,500 craft villages nation-wide and they create jobs for about 200,000 – 400,000 labourers (Dzung 2000). Amounts of raw material from major NTFP harvested is given in Table 12.

Table 12. Amount of NTFP harvested in the year 2000 and 2003 (MARD 2007).

NTFP	2000		2003	
	Amount (tons)	Value (million USD)	Amount (tons)	Value (million USD)
Pine resin	5,000	0.750	23,500	3.525
Cinnamomum spp.	3,000	2.100	7,400	5.180
Illicium spp.	3,500	12.250	7,008	24.528
Rattan spp.	120,000	24.000	150,000	30.000
Amomum aromaticum	120	0.600	210	1.050
Amomum spp.	250	0.375	450	0.675
Honey	5,000	25.000	5,100	25.500
Bamboo spp.	-	-	620,766	-

- NTPF in the household's economy

NTFP are important to the livelihoods of people in the remote uplands of Vietnam. These people tend to live near or in remaining stands of natural forests, and they rely heavily on fuelwood and on a variety of other NTFP for food, fodder, medicines, construction materials and other items. Some NTFP are sold for supplementary household cash income or traded for essentials such as rice. It is estimated that 25 million people living in or near forest lands (Forest Department 2004, FOMIS 2008), and about 8.5 million ethnic minority people spend much of their time gathering forest products and hunting (Poffenberger 1998, Dzung 2000, Sunderlin and Ba 2005, FSSP 2006). NTFP provide an important safety-net function through direct consumption and also through sales (Bang 1999, MRDP 2000). Case studies show that the contribution of NTFP to a household's income differs regionally. It is estimated that about 15% of the total household's income comes from NTFP in Bac Kan province (Raintree et al. 1999) and 24% in Hoa Binh province (Mai 1999). In the Northwest region, the NTFP account for 23% of the total incomes generated from agroforestry and aquaculture productions, which is 5 more times than the national average (4.8%). For the Northeast region, this rate is 11.7% (NTFP 2006, FOMIS 2008).

Fuelwood is the most important NTFP for people residing in and around forests. Annually, 22 to 23 million tons of fuelwood are harvested (Dang et al. 2001, Nhat 2001, Chien 2006, FSSP 2006). It is estimated that from 2010 to 2020, about 26 million tons of fuelwood will be harvested annually (MARD 2007).

In Vietnam reliance on NTFP is especially common among ethnic minorities (ADB 2003). They tend to specialise in an array of NTFP that are specific to the forest ecological system they inhabit. For example the Dzao people in the north collect medicinal plants, cinnamon and lacquer; the Hmong focus on high quality bamboo and rattan; and the Khmer in the south collect aromatic oil from *Melaleuca* forests and other high value products from mangrove forests (Poffenberger 1998, Sunderlin and Ba 2005).

- *NTFP trade*

A significant part of the NTFP is harvested for trading since it has a high economic value. In areas bordering on China, local people harvest NTFP for trade with the Chinese. Traded products are anise star, cinnamon, medicinal herbs, rhino horn, ivory (FSSP 2006), but it is impossible to assess the real total value of these NTFP exports from Vietnam, because most of it, including a large volume of endangered plants and animal species, leaves the country unregistered (Donovan 1998, Dzung 2000). The picture is more complicated by the fact that a considerable part of Vietnam's NTFP export is in fact re-export from Laos and Cambodia. The potential international market for Vietnam's NTFP products includes Japan, Taiwan, France and the United States of America. Statistics from Customs on the value of exported NTFP to some main importing countries are given in Table 13.

Table 13. Export value of NTFP to the world market (Sinh 2004).

Unit: USD million

Year	Japan	Taiwan	China	Germany	Korea	France	Hongkong	USA	Others
1999	10.797	16.611	-	-	8.414	-	5.374	-	-
2000	16.807	15.525	26.449	-	9.496	6.014	-	-	-
2001	18.974	15.810	27.162	-	8.647	-	-	7.627	-
2002	27.002	13.198	10.741	-	-	-	-	20.091	-
2003	26.784	11.894	-	11.190	-	8.562	-	21.389	-
2004	26.469	14.908	-	19.909	-	9.799	-	30.936	-
Total	126.83	87.946	64.352	31.099	26.557	24.375	5.374	80.043	329.27

Among the various kinds of NTFP products, bamboo, rattan handicrafts, honey, cinnamon and *Illicium verum* are the main export products. During the period 2000-2005, the average NTFP export growth rate was 17-27% per year (FOMIS 2008). Total export turnover of NTFP in 2004 was nearly USD 200 million of which

USD 138 million came from bamboo and rattan products (GDC 2005, FOMIS 2008). As Vietnam has a shortage of NTFP raw materials, especially rattan, these are being imported to Vietnam mainly from Laos and Myanmar to produce export products. During 2000-2005, the import turnover of NTFP was about USD 20-40 million annually (GDC 2005, FOMIS 2008). According to Vietnam Forest Development Strategy toward 2020 (VFDS), the export volume of the NTFP are projected to reach an estimated USD 300 million by 2010, USD 600 million by 2015 and USD 700-800 million by 2020, employing 1.5 million labourers in the gathering, processing and trading of NTFP (VFDS 2006, FOMIS 2008).

Rattan in Vietnam

Taxonomy and diversity

The rattan flora of Vietnam has been studied and classified first by Gagnepain, a botanist working from 1908 to 1937 in the time when Indochina was a French colony. Gagnepain distinguished 26 rattan species, belonging to 5 genera in Vietnam (Lecomte 1937, Dzung and Cuong 1996). At present, 36 species belonging to 6 genera are distinguished in Vietnam (Henderson 2009). If thoroughly inventoried nationwide, the number of rattan species may be higher, and about 50 species are estimated to occur (Nghia et al. 2000). In the most recent classification of the palms family (Arecaceae) the rattan genera are included in subfamily *Calamoideae*, in tribe *Calameae* (Table 14).

Table 14. Classification of rattan genera in Vietnam (Uhl and Dransfield 1987, Dransfield and Manokaran 1994, Anh 2008, Dransfield et al. 2008, Henderson 2009).

Palmae (Arecaceae)				
	Subfamily *Calamoideae*			
		Tribe *Calameae*		
			Subtribe *Calaminae*	
				Calamus: 28 species
				Daemonorops: 3 species
			Subtribe *Korthalsiinae*	
				Korthalsia: 1 species
			Subtribe *Plectocomiinae*	
				Myrialepis: 1 species
				Plectocomia: 2 species
				Plectocomiopsis: 1 species

- Calamus

It is the largest of the six rattan genera. Outside Vietnam, it is found in India, Sri Lanka, Brunei Darrussalam, Burma, Malaysia, Singapore, Indonesia, the Philippines, Thailand, Cambodia, Laos, South China, New Guinea, Fiji, Vanuatu, Queensland and West Africa (DST 1991, Dransfield and Manokaran 1994, Dzung and Cuong 1996). Species of this genus exhibit a wide range of vegetative and reproductive structures. They grow solitary or clustered and have usually spiny leaf sheaths. The leaf sheath may or may not contain a flagellum, which is a climbing whip derived from a sterile inflorescence. Knee frequently presents. Leaves are pinnate, with or without cirrus. Leaflets are many and vary in arrangement. The rattans in this genus are dioecious. Both male and female inflorescences are superficially similar and usually end in a long flagellum. The male branches to 3 orders while the female to 2 orders. The female flowers are longer than the males. Fruit are ovoid and 1 to 3 seeded (DST 1991, Dransfield and Manokaran 1994, Anh 2008).

- Daemonorops

It is the second largest genus of rattans in Vietnam. The genus is found in Indochina, India, Nepal, Burma, Malaysia, Indonesia, Singapore, Brunei, the Philippines, China and New Guinea. Morphologically, it is superficially similar to *Calamus.* Species have a solitary or clustered habit, have spiny leaf sheaths and are dioecious. However, the leaf sheaths have no flagellum. Knee frequently presents. Leaves are pinnate, regular or irregular leaflets and with a long cirrus. The male and female inflorescences, which are superficially similar and have variously armed bracts, are of two basic types: (1) outermost bract enclosing inner bracts; and (2) bracts borne on an elongated inflorescence which are tubular in the bud stage and split along their entire length during flowering. The male branches to 3 orders while the female to 2 orders. Female flowers are usually larger than the males. The fruits have different shapes, are covered with reflexed scales and are usually one seeded (DST 1991, Dransfield and Manokaran 1994, Anh 2008).

- Korthalsia

It occurs from Burma and Indochina through the Malay Archipelago to New Guinea. Morphologically, this genus is easy to recognize. They are clustering and branching, high-climbing rattans with spiny leaf sheaths, diamond-shaped leaflets and a cirrus. It has no knee. They are hermaphroditic. The inflorescences are produced in the axils of the uppermost reduced leaves. The branch which bears the inflorescence dies after fruiting. Flowers are hermaphrodite. Fruits are ellipsoid or globose, covered with scales, fleshy and one-seeded (DST 1991, Dransfield and Manokaran 1994, Anh 2008).

- *Myrialepis*

This genus is found in Indochina, Thailand, Burma, Peninsular Malaysia and Sumatra. This is a clustering, high-climbing rattan with spiny leaf sheaths. The leaf sheath has no knee and has long, golden spines in long combs. Leaves are large, pinnate, terminating in a cirrus. Leaflets are mostly regular. The underside of the leaflet has many tiny, white dots. Inflorescences are produced at the axils of the uppermost leaves. The female flowers are larger than the males. It bears flowers only once and eventually dies (hapaxanthy). Fruits are globose and covered with very many, tiny, grey green scales and one-seeded (Dransfield and Manokaran 1994, Evans et al. 2001, Anh 2008).

- *Plectocomia*

This genus occurs from the foothills of the Himalayas to Indochina, Malaysia, Indonesia and the Philippines. These are solitary or clustered, high-climbing rattans with spiny leaf sheaths. The leaf sheath has no knee and is armed with comb like spines. Leaves are large, pinnate, and terminate in a cirrus. Leaflets are numerous, usually in groups of 2 to 4. Inflorescences are produced in the axils of the uppermost leaves. The female flowers are larger than the males enclosed by closely overlapping, boat-shaped and leathery bracts. They are hapaxanthic. Fruits are round or ovoid and covered with overlapping scales (DST 1991, Dransfield and Manokaran 1994, Anh 2008).

- *Plectocomiopsis*

Outside Vietnam, it can be found in Thailand, Malaysia, Sumatra and Borneo. Morphologically, this rattan is similar to Plectocomia. It is a clustering, high-climbing rattan with spiny leaf sheaths. The leaf sheath has no knee and has scattered spines. Most species have rigide leathery entire ocreas. Leaves are large, pinnate, terminated by a cirrus. Leaflets are regular with one line of golden bristles on the upperside. Leaflets have long hair-like tips. Inflorescences are produced in the axils of the uppermost leaves with no flagellum. The female flowers are larger than the males. Each stem flowers once then dies. Fruits are round and covered with overlapping scales (Dransfield and Manokaran 1994, Evans et al. 2001, Anh 2008).

Distribution

Rattans occur nation-wide in Vietnam (Nghia et al. 2000, Dzung 2001, FSSP 2006). Some species have wide distributions and are found throughout the country, e.g. *Calamus tetradactylus, Calamus rudentum* and *Calamus walkeri,* while others have narrow distributions and occur only in one or two provinces (Dzung and Cuong 1996). *Calamus ceratophorus* is only found in open forests in Nha Trang and Phan Rang provinces and *Plectocomia elongata* is limited to the Ba Na in Quang Nam province, Bach Ma (Thua Thien Hue) and Ba Ren (Quang Binh) (Dzung and Cuong 1996, Nghia et al. 2000, Anh 2008).

Quang Nam, Da Nang and Thua Thien Hue provinces, in the middle of Vietnam, have the highest diversity of rattan species (Dzung and Cuong 1996). At present, the three main regions of rattan resources are (Nghia et al. 2000, Dzung 2000, MARD 2007):

- Northwest: Rattans grow in natural forests in provinces along the Red River and Da River valleys, including Hoa Binh, Phu Tho, Yen Bai, Lao Cai, Son La and Lai Chau provinces.
- North central: Rattans grow in natural forests along the border with Lao PDR, including Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang tri and Thua Thien Hue provinces.
- South central and Central Highlands: Rattans grow in the Truong Son Range and in Central Highland areas including Da Nang, Quang Nam, Kon Tum, Gia Lai, Dac Lac, Lam Dong, Dong Nai and Binh Phuoc provinces.

Rattans occur from sea level to about 1,500 m (Thin 1992, Dzung and Cuong 1996). About two third of the rattan species grow at elevations from 0 to 700 m above sea level. With increasing elevation less rattan species are found. Above 1,500 m only large-size rattan species are found, such as *Calamus platyacanthoides* and *Daemonorops poilanei.* The distribution of rattan species according to altitude is summarized in the Table 15.

Rattans can be found in many types of forest in Vietnam, except mangrove forests. Rattans are rarely found on limestone or coniferous and bamboo forests: these habitats do not seem to be favourable for rattans (Thin 1992, Dzung and Cuong 1996). Rattans mostly occur at open areas, at the edge of the forest and along the trails or streams in the forest, but can also occur in the interior of the forest (Dzung 2000). In secondary forests, following selected logging and a remaining forest cover of about 40 – 50 %, several species of rattan grow up very quickly and abundantly (Dzung and Cuong 1996). Planted rattans are found in home gardens as fences and hedgerows, surrounding villages or lowland terrace fields (Forest Department 2007). The geographical distribution of the rattan species in Vietnam are summarized in Table 16.

Table 15. Known distribution of rattans by altitude in Vietnam (Dzung and Cuong 1996).

Altitude (above see level)	Rattan species
0-700 m	*Calamus tenuis, C. bousigonii, C. ceratophorus, C. dioicus, C. tetradactylus, C. walkeri, C. rhabdocladus, C. flagellum, C. platyacanthoides, C. salicifolius, C. viminalis, Daemonorops jenkinsiana, D. poilanei, D. mollispina, Plectocomia elongata, P. elongata* var. *elongata, Korthalsia laciniosa, Plectocomiopsis geminiflora* and *Myrialepis paradoxa.*
700-1500 m	*Calamus dioicus, C. poilanei, C. rudentum, C. dongnaiensis, C. platyacanthoides, C. bousigonii, C. modestus, C. rhabdocladus, Daemonorops jenkinsiana, Plectocomia elongata* and *Plectocomiopsis geminiflora.*
> 1500 m	*Calamus platyacanthoides* and *Daemonorops poilanei.*

Table 16. Known distribution of rattans in Vietnam (Dzung and Cuong 1996, Nghia et al. 2000, Anh 2008). Note that number of species per genus does not always match with Henderson (2009).

Genera	Species	Distribution area
Calamus	*Calamus bousigonii*	Central, Tay Nguyen and South
	Calamus ceratophorus	Nha Trang and Phan Rang
	Calamus dioicus	Thua Thien Hue towards South
	Calamus dongnaiensis	Lam Dong and Dong Nai
	Calamus flagellum	North
	Calamus modestus	Central and Tay Nguyen
	Calamus platyacanthoides	Thua Thien Hue towards North
	Calamus poilanei	Thanh Hoa towards South
	Calamus rhabdocladus	North, Central and South
	Calamus rudentum	North, Central and South
	Calamus salicifolius	South
	Calamus tenuis	North and North central

	Calamus tetradactylus	North, North central and South
	Calamus walkeri	Northeast and Central
	Calamus viminalis	North central
Daemonorops	*Daemonorops jenkinsiana*	North, Central, Central Highland and South
	Daemonorops mollispina	Ha Tinh towards South
	Daemonorops poilanei	Central, South and Southeast
Korthalsia	*Korthalsia laciniosa*	North central, Tay Nguyen and Dong Nai
Myrialepis	*Myrialepis paradoxa*	Binh Thuan, Ninh Thuan and Dong Nai
Plectocomia	*Plectocomia elongata*	Quang Binh, Hue and Quang Nam
Plectocomiopsis	*Plectocomiopsis geminiflora*	Lam Dong and Dong Nai

Social economic value of rattan

Rattan has been used by the Vietnamese people for a long time as raw material for weaving and making home appliances for domestic use (Dzung 2000, Nghia et al. 2000). For many people in remote areas rattan collecting is the sole option for obtaining cash income. Usually rattans are harvested when money is needed. Many rattan collectors are women and they work to earn money to meet their basis needs (Dzung 2000). Rattan canes and leaves can be harvested throughout the year. However, the canes are mainly collected during April-September due to better weather conditions (Olivier 2003). But in less remote area it has to compete with alternative ways of making a living that sometimes are regarded as "less primitive" or simply more profitable (Van Valkenburg 1997). As long as the daily income from rattan collecting is higher than the other alternative ways of making a living people will collect rattan. Most costs involved in the collection of rattan canes is the time used to search for the rattan stems, respectively to walk to the clumps. In order to harvest rattan canes, collectors generally have to walk between 0.83 days to 1.5 days. Once they reach the clumps, they can harvest a lot of rattan canes at once (Olivier 2003). Therefore, local use of rattan, especially in remote areas is of great importance and definitely has a high replacement value which, however, has not been studied in detail.

Rattan not only provides cash income to the collectors but also provides jobs to people both in remote areas and urban centers. People are involved in transportation and trade and also in the production of handicrafts and furniture for the export market (Van Valkenburg 1997). Vietnam now has around 40 rattan processing enterprises with the capacity of around 100,000 tons per year and about 700 rattan knitting handicrafts villages (FOMIS 2008). Annually, some 100,000 labourers are involved in rattan exploitation and processing, which makes the industry an important contributor to employment (Dzung 2001, FAO 2002). Statistics (2005) show that the income for a main labourer varies from VND 1.2-1.5 million per month (about USD 100-130) and for a subordinate labourer from VND 0.6-0.8 million per month (about USD 50-70).

Rattan is a forest product with an economic value ranked third after timber and bamboo in Vietnam (Dzung 2000, FSSP 2006). With the development of the rattan industry, many varieties of handicrafts, furniture, and household appliances are made with this material for both domestic and international markets. The value of rattan production in Vietnam increased rapidly in the late 1980s, reaching USD 1 million in 1990 (FAO 2002). This favourable economic development is supposed to continue. Vietnam is the third largest exporter of rattan in the world, after Malaysia and Indonesia (Dzung 2000, FAO 2002). Vietnam exports 2,000,000 m^2 of rattan-woven products and 500,000-600,000 m^2 of other rattan-based products annually (Dzung 2000, FSSP 2006). About 70% of NTFP export in 2004 accounted for rattan products (GDC 2005, FOMIS 2008) and in 2005 the export of rattan products had a value of more than VND 180 million (FOMIS 2008). It is expected that the average export turnover of rattan products will increase by 10-15% per year (FOMIS 2008). Most of Vietnam's rattan products are exported to Germany, Italy and Japan; the rest is exported to Hong Kong, Singapore and Cuba (GDC 2005, FOMIS 2008). However, local trade is not included in government statistics and official export figures, thus the actual value of the rattan trade is higher than the reported figures.

The greatest challenges facing Vietnam's rattan production is its dependence on natural forests for the supply of the raw material. Meanwhile, rich and medium forests with many species of rattan are being seriously depleted. These supplies of raw rattan will disappear within 10-20 years if no extensive rattan plantation plan is implemented (Dzung 2001).

Plantation of rattan

Rattan was first planted in Vietnam hundreds of years ago. It was first grown in Thai Binh province (Dzung and Cuong, 1996). Plantations were small and mainly concerned home gardens, forest gardens and fences, etc. Even at present, there are no extensive plantation areas yet (FSSP 2006). About 10 rattan species are cultivated, including three major species: *Calamus tetradactylus, Calamus walkeri* and *Calamus tenuis.* In recent years, *Calamus platyacanthoides* was also planted in some areas (FSSP 2006). These species are grown based on the experience of local communities. Seedlings are collected in natural forests or in surrounding areas (Dzung and Cuong 1996). *Calamus rudentum* mainly grows naturally in the South and a cultivation trial was done in the North, while *Calamus platyacanthoides* was brought from the North to be tested in the South (Nghia et al. 2000).

In order to support the growing handicrafts industry, the Government is encouraging the cultivation of rattan (FAO 2002). In the Five Million Hectares Reforestation Programme, about 80,000 hectares of rattan is planned to be planted to supply raw material for local use and for export purposes. At present, the Government has encouraged rattan development through enrichment planting in natural forest (Forest Department 2007). This is especially appropriate where forest has been selectively logged. This approach has been practised with some success in India and Indonesia (Sunderland and Dransfield 2002). Besides, planting of rattan in association with tree cash crops has been introduced in Vietnam (Forest Department 2007). This has proven relatively successful in Indonesia where rattan was planted with coffee *(Coffea canephora)* and cacao *(Theobroma cacao)* in agroforestry systems (Siebert 2000b). In Thai Binh, Hai Duong, Ha Tinh and Nam Ha provinces rattan has been planted in home gardens as a multipurpose tree. Annually, about 1,500 to 2,000 tons of rattan cane is estimated to be produced from the home gardens (Nghia et al. 2000). Recent research efforts in term of provenance improvement, propagation, seed source improvement and silvicultural techniques have led to the planting of *Calamus tetradactylus, Calamus platyacanthoides*, *Calamus rudentum, Calamus walkeri* and *Calamus poilanei* (Evants 2002). Planted rattan species and their locations are summarized in Table 17.

Table 17. List of planted rattan species in Vietnam (Nghia et al. 2000).

Species	Locations
Calamus tenuis	Thai Binh, Hung Yen and Hai Duong provinces
Calamus dioicus	Various places
Calamus platyacanthoides	Hoa Binh and some southern provinces
Calamus rudentum	Vinh Phu and some southern provinces
Calamus tetradactylus	Various places
Calamus walkeri	Bac Giang, Quang Ninh, Nha Trang and Phan Rang provinces

Use of rattan

The main product of rattan palms is cane; this is the rattan stem stripped of its leaf sheaths (Sunderland and Dransfield 2002). Because of their strength, flexibility and uniformity and because rattan is easy to combine with other materials such as metals, wood, leather, plastic, etc., rattan stems have been used in daily life and in industries for a long time. The canes are used either in whole especially for furniture frames, or are split, peeled or cored for matting and basketry (Dzung and Cuong 1996, Sunderland and Dransfield 2002). Different rattan species have different diameters ranging from 3 to 70 mm (Dransfield and Manokaran 1994). It is estimated that only 20% of the known rattan species are used to make commercial products. The remaining species are not used probably because of their inflexibility, small quantity, short stems or their rarity (Dransfield and Manokaran 1994, Sunderland and Dransfield 2002).

Other plant parts of some rattan species are also utilised and contribute to the indigenous survival strategies of many forest based communities (Dzung 2000, Sunderland and Dransfield 2002). Mature leaves can be used to roof houses while young leaves can be used as cigarette paper. Shoots also can be eaten. The fruits are edible too or can be used to make certain medicines. The shells of the fruits of some species produce resin which is used to make dye, varnish or local medicine (Dransfield and Manokaran 1994, Dzung 2000).

The most common of 10 rattan species in Vietnam and their distribution are briefly described as follows based on their economic value and local uses (Dzung and Cuong 1996, Nghia et al. 2000, World Checklist 2009).

- *Calamus tetradactylus*

This is the most popular species in Vietnam. Annual harvesting capacity varies from 1,500-2,000 tons for home consumption and finished products. This multi-stemmed species is commonly planted in the delta and midland areas in the North. It grows and develops very fast, about 2-3 m/year, and can be harvested after 5-7 years. Its stem has long internodes and is whitish and very flexible. There is a high demand for it for the production of furniture, handicrafts such as trays, baskets, cosmetic boxes, etc. Distribution: China, Cambodia, Lao, Thailand and Vietnam.

- *Calamus platyacanthoides*

This multi-stemmed species has long stems that are equally round along its stems and their diameter is large (2-5 cm). It is found all over the North from Thua

Thien Hue province northwards. Its stem is very strong and flexible and is used for binding, raft wrapping, furniture, bookshelves, cradles, etc. Products from this species are favoured on the international markets. Distribution: China, Lao and Vietnam.

- *Calamus rudentum*

Its distribution is nationwide. This multi-stemmed species is degrading and its volume production reduced due to overexploitation. Its diameter reaches 2.5-4 cm. The climbing stems reach 50-60 m in length and they carry broad leaves (4 m). Its stem is used for making frames of chairs, tables and sofas and for basket weaving. Its finished products are exported but at a lower price than those of *Calamus platyacanthoides*. Stems and leaves are favoured as fodder for rhino and used for thatching. Distribution: Cambodia, Lao, Myanmar, Thailand and Vietnam

- *Calamus poilanei*

Stems of this single stemmed species have a large diameter of 4-6 cm and are equally round, with a smooth surface and a showy appearance. It occurs from Thanh Hoa province southwards and reaches dense populations in the North Central region. This species becomes scarce and endangered. It is commonly used for making frames of tables, chairs and bookshelves, etc. and it has the highest export value. Distribution: Lao, Thailand and Vietnam.

- *Calamus walkeri*

The diameter of this multi-stemmed species is small (1-2 cm). It occurs mainly in the North and Central regions. It has flexible and whitish stems but with short internodes and it is not used for making handicrafts but only for roping in house construction and lines for hanging clothes. Its young shoots are eaten; they taste bitter. Some ethnic people use it as a kind of vegetable. Distribution: China and Vietnam.

- *Plectocomiopsis geminiflora*

With its medium-sized diameter (3 cm), this multi-stemmed species is abundant in Cat Tien, Lam Dong and along the Dong Nai River. It is known for its quick regeneration from seed and suckers. Local people usually collect the suckers as browse for their animals. This species is the favorable food for the Javanese rhino in Vietnam. Distribution: Cambodia, Lao, Myanmar, Thailand, Vietnam, Borneo, Malaya and Sumatera.

- *Daemonorops poilanei*

The average diameter of this multi-stemmed species is 1.5-2.5 cm. It is found mostly in the Central and southern provinces from Hai Van Pass to Phu Yen, Khanh Hoa, Ninh Thuan, Binh Thuan, Dong Nai and Song Be provinces. It also occurs from Hai Van Pass northward in Thua Thien Hue, Quang Binh and Ha Tinh provinces. It is mainly used as string, for carrying poles and to make table and chair frames.

- *Calamus tenuis*

This multi-stemmed species has a diameter of 1-1.5 cm. It occurs in most of the northern provinces. Its stem is white and its internodes are shorter than *Calamus tetradactylus.* It is commonly cut for household use but it is not as much preferred as the other species. Distribution: Assam, Bangladesh, Himalaya, India, Cambodia, Lao, Myanmar, Thailand, Vietnam, Jawa and Sumatera.

- *Calamus dioicus*

This multi-stemmed rattan has a small diameter of 5-8 mm. It occurs from Thua Thien Hue southward. Its stem is flexible, strong and whitish and is used in making baskets, chair surfaces, clothes lines and for making cottage products for export. Distribution: Vietnam.

- *Calamus rhabdocladus*

This multi-stemmed species has short internodes, a hard stem, and an average diameter of 2-2.5 cm. It occurs nationwide. It grows densely in secondary forests. Its stem is easily split and hard to bend. Its stems have a thick and rigid outer layer and therefore these rattans are often used for making walking sticks, frames for tables, sofas, etc. Its leaves are used for thatching. Distribution: China, Lao and Vietnam.

Genetic conservation, development and management

For sustainable conservation and development of rattan resources, it is imperative that the practice of uncontrolled exploitation should be abandoned and replaced by effective measures of conservation, cultivation, sustainable management that would also help the rural people improving the economic status in the long term (Hong et al. 2002). Since the late 1980s, the development of large scale processing of rattan based products for export led to over-exploitation and caused genetic degradation of the rattan species in Vietnam (FSSP 2006). Thus, many rattan species are being threatened. *Calamus poilanei* and *Calamus platyacanthoides* are under threat of extinction in the wild and listed already in Vietnamese Red Data Book (FSSP 2006).

So far, genetic conservation of rattan species is not systematically done (FSSP 2006). In addition, knowledge on the genetic diversity within and between species is still scarce for rattan. With the fast depletion of the tropical forests it is imperative to obtain this knowledge in order to be able to sustainably manage the remaining rattan resources (Hong et al. 2002). Rattan plantations for conservation purposes have been established in some places as given below (Nghia et al. 2000):

- Cuc Phuong National Park: *Calamus tetradactylus* and *Calamus rudentum,* since 1992
- Ben En National Park: *Calamus tetradactylus* and *Calamus rudentum,* since 1997
- Cau Hai Silviculture Center: *Calamus platyacanthoides* and *Calamus* spp., since 1994
- Hoa Binh Silviculture Center: *Calamus platyacanthoides* and *Calamus rudentum,* since 1994

Currently, in Vietnam a policy has been adopted to reduce exploitation activities and come to a "logging ban" in natural forests. Recent policies of forests and forest land allocation delegated to households and communities have encouraged local people to harvest the rattan resources more carefully. This is hoped to be a major move to involve local people in conservation, development and sound harvesting of the rattan resource.

Long term in situ management of rattan in the wild is rare (Belcher 1999, Sunderland and Dransfield 2002). However, based on experimental work in Southeast Asia, four production systems of rattan exploitation can be identified (Sunderland and Dransfield 2002):

- Natural regeneration in high forest: This level of management requires the development and implementation of management plans based upon sound inventory data and an understanding of the population dynamics of the species concerned. This is particularly appropriate for forest reserves, community forests and other low-level protected areas. These models are highly appropriate for rattan.
- Enhanced natural regeneration, through enrichment planting and canopy manipulation, in natural forest: This is especially appropriate where forest has been selectively logged. Management inputs are fairly high, with the clearance of competing undergrowth vegetation and subsequent selective felling to create “artificial” gaps. This has been practiced in India,

Indonesia and Malaysia, with some success for rattan species. It suggests that enrichment planting is perhaps the most beneficial from of cultivation, both in terms of productivity and the maintenance of ecological integrity.

- Rattan cultivation as part of shifting cultivation or in formal agroforestry systems: The general principle is that, upon harvesting ephemeral or annual crops, rattan is planted and the land is then left fallow. When the rotation is repeated, usually on a 7-15 year cycle, the farmer first harvests the rattan and then clears the plot again to plant food crops. The income generated from the harvesting of rattan in this way is significant.
- Silvicultural trials: These have concentrated on the incorporation of rattan within tree based plantation type systems. The need for a framework for the rattan to grow on is imperative and the planting of rattan in association with tree cash crops was begun in the 1980s. Planting under rubber, intercropping with coffee and cacao or other fast growing tree crops has proven relatively successful (Siebert 2000b).

To achieve a sustainable rattan development, some major issues should be addressed in Vietnam. These include (Dzung 2001, FSSP 2006):

- Basic surveys should be done on the distribution and biological characteristics of rattans to select important species for development.
- Rattan should be produced in both home gardens, forest gardens and on large scales. Rattan plantations at catchments and regeneration areas can potentially resolve raw material limitation.
- *Calamus tetradactylus* is recommended to plant in the midlands and mountainous areas. Local authorities and extension centers should facilitate this by providing technical instructions to growers, and provide seedlings to possibly expand planted areas. As an example, in Do Luong district, Nghe An province, authorities provided each household with 300-500 seedlings of *Calamus tetradactylus* to plant around their houses. After 3-4 years, when harvesting, the growers will sell the rattan and repay for the seedlings; this amount will be rotated to new rattan growers.
- There is an urgency to take protective measures for seeds or seedlings of *Calamus tetradactylus* (in Tu Ly district, Hoa Binh province), *Calamus poilanei* (in Quang Tri, Thua Thien Hue and Gia Lai provinces), *Calamus tenuis* (in Quang Binh, Quang Tri and Thua Thien Hue provinces), and *Calamus rudentum* (in Cat Tien National Park and Dong Nai province).

If this is not established soon, there will not be enough seed sources to promote rattan plantation in the future.

- As regards the processing stage, advanced processing facilities and technology from other countries as Taiwan, Hongkong or Singapore should be applied in Vietnam in order to improve the quality of rattan-based export products.

To summarize, Vietnam lies in the tropics with plentiful monsoon rains and favourable growth conditions. The country is endowed with abundant and diverse natural forest and NTFP resources, both in flora and fauna. The forests of Vietnam not only provide valuable forest products and play a substantial role in the country's ecological environment, but also provide important contributions to the sustainable development in the rural areas. Forests provide major income sources for ethnic people who live in or near forests and help them to reduce poverty and eliminate hunger.

In Vietnam, rattan species occur all over the country. It is one of the important NTFP, ranked third after timber and bamboo. In rural areas, rattan has been used in daily life since ages. It also provides cash income for local people. During the past two to three decades, rattan has served as an essential material for the manufacture of cane furniture and handicrafts for both domestic consumption and export.

However, for many reasons, during the past decades, the forest resources of Vietnam have been severely reduced including rattan resources. Recently, the Government has paid much attention to manage, protect and exploit forest resources in a sustainable way. Because of the implementation of the 5 million ha reforestation programme, forest resources have gradually improved both in quantity and quality. The production of NTFP, especially rattan, has been encouraged. Rattan has been protected, cultivated and managed in a better way to improve the growth and production of these species.

In this dissertation I will report the results of my research on the population biology and the impacts of rattan harvesting on the population dynamics of three Vietnamese rattan species: *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei*.

Acknowledgements

We are grateful to Pieter Zuidema for valuable discussion and comments on this chapter. We also acknowledge Shouli Li for preparing maps for figures.

A clump of *Daemonorops cf. poilanei* may consist of many stems

Stems of *Daemonorops cf. poilanei* on the ground

3

Chapter 3

Determinants of growth, survival and reproduction of three rattan species in a Vietnamese rain forest

With Pieter A. Zuidema, Marinus J. A. Werger and Trieu Van Hung

Abstract

Rattans are spiny climbing palms belonging to the Arecaceae family, occurring in the Old World tropics and subtropics. Rattans may be single-stemmed or multi-stemmed in which stems (ramet) are clustered in a clump (genet). Rattan is an important non-timber forest product (NTFP) in almost all Southeast Asian countries. As demand for rattan products increases, there is high pressure on the natural populations of rattan. So far, little is known about the factors determining rates of rattan stem growth, survival and reproduction (vital rates) in natural populations.

339 ramets and 215 genets of *Calamus platyacanthoides*, 526 ramets and 93 genets of *Calamus rhabdocladus* and 533 ramets and 60 genets of *Daemonorops cf. poilanei* in tropical rain forests of Vietnam were studied in natural populations for basic knowledge on population size and vital rates. We measured growth, survival and reproduction of these species over three years from 2004 to 2006. Data was analysed by using linear, multiple linear, non-linear, binominal and multinomial logistic regressions. Effect of stem length, clump size and light availability on vital rates was also tested.

Population structures showed inverse J-shaped curves in both clump size and stem length for all three study species, indicating abundance and continuous natural regeneration. There was no effect of stem length and clump size on survival of stems and the average survival of stems was from 91% to 98% per year. Rattan stem growth depended on initial stem length, clump size and light availability. Stem growth was fast (at an almost constant rate) up to the initial stem length of 10 m. Thereafter, stem growth seemed stable for a while and then gradually became reduced. Clump support to growth rate was gradually reduced for longer stems and clump size had no longer effect on stem growth rates when stems were > 10 m. The three rattan species reproduced clonally and sexually simultaneously in all years of the study. Shoot production was positively related to clump size while number of infructescences increased with stem length. There was more male than female flowering in the three study species.

Finally, we suggest that liberation thinning may be a suitable way to stimulate rattan productivity in managed populations. Harvest intensity and rotation should be based on basic information on growth rates and its determinants, as well as on survival and reproduction rates of rattan populations. *C. platyacanthoides* and *D. cf. poilanei* are suitable NTFP species for cultivation, natural regeneration and enrichment planting in natural forests in Vietnam.

Key words: rattans, clonal, shoot, stem, clump, vital rate, growth, survival, reproduction, *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei*.

Introduction

Rattans are conspicuous elements of tropical forests in the Old World tropics. They often form dense patches, their stems wind on the forest floor for many meters and their climbing stems may form networks connecting tree crowns (Dransfield and Manokaran 1994, Watanabe and Suzuki 2008). Most of the rattan species are climbers that attain the forest canopy (Sunderland and Dransfield 2002). Many rattan species have a clonal growth form, in which stems (ramets) are clustered in clumps (genets), and sucker shoots appear as basal sprouts (Dransfield and Manokaran 1994, Watanabe et al. 2006). A large share of the rattan species are strong light demanders that thrive in disturbed forest patches (Sunderland and Dransfield 2002).

Stems of some rattan species are highly valued non-timber forest products (NTFP) throughout Southeast Asia (Dransfield and Manokaran 1994) and provide income for millions of people (Sastry 2002, Shaanker et al. 2004, Siebert 2005). The enormous pressure on rattan resources has led to uncontrolled harvesting and overexploitation (Sastry 2002, Sunderland and Dransfield 2002, Meitram and Sharma 2005).

In spite of their importance for forest ecosystems and economy, surprisingly little is known about the ecology of rattans in natural populations. For instance, basic information on the vital rates of rattan stems – growth, survival and reproduction – is scarce (Sunderland and Dransfield 2002) while even less is known about the factors determining these vital rates. Some studies have reported rates of stem growth for rattans (Bogh 1996, Van Valkenburg 1997), but without evaluating whether stem growth was determined mainly by initial stem length, light level and/or size of the cluster. Similarly, rates of clonal and sexual reproduction have been measured for certain species (Bogh 1995, Kouassi et al 2008), but their relation with stem characteristics or cluster size was not evaluated, so far.

In this chapter, we present and analyze rates of growth, survival and reproduction for three Vietnamese rattan species: *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei*. All occur in tropical rain forests in Vietnam and are exploited there (Dzung and Cuong 1996). We monitored stem growth, survival and reproduction of these species in unharvested stands over three years. Here we report rates of stem growth and shoot production, and probabilities of stem survival, sexual and clonal reproduction, all for the full size range of the species (excluding seedlings). We then relate these rates and probabilities to characteristics of stems (length, leaf number) and clumps (number of stems, summed stem length) and the growth environment (crown exposure), to identify the determinants of vital rates in our study species.

Study species

Calamus platyacanthoides, *Calamus rhabdocladus* and *Daemonorops cf. poilanei* are dioecious and multi-stemmed (clonal) palm species. Flowering is pleonanthic; not resulting in stem mortality. Only nodes at the base of the stem can produce new shoots (suckers), which in turn may produce other new shoots, etc. Large clump are built up in this way. Each stem has a limited ability to produce new shoots from few nodes at its base (Dransfield and Manokaran 1994). In this thesis, an individual ramet can be either shoot or stem: shoot refers to a sucker shoot which is vegetatively produced by a clump (it is a new ramet); stem refers to a ramet that has grown sufficiently large to expose the stem beyond the leaf sheets. Thus, a shoot gradually becomes a stem during the growth of the three rattan species. Specimens of all species were collected and sent to the herbarium of the Institute of Ecology and Biological Resources (IEBR) and to the Royal Botanic Gardens Kew for indentification. At the IEBR herbarium, the specimens are stored under voucher number PA142 *(Calamus platyacanthoides)*, PA 136 *(Calamus rhabdocladus)* and PA 140 (*Daemonorops cf. poilanei*). Characteristics and distribution of the study species are given in Table 1 and Figure 1, and further described below.

Calamus platyacanthoides occurs in China, Lao and Vietnam, usually occurring in natural montane rain forests between 100-1,500 m above sea level (a.s.l), but mostly at 400-900 m where the annual rainfall is about 1,300-2,500 mm (Dzung and Cuong 1996, Anh 2008). It forms small clusters with long stems. Its stems are very strong and flexible, and used for handicraft and furniture (Figure 1a). In Vietnam, the species has been heavily exploited over the last two decades. Their populations are reduced in both the number of individuals and the range of distribution. At present, the species is under threat of extinction and is listed in Vietnam's Red Data Book (Nghia et al. 2000).

Table 1. Characteristics of three studied rattan species in Bach Ma National Park, Central Vietnam

Species	*Calamus platyacanthoides*	*Calamus rhabdocladus*	*Daemonorops cf. poilanei*
Growth habit	Climbing with cirri, knee conspicuous	Climbing with flagella, no knee	Climbing with cirri, knee conspicuous
Max # of stems	10-12	20-25	50-60
Max stem length	> 30 m	40 m	50 m
Stem diameter	20-50 mm	20-25 mm	15-25 mm
Internodes length	15-25 cm	9-13 cm	20-30 cm
Max leaf length	2-3 m plus a cirrus	1-2 m	1-2.5mplusa cirrus
Max # leaflets on one side and arrangement	30, interrupted and grouped	70, regular or interrupted	60, regular
Inflorescence	> 1.5 m, no flagellum	2-4 m plus flagellum	> 1 m, no flagellum
Uses	Stem: handicrafts, furniture; Shoot edible	Stem: furniture, sticks; Shoot edible; Leaves used as thatch	Stem: handicrafts, furniture; Shoot edible; Leaves used as thatch

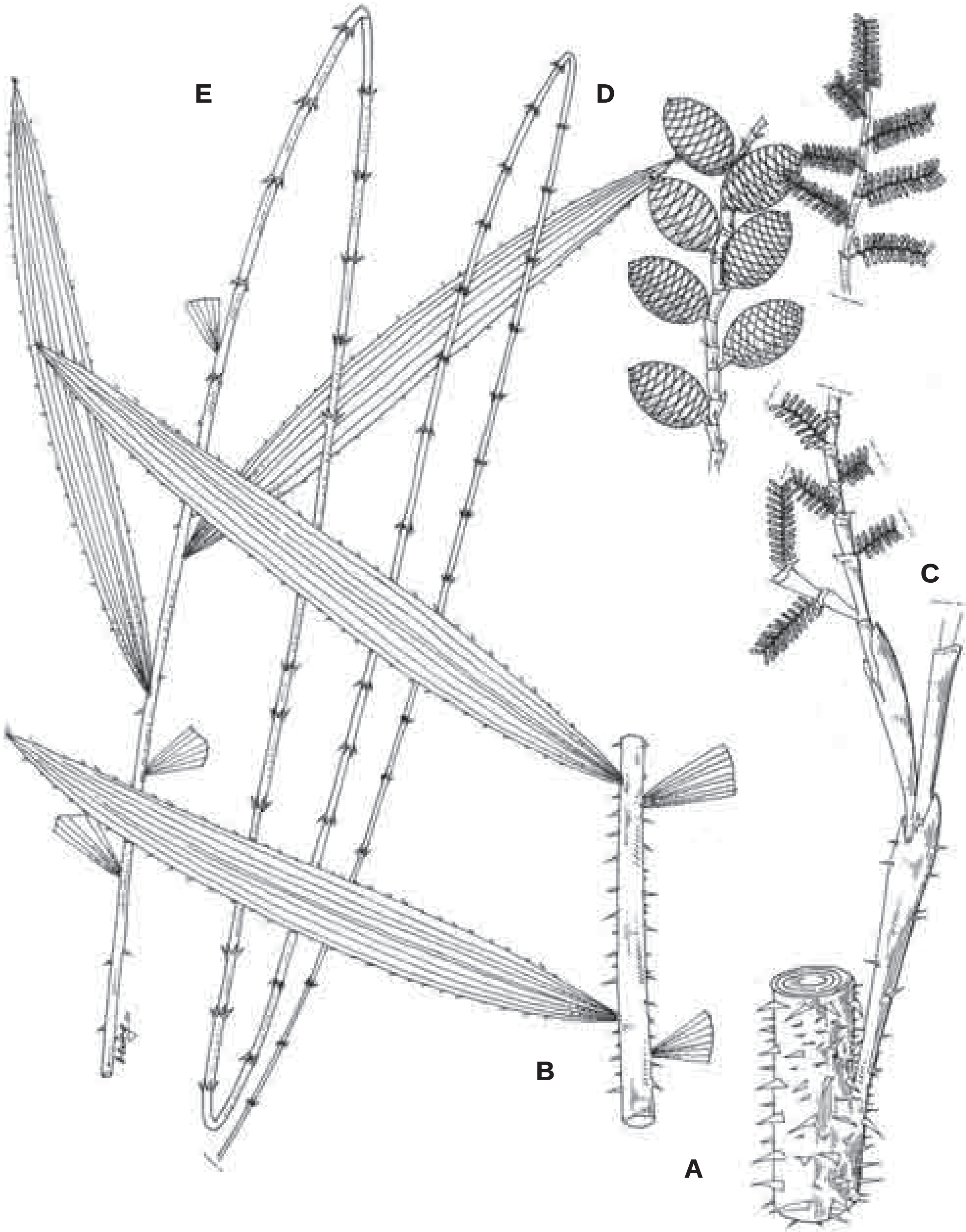


Figure 1a. *Calamus platyacanthoides*. A: part of sheathed stem; B: part of leaf rachis and leaflets; C: inflorescence; D: part of infructescence; E: leaf tip (drawing reproduced from Anh 2008).

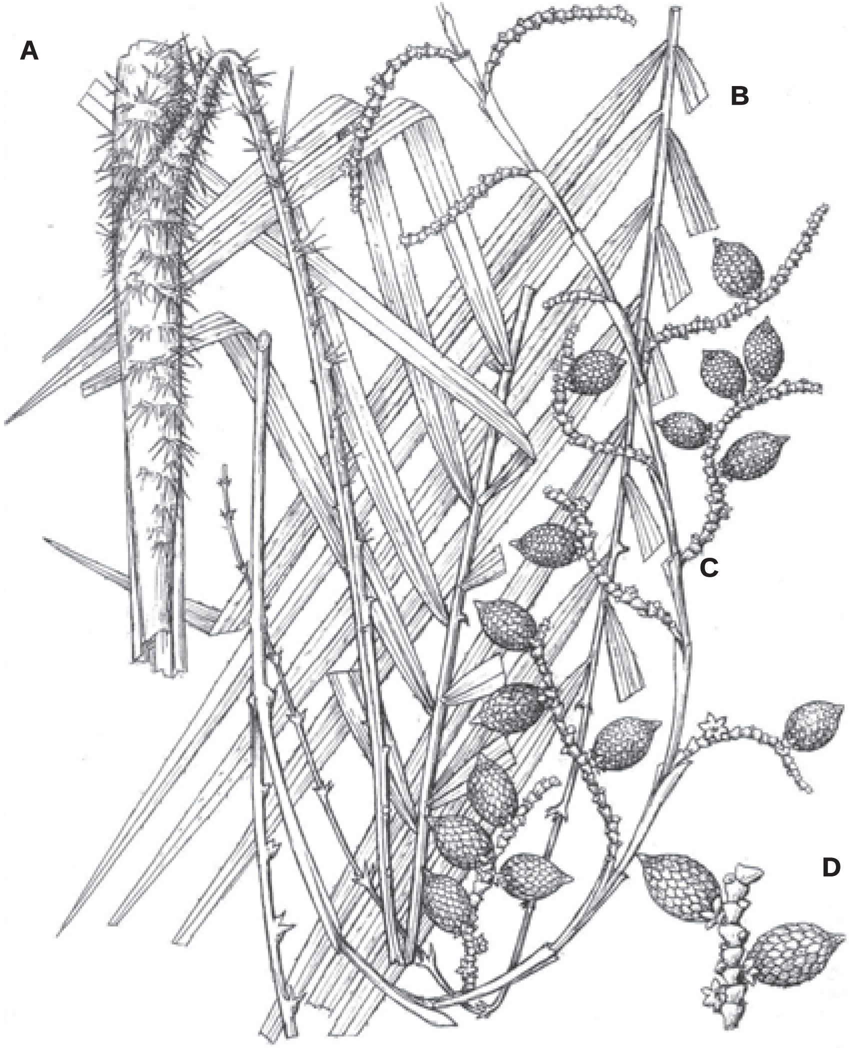


Figure 1b. *Calamus rhabdocladus.* A: portion of leaf sheath and basal part of petiole; B: part of leaf rachis and leaflets; C: part of infructescence; D: immature fruit (drawing reproduced from Anh 2008).

Figure 1c. *Daemonorops poilanei.* A: portion of stem with leaf sheath; B: part of leaf rachis and two leaflets; C: young infructescence, showing persistent prophyll; D: tip of prophyll; E: portion of staminate inflorescences; F: staminate flower; G: staminate flower opened out; H: pistillate flower; J: mature fruit (drawing reproduced from Dransfield 2001).

Calamus rhabdocladus occurs in China, Lao and Vietnam. This species usually grows in evergreen forests and secondary forest at 500-800 m a.s.l (Evans et al. 2002) at an annual rainfall of 800-2,500 mm. It also survives well at 1,000-1,600 m a.s.l (Dzung and Cuong 1996). It forms medium-sized clusters and high-climbing stems. Stems have a thick and rigid outer layer and are used for furniture (Figure 1b).

Daemonorops cf. poilanei is found from Ha Tinh toward south, occurring in evergreen forests at 400-700 m a.s.l, especially near streams and forest edges, at an annual rainfall of 1,200-3,000 mm (Dzung and Cuong 1996, Dransfield 2001, Evans et al. 2001, Anh 2008). It forms large clusters and has fast growing stems. Its stems are strong and flexible and used for handicraft and furniture (Figure 1c).

Methods

Study site

This study was carried out in Bach Ma National Park (16°12' N; 107°52' E), Central Vietnam. The park was established in 1991 and extended in 2008, covering an area of about 37,487 ha. Before the establishment of the park, harvesting of timber and rattan occurred in the area for several decades. The terrain is hilly with slopes of 35 to 60 degrees. The highest peak is 1,450 m. Annual average temperature in Bach Ma is 25°C at an altitude below 900 m a.s.l and annual rainfall amounts to 3,000-3,500 mm, with a wet season from September to January. Humidity is high throughout the year (85%). Bach Ma experiences tropical monsoons from both northwest and southeast (Gilmour and San 1999).

Forests in the study region can be classified as closed evergreen tropical rain forests, containing an extremely diverse range of habitats and species because of the topography and climate. The flora and fauna of Bach Ma are representative of the migratory tracks of animals and plants from North of Vietnam to the South and vice versa (Gilmour and San 1999, Dzung 2002, Keo 2003). There are 13 rattan species belonging to 5 genera in Bach Ma.

Field measurement

In an area with high densities of the study species we established three plots of 0.5 ha per species in June-August 2004. No rattan harvesting occurs in the study plots. Plots were established at 450-500 m a.s.l for *Calamus platyacanthoides*, at 650-

700 m a.s.l for *Calamus rhabdocladus* and at 420-450 m a.s.l for *Daemonorops cf. poilanei*. All rattan clumps containing at least one stem ≥ 0.5 m (total height) of the study species that rooted in the plot were included and marked with numbered aluminium tags. In each clump, all stems were tagged individually. For each stem, stem length was measured and the youngest leaf was marked. For stems shorter than 3 m, also leaf number, number of leaflets on one side of the leaf and total height were recorded. The length of long stems was measured, using measuring tape and telescopic fiberglass rod. In order to estimate stem growth, the base of the youngest leaf was painted for all stems. The reproductive status of all stems was assessed based on the presence of flowers or fruits, and the gender was determined. The light conditions of each individual were assessed using the crown exposure (CE) index 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).

The measurements were repeated in June-August 2005 and 2006. At these re-measurements, survival of stems and clumps was assessed and new shoots of the clumps were labeled and measured. Stem growth were measured from the last painted point to the base of the then youngest leaf. Paintings were carried out for the base of the then youngest leaf each year. In total, the numbers of shoots, stems and clumps recorded are 16, 323 and 215 for *Calamus platyacanthoides*, 132, 394 and 93 for *Calamus rhabdocladus,* and 91, 442 and 60 for *Daemonorops cf. poilanei*.

Data analysis

Data on vital rates (survival, growth and reproduction) of the three plots were pooled as no significant differences were found among plots (Kruskal-Wallis tests, $P > 0.05$). We used 2-year data in all analyses.

Multinomial logistic regression was used to analyse the relation between stem length and crown exposure (CE). A dummy variable was assigned to each crown exposure class (except for reference class 1). The predicted mean CE at any given stem length was calculated as the weighted average of the four CE classes (Poorter et al. 2005). We used linear, non-linear and logistic regression models to relate vital rates to total height, stem length, gender, light availability and clump size. Survival probability was related to the initial stem length or shoot height in logistic regressions.

Length growth of stems is typically non-linearly related to the initial length, with slow growth for short stems and fast growth for intermediate sized individuals. We therefore fitted the Hossfeld IV equation to describe this pattern (Zeide 1993):

$$\Delta St = \frac{b \times c \times St^{(c-1)}}{\left[b + (St^{c} / a)\right]^{2}} \qquad (1)$$

where ΔSt is the annual stem growth rate (m yr^{-1}), St is stem length (m) and a, b and c are fitted parameters. We applied a least-square loss function.

We observed two distinct phase in the size-dependent growth patterns (see results): stems < 10 m showed an increase in stem growth with size, while those of > 10 m generally had equal growth or slightly declined in growth with increasing size. As we were interested in the determinants of growth, we performed multiple linear regressions for these size categories, splitting the former categories into 0-3 m and 3-10 m, as we had additional measurements on leaf size and number for the 0-3 m individuals. The following independent variables were included in the regression models: stem length, number of stems in the clump and CE class (as dummies, CE 1 as reference). We performed a similar multiple regression for shoot growth.

Clonal reproductive status in relation to clump size was analysed using logistic regression. Another logistic regression was performed to relate sexual reproduction status to stem length and gender (as dummy, male as reference class). Gender was assigned for small stem randomly with assumption that a sex ratio of small stems was the same as that of large stems (> 10 m). Linear regressions were used to analyse shoot production and infructescences in relation to clump size and stem length, respectively.

Results

Size distribution and light availability

Population structures showed inverse J-shaped curves in both clump size (Figure 2: a, b, c) and stem length (Figure 2: d, e, f) for all three study species with most individuals present in the small size categories. Clump size differed strongly among the three study species with smallest number of stems for *C. platyacanthoides* (maximum 7), highest for *D. cf. poilanei* (maximum 52) and intermediate *C. rhabdocladus* (maximum 20 stems). Maximum stem length also differed among species: *D. cf. poilanei* possesses stems of up to 30 m while *C. platyacanthoides* and *C. rhabdocladus* reached 22 m and 14 m, respectively. The maximum size is likely related to forest structure: *D. cf. poilanei* occurs at lower elevation in forests with a tall canopy (20-25 m), while *C. rhabdocladus* grows at higher elevation with a lower canopy (15-20 m).

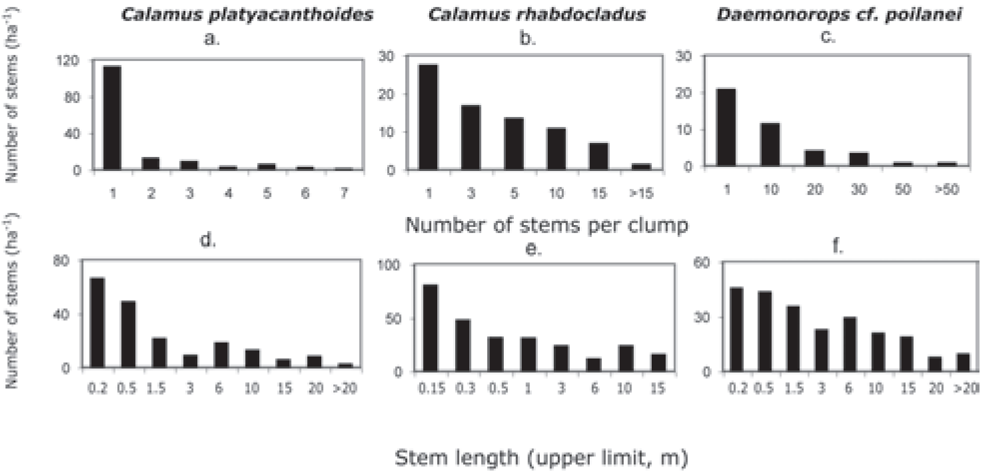


Figure 2. Size distribution of clumps and stems per ha for three rattan species in Central Vietnam.

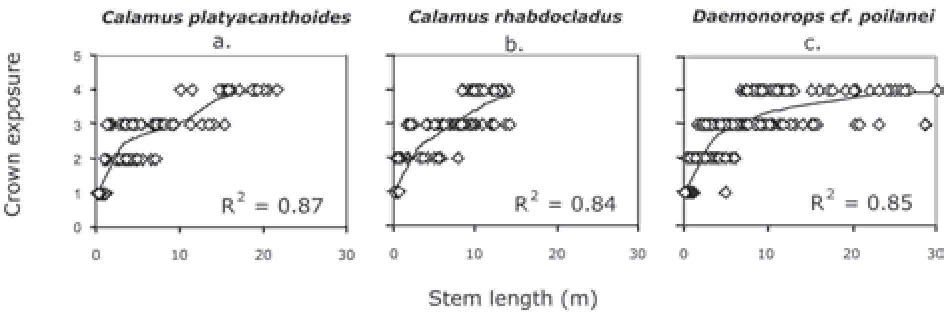


Figure 3. Relation between crown exposure (CE) and stem length of three rattan species in Central Vietnam. Dots are observed values and lines are the predicted mean crown exposure based on the multinomial regression (Poorter et al. 2005).

Rattan stems gradually grow to the forest canopy but start in the dark understorey. A large share of all stems (47-48%) was strongly shaded (CE 1) in the three study species, and only 4-13% of all stems received direct overhead light (CE 4). Stems of 3 m length had an average CE of 2.3-2.4 for all species, while this was 3.1-3.4 for stems of 10 m length, with little variation among species (Figure 3). Stems of 20 m in length generally were received overhead light (CE 4).

Survival

The annual survival probability of the shoots ranged from 71% for *D. cf. poilanei* to 89% for *C. platyacanthoides.* For two of the three species, survival probability increased with shoot height, but it was not related to clump size or light level for any species (Table 2, Figure 4).

Table 2. Survival of three rattan species in Central Vietnam in relation to stem length (or shoot height), clump size and crown exposure (reference score as CE=1; test and significance; -: not tested, ns: $p \geq 0.05$, *:$p<0.05$, **:$p<0.01$, ***:$p<0.001$

Species	*C. platyacanthoides*		*C. rhabdocladus*		*D. cf. poilanei*	
	Shoot	Stem	Shoot	Stem	Shoot	Stem
R^2	0.653	0.101	0.489	0.040	0.190	0.041
Constant	-4.422	-2.206	-3.900	-1.759	-0.179	-2.029
Stem length	ns	ns	0.444**	ns	0.650**	ns
Clump size	ns	ns	ns	ns	ns	ns
CE2	ns	ns	ns	ns	ns	ns
CE3	-	ns	-	ns	-	ns
CE4	-	ns	-	ns	-	ns

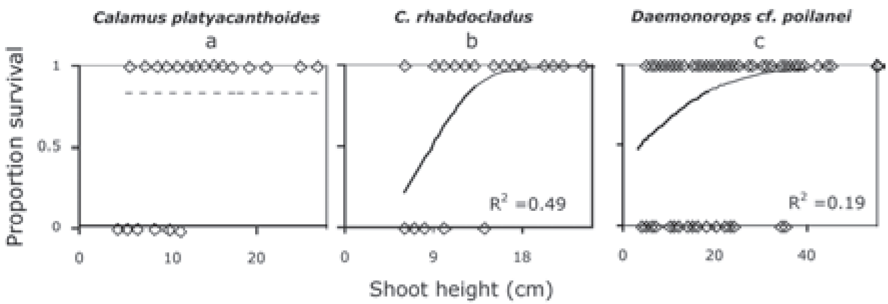


Figure 4. Relation between shoot survival and shoot height for three rattan species in Central Vietnam. Dots are observed values for survival, dotted line is average survival, and lines are fitted by logistic regression.

Annual survival of stems was generally high, varying from 93%-96% for small stems (< 1 m) to 96%-98% for large stems (> 10 m). Variation in stem survival could not be explained by stem length, clump size or light level (Table 2).

Growth

Shoots had moderate growth rates, of 15, 19 and 22 cm (yr^{-1}) for *C. platyacanthoides, C. rhabdocladus* and *D. cf. poilanei.* Shoot height growth was positively related to initial height and clump size (Table 3). In all species, these variables explained 49-85% of the variation in shoot growth, with a stronger relative importance of shoot height in *D. cf. poilanei* and of clump size in the two *Calamus* species (higher partial correlation coefficient, Table 3). There was no effect of light availability on shoot growth, probably because almost all shoots were strongly shaded (CE = 1).

Stems greatly differed in length growth rates depending on their size. The general pattern was similar in the three species: growth rate increased with size up to c. 10 m and then levels off at some size or declined (Figure 5). The average growth rate of *C. platyacanthoides, C. rhabdocladus* and *D. cf. poilanei* of large stem (> 10 m) was 2.4 m, 1.5 m and 2.8 m (yr^{-1}), respectively. There were large differences between species in the maximum growth rate: 2.7 m, 1.6 m and 3.3 m (yr^{-1}) for *C. platyacanthoides, C. rhabdocladus* and *D. cf. poilanei,* respectively. The fits of the non-linear curves were good (R^2 = 0.87-0.92), and the degree of variation around the mean curve was small.

For small stems (< 3 m); 83-94% of the variation in stem growth could be explained by initial stem length, clump size and light availability. In all species initial stem length was most important, but partial correlation for clump size and light availability were also high (Table 3). In two *Calamus* species partial correlation for clump size was higher than that of light availability, while in *D. cf. poilanei* it was a way round. There were no effects of number of leaves or leaflets on stem growth for all three species.

In the juvenile stem category (3-10 m); a higher proportion of the variation in stem growth could be explained (92-95%). Again, the same variables determined growth but their relative importance changed: light level became more important and clump size less important. Stem growth of *C. rhabdocladus* was still mostly correlated to initial stem length while for *C. platyacanthoides* and *D. cf. poilanei* it was mostly correlated to light availability (Table 3). The effect of clump size on stem growth gradually declined in comparison with the shoot and small stem classes while the effect of light availability gradually increased with stem length for all three species.

Finally, for large stems (> 10 m); the proportion of growth variation explained was 51-57%. The most important factor now was light level in all species. The effect of clump size on stem growth was not found for the large stem (Table 3). Stem growth of *C. platyacanthoides* and *D. cf. poilanei* slightly decreased with increasing stem length. Male and female stems did not differ in growth rate.

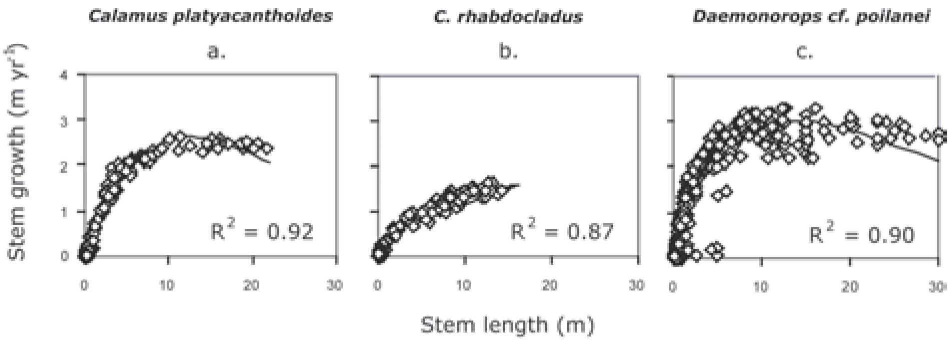


Figure 5. Size-dependent pattern in stem growth of three rattan species in Central Vietnam. Shown are fitted Hossfeld IV equations (lines), and dots are observed value.

Reproduction

The three study species reproduced sexually and clonally in all observation years. Clonal reproduction probability increased with clump size for all species (Table 4): 50% of the clumps with 5 stems and almost all clumps with 10 stems produced shoots annually. The maximum number of new shoots produced was 2, 4 and 13 shoots per year for *C. platyacanthoides, C. rhabdocladus* and *D. cf. poilanei,* respectively (Figure 6: a, b, c). Shoots were produced mostly at the end of the rainy season (February, March).

The onset of sexual reproduction was positively related to stem length (8-10 m for all species) and was not dependent on clump size. The probability of male flowering was higher than that of female flowering at a given stem length in *C. rhabdocladus* and *D. cf. poilanei* (Table 4). The abundance of male stems (> 10 m) was higher than that of female stems, for all three species. Male to female ratios were 1.13, 1.27 and 1.39 for *C. platyacanthoides, C. rhabdocladus* and *D. cf. poilanei,* respectively.

Table 3. Growth of three rattan species in Central Vietnam in relation to stem length (or shoot height), clump size and crown exposure; test and significance (-: not tested, ns: p≥0.05, *:p<0.05, **:p<0.01, ***:p<0.001).

Species	*Calamus platyacanthoides*				*Calamus rhabdocladus*				*Daemonorops cf. poilanei*			
	Shoots	St < 3 m	3<St<10 m	St > 10 m	Shoots	St < 3 m	3<St<10 m	St > 10 m	Shoots	St < 3 m	3<St<10 m	St > 10 m
R^2	0.486	0.941	0.922	0.505	0.524	0.833	0.953	0.513	0.832	0.849	0.915	0.576
Constant	0.003	-0.051	0.010	2.563	0.023	0.023	0.052	0.936	0.116	-0.016	0.109	2.629
Stem	0.130*	0.465***	0.124***	-0.016*	0.647***	0.242***	0.088***	0.037*	0.125**	0.399***	0.019***	-0.009*
length	*0.370*	*0.909*	*0.588*	*-0.537*	*0.484*	*0.679*	*0.786*	*0.528*	*0.898*	*0.521*	*0.180*	*-0.264*
Clump	0.044***	0.022***	0.027***	ns	0.009***	0.004***	0.004***	ns	0.002***	0.006***	0.004**	ns
size	*0.645*	*0.448*	*0.198*		*0.524*	*0.506*	*0.235*		*0.423*	*0.343*	*0.156*	
CE 2	ns	0.052*	0.688***	-	ns	0.049***	0.189***	-	ns	0.397***	0.969***	-
		0.163	*0.617*			*0.245*	*0.535*			*0.448*	*0.712*	
CE 3	-	0.158***	1.030***	ns	-	0.065*	0.383***	ns	-	0.840***	2.056***	ns
		0.285	*0.639*			*0.110*	*0.555*			*0.460*	*0.864*	
CE 4	-	-	0.337*	0.200***	-	-	0.438***	0.148**	-	-	2.470***	0.466***
			0.112	*0.709*			*0.480*	*0.706*			*0.801*	*0.759*
Gender	-	-	-	ns	-	-	-	ns	-	-	-	ns

Table 4. Probability of clonal and sexual reproductive of three rattan species in Central Vietnam. Results are based on multiple logistic regression (male stems = 0); test and significance (-: not tested, ns: p≥0.05, *:p<0.05, **:p<0.01, ***:p<0.001).

Species	*C. platyacanthoides*		*C. rhabdocladus*		*D. cf. poilanei*	
	Clonal	Sexual	Clonal	Sexual	Clonal	Sexual
R^2	0.369	0.686	0.796	0.677	0.704	0.741
Constant	-4.960	-5.285	-6.184	-11.719	-4.175	-12.034
Stem length	ns	0.647**	ns	1.342***	ns	1.098***
Clump size	0.997***	ns	1.078***	ns	0.895***	ns
CE2	-	ns	-	ns	-	ns
CE3	-	ns	-	ns	-	ns
CE4	-	ns	-	ns	-	ns
Gender	-	ns	-	-1.768*	-	-1.713*

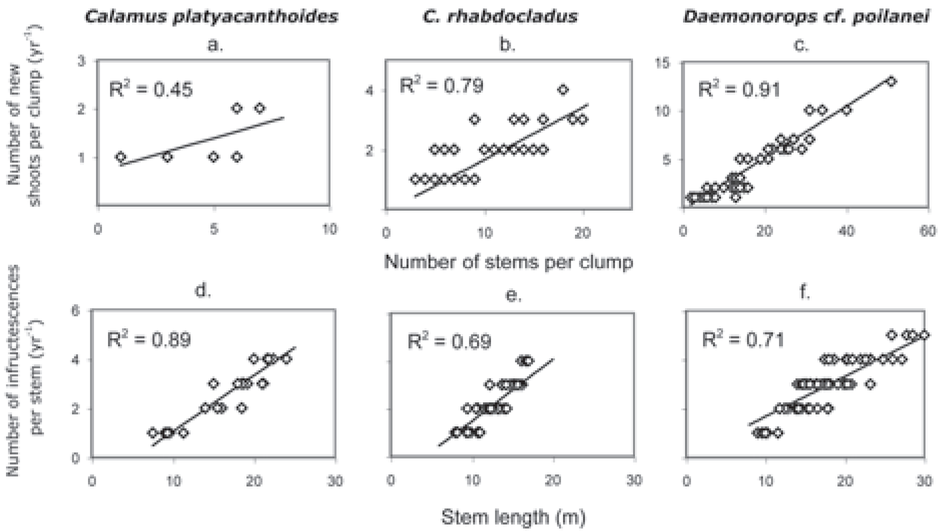


Figure 6. Clonal and sexual reproduction for three rattan species in Central Vietnam. Dots are observed values; Lines are fitted by linear regression. Upper panels: Clump size in relation to shoot production. Lower panels: Relation between stem length and number of infructescences.

The number of infructescences produced per stem was positively related to stem length for all study species (Figure 6: d, e, f). The maximum number of infructescences per stem was four or five for our study species. The flowering season is in the dry months from May to June for the two *Calamus* species and from April to May for *D. cf. poilanei.* Fruiting usually started in June and lasts until the end of the year. Our observations showed that the period from emergence of the inflorescence, flowering, to dying of the floral parts varied from five to ten weeks for the study species.

Discussion

Factor determining rattan stem growth

Growth rates vary among rattan species depending on environmental factors and genetic variation (Dransfield and Manokaran 1994). This study showed that stem growth of three Vietnamese rattan species, growing in their natural environment, are relatively fast growing species and reached comparable values with other rattans. Growth rate of *C. rhabdocladus* was comparable with that of *Calamus peregrinus* (1.24 m year^{-1}) and *C. rudentum* (1.42 m year^{-1}) for natural populations in Thailand (Bogh 1996), while growth rates of *C. platyacanthoides* and *D. cf. poilanei* reached comparable values with those of *C. caesius* (2.5 m year^{-1}), *C. trachycoleus* (3.5-7 m year^{-1}) and *C. manan* (0.5-4 m year^{-1}) from trial cultivation (Tan and Woon 1992, Aminuddin et al. 1992, Bogh 1996).

In our study species, stems strongly varied in length growth depending on initial stem length, clump size and light availability, which could explain large share of variation (49-95%) in stem growth (Table 3). In all species initial stem length and clump size were most important for shoot and small stems (< 3 m), while light availability was most important for large stems (> 10 m). In juvenile stems (3-10 m) initial stem length and light availability were most important for stem growth. Initial stem length had a strong effect on stem growth of shoots, small and juvenile stems and showed a non-linear pattern. There was an increase in growth rates with increasing size up to 10 m, which then leveled off at some size, and slightly decreased (> 20 m) in two of three study species. Decreasing length growth of long stems is probably caused by shortening of internodes. Putz (1990) found that internode length decreased with distance along stem for two *Calamus* spp. in Australia. He suggested that shorter internodes are functional when rattan stems have reached the canopy as further height growth is disadvantageous.

The effect of clump size on stem growth gradually declined from shoots to juvenile stems and there was not support of clump size for large stems in three species. Stem growth rates were substantially higher in large clusters, like in other clonal palms (Chazdon 1991, Zuidema 2000, Souza et al. 2003) and bamboos (Li et al. 1998, 2000). The interesting results in our rattan species was that there were clonal support even for juvenile stems up to 10 m in length which are often in CE3 or CE4 (Table 3). To our knowledge, the transfer of nutrients and carbohydrates to individual stems in a cluster of rattans has not been studied. Although the physiological integration among stems within a clump was not directly identified by us, our results do suggest that the growth of small stems is supported by reserves stored elsewhere in the clump. The common root system may act as a storage organ for reserves (Li et al. 1998, 2000, Zuidema 2000). Physiological integration was observed to support growth and survival of the deeply shaded juvenile ramets of tropical palms with a negative carbon balance (Chazdon 1986, Putz 1990, Souza et al. 2003). An impact of clump size on shoot survival was not observed here, but this may be due to the limited sample size.

The effect of light availability gradually increased from shoots to large stems in our study species. Increased rattan crown exposure to light resulted in higher growth rates. A similar result was obtained for three rattan species in natural populations in Thailand (Bogh 1996). Cultivation experiments also showed strong growth responses to increased light (Supardi and Razali 1989).

In our study species, *C. rhabdocladus* reached the forest canopy (CE = 4) at a stem length of 15 m while this was 20 m for *C. platyacanthoides* and *D. cf. poilanei* (Figure 3). Crown exposure may be related to growth form of a species: *C. rhabdocladus* has short internodes and its stems have a thick, rigid outer layer and flagella (Evans et al. 2002, Dzung and Cuong 1996), so that the stems can grow erect up to a length of 10 m while the other two species have long internodes, slender stems and cirri so that there is more chance that the growing stems lie partly on the ground or are bended or draped over understorey vegetation. Putz (1990) mentioned another advantage of having flagella: that they can span larger gaps between successive points of support.

Sexual and clonal reproduction

Our study species had both sexual and clonal reproduction in the years of study and data did not indicate a trade-off between vegetative and sexual reproduction.

Chazdon (1992) and Mendoza and Franco (1998) reached similar results for other clustered understory palms *Geonoma congesta* in Costa Rica and *Reinhardtia gracilis* in Mexico. Mendoza and Franco (1998) suggested that sexual and vegetative reproduction modes would not be antagonistic processes. Instead, both would be favoured by environment conditions (De Steven 1989, Souza et al. 2003). Unlike many other palms with a sex ratio 1:1 (Oyama 1990, Ataroff and Schwarzkopf 1992, Bernal 1998), our three species have male to female ratios > 1. Higher proportion of male than female stems was also found in rattan plantations in the Philippines for *Calamus filispadix* and *Daemonorops ochrolepis* (DST 1991), and in Malaysia for *Calamus manan* (Aminuddin and Supardi 1993). We also found that male stems start producing flowers at a smaller size than female stems in two of three species. The high male/female ratio and the earlier start of flower production by male stems may represent a way to increase total pollen production in order to enhance the success of cross pollination. Infructescence production increased with stem length but was not related to clump size in three rattan species. Size-dependency in sexual reproduction is the rule in palms (Svenning 2000), and has been found in a number of species (De Steven 1989, Chazdon 1992, Mendoza and Franco 1998, Svenning 2000, Souza et al. 2003).

Size-dependency in vegetative reproduction has been also found in some clonal palms (De Steven 1989, Chazdon 1992, Svenning 2000, Souza et al. 2003). Shoot production of three rattan species increased with clump size but was not related to stem length. Like other clonal plants, vegetative reproduction were occurred at an earlier growth stage (> 3 m), whereas sexual reproduction carried out only in larger stems at later growth stages (> 8 m) in our study species (Araki and Ohara 2008). Clonal growth form may be adaptive as it extends the genet's reproductive life span by continuous replacement of ageing ramets and increases the number of modules that can contribute to the genet's reproductive output (Chazdon 1992, Mendoza and Franco 1998, Zuidema 2000). In our rattan species, no clump mortality was found for a clump with more than 3 stems. The risk of genet mortality is spread among its ramets and the risk is reduced as the number of ramets is increased (De Steven 1989, Zuidema 2000). Both sexual and clonal reproduction modes contribute in general to population growth and they may have different roles for the dynamics of each species.

Implications for management

Any sustainable forest management or production system should be based on knowledge of reproduction, recruitment and requirements for growth and survival in the relevant growth phases of the exploited species (Boot and Gullison 1995). Wild rattan resources are rarely managed partly due to a lack of such basic information (Dransfield and Manokaran 1994). We showed that rattan stem growth increases at higher light availability because of higher a level of crown exposure. From these results it can be inferred that liberation thinning may be an effective way to stimulate rattan productivity in managed population. As rattans are climbers so the removing of host trees should not too much as they are harmful for rattan stem growth. Girdling practice may be applied for host trees in managed rattan population. Sunderland and Dransfield (2002) reported that selective felling to create 'artificial' gaps has been practiced in India, Indonesia and Malaysia, with some success for a better survival and growth of rattan plants in forests.

The finding that rattan stem growth was related to clump size in our study species has implications for harvesting practices. If a large portion of (big) stems are harvested from a clump, it is likely that the growth of remaining stems will be reduced. This implies that the rate of recovery of rattan resources decreases with the intensity of harvest. It seems appropriate to advise management guidelines which assure that clumps retain a certain minimum size (number of stems). Indian harvesting regulations have been stipulated that clumps consisting of less than six stems shall not be exploited (Dransfield and Manokaran 1994). The traditional management system in the Bahau area ensures recovery of the clumps because after large-scale commercial harvesting of the rattan, the harvested area is protected from re-cutting for 10 years (Van Valkenburg 1997). Moreover, for big clumps like *D. cf. poilanei,* harvesting should be carried out carefully, i.e. when long stems are cut care should be taken to not damage or destroy the shorter stems in the clump that will provide future sources of cane. Harvest intensity and rotation should be based on basic information on growth rates and its determinants, and on survival and reproduction rates of rattan populations. A more profound understanding of the clonal demography of rattans and harvesting impacts on the populations is needed to guide rattan harvesting regimes and cultivation practices.

Acknowledgements

The work would not have been carried out without assistance and encouragement of many individuals. We would like to thank Dr. Huynh Van Keo for permission and help during our study. We are very grateful to Nguyen Van Quyet and his family, Nguyen Quang, Nguyen Le Tho, Quoc Khanh, Nguyen Hoang Trung and others for their assistance with the field work. We acknowledge Shouli Li for preparing maps for figures. We would also like to thank Tropenbos International Vietnam and the Netherlands Fellowship Programme (Nuffic) for their financial support to this study.

Calamus platyacanthoides

Calamus rhabdocladus

Daemonorops cf. poilanei

4

Chapter 4

Clonal demography in clustered rattan species: the significance of clonal support and the roles of sexual and vegetative reproduction

With Pieter A. Zuidema

Abstract

A clustered growth form is common in clonal plants in tropical rain forests. Many rattans are clustered species in which stems (ramets) are clustered in a clump (genet). Little is known about the clonal demography of clustered rattans. We investigated the population dynamics of three clustered rattan species in tropical rain forests of Vietnam: *Calamus platyacanthoides*, *C. rhabdocladus* and *Daemonorops cf. poilanei.* Specifically, we evaluated the importance of clonal supports to the population growth (λ), and quantified the relative contributions of clonal and sexual reproduction to λ. In a field study from 2004 to 2006, we quantified recruitment, growth and survival, and constructed matrix models based on these data with rattan stem categories nested within clump categories. We found that λ value were > 1 for the three study species, indicating that populations are growing. Elasticity analysis showed that large stems in big clumps contributed most to λ in all study species. Elasticity values of clonal support for shoot growth were higher than those of initial shoot height, indicating that the contribution of clonal supports is important to the population growth. The contribution of sexual and clonal reproduction modes to λ varied between species with clonal reproduction being more important for two of the three species. Our study find the same result with others that λ close to 1 are commonly found for long-lived species, clonal supports is important for λ and sexual reproduction is important for small clump size species while vegetative reproduction is important for large clump size of clustered rattan species.

Key words: rattans, clustered species, shoot, stem, clump, vital rate, matrix population model, elasticity analysis, loop analysis, *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei.*

Introduction

Many clonal species in the tropical rain forest have a clustered growth form, in which ramets (stems) of one genet (clump) occur in more or less dense clumps. This includes species of bamboos, rattans, palms and multi-stemmed trees (Chazdon 1992, Dransfield and Manokaran 1994, Mendoza and Franco 1998, Zuidema 2000, Li et al. 2000, Souza et al. 2003, Watanabe et al. 2006, Bellingham and Sparrow 2009). In these species, the clonal life form is considered a means to extend the lifetime of genets, rather than a way to spread horizontally (De Steven 1989, Chazdon 1992, Mendoza & Franco 1998, Zuidema 2000). Also, in these species, ramets tend to remain a connected part of the genet throughout their lives and are unable to function independently as they share a common root system (Eriksson 1993, Araki and Ohara 2008). As a result, clonal integration is maintained throughout the lifetime of ramets and genets, and common reserve pools may be maintained at the genet level (Chazdon 1991).

Clonal species with a clustered growth form possess two important advantages for demographic studies, compared to species in which connections between ramets are invisible or disappear. First, new daughter ramets in clustered species can be readily assigned to genets or mother ramets (De Steven 1989, Chazdon 1992). This offers the opportunity to quantify the rate of vegetative reproduction and compare its contribution to population growth to that of sexual reproduction. In this way, direct comparisons can be made between the roles of the two reproductive modes (Zuidema 2000, Araki and Ohara 2008). A second important advantage is that the dynamics of ramets can be studied in the context of genets, as ramets remain attached to the genet throughout their lives (De Steven 1989, Zuidema 2000, Souza and Martins 2006). Thus, it becomes possible to evaluate the degree of clonal support provided to daughter ramets, and to evaluate the relevance of such support for population growth (Damman and Cain 1998, Souza and Martins 2006). So far, clonal integration and support to daughter ramets have been studied at the level of individuals (Chazdon 1992, Zuidema 2000, Li et al. 2000, Souza and Martins 2006), but its population (and fitness) consequences have not been evaluated.

Here we present the results of a study on the clonal demography of three clustered rattan species. Specifically, we evaluated the significance of the two reproduction modes and quantified the contribution of clonal support to population growth. Our aims were to i) analyse the clonal demography of the study species; ii) evaluate the contributions of sexual vs. vegetative reproduction to the population growth rates (l) and iii) evaluate the contribution of clonal support to λ. We monitored growth, survival and reproduction of stems (ramets) over three growth seasons, and used these data to construct matrix models. We applied multi-state matrix models in which rattan stem (ramet) categories are nested within clump (genet) categories (Zuidema 2000, Zuidema et al. 2007). We then conducted elasticity analyses and applied a new algorithm for loop analysis to evaluate the contributions of reproduction modes and clonal support to λ.

Study species and sites

Rattans are ecologically important but understudied components of Old World tropical forests (Sunderland and Dransfield 2002). The vast majority of rattan species possess a clustered growth form (Dransfield 1979). We studied three clustered, multi-stemmed, long-lived rattan species: *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei.* All study species grow in tropical evergreen forests, mostly at 400-900 m above sea level (a.s.l) and an annual rainfall of 800-3,000 mm. The study species have been heavily exploited for their stems which are used for handicraft and furniture. *C. platyacanthoides* is included in Vietnam's Red Data Book as a threatened species (Nghia et al. 2000). Main characteristics of the three study species are given in Table 1 and described in detail in Chapter 3.

The study was carried out in Bach Ma National Park, Thua Thien Hue province, Vietnam. The forest type in this area is classified as closed evergreen tropical rain forests. Annual average temperature in Bach Ma is 25^{o}C at an altitude below 900 m a.s.l and annual rainfall amounts to 3,000-3,500 mm. Study plots were established in unharvested stands at the elevation of 450-500 m a.s.l for *C. platyacanthoides*, at 650-700 m a.s.l for *C. rhabdocladus* and at 420-450 m a.s.l for *D. cf. poilanei* (for details see Chapter 3).

Table 1. Main characteristics of three study species in Bach Ma National Park, Vietnam.

Species	*Calamus platyacanthoides*	*Calamus rhabdocladus*	*Daemonorops cf. poilanei*
Growth habit	Climbing with cirri, knee conspicuous	Climbing with flagella, no knee	Climbing with cirri, knee conspicuous
Maximum # of stems per clump	10-12	20-25	50-60
Maximum stem length (m)	> 30	40	50
Stem diameter (mm)	20-50	20-25	15-25
Internode length (cm)	15-25	9-13	20-30

Methods

Field measurement

To quantify the vital rates of the three study species, we established three plots (0.5 ha/plot) for each species in June-August 2004, and performed measurements in 2004, 2005 and 2006. All rattan clumps included at least one stem ≥ 0.5 m (total height) that occurred in the plot were marked with numbered aluminium tags. Within a clump, all stems were tagged individually. We measured stem length and painted the base of the youngest leaf of all stems. For small stems (< 3 m stem length), we also measured leaf number, number of leaflets on one side of the leaf and total height. During re-measurements, stem growth was measured from a last painted point to the base of the then youngest leaf. Paintings were carried out for the base of the then youngest leaf each year. At each census, survival and reproductive status of stems and clumps was assessed and height of new shoots was measured (for details see Chapter 3).

Seedlings were searched, tagged and measured within one sub-plot (20 x 20 m) per plot in 2004, 2005 and 2006. Seedling height, number of leaves and number of leaflets on one side of the leaf were recorded during each census. At re-measurements, we recorded growth, survival and recruitment of seedlings.

Data analysis

We tested for whether vital rates (survival, growth, sexual and vegetative reproduction) differed across plots for all species (Kruskal-Wallis tests). As we did not found significant differences ($P > 0.05$), data were pooled for further analyses and model construction.

We related seedling growth to initial height using linear regressions. Logistic regressions were used to relate survival probability of seedlings and shoots to initial height. Shoot and stem growth were analysed using multiple linear regressions, with initial height or length, clump size and light availability as independent variables. Logistic regressions were used to analyse clonal and sexual reproductive status. Finally, the production of shoots and infructescences per stem were related to clump size and stem length using simple linear regressions.

Matrix population models

We used the Lefkovitch matrix model (Caswell 2001) to describe the ramet population dynamics of our study species. These models use the equation:

$\mathbf{n}(t+1) = \mathbf{An}(t)$, where $\mathbf{n}(t)$ and $\mathbf{n}(t+1)$ are the population structures at time t and $t+1$, respectively, and $\mathbf{A}$ is a square matrix containing transition probabilities among categories. The matrix element contains all important dynamical information on survival, growth and reproduction of the population from one time step to the next. When a stable size distribution is reached, the dominant eigenvalue (λ), the right eigenvector $\mathbf{w}$ and the left eigenvector $\mathbf{v}$ of matrix $\mathbf{A}$ are equal to the population growth rate, the stable stage distribution of the population and the reproductive value distribution, respectively (Caswell 2001).

Multi-state matrix models were constructed in which ramets (stems) are nested within a genet (Zuidema 2000, Zuidema et al. 2007). Thus, each ramet is assigned to a category according to its own size and to the size of the genet (clump) to which it belongs (Figure 1). This ramet-within-genet model may be more realistic than models constructed for only ramets or genets as it allows vital rates of equally sized ramets to differ among genet categories. In this way, clonal support is explicitly included in the model. The model simulates ramet dynamics. Our limited sample sizes for genets did not allow constructing genet-level population models.

Category boundaries for genets and ramets were chosen such that they maximized differences among categories. The first three genet categories are for seedlings (1-

3). The boundary between category 3 (based on total height) and the successive category (based on stem length) was identified by a linear regression of stem length on total height. All other genet individuals were classified in categories 4-6 for two *Calamus* species and 4-7 for *D. cf. poilanei* based on numbers of stems within a clump. New shoots that are produced vegetatively are included in ramet category a. The remaining ramet individuals were classified in categories b-i based on stem length (Appendix 1).

Parameterization of transition matrix

Matrix elements were composites of transitions between ramet categories and transitions between genet categories. These two sets of transitions were calculated using information on vital rates survival (σ), growth (γ), vegetative reproduction (v) and sexual reproduction (f). Table 2 shows how matrix elements in the ramet-within-genet model were calculated based on these underlying vital rates.

The value of each vital rate for a given ramet or genet category was calculated using regression equations that related the vital rate to the size of the ramet and/or genet. In cases where no significant size-dependent relations were found, average values over multiple categories were calculated and used. Vegetative reproduction of ramets was assumed the same for all stems (≥ 3 m). Sexual reproduction of ramets was not influenced by genet categories. Finally, survival rates of the largest ramet category were in some cases slightly reduced to obtain realistic stable size distributions.

Matrix model analyses

Dominant eigenvalues (λ), stable stage distributions (w) and reproductive values (v) were calculated for the matrix models of all three species (Caswell 2001). If λ > 1 populations are projected to grow, whilst they decrease if λ < 1. The similarity between the stable stage structures resulting from the matrix models and the observed population structures was estimated by calculating the PS index (Horvitz & Schemske 1995): $PS = \sum(\min[ops_i, ssd_i] \times 100)$, where ops_i, and ssd_i are vectors of observed population structures and stable size distribution, respectively. Both vectors were scaled to sum to one, and the sum is taken over all categories. High values of PS indicate high values of similarity.

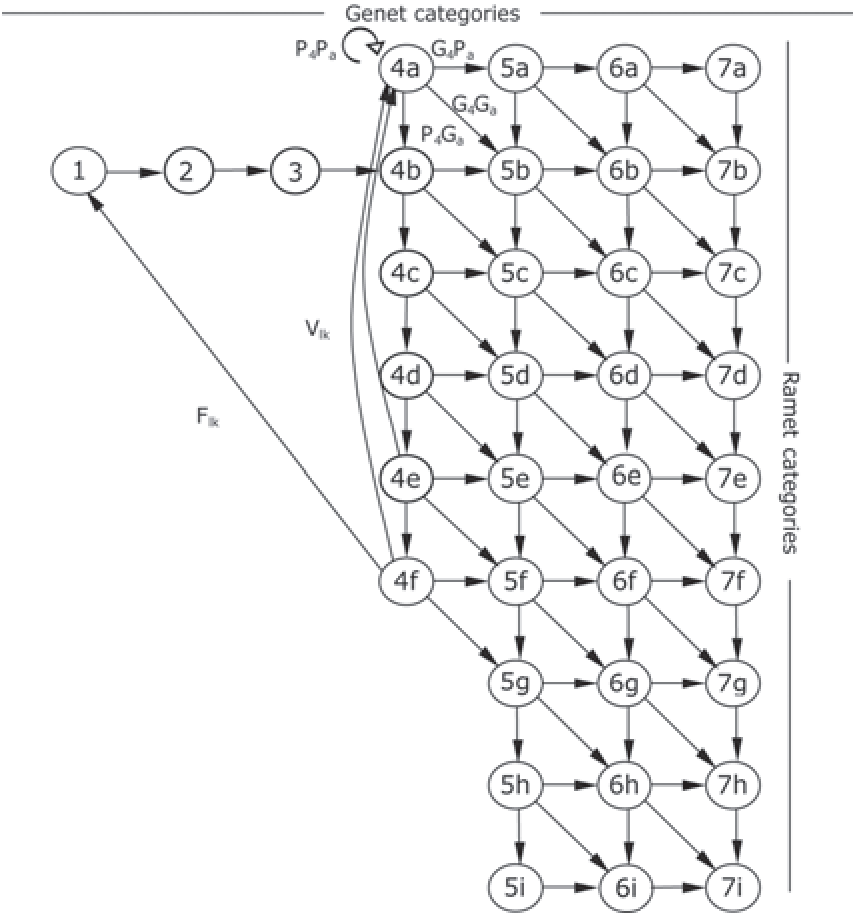


Figure 1. Life cycle graph for population matrix models of *Daemonorops cf. poilanei* in Central Vietnam. Cycles denote size categories: numbers refer to genet (clump) size and letters to ramet (stem) size. Arrows denote transitions among categories: straight arrows are progression probabilities (G), straight arrows to category 1 denote sexual reproduction, curved arrows to category 4a denote vegetative reproduction of large ramet categories within the same clump category 4. For the sake of clarity transitions for stasis (P, present in all categories), sexual and vegetative reproduction (for categories 5-7) are not shown.

Life cycle graphs for *Calamus platyacanthoides* and *Calamus rhabdocladus* were similar to that for *Daemonorops cf. poilanei* but without genet category 7 (7a-7i) for both species, and including categories 4g, 4h and 4i for *C. platyacanthoides* and 4g, 4h for *C. rhabdocladus*.

Table 2. Parameters and equations used to calculate transition probabilities for three rattan species in Central Vietnam. These calculations apply to ramet categories (*k*) a-i and genet categories (*l*) 1-7. Vital rates and other parameters: σ = survival probability (yr^{-1}); g = growth rate (in shoot height or stem length, m yr^{-1}); c = width of size category (m); abnewsh = abundance of new shoots (ha^{-1}); abnewsdl = abundance of new seedlings (ha^{-1}); abinfruc = abundance of infructescences (ha^{-1}); abfemst = abundance of female stems (ha^{-1}); abstem = abundance of stems (ha^{-1}, ≥ 3 m for vegetative reproduction, and ≥ 10 m for sexual reproduction); N(infruc) = number of infructescences produced by a female stem; $Pr(f)_k$ = probability of flowering for a female stem (yr^{-1}).

Variable	Calculation	
Transitions between genet categories		
Growth probability	γ_l	$= g_l / c_l$
Progression probability	G_l	$= \sigma_l \times \gamma_l$
Stasis probability	P_l	$= \sigma_l - G_l$
Transitions between ramet categories		
Growth probability	γ_k	$= g_k / c_k$
Progression probability	G_k	$= \sigma_k \times \gamma_k$
Stasis probability	P_k	$= \sigma_k - G_k$
Composite transitions		
Progression of ramets to the next ramet category in a genet that moves to next genet category	$G_l G_k$	$= G_l \times G_k$
Progression of ramets to the next ramet category in a genet that remains in the same genet category	$P_l G_k$	$= P_l \times G_k$
Stasis of ramets in the same category in a genet that moves to next genet category	$G_l P_k$	$= G_l \times P_k$
Stasis of ramets in the same category in a genet that remains the same genet category	$P_l P_k$	$= P_l \times P_k$
Vegetative reproduction	V_{ki}	$= \sigma_k \times \sigma_l \times$ abnewsh/abstem
Sexual reproduction	F_{ki}	$= \sigma_k \times \sigma_l \times Pr(f)_k \times$ abfemst/abstem x $N(infruc)_k \times$ abnewsdl/abinfruc

The elasticity of vital rates was analysed to determine the proportional change in population growth rates (λ) by a proportional change in a vital rate of the matrix elements (de Kroon et al. 1986, 2000, Caswell 2001). We summed elasticity values for sexual and vegetative reproduction transitions in order to quantify the relative contributions of these two reproduction modes to λ.

Stem growth of ramets (γ_k) of our study species was positively related to initial stem length and clump size (see Chapter 3 and Results). The latter is the result of clonal support. Thus, ramets in a large clump have a higher growth rate (higher γ_k) compared to equally-sized ones in a smaller genet. To determine the demographic importance of clonal support, we calculated elasticity for the part of progression transitions (G), that can be attributed to clonal support (e_{NrSt}). The value of e_{NrSt} was calculated as a proportion to e_G, such that e_{NrSt} / e_G equals γ_{NrSt} / γ, the contribution of clonal support to γ obtained from regression models (see Chapter 3).

Loop analysis was carried out to determine the relative contributions of the two reproductive modes to λ. Loops are pathways through the life cycle with the same starting and ending category. Loop analyses can be easily conducted for species with simple life cycles, as then the unique elements that are required for each loop can be readily identified (van Groenendael et al. 1994). However in more complex life cycles such as the one included in the ramet-within-genet models, such unique elements cannot be found and a different approach is required (Wardle 1998). We applied the approach of Güneralp (2007) that allows to calculate loop elasticity for complex life cycles. For our study species, there are three types of loops: self-loop, vegetative reproduction loop and sexual reproduction loop. Sexual reproduction loops start in category 1, while the vegetative reproduction loops start in ramet category a (4a, 5a, etc.).

Results

Transition values

The ramet-within-genet transition matrices were characterized by high values for remaining in the same ramet category (P_kP_l) and high probabilities for growth of small stems (G_kP_l) that were part of medium or large-sized clumps (Appendix 2). Mortality rates were high for seedlings (33-68% yr^{-1} in category 1), and strongly declined towards large stems (Appendix 1). Annual mortality rates of mature stems (>10 m) were typically 2-5%. Seedlings had low growth rates, with an average of 8, 8.7 and 12.2 cm yr^{-1} for *C. platyacanthoides*, *C. rhabdocladus* and

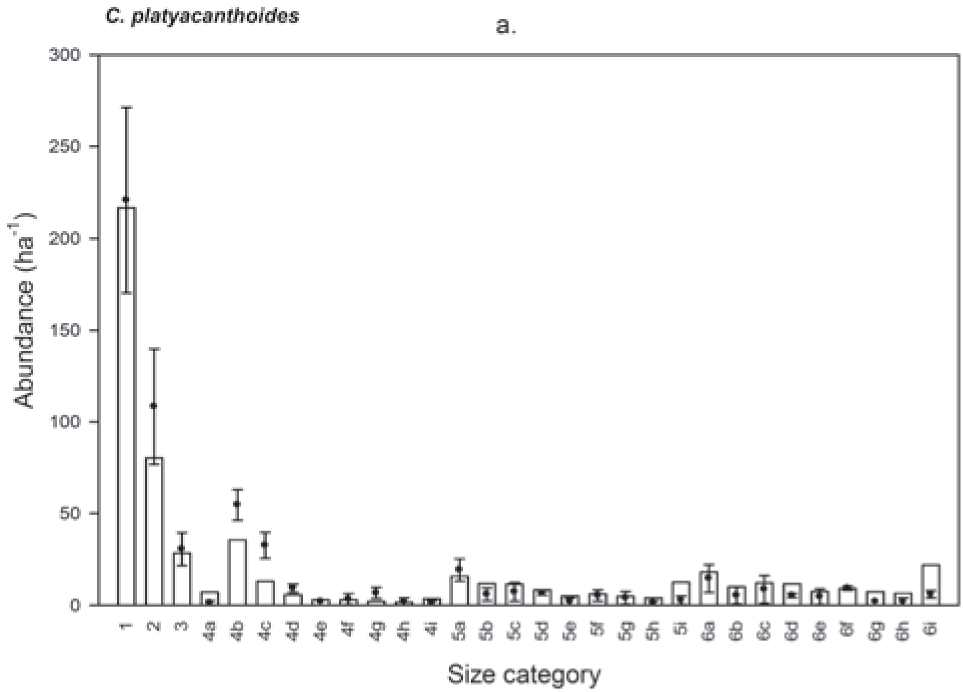
D. cf. poilanei, respectively. Seedling height growth was linearly related to initial seedling height for all species. Shoot height growth was twice as high as that of seedling, with an average of 15, 19 and 22 cm yr^{-1} for *C. platyacanthoides*, *C. rhabdocladus* and *D. cf. poilanei*, respectively. Shoot length growth was positively related to initial length and clump size (see Chapter 3). Stem growth was strongly size-dependent on initial stem length and clump size in all species (see Chapter 3, Appendix 1). Clonal support for stem growth was found for stems up to 10 m for the three study species. The contribution of clonal support to stem growth gradually declined with increasing stem length and we found no clump support for stems > 10 m (see Chapter 3).

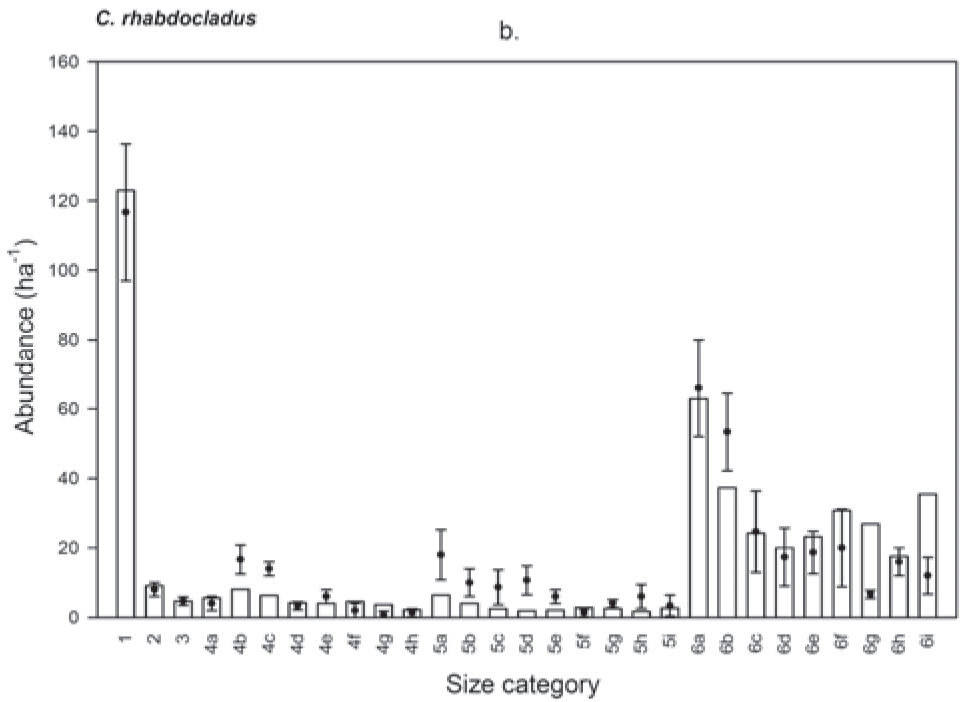
Sexual and vegetative reproduction occurred simultaneously in genets of our study species. The onset of sexual reproduction was related to stem length (8-10 m) and was not dependent on clump size for all species. Average seedling recruitment was 6.7, 4.4 and 4.8 seedlings produced per infructescences (yr^{-1}) for *C. platyacanthoides*, *C. rhabdocladus* and *D. cf. poilanei*, respectively. The rate of clonal reproduction increased with clump size for all species. New shoots were produced 1.0, 1.8 and 3.7 per clump per year, and 0.28, 0.59 and 0.46 per stem (> 3 m) per year for *C. platyacanthoides*, *C. rhabdocladus* and *D. cf. poilanei*, respectively (see Chapter 3).

Population growth rates and stable size structure

Asymptotic population growth rates (λ) were > 1 for all species: 1.011 for *C. platyacanthoides*, 1.013 for *C. rhabdocladus* and 1.068 for *D. cf. poilanei*. This suggests that in all study species the populations are growing.

Stable stage distributions for all species resembled observed population structures rather well: the relative abundances observed in the three plots were close to values obtained from the models (Figure 2). The values of similarity index (PS) of observed and stable stage distribution were rather high, ranging from 80 to 85%. These results indicate that our matrix models provide a realistic projection of the real population dynamics. In *C. platyacanthoides* distribution of stems were rather even among different clump size, while in *C. rhabdocladus* and *D. cf. poilanei* the distribution of stems within large clump size were much higher than that of small and medium clumps (Figure 2).


C. platyacanthoides
a.
300
250
200
150
100
50
0
Abundance (ha^{-1})
1 2 3 4a 4b 4c 4d 4e 4f 4g 4h 4i 5a 5b 5c 5d 5e 5f 5g 5h 5i 6a 6b 6c 6d 6e 6f 6g 6h 6i
Size category


C. rhabdocladus
b.
160
140
120
100
80
60
40
20
0
Abundance (ha^{-1})
1 2 3 4a 4b 4c 4d 4e 4f 4g 4h 5a 5b 5c 5d 5e 5f 5g 5h 5i 6a 6b 6c 6d 6e 6f 6g 6h 6i
Size category

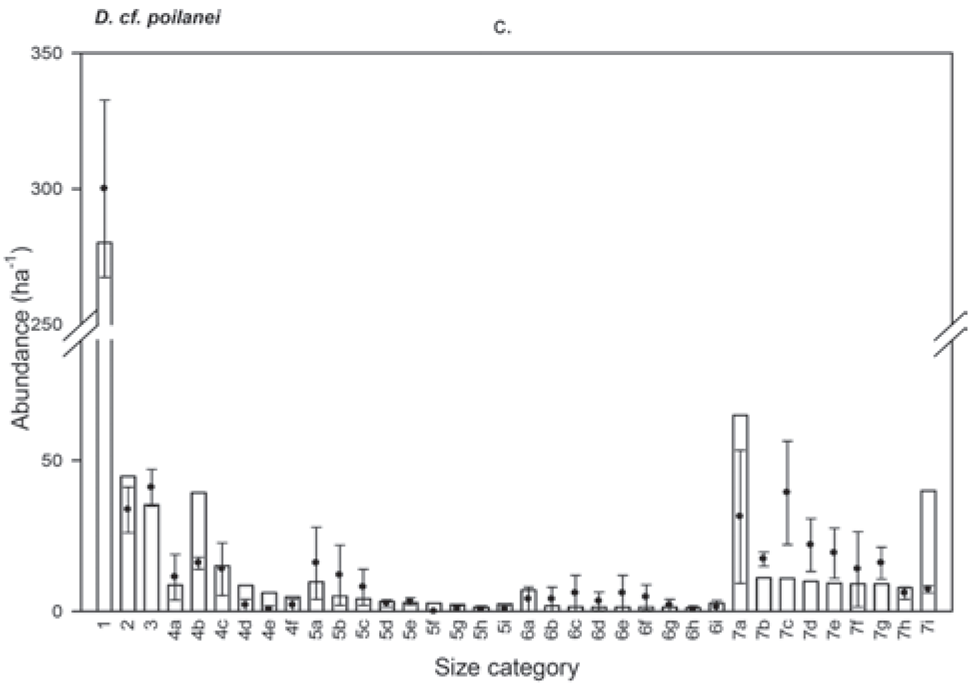


Figure 2. Stage distributions of three rattan species in Central Vietnam. Dots are observed population structures (mean ± 1 SD). Bars are stable stage structures resulting from matrix models. Numbers refer to clump size (genet categories) and letters to stem length (ramet categories).

Elasticity analysis

A comparison of the distribution of elasticities over matrix element types shows similarities among the three species. Stasis elasticities were highest, followed by growth and reproduction. Both vegetative and sexual reproduction transitions contributed very little to population growth rates. Sexual reproduction elasticity was higher than that of vegetative reproduction for *C. platyacanthoides* and vice versa for other two species (Table 3).

Table 3. Elasticity values obtained from the matrix models of *C. platyacanthoides*, *C. rhabdocladus*, *D. cf. poilanei*. P = stasis; G = progression; V = vegetative reproduction; and F = sexual reproduction.

Species	P	G			V	F
		$e_{(NrSt)}$	$e_{(St\ length)}$	Total		
Calamus platyacanthoides	0.5799	0.0551	0.3210	0.3761	0.0196	0.0244
Calamus rhabdocladus	0.5381	0.1235	0.2835	0.4070	0.0473	0.0077
Daemonorops cf. poilanei	0.5155	0.0745	0.3539	0.4284	0.0382	0.0180

Elasticity analyses showed that, at ramet level the largest stem categories had the highest elasticities, indicating that big stems were important for the population growth rates of study species (Figure 3: a,b,c). At genet level, the medium clump category of *C. platyacanthoides* and the biggest clump category of *C. rhabdocladus* and *D. cf. poilanei* had the highest elasticities (Figure 3: d,e,f); thus they contributed most to population growth rates in comparison with other clump categories and dynamics of ramets in large genet is very important than that in small genet.

The contribution of clonal support to the population growth

The contribution of clonal support to λ was evaluated by decomposing elasticity values of growth elements. Growth elasticities were decomposed to elasticities of growth by clonal support (e_{NrSt}) and by stem length ($e_{St\ length}$) based on the contribution of clonal supports and stem length to the growth of stems (initial stem length < 10 m). The results show that the contribution of clonal support to population growth was high for shoot category (a) and small stem categories (b, c), this contribution was gradually reduced with longer stem categories for the three rattan species though with a somewhat different pattern for the three species (Figure 4).

The growth elasticity values contributed by clonal support were highest for *C. rhabdocladus* in comparison with other two species (Table 3). In the category 'shoots' (a) growth elasticity of clonal support were highest, indicating that the contribution of clonal supports are important to the population growth, especially for *C. platyacanthoides.*

We also analysed the demographic significance of clonal support by setting the parameter of clump support to stem growth to zero in the regression equation that were used to construct matrix models. The resulting transition matrix had considerably lower λ values: 0.963 (instead of 1.011) for *C. platyacanthoides*, 0.993 (instead of 1.013) for *C. rhabdocladus* and 1.049 (instead of 1.068) for *D. cf. poilanei*. The differences in λ were highest for *C. platyacanthoides* (0.049) and lowest for *D. cf. poilanei* (0.019). Without clonal support, the population growth rates were < 1 for the two *Calamus* species, indicating that their populations would be decreasing. In contrast, the population of *D. cf. poilanei* remained growing.

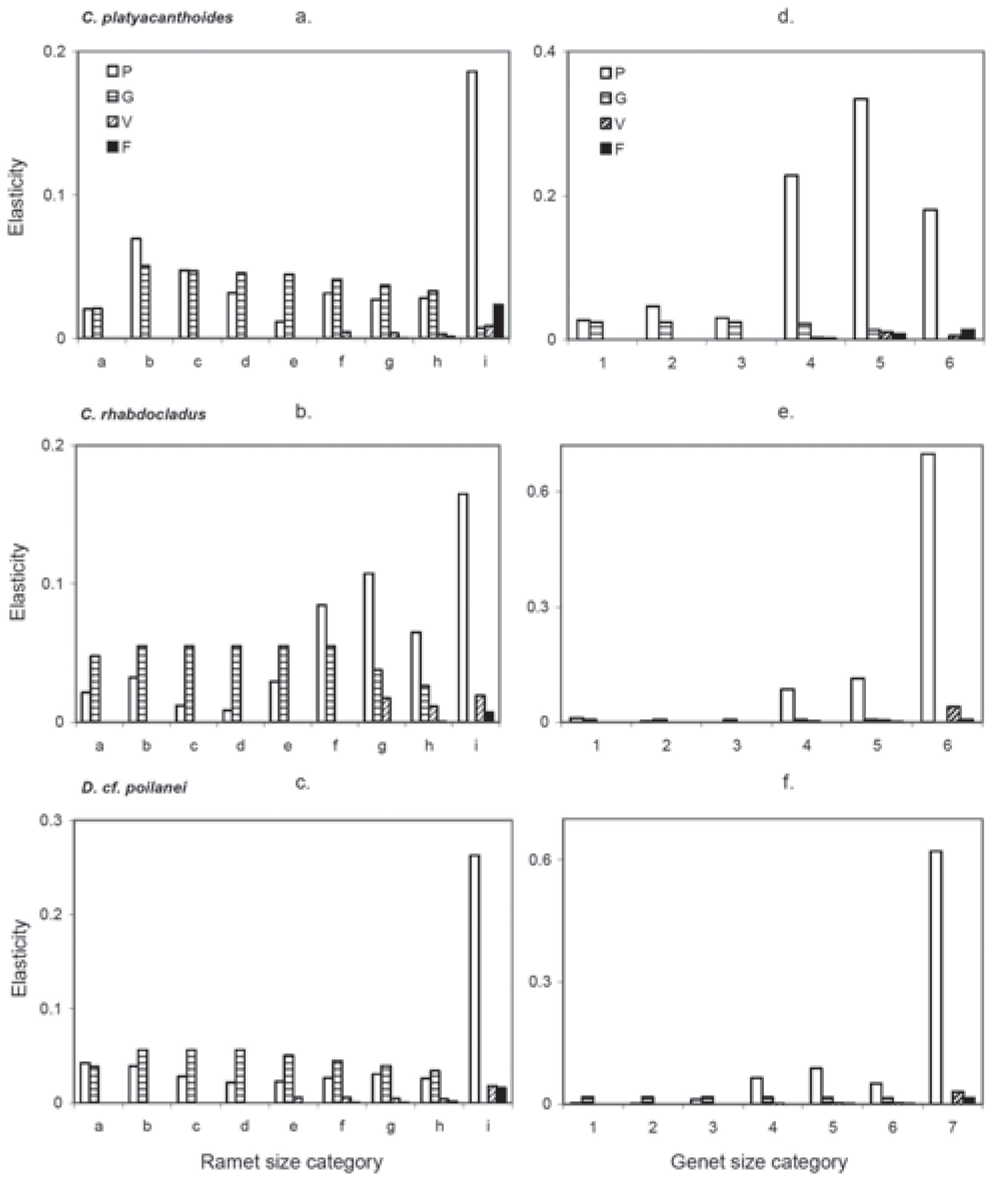


Figure 3. Elasticity values obtained from the matrix models in which ramets are nested in genets for three rattan species in Central Vietnam. Numbers refer to genet (clump) categories and letters to ramet (stem) categories. Elasticities are summed over all types of matrix elements for each category. P: stasis; G: growth; V: vegetative reproduction; F: sexual reproduction. In a, b, c: $P = P_lP_k + G_lP_k$; $G = G_lG_k + P_lG_k$. In d, e, f: $P = P_lP_k + P_lG_k$; $G = G_lG_k + G_lP_k$ (Table 2).

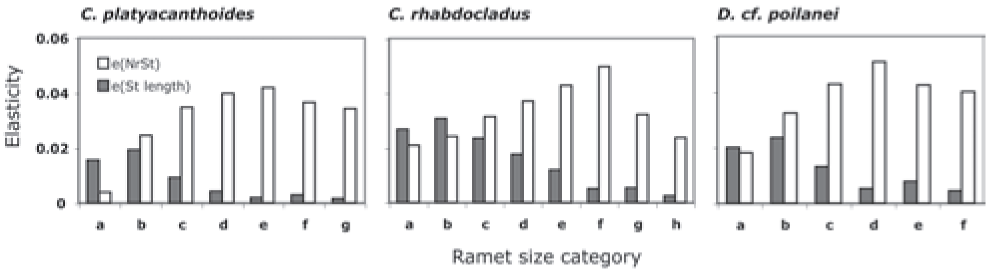


Figure 4. Decomposing the growth elasticity values into growth elasticity of clonal support (number of stems) and of stem length from the transition matrix models of three rattan species in Central Vietnam.

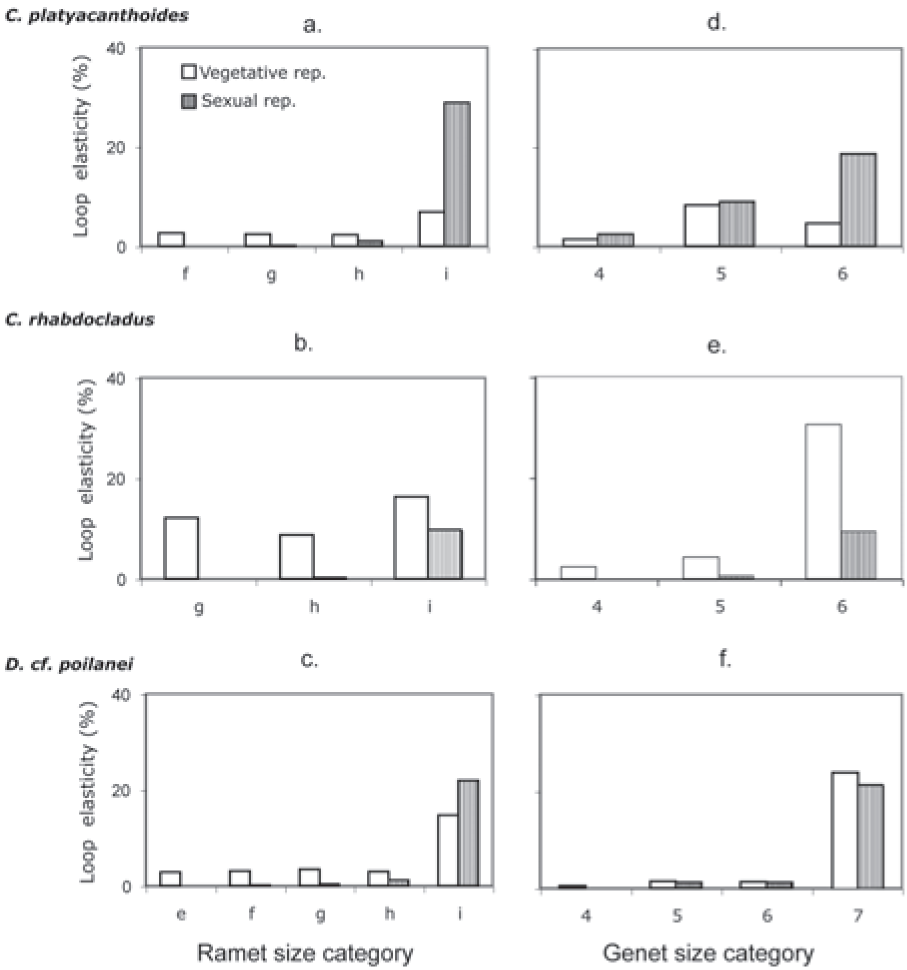


Figure 5. Elasticity of reproductive loops for three rattan species in Central Vietnam. Loop elasticities are summed over.

Demographic loop analysis

The life cycles of the study species (Figure 1) resulted in the formation of 83, 73 and 109 loops for *C. platyacanthoides*, *C. rhabdocladus* and *D. cf. poilanei*, respectively, belonging to three loop categories: self-loops (stasis), vegetative reproduction and sexual reproduction. Summed loop elasticity of self-loop was 56, 53 and 49% for *C. platyacanthoides*, *C. rhabdocladus* and *D. cf. poilanei*, respectively, the highest values in compared with those of vegetative or sexual loops for all three species.

The relative contribution of vegetative and sexual reproduction modes to the population growth rates varied among the three species. For *C. platyacanthoides* loop elasticity of sexual reproduction (30%) were higher than that of vegetative reproduction (14.3%); thus sexual reproduction is of major importance in reproduction modes of the species. In contrast, loop elasticities of vegetative reproduction (37.2% and 27.2%) were higher than those of sexual reproduction (10% and 23.7%) for *C. rhabdocladus* and *D. cf. poilanei*, respectively. So, vegetative reproduction contributed more to λ than sexual reproduction for these two species.

The largest stem category had the highest loop elasticities for both vegetative and sexual reproduction (Figure 5: a, b, c), indicating that the largest stems were the most important for reproduction in the three study species. Loop elasticities of both vegetative and sexual reproduction were also highest for the big clump category of *C. rhabdocladus* and *D. cf. poilanei*. For *C. platyacanthoides*, loop elasticity of sexual reproduction was also highest for the big clump category and for vegetative reproduction it was highest for the medium clump category (Figure 5: d, e, f). So, the largest stem category within big and medium clump categories contributed most to the reproduction modes of the study species.

Discussion

Analyzing clonal demography using multi-state matrix models

So far, most demographic studies on clonal plant species have been conducted for populations of either ramets or genets (Pinard 1993, Bogh 1995, Damman and Cain 1998, Barot et al. 2000, Souza and Martins 2006, Kouassi et al. 2008). This approach has the disadvantage that the demographic relevance of clonal integration and clonal support cannot be evaluated. We applied a multi-state matrix model in which ramets are categorized by their own size and that of the genet to which they belong. In such a model, the dynamics of ramets are related to genet size, which allows for a more detailed analysis of the roles of ramets in different sized genets and for the relevance of genet size in determining ramet performance. A similar type of model has been applied to analyze the clonal demography of an understory palm species (Zuidema et al. 2007).

In multi-state matrix models, loop analysis may be hampered by the difficulty to identify life cycle pathways by simple inspection of the life cycle graph (Wardle 1998, Güneralp 2007). The many loops in such life cycles do not all have unique loop elements. The transition matrices constructed for our study species were based on complex life cycle (Figure 1), in which many loops lacked a unique element. Presently, it is possible to perform loop analysis also in this case, by using a new algorithm introduced by Güneralp (2007). This algorithm does not identify unique elements in loops, but selects the transition with the lowest elasticity in each loop and uses this as characteristic elasticity. In the context of this study, this algorithm allowed us to calculate the relative contributions of vegetative and sexual reproduction to population growth rate.

Rattan demography

In spite of their ecological and economic importance, very little is known about the demography of rattans (Sunderland and Dransfield 2002). So far, two studies have dealt with rattan demography: Bogh (1995) studied the population dynamics of three *Calamus* species in Thailand and Kouassi et al. (2008) analyzed the demography of an *Eremospatha* and *Laccosperma* species in Cote d'Ivoire. As both studies quantified the dynamics of genets, there is no knowledge on ramet demography in rattans. These studies also did not provide information on the relative importance of clonal and sexual reproduction to rattan population growth. Thus, this is the first study to provide a detailed analysis of the clonal demography of rattans.

The asymptotic population growth rates (λ) that we found for ramet populations were close to 1 (1.011-1.013) for the two *Calamus* species and higher (1.068) for *Daemonorops cf. poilanei*. Direct comparison of these population growth rates with previously published rates for rattans is difficult as the latter are for populations of genets, not ramets. Nevertheless, it is of interest to mention that published rates of genet population growth for rattans are also close to 1: λ = 1.029 for *Calamus peregrinus*, λ = 1.011 for *C. rudentum* and λ = 1.030 for *C.* sp.

in Thailand (Bogh 1995), and λ = 0.979 for *Eremospatha macrocarpa* and λ = 0.959 for *Laccosperma secundiflorum* in Cote d'Ivoire (Kouassi et al. 2008). Values of λ close to 1 are typically found for (clustered) palms (Pinard 1993, Bogh 1995, Olmsted and Alvarez-Buylla 1995, Bernal 1998, Barot et al. 2000, Zuidema et al. 2007, Kouassi et al. 2008) and long-lived species in general (Zuidema 2000, Franco and Silvertown 2004).

The distribution of elasticity values over matrix element types was similar to that obtained for other rattans species (Bogh 1995, Kouassi et al. 2008), clonal palms (Souza and Martins 2006, Zuidema et al. 2007), and long-lived plants in general (Silvertown et al. 1993). For these species, typically high elasticity of stasis and low total elasticity of reproduction are found. This typical distribution is partially caused by the relatively wide categories that are used in matrix models for long-lived species (Enright et al. 1995, Zuidema 2000, Chien 2006).

Elasticity analysis also showed that the contribution of ramets to λ depends to a large extent on the genet category to which they belong. For instance, in *C. platyacanthoides* stems (ramets) in small and medium-sized clumps (genets) contribute more to λ than those in large clumps (Figure 3d). In contrast, stems in big clumps are more important for λ than those in small and medium clumps in the other two study species (Figure 3: e, f). These differences across species may be explained by variation in the stable stage distributions. In *C. platyacanthoides*, a larger proportion of the ramets are contained in small and medium-sized genets (78%), while this proportion is smaller for the other two species (48-54%, Figure 2). This result shows that to fully understand what determines the growth of ramet populations, it is important to evaluate the dynamics of ramets in the context of the genets to which they belong.

Contribution of vegetative and sexual reproduction to population growth rate

Our study species reproduced both sexually and vegetatively during the study period. Both reproduction modes are generally found in most clustered rattan species (Dransfield and Manokaran 1994, Kouassi et al. 2008) and also in other clustered palm species: *Geonoma deversa* (Zuidema 2000) and *G. brevispatha* (Souza et al. 2003).

We evaluated the relative contribution of vegetative and sexual reproduction using loop analysis. This revealed that sexual reproduction loops contributed 10-30%

to λ, while this was 14-37% for vegetative reproduction loops. Thus, both types of reproduction contribute considerably to the population growth. However, the relative importance of the two reproduction modes differed across species: in *C. platyacanthoides*, sexual reproduction was more important than vegetative reproduction, while the reverse was found in *C. rhabdocladus* and *D. cf. poilanei* (Figure 5). These differences can be explained by variation in the transition rates of sexual and vegetative reproduction: among the study species, *C. platyacanthoides* produced most seedlings and fewest shoots, while *C. rhabdocladus* had the highest rates of vegetative reproduction and the lowest for sexual reproduction. Probably, the relative investments in vegetative and sexual reproduction are related to maximum clump size: sexual reproduction is most important for species with small clumps and vegetative reproduction is essential to form and maintain large clumps (Table 1). Thus, our loop analysis results appear to support the view that vegetative reproduction in clustered plant species enhances the genet's reproductive life span by continuous replacement of aging ramets, which will increase genet's reproductive output (De Steven 1989, Chazdon 1992, Mendoza and Franco 1998, Zuidema 2000).

The demographic importance of clonal support

Clonal support to small ramets is generally thought to be beneficial for population growth of clonal plants (Cook 1985, Chazdon 1992, Eriksson 1993, Hutchings and Wijesinghe 1997, Li et al. 1998, 2000, Fischer and Kleunen 2002, Souza and Martins 2006). But so far, the demographic significance and fitness consequences of clonal integration and clonal support have not been quantified. This study is one of the first analysis of it's type that show the fitness consequences of clonal support.

In three clustered rattan species, we detected clonal support as the growth of stems up to 10 m length was faster in larger clumps (Chapter 3). The mechanism by which clump size increases stem growth is not clear. Support may come directly from the "mother stem", or it may come from the entire clump through translocation of resources from large stems to other small stems within a clump as a common phenomenon in clonal plants (Cook 1985, Chazdon 1992, Hutchings and Wijesinghe 1997, Zuidema 2000, Li et al. 1998, 2000, Souza and Martins 2006). Despite the lacking clarity about the causes, it is evident from our results that clonal support has important consequences for population growth. We found that the stem growth increase due to clonal support contributed significantly to population growth. A large share of elasticity for growth transition is due to clonal support (5-12%), and the elasticity of clonal support is even higher than that of both vegetative and sexual reproduction (4-6%) in our study species (Table 3). Also, blocking of clonal support resulted in a 2-5% reduction of population growth. We therefore conclude that large clumps are important to maintain populations of these clustered rattan species. To the extent that clonal support is also present in other species, the demographic contribution of fitness consequences that we found here may be more widespread across clonal species with a clustered life form. A more profound understanding of the clonal demography of clustered species requires that similar population studies are conducted for a wide range of other species.

Acknowledgements

We would like to thank Marinus Werger for valuable information and discussion on draft versions of this chapter. We would like to thank Tropenbos International Vietnam and the Netherlands Fellowship Programme (Nuffic) for their financial support to this study.

Appendix 1. Values of vital rates used in the ramet-within-genet transition models for three rattan species in Central Vietnam. Numbers refer to genet (clump) categories and letters to ramet (stem) categories. σ = survival probability; g = growth rate (in shoot height, or in stem length); n = number of measured individuals at the start of the study.

Calamus platyacanthoides

Cat	Height or stem length (m)	# stems per clump	g ($m\ yr^{-1}$)	Prob. clonal rep.	Prob.sex.rep. of female stem	# infruc-tescence	σ	n
1	0-0.2	1	0.0390	0	0	0	0.6630	53
2	0.2-0.5	1	0.0584	0	0	0	0.8223	26
3	> 0.5	1	0.2415	0	0	0	0.9362	46
4a	< 0.5	1	0.0800	0	0	0	0.8902	2
4b	< 0.2	1	0.0275	0	0	0	0.9662	82
4c	0.2-0.5	1	0.0891	0	0	0	0.9662	49
4d	0.5-1.5	1	0.4724	0	0	0	0.9662	14
4e	1.5-3	1	1.0862	0	0	0	0.9662	3
4f	3-6	1	1.4824	1	0	0	0.9662	5
4g	6-10	1	2.0399	1	0.0255	0.5971	0.9662	10
4h	10-15	1	2.4471	1	0.1072	1.6210	0.9662	3
4i	> 15	1	2.4766	1	0.4360	2.8725	0.9500	2
5a	< 0.5	2-3	0.1688	0	0	0	0.8902	29
5b	< 0.2	2-3	0.0725	0	0	0	0.9662	9
5c	0.2-0.5	2-3	0.1341	0	0	0	0.9662	11
5d	0.5-1.5	2-3	0.5173	0	0	0	0.9662	10
5e	1.5-3	2-3	1.1311	0	0	0	0.9662	3
5f	3-6	2-3	1.5361	1	0	0	0.9662	8
5g	6-10	2-3	2.0936	1	0.0255	0.5971	0.9662	6
5h	10-15	2-3	2.4471	1	0.1072	1.6210	0.9662	2
5i	> 15	2-3	2.4766	1	0.4360	2.8725	0.9500	4
6a	< 0.5	≥ 4	0.3019	0	0	0	0.8902	22
6b	< 0.2	≥ 4	0.1399	0	0	0	0.9662	8
6c	0.2-0.5	≥ 4	0.2015	0	0	0	0.9662	13
6d	0.5-1.5	≥ 4	0.5847	0	0	0	0.9662	8
6e	1.5-3	≥ 4	1.1985	0	0	0	0.9662	7
6f	3-6	≥ 4	1.6168	1	0	0	0.9662	14
6g	6-10	≥ 4	2.1743	1	0.0255	0.5971	0.9662	3
6h	10-15	≥ 4	2.4471	1	0.1072	1.6210	0.9662	3
6i	> 15	≥ 4	2.4766	1	0.4360	2.8725	0.9500	9

Calamus rhabdocladus

Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infruc-tescence	σ	n
1	0-0.25	1	0.0172	0	0	0	0.6667	30
2	0.25-0.5	1	0.2035	0	0	0	0.7503	13
3	> 0.5	1	0.3898	0	0	0	0.8214	8
4a	< 0.5	1-3	0.1984	0	0	0	0.7832	7
4b	< 0.15	1-3	0.0880	0	0	0	0.9365	31
4c	0.15-0.3	1-3	0.0849	0	0	0	0.9365	25
4d	0.3-0.5	1-3	0.1330	0	0	0	0.9365	5
4e	0.5-1	1-3	0.2603	0	0	0	0.9365	10
4f	1-3	1-3	0.6148	0	0	0	0.9832	5
4g	3-6	1-3	0.7605	1	0	0	0.9832	1
4h	6-10	1-3	1.1519	1	0.0664	0.9602	0.9832	2
5a	< 0.5	4-6	0.2250	0	0	0	0.7832	45
5b	< 0.15	4-6	0.0665	0	0	0	0.9365	54
5c	0.15-0.3	4-6	0.0974	0	0	0	0.9365	35
5d	0.3-0.5	4-6	0.1455	0	0	0	0.9365	20
5e	0.5-1	4-6	0.2729	0	0	0	0.9365	12
5f	1-3	4-6	0.6274	0	0	0	0.9832	7
5g	3-6	4-6	0.7712	1	0	0	0.9832	8
5h	6-10	4-6	1.1626	1	0.0664	0.9602	0.9832	15
5i	> 10	4-6	1.5016	1	0.5601	2.0465	0.9500	7
6a	< 0.5	≥ 7	0.3022	0	0	0	0.7832	67
6b	< 0.15	≥ 7	0.1030	0	0	0	0.9365	56
6c	0.15-0.3	≥ 7	0.1339	0	0	0	0.9365	28
6d	0.3-0.5	≥ 7	0.1820	0	0	0	0.9365	13
6e	0.5-1	≥ 7	0.3094	0	0	0	0.9365	20
6f	1-3	≥ 7	0.6639	0	0	0	0.9832	10
6g	3-6	≥ 7	0.8024	1	0	0	0.9832	6
6h	6-10	≥ 7	1.1938	1	0.0664	0.9602	0.9832	15
6i	> 10	≥ 7	1.5016	1	0.5601	2.0465	0.9500	14

Daemonorops cf. poilanei

Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infructescence	σ	n
1	0-0.15	1	0.0720	0	0	0	0.3198	72
2	0.15-0.3	1	0.1247	0	0	0	0.6291	8
3	>0.3	1	0.1985	0	0	0	0.9399	9
4a	< 0.98	1-3	0.1575	0	0	0	0.7099	17
4b	< 0.3	1-3	0.0912	0	0	0	0.9099	20
4c	0.3-1	1-3	0.3541	0	0	0	0.9614	24
4d	1-3	1-3	1.2882	0	0	0	0.9614	3
4e	3-6	1-3	1.9741	1	0	0	0.9614	1
4f	6-10	1-3	2.4049	1	0.0493	1.7701	0.9614	2
5a	< 0.98	4-8	0.1653	0	0	0	0.7099	26
5b	< 0.3	4-8	0.1136	0	0	0	0.9099	18
5c	0.3-1	4-8	0.3764	0	0	0	0.9614	14
5d	1-3	4-8	1.3105	0	0	0	0.9614	4
5e	3-6	4-8	1.9899	1	0	0	0.9614	5
5f	6-10	4-8	2.4207	1	0.0493	1.7701	0.9614	0
5g	10-15	4-8	2.7464	1	0.1270	2.3583	0.9614	1
5h	15-20	4-8	2.7932	1	0.3140	3.0118	0.9614	1
5i	> 20	4-8	2.8169	1	0.7187	3.9920	0.9500	1
6a	< 0.98	9-15	0.1790	0	0	0	0.7099	13
6b	< 0.3	9-15	0.1526	0	0	0	0.9099	17
6c	0.3-1	9-15	0.4155	0	0	0	0.9614	18
6d	1-3	9-15	1.3496	0	0	0	0.9614	5
6e	3-6	9-15	2.0175	1	0	0	0.9614	10
6f	6-10	9-15	2.4484	1	0.0493	1.7701	0.9614	7
6g	10-15	9-15	2.7464	1	2.3583	2.3583	0.9614	5
6h	15-20	9-15	2.7932	1	0.3140	3.0118	0.9614	1
6i	> 20	9-15	2.8169	1	0.7187	3.9920	0.9500	2
7a	< 0.98	> 15	0.2160	0	0	0	0.7099	54
7b	< 0.3	> 15	0.2586	0	0	0	0.9099	38
7c	0.3-1	> 15	0.5215	0	0	0	0.9614	62
7d	1-3	> 15	1.4556	0	0	0	0.9614	44
7e	3-6	> 15	2.0926	1	0	0	0.9614	32
7f	6-10	> 15	2.5235	1	0.0493	1.7701	0.9614	30
7g	10-15	> 15	2.7464	1	0.1270	2.3583	0.9614	32
7h	15-20	> 15	2.7932	1	0.3140	3.0118	0.9614	11
7i	> 20	> 15	2.8169	1	0.7187	3.9920	0.9500	15

Appendix 2. Population transition matrices for the ramet-within-genet model of three rattan species in central Vietnam.

a. *Calamus platyacanthoides*

Category at *t*+1	Category at *t* 1	2	3	4a	4b	4c	4d	4e	4f	4g	4h	4i	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i
1	0.53	0	0	0	0	0	0	0	0	0.03	0.35	2.49	0	0	0	0	0	0	0.03	0.37	2.60	0	0	0	0	0	0	0.03	0.37	2.60
2	0.13	0.66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.16	0.56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.65	0	0	0	0	0.25	0.25	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.38	0.12	0.69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.15	0.59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.25	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.40	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.61	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4g	0	0	0	0	0	0	0	0	0.42	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4h	0	0	0	0	0	0	0	0	0	0.43	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4i	0	0	0	0	0	0	0	0	0	0	0.41	0.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.06	0	0	0	0	0	0	0	0	0.53	0	0	0	0	0.26	0.26	0.26	0.26	0	0	0	0	0	0	0	0	0
5b	0	0	0	0.01	0.07	0	0	0	0	0	0	0	0.27	0.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	0	0	0	0.01	0.06	0	0	0	0	0	0	0	0.42	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5d	0	0	0	0	0	0.02	0.04	0	0	0	0	0	0	0	0.39	0.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5e	0	0	0	0	0	0	0.04	0.02	0	0	0	0	0	0	0	0.45	0.21	0	0	0	0	0	0	0	0	0	0	0	0	0
5f	0	0	0	0	0	0	0	0.06	0.04	0	0	0	0	0	0	0	0.65	0.42	0	0	0	0	0	0	0	0	0	0	0	0
5g	0	0	0	0	0	0	0	0	0.04	0.04	0	0	0	0	0	0	0	0.44	0.41	0	0	0	0	0	0	0	0	0	0	0
5h	0	0	0	0	0	0	0	0	0	0.04	0.04	0	0	0	0	0	0	0	0.45	0.44	0	0	0	0	0	0	0	0	0	0
5i	0	0	0	0	0	0	0	0	0	0	0.04	0.08	0	0	0	0	0	0	0	0.42	0.85	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0.31	0	0	0	0	0.26	0.26	0.26	0.26
6b	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.05	0	0	0	0	0	0	0	0.47	0.06	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.05	0	0	0	0	0	0	0	0.78	0.28	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.05	0	0	0	0	0	0	0	0.56	0.35	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.02	0	0	0	0	0	0	0	0.49	0.17	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.05	0	0	0	0	0	0	0	0.67	0.39	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.05	0	0	0	0	0	0	0	0.45	0.38	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.05	0	0	0	0	0	0	0	0.46	0.43	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.10	0	0	0	0	0	0	0	0.41	0.82

b. *Calamus rhabdocladus*

Category	Category at *t*																												
at *t*+1	1	2	3	4a	4b	4c	4d	4e	4f	4g	4h	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i
1	0.61	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0.07	1.27	0	0	0	0	0	0	0	0.07	1.27
2	0.06	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.51	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.43	0	0	0	0	0	0.56	0.56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.80	0.28	0.55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.31	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.48	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.57	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.45	0.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4g	0	0	0	0	0	0	0	0	0.28	0.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4h	0	0	0	0	0	0	0	0	0	0.23	0.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.02	0	0	0	0	0	0	0	0.38	0	0	0	0	0	0.58	0.58	0.56	0	0	0	0	0	0	0	0	0
5b	0	0	0	0.01	0.02	0	0	0	0	0	0	0.31	0.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	0	0	0	0.01	0.02	0	0	0	0	0	0	0.37	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5d	0	0	0	0	0	0.02	0.01	0	0	0	0	0	0	0.54	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5e	0	0	0	0	0	0	0.03	0.02	0	0	0	0	0	0	0.61	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0
5f	0	0	0	0	0	0	0	0.02	0.03	0	0	0	0	0	0	0.45	0.60	0	0	0	0	0	0	0	0	0	0	0	0
5g	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0	0	0.27	0.65	0	0	0	0	0	0	0	0	0	0	0
5h	0	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0	0	0.22	0.62	0	0	0	0	0	0	0	0	0	0
5i	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.25	0.84	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0.28	0	0	0	0	0	0.58	0.58	0.56
6b	0	0	0	0	0	0	0	0	0	0	0	0.04	0.06	0	0	0	0	0	0	0	0.43	0.27	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.04	0	0	0	0	0	0	0	0.59	0.09	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.03	0	0	0	0	0	0	0	0.77	0.08	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.05	0	0	0	0	0	0	0	0.78	0.33	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.07	0	0	0	0	0	0	0	0.53	0.60	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.08	0	0	0	0	0	0	0	0.30	0.66	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.07	0	0	0	0	0	0	0	0.24	0.63	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.10	0	0	0	0	0	0	0	0.27	0.87

c. *Daemonorops cf. poilanei*

Category at t

Category at $t+1$	1	2	3	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i	7a	7b	7c	7d	7e	7f	7g	7h	7i
1	0.17	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0.15	0.53	1.67	5.00	0	0	0	0	0	0.15	0.53	1.67	5.00	0	0	0	0	0	0.15	0.53	1.67	5.00
2	0.15	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.52	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.53	0	0	0	0.43	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.53	0.10	0.57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.25	0.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.43	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.55	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.57	0.34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.05	0	0	0	0	0	0.50	0	0	0	0.44	0.44	0.44	0.44	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5b	0	0	0	0.01	0	0	0	0	0	0.10	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	0	0	0	0	0.04	0	0	0	0	0.29	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5d	0	0	0	0	0	0.04	0.03	0	0	0	0	0.44	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5e	0	0	0	0	0	0	0.05	0.03	0	0	0	0	0.53	0.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5f	0	0	0	0	0	0	0	0.05	0.03	0	0	0	0	0.54	0.32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5g	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0.49	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.45	0.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.46	0.81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0.45	0	0	0	0.44	0.44	0.44	0.44	0.43	0	0	0	0	0	0	0	0	0
6b	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0.10	0.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0.05	0.06	0	0	0	0	0	0	0	0.36	0.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0.08	0.05	0	0	0	0	0	0	0	0.44	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.05	0	0	0	0	0	0	0	0.50	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.06	0	0	0	0	0	0	0	0.50	0.29	0	0	0	0	0	0	0	0	0	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.06	0	0	0	0	0	0	0	0.45	0.33	0	0	0	0	0	0	0	0	0	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0.06	0	0	0	0	0	0	0	0.41	0.33	0	0	0	0	0	0	0	0	0	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0.14	0	0	0	0	0	0	0	0.42	0.73	0	0	0	0	0	0	0	0	0
7a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0	0	0	0	0	0	0	0	0.55	0	0	0	0.44	0.44	0.44	0.44	0.43
7b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.10	0	0	0	0	0	0	0	0.16	0.12	0	0	0	0	0	0	0
7c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.10	0.09	0	0	0	0	0	0	0	0.78	0.24	0	0	0	0	0	0
7d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0.07	0	0	0	0	0	0	0	0.71	0.26	0	0	0	0	0
7e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0.07	0	0	0	0	0	0	0	0.70	0.29	0	0	0	0
7f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0.08	0	0	0	0	0	0	0	0.67	0.35	0	0	0
7g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0.10	0	0	0	0	0	0	0	0.60	0.43	0	0
7h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.12	0.09	0	0	0	0	0	0	0	0.53	0.42	0
7i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.12	0.21	0	0	0	0	0	0	0	0.53	0.95

A new shoot of *Calamus rhabdocladus*

Recently germinated seedlings of *Daemonorops cf. poilanei*

Harvest of rattan stems

Recently harvested rattan stems along the road

Chapter 5

Effects of rattan harvesting and options for sustainable management of two Vietnamese rattan species

With Pieter A. Zuidema

Abstract

The harvest of wild non-timber forest products (NTFP) represents important sources of income to millions people world-wide, especially rural poor people. In spite of increasing concern over the roles of NTPF species in forest conservation and sustainable management and exploitation, information on the ecological impacts of harvesting is limited in many cases in the tropics.

Rattan, a climbing palm, is one of the most highly valuable NTFP in Southeast Asia. Its stems are harvested for both market and subsistence of local people. We analysed the impact of stem harvesting in two clustered rattan species, *Calamus rhabdocladus* and *Daemonorops cf. poilanei*, at the levels of the individual and the population. We censused experimentally harvested and undisturbed populations, monitoring stem growth, survival and reproduction for a period of three years. We then constructed individual matrix and periodic matrix models to evaluate the impact at individual- and population-level of harvesting for these species by harvest simulations of four regimes (harvest cycle every 1, 5, 10 and 15 years).

Harvesting had an overall negative impact on survival, growth and reproduction of the study species. But it had a positive impact on vegetative reproduction during the first year after the harvest. Stem harvesting had a strongly negative impact on the population growth of *C. rhabdocladus* and *D. cf. poilanei* in comparison with undisturbed populations. The results from simulations showed that the abundance of harvestable stems rapidly declined when short harvest cycles were used. The number of harvestable stems recovered to initial number under a harvest cycle of 15 years in *C. rhabdocladus* and under harvest cycles of 10 and 15 years in *D. cf. poilanei*.

The challenge is how to manage rattan extraction in a sustainable way. Without any silvicultural application, it is suggested to harvest wild rattan not more often than once in 15 years for *C. rhabdocladus* and *D. cf. poilanei* in order to maintain long-term harvests of these species. Recent extraction rates of *C. rhabdocladus* and *D. cf. poilanei* in Vietnam have exceeded their growth rates and resulted in the depletion of these rattans.

Key words: rattans, clustered species, vital rates, matrix population model, demography, non-timber forest products, harvesting, *Calamus rhabdocladus* and *Daemonorops cf. poilanei*.

Introduction

In most tropical countries, non-timber forest products (NTFP) play an important role in the daily lives of the rural population (Dransfield and Manokaran 1994, FAO 1997, Sastry 2002, Sunderland and Dransfield 2002, Shaanker et al. 2004). Over 4,000 NTFP species are used for commercial purposes and thousands more are utilized for subsistence use (Iqbal 1993, Endress et al. 2006). Harvesting NTFP is considered as a means to simultaneously conserve biodiversity and provide a source of income to rural communities in the tropics (Peters et al. 1989, FAO 1997, Siebert 2001, 2004). In spite of the interests in NTFP for their sustainable development and concerns over their exploitation, ecological impacts of harvests are poorly known in many cases (Endress et al. 2006). At the level of an individual plant, the plant parts harvested, harvesting pattern and intensity determine the impacts on individual plant performance. For instance, in the case of harvesting palm leaves or resins, individual plants often tolerate these practices (Ticktin et al. 2002, Anten et al. 2003, Endress et al. 2004, Zuidema et al. 2007, Calvo-Irabien et al. 2009, Martinez-Ramos et al. 2009). But in case of intensive bark removal or stem cutting, individuals are much less tolerant to harvesting (e.g. Olmsted and Alvarez-Bullya 1995, Zuidema 2000, Endress et al. 2006). Apart from the impact of harvesting on individuals, also the effect on population dynamics determines whether a particular exploitation system may be considered sustainable (Boot & Gullison 1995). These population-level effects provide direct information on the future availability of specific NTFP resources in harvested populations (Hall and Bawa 1993, Zuidema 2000).

Rattans are one of the most important and most highly valued NTFP in the

World. Rattans are climbing palms that are exploited throughout South East Asia (Dransfield and Manokaran 1994, FAO 2002). Rattan stems are widely used for binding, basketry, furniture, food and subsistence uses for centuries. Over 700 million people trade in or use rattan for a variety of purposes (Sastry 2002, Sunderland and Dransfield 2002, Shaanker et al. 2004, Lyngdoh 2005). The vast majority of rattan production is obtained from natural populations in primary and secondary forests. The increase in (inter)national trade in rattan products has led to substantial overexploitation of wild rattan resources (Sunderland and Dransfield 2002). In spite of their economic importance, very little is known about the ecological impacts of harvesting on natural rattan populations. So far, just two studies have quantified the impact of rattan stem harvesting on performance of individuals and populations (Van Valkenburg 1997, Siebert 2004). No study has projected future rattan availability under distinct harvesting regimes.

This chapter analyses the impact of stem harvesting in two clustered rattan species, *Calamus rhabdocladus* and *Daemonorops cf. poilanei*, at the levels of the individual and the population. We monitored stem growth, survival and reproduction in an unharvested and an experimentally harvested stand in central Vietnam, for a period of three years. We then constructed matrix models to evaluate the impact of harvesting at population-level.

The following questions are addressed: i) what is the impact of harvesting of large stems on vital rates (survival, growth and reproduction) after 1-3 years? ii) what are the consequences of harvesting on population growth? and iii) how do different harvest regimes influence the availability of harvestable stems?

Study species and sites

We studied two dioecious and multi-stemmed (clonal) rattan species: *Calamus rhabdocladus* and *Daemonorops cf. poilanei*. Both species grow in tropical evergreen forests, mostly at 400-800 m above sea level (a.s.l) and under an annual rainfall of 800-3,000 mm. Their stems are harvested to produce handicrafts and furniture. Characteristics and distribution of the two study species are described in detail in Chapter 3.

C. rhabdocladus and *D. cf. poilanei* have a clustered growth form and clumps may contain up to 4 and 17 harvestable stems (≥ 6 m), respectively. The average abundance of harvestable stems in our study plots for *C. rhabdocladus* and *D. cf. poilanei* amounted to 38 ± 12 and 56 ± 22 stems per ha, possessing a total of 371 ± 109 m and 751 ± 240 m in stem length per ha, respectively. A detailed description of ramet-within-genet demography in undisturbed populations of the study species is provided in Chapter 4.

The study was carried out in Bach Ma National Park, Thua Thien Hue province, Vietnam. There the annual average temperature is 25°C at altitudes below 900 m a.s.l and the annual rainfall is 3,000-3,500 mm. Forests of the area are classified as closed evergreen tropical rain forests. Study plots were established at the elevation of 650-700 m a.s.l for *C. rhabdocladus* and at 420-450 m a.s.l for *D. cf. poilanei* (see Chapter 3).

Methods

Harvesting experiment and measurements

The harvesting experiment was conducted parallel to a demographic study on undisturbed populations which also served as a control for the experiment (Chapter 4). The harvesting experiment was carried out in two plots of 0.5 ha each, adjacent to the plot used for the undisturbed study populations. In each experimental plot, all clumps with at least one ramet ≥ 0.5 m height were tagged and measured. The harvesting treatment consisted of cutting all ramets ≥ 6 m stem length in August 2004. This treatment copied normal harvesting practices of rattan stems in Vietnam. Subsequent measurements on harvested clumps were carried out in August 2005, 2006 and 2007.

Survival, growth and reproduction of stems in harvested plots were monitored in the same way as in the study on undisturbed populations, but did not include any measurement on small individuals (with all stems < 0.5 m). The light conditions of each individual were assessed using the crown exposure (CE) index developed by Dawkins (see Chapter 3). The parameters measured are listed briefly here and details can be found in Chapter 3. We measured stem length and painted the base of the youngest leaf of all stems. We also measured leaf number and number of leaflets on one side of the leaf for stems < 3 m stem length. During re-measurement stem survival, growth and reproduction were measured and the base of the then youngest leaf was painted. The number of newly emerged shoots was counted and their length measured at each census to estimate the rate of vegetative reproduction and shoot growth.

Data analysis

Data on vital rates (survival, growth and reproduction) of the two harvested plots were pooled as no significant differences were found between these plots (Mann-Whitney tests, $P > 0.05$). We also tested for differences in vital rates between years for the harvested population. As significant differences were found (Friedman tests, $P < 0.05$), we carried out subsequent analyses for each year separately.

In all analysis, data obtained from the undisturbed population study (Chapter 3 and Chapter 4) were used as a control for the harvested populations. Logistic regressions were used to analyse the relation of shoot or stem survival with initial shoot height or stem length, clump size and the effect of harvesting. We used multiple regressions models to analyse the relation of shoot or stem growth with initial shoot or stem length, clump size, light availability and the effect of harvesting. Multiple regressions were also performed to relate the number of shoots with clump size and the effect of harvesting, and the number of infructescences with stem length and the effect of harvesting.

Matrix population models

Size-based matrix population models (Caswell 2001) were applied to describe population dynamics in the first, second and third year after harvest. These models are of the form: $\mathbf{n}(t+1) = \mathbf{A}\mathbf{n}(t)$, where $\mathbf{n}(t)$ and $\mathbf{n}(t+1)$ are the population structures at time t and $t+1$, respectively, and **A** is a square matrix containing transition probabilities among categories. When projected over a long time period, the predicted size structure becomes stable and the population grows or decreases at a constant rate. This stable stage structure can be shown to be the right eigenvector **w** of matrix **A** and the population growth rate is the dominant eigenvalue λ of **A** (Caswell 2001).

Transition matrices were constructed at ramet level in which ramets (stems) were described in relation to the genet to which they belong (Chapter 4). In this ramet-within-genet model, ramets are categorised by their own size and that of the genet to which they belong, so that ramet categories are nested in genet categories (Appendix 1). Annual transition matrices were constructed for ramet populations during the first (**H1**), the second (**H2**) and the third (**H3**) year after harvesting (Appendix 2). All matrices are modifications of those for an undisturbed population (**C**) which were presented in Chapter 4. Matrix **H1** contains both the actual harvesting (100% mortality of all ramets ≥ 6 m, retrogression of clumps to smaller size classes) and the responses of the remaining (unharvested) stems to harvesting during the first year.

Transition probabilities among categories 1-3 for the harvest matrices are equal to those in the undisturbed population matrix (**C**) as we assumed that harvesting does not affect these transitions. As understorey light levels in the forest change only little after rattan stem harvesting, we do not expect changes in growth or survival of small individuals. Values for all other matrix elements were calculated by combining values for vital rates, obtained from regression models or category means. Those vital rates that were found to be significantly different in the harvesting treatment were changed. In this case, the vital rate for a certain size category was obtained from the regression equation, and this was applied to the value for the undisturbed population. Information on the parameterization of control matrices is provided in Chapter 4. Harvesting removes stems from a clump and can thus lead to retrogression of clumps to a previous size class, because clump size classes are based on number of stems. Thus, matrix **H1** contains transitions of stems from large clumps to smaller clumps, e.g. from category 6a to 5a, or from 6c to 5b.

Population matrix analyses

The transition matrices for the control and harvested population were combined in a time-varying matrix model to obtain projection of population size over sequences of years after harvest events. Population dynamics after harvesting was described as follows: for the first year after the harvest transition matrix **H1** was applied; for the second year after the harvest transition matrix **H2** was applied; and **H3** was applied for the third year after the harvest. We assumed that after 3 years, the harvested population had fully recovered and thus used matrices of the control population (**C**) from the fourth year onwards. The impact of harvest regimes was assessed both for total population size and for the abundance of harvestable stems.

We simulated various harvesting regimes. We did not change harvest intensity, as it is customary to harvest all stems > 6 m, and as this is the intensity that we applied in our harvesting treatment. Thus, we only changed harvest frequency to simulate different harvesting regimes. The frequencies of harvesting we used are every 1, 5, 10 and 15 years. The first three regimes are applied in Southeast Asia, especially the first two regimes are very commonly practised in Vietnam. Harvest simulations were carried out with the same intensities at different harvest cycle lengths (allowing recuperation for 1, 5, 10 and 15 years). Stem harvests were simulated by making the number of stems ≥ 6 m become zero in the population vector. Simulation always started with a harvest, which was then repeated every 1, 5, 10 and 15 years, for a period of 30 years. The following models were used to describe time-varying population dynamics for a situation without harvest (Eq. 1) and for situations with repeated harvest every 1, 5, 10 and 15 years (Eqs. 2, 3, 4 and 5, respectively):

$$n(t+1) = \mathbf{C} \times n(t) \qquad \text{(Control)} \qquad (1)$$

$$n(t+1) = \mathbf{H1} \times n(t) \qquad \text{(Harvest every year)} \qquad (2)$$

$$n(t+5) = \mathbf{C}^{2} \times \mathbf{H3} \times \mathbf{H2} \times \mathbf{H1} \times n(t) \qquad \text{(Harvest every 5 years)} \qquad (3)$$

$$n(t+10) = \mathbf{C}^{7} \times \mathbf{H3} \times \mathbf{H2} \times \mathbf{H1} \times n(t) \qquad \text{(Harvest every 10 years)} \qquad (4)$$

$$n(t+15) = \mathbf{C}^{12} \times \mathbf{H3} \times \mathbf{H2} \times \mathbf{H1} \times n(t) \qquad \text{(Harvest every 15 years)} \qquad (5)$$

It should be noted that the chronological order in these equations is from right to left, e.g. starting with a first year harvest matrix (**H1**) in equation 2. Population growth rate (λ) were calculated for the individual matrix (**H1, H2, H3**) and for periodic models (Eqs. 2-5). The observed population structure of undisturbed model (**C**) was used in simulating the population structures of harvesting regimes. For each simulation step, the harvestable stem length was estimated. To do so, size distributions were projected at each time step (Eqs. 2-5). The projected harvestable length in a category was then calculated by multiplying the abundance of projected harvestable stems in a category with midpoints of stem length for each category. For the last category (i), the mean stem length was used to calculate the stem lengths produced.

Results

Impact of harvest on vital rates

Table 1. Effect of harvest on survival of two rattan species in Central Vietnam. Results are based on multinomial logistic regression tests in relation to stem length (or shoot height), clump size and crown exposure (reference score as CE=1); test and significance (-: not tested, ns: p≥0.05, *:p<0.05, **:p<0.01, ***:p<0.001).

a.

Calamus rhabdocladus

Time after harvest	1 year		2 years		3 years	
	Shoot	Stem	Shoot	Stem	Shoot	Stem
R^2	0.066	0.110	0.131	0.116	0.062	0.019
Constant	0.225	1.855	-0.632	7.854	0.844	1.870
Stem length	2.642*	2.485***	9.599**	ns	ns	ns
Clump size	ns	ns	ns	ns	ns	ns
CE2	ns	ns	ns	ns	ns	ns
CE3	-	ns	-	ns	-	ns
CE4	-	-	-	ns	-	ns
Harvest	ns	-1.013*	ns	ns	ns	ns

b.

Daemonorops cf. poilanei

Time after harvest	1 year		2 years		3 years	
	Shoot	Stem	Shoot	Stem	Shoot	Stem
R^2	0.147	0.082	0.077	0.020	0.042	0.011
Constant	0.920	1.932	0.560	2.347	0.078	-1.417
Stem length	0.388*	0.617**	4.34**	ns	3.202*	ns
Clump size	ns	ns	ns	ns	ns	ns
CE2	ns	ns	ns	ns	ns	ns
CE3	-	ns	-	ns	-	ns
CE4	-	-	-	ns	-	ns
Harvest	-0.616*	-0.625*	ns	ns	ns	ns

The impact of harvest on vital rates differed across the three measurement years following harvesting in both species. Survival of the remaining stems was lower during the first year after harvest in both species, but no effect on survival was found in the second and third year (Table 1). Shoot survival was reduced only in *D. cf. poilanei* during the first year. Over three years after harvesting, shoot survival increased from 71% to 74% for *C. rhabdocladus* and from 60% to 71% for *D. cf. poilanei*. The increase in survival was stronger for stems: from 75% to 98% and from 80% to 96% of *C. rhabdocladus* and *D. cf. poilanei*, respectively.

The effects of harvesting on growth of shoots and stems of both species are shown in Figure 1. Stem harvest negatively affected growth of shoots and stems of both species in the first year after harvest (Table 2). Growth reduction ranged from 5 to 9 cm/y for *C. rhabdocladus* and from 13 to 17 cm/y for *D. cf. poilanei* with a stronger effect for stems < 3 m compared to medium-sized stems. In the second year after harvest, growth of shoots and stems was still reduced for *C. rhabdocladus* but no significant difference in growth were found for *D. cf. poilanei*. In the third year after harvest no effect on shoot and stem growth was found for both species (Figure 1, Table 2).

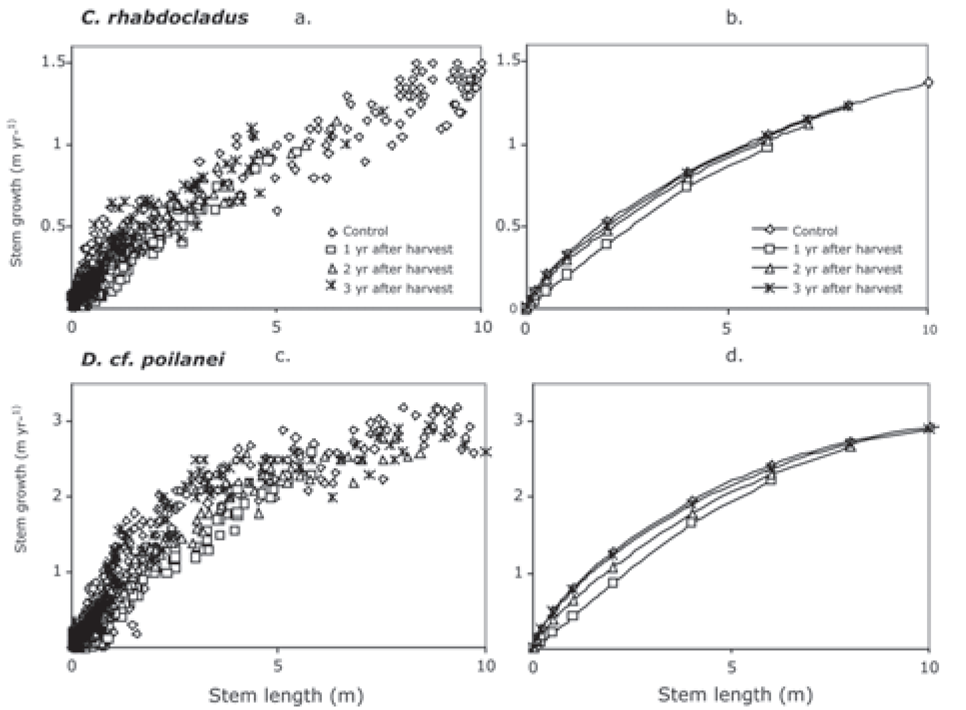


Figure 1. Stem growth in relation with stem length of two rattan species in Central Vietnam. Dots are observed values (a, c) and curved lines are fitted non-linearly for observed data (b, d).

Table 2. Effect of stem harvesting on growth of two rattan species in Central Vietnam. Results of multiple linear regression tests in relation to stem length (or shoot height), clump size and crown exposure (reference score as CE=1) ; test and significance (-: not tested, ns: p≥0.05, *:p<0.05, **:p<0.01, ***:p<0.001).

a.

Calamus rhabdocladus										
Time after harvest	1 year			2 years			3 years			
	Shoots	St < 3 m	3<St<10 m	Shoots	St < 3 m	3<St<10 m	Shoots	St < 3 m	3<St<10 m	St > 10 m
R^2	0.245	0.834	0.933	0.615	0.827	0.851	0.418	0.751	0.875	0.387
Constant	0.146	0.035	0.056	0.019	0.064	0.097	0.034	0.080	0.105	1.206
Stem length	0.530***	0.189***	0.097***	1.001***	0.199***	0.069***	0.731**	0.264***	0.145***	0.019*
Clump size	ns	0.005***	0.004***	0.002**	0.004***	0.003**	0.002*	0.002***	0.002***	ns
CE 2	ns	0.025***	0.122***	ns	0.067***	0.165***	ns	0.020*	0.087***	-
CE 3	-	0.035**	0.313***	-	0.114***	0.394***	-	0.099***	0.245***	ns
CE 4	-	-	0.339***	-	-	0.509***	-	-	ns	0.113*
Harvest	-0.089**	-0.054***	-0.051***	-0.038***	-0.042***	-0.031***	ns	ns	ns	-

b.

Daemonorops cf. poilanei											
Time after harvest	1 year			2 years				3 years			
	Shoots	St < 3 m	3<St<10 m	Shoots	St < 3 m	3<St<10 m	St > 10 m	Shoots	St < 3 m	3<St<10 m	St > 10 m
R^2	0.347	0.796	0.899	0.439	0.841	0.820	0.388	0.463	0.843	0.866	0.194
Constant	0.114	0.796	0.117	0.122	-0.066	0.059	0.936	0.129	0.175	0.153	3.212
Stem length	0.127***	0.149***	0.029***	0.284***	0.526***	0.043***	0.037*	0.127**	0.111***	0.063***	-0.021***
Clump size	0.002*	0.130***	0.005***	0.002***	0.006***	0.006***	ns	0.002*	0.005***	0.004**	ns
CE 2	ns	0.581***	0.872***	ns	0.168***	0.841***	-	ns	0.805***	0.925***	-
CE 3	-	1.083***	1.931***	-	0.360***	1.663***	ns	-	1.288***	1.694***	ns
CE 4	-	-	2.251***	-	-	0.705***	0.148**	-	-	1.257***	ns
Harvest	ns	-0.174***	-0.129***	ns	ns	ns	ns	ns	ns	ns	ns

Stem harvesting also affected shoot production, again with varying impacts during three years after harvesting (Table 3). During the first year, there was a positive impact of harvesting on shoot production. Each clump produced 0.37 and 0.73 shoot more compared to the control treatment in *C. rhabdocladus* and *D. cf. poilanei*, respectively. In the second year, shoot production was reduced compared to the control, while in the third year no effect was found for *C. rhabdocladus* and a negative (but smaller) effect for *D. cf. poilanei*. On average, new shoots were produced at a rate of 0.73, 0.52 and 0.57 per stem for *C. rhabdocladus*, and 0.59, 0.31 and 0.39 per stem (> 3 m) for *D. cf. poilanei* at 1, 2, and 3 years after harvesting, respectively.

Table 3. Effect of harvest on shoot production of two rattan species in Central Vietnam. Results of multiple linear regression tests in relation to clump size; test and significance (ns: p≥0.05, *:p<0.05, **:p<0.01, ***:p<0.001).

Time after harvest	*C. rhabdocladus*			*D. cf. poilanei*		
	1	2	3	1	2	3
R^2	0.571	0.629	0.65	0.853	0.911	0.879
Constant	0.155	-0.106	-0.14	-0.355	-0.047	0.683
Clump size	0.179***	0.152***	0.155***	0.273***	0.226***	0.185***
Harvest	0.371*	-0.125*	ns	0.734*	-0.769*	-0.587*

Sexual reproduction was strongly affected by stem harvesting: during the first year, no inflorescences were produced as all reproductive stems were harvested. In the 2nd and 3rd year new reproductive stems appeared, and no impact of harvesting on the relation between stem length and reproductiveness was found (logistic regression, P > 0.05). Impact of harvesting on sexual reproduction may be underestimated as we did not include information on the impact of harvesting on seed output per infructescence.

Impact of harvesting on population dynamics

The vital rates that were used for the construction of transition matrices in harvested populations are included in Appendix 1. The resulting transition matrices for ramet-within-genet models during the first (**H1**), second (**H2**) and third (**H3**) year following harvest are shown in Appendix 2. The transition matrix for the undisturbed model is included in Chapter 4. Population growth rates (λ) of the transition matrices is shown in Table 4.

Table 4. Population growth rates for different matrix modes of two rattan species in Central Vietnam.

Transition matrix models		*C. rhabdocladus*	*D. cf. poilanei*
Individual matrix	Control (**C**)	1.013	1.068
	1 yr after harvest (**H1**)	0.793	0.782
	2 yr after harvest (**H2**)	0.969	0.854
	3 yr after harvest (**H3**)	1.002	0.925
Harvest Regimes	Every 1 year (Eq. 2)	0.793	0.782
	Every 5 years (Eq. 3)	0.959	0.889
	Every 10 years (Eq. 4)	0.982	0.967
	Every 15 years (Eq. 5)	0.994	1.009

Population growth rates of transition matrices during the first three year after harvesting and in all harvest regimes in both study species were lower than those for an undisturbed population. Population growth was lowest during the first year after harvest (**H1**) and gradually increased in the following years for both species. The population of *C. rhabdocladus* increased during the third year after harvesting ($\lambda > 1$), while in *D. cf. poilanei* three years after harvesting the population still decreased (Table 4). The changes in λ were relatively large, probably due to the fact that survival probability was altered as a result of stem harvesting.
We simulated the impact of different harvesting regimes (harvesting every 1, 5, 10 and 15 years) on population growth in two ways. The first set of simulation results presents the impact of harvesting on population growth with relative population sizes. The population of *C. rhabdocladus* and *D. cf. poilanei* decreased in all harvest regimes, except for the 15 year harvest regime in *D. cf. poilanei*, where the population increased (Table 4). Simulation results on population size were expressed relatively to the undisturbed population at the same time step (Figure 2: a, b). Due to the decline in population size ($\lambda < 1$), harvested populations did not recuperate to the initial size in absolute terms under all harvest regimes in *C. rhabdocladus*. In *D. cf. poilanei*, harvested population completely recovered to the initial size for the harvest regime of 15 years. Shorter harvesting cycles caused trajectories of exploited populations to deviate more from that of an undisturbed population, indicating population decline relative to the undisturbed situation.

Very strong reductions were found when harvests were repeated every year in both species (Table 4, Figure 2: a, b).

When effects of a single extraction are simulated, the total size of harvested populations and abundance of harvestable stems never reached 100% of that for an undisturbed population within the same simulation period. The maximal proportion of the undisturbed population size that is recuperated in the harvested populations amounted to 72, 65 and 56% in *C. rhabdocladus*, and 63, 57 and 44% in *D. cf. poilanei* for the harvest cycles of 15, 10 and 5 years, respectively (Figure 2: c, d). Although the rate of shoot production is higher in the population one year after the harvest than in the undisturbed population, there is no recovery of the population in both study species for the harvest cycle of 1 year.

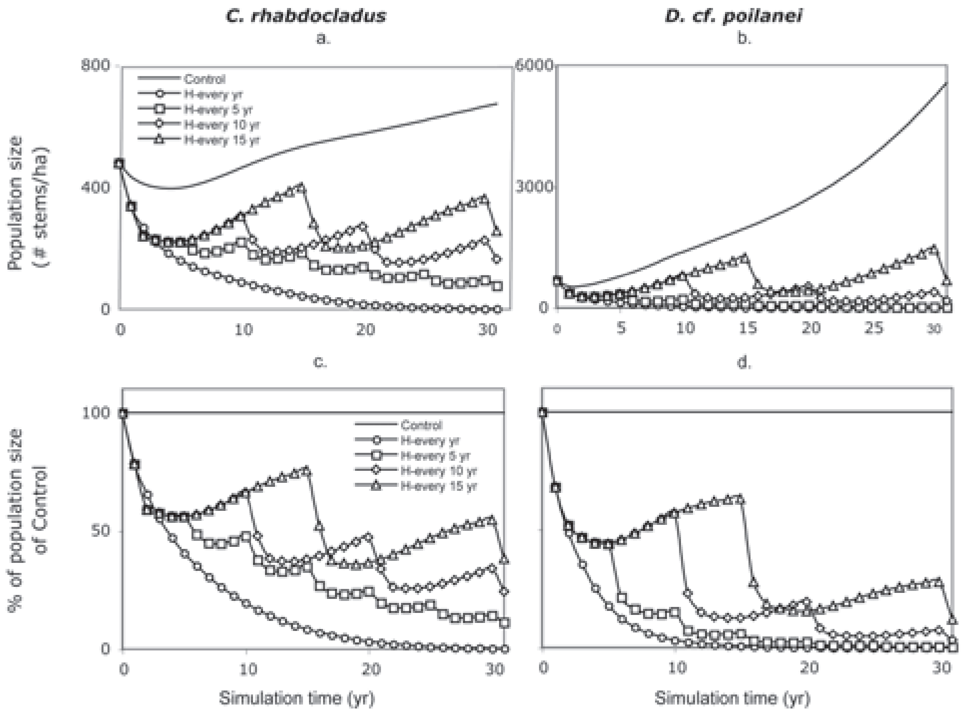


Figure 2. Simulated population trajectories under different harvest regimes for two rattan species in Central Vietnam. Shown are projections using periodic matrix models described in Eqs. 1-5, for an undisturbed population and for a population harvested once every 1, 5, 10 and 15 years.

The second set of simulation results shows the impact of harvesting on the availability of rattan resources. From theses simulations it also becomes clear that frequent harvesting (every year, or every 5 years) has severe impacts on the populations, and depletes rattan resources (Figure 3). In *C. rhabdocladus* the abundance of harvestable stems and harvestable stem length recovered to the initial size only when long harvest cycles (15 years) were simulated. In *D. cf. poilanei*, recovery also occurred using harvest cycles of 10 and 15 years, with even higher number of harvestable stems compared to the initial population. Clearly, this increase is related to the high population growth values (λ = 1.068) of the control population.

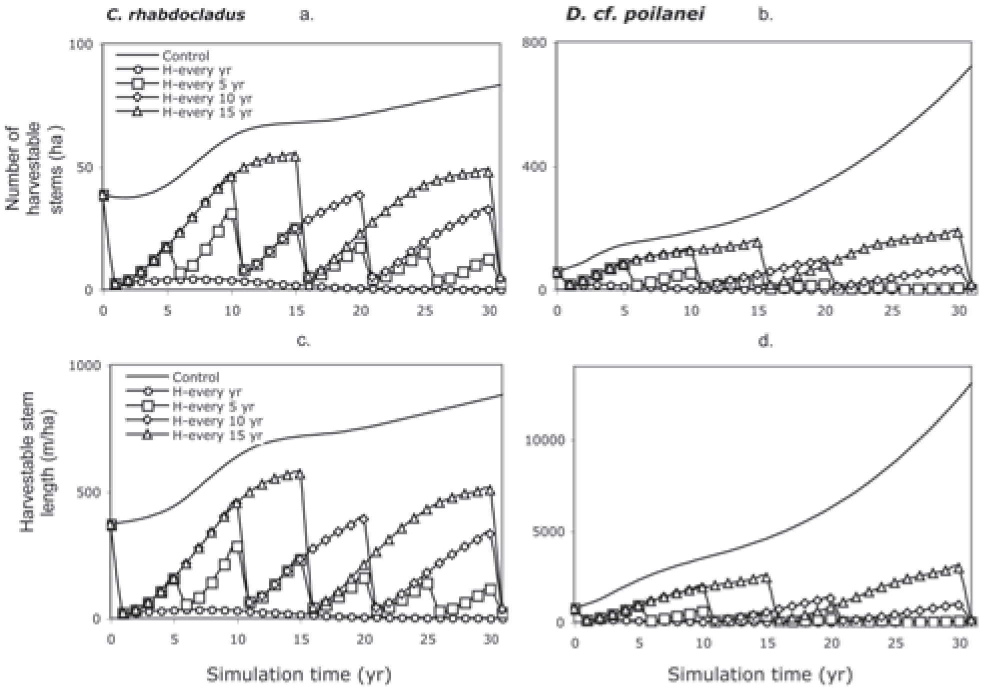


Figure 3. Impact of stem harvesting on rattan availability for two rattan species in Central Vietnam. Upper panels: simulated number of harvestable stems under different harvest regimes. Lower panels: simulated summed length of harvestable stems under different harvest regimes. Shown are projections using periodic matrix models described in Eqs. 1-5 and category-specific values of stem length. Only stem ≥ 6 m length are included.

To estimate the harvest productivity for the four harvest regimes, we calculated the total stem length harvested over 30 years for each regime (Table 5). Short cycle harvests gave the lowest productivity while longer cycles gave higher cumulative rattan harvests in both species. The amount of harvested rattan was higher than that of the first harvest in *C. rhabdocladus* for the harvest cycle of 10 and 15 years and in *D. cf. poilanei* for the harvest cycles of 5, 10 and 15 years although their population size was incompletely recovered. The very good results in *D. cf. poilanei* for the long cycles is probably caused by high λ value for the control population.

Table 5. Total stem length harvested in 30 years in one hectare over different harvest regimes of two rattan species in Central Vietnam.

Harvest scenario	*C. rhabdocladus*		*D. cf. poilanei*	
	Σ stem length harvested in 30 years (m)	% stem length harvested at 2^{nd} / 1^{st} harvest	Σ stem length harvested in 30 years (m)	% stem length harvested at 2^{nd} / 1^{st} harvest
Harvest every year	849	5	1,775	18
Harvest every 5 years	3,430	42	6,798	120
Harvest every 10 years	6,721	122	22,009	252
Harvest every 15 years	9,904	154	45,590	326

Discussion

Impact of harvest on vital rates

Stem harvesting from rattan clumps changes the clump size, and may therefore impact the growth and survival of the remaining clumps. As reported in Chapter 3, the growth of shoots and small stems depends to an important degree on the size of the clump. This relation between clump size and stem growth probably explains why in the harvesting experiment, we found the growth of remaining stems to be reduced after harvesting in both study species. A similar result was found for *D. sabut* in a study in Indonesia: harvesting of all commercial stems from clumps of that species resulted in a strong growth reduction of the remaining stems (Van Valkenburg 1997). These results suggest that carbohydrates necessary to support the growth of small stems are derived from other stems, either from reserves or directly from photosynthesis in those stems. Such a mechanism was also suggested for the fast growth of young shoots in the clonal bamboo *Phyllostachys pubescens* (Li et al. 1998, 2000). However, contrasting results have also been found. In other rattan and palm species (*Calamus javensis*, *Neodypsis decaryi* and *Desmoncus orthacanthos*), harvesting led to an increase in the growth of the remaining stems as compared with undisturbed clumps (Ratsirarson et al. 1996, Van Valkenburg 1997, Siebert 2000a). In again other cases stem harvesting (*Calamus ornatus*) or defoliation (*Geonoma deversa*, *Chamaedorea elegans*) did not result in changes in growth or had small effects on the growth of ramets within harvested or defoliated genets (Van Valkenburg 1997, Zuidema 2000, Anten et al. 2003, Martinez-Ramos et al. 2009). Thus, clustered palm species appear to respond in widely varying ways to leaf and stem cutting.

Stem harvesting decreased the survival of remaining stems in harvested clumps in our study species. The same results were reported for *Daemonorops sabut* and *Calamus javensis* (Van Valkenburg 1997) and *Chamaedorea radicalis* (Endress et al. 2004). In contrast, Van Valkenburg (1997), Chazdon (1991), Zuidema (2000) and Martinez-Ramos et al. (2009) found no effect or small effects of stem harvest and defoliation on survival of *Calamus ornatus*, *Geonoma congesta*, *G. deversa* and *Chamaedorea elegans*. During the year of harvest, survival of the remaining stems was affected by cutting of large stems and removing of leaf sheaths without taking much care for the remaining stems in harvested clumps (personal observation). This has likely affected survival of shoots and stems in our experiment, but is also likely to happen in actual harvesting practices.

As all adult stems were removed during stem cutting, harvesting resulted in zero sexual reproduction during the first year. Strong negative effects of leaf and stem harvesting on sexual reproduction were also found in *Neodypsis decaryi*, *Chamaedorea radicalis*, *C. elegans* and *Geonoma deversa* by complete leaf removal (Ratsirarson et al. 1996, Anten et al. 2003, Endress et al. 2004, Zuidema et al. 2007, Martinez-Ramos et al. 2009). In the 2^{nd} and 3^{rd} year after harvesting, there was no difference between harvested and unharvested mature stems in their production of infructescences in our study species: the number of infructescences depends on stem length itself (Chapter 3). But total seed output per hectare was probably lower than in undisturbed populations. The long-term effects of rattan harvesting in short harvest cycles on sexual reproduction are unknown, but probably lead to no sexual reproduction in an annual harvest cycle in our study species.

Harvesting stimulated the vegetative reproduction in the first year, while it decreased the number of new shoots in the 2nd and 3rd year in both *C. rhabdocladus* and *D. cf. poilanei*. Stimulation of shoot production by harvesting was also found in *Calamus zollingeri* (Siebert 2004). It is common in other clonal plants that after large damage the vegetative reproduction is higher than that of an undisturbed population (Chazdon 1991). However in *Geonoma deversa* and *Chamaedorea radicalis*, vegetative reproduction was reduced by defoliation (Zuidema 2000, Flores and Ashton 2000, Endress et al. 2004, Zuidema et al. 2007), and it had no effect in *Geonoma congesta* (Chazdon 1991).
Our results are based on maximum harvest intensity (100% stem ≥ 6 m) in the experiments. It would be useful to conduct similar experiments with varying harvest intensities (e.g. 25%, 50% or 75%) in order to better understand responses of vital rates to harvesting.

Population responses to harvesting

In this study the impact of harvesting was assessed by comparing the projection of population size and abundance of harvestable stems for harvested populations with those for an undisturbed population. Stem harvesting had a strongly negative impact on the population growth of *C. rhabdocladus* and *D. cf. poilanei* in comparison with an undisturbed population, as λ was highly sensitive to changes in survival probability in the last categories (Chapter 4). Similar results were reported by Zuidema (2000) in palm heart extraction of *Euterpe precatoria*, by Flores and Ashton (2000) in complete crown removal in *Geonoma deversa*, and by Endress et al. (2004) in defoliation for *Chamaedorea radicalis*. However, in leaf harvesting of other palms the population growth did not differ significantly from the unharvested stands (Pinero et al. 1984, Mendoza et al. 1987, Flores and Ashton 2000, Zuidema et al. 2007).
Harvest simulations using population matrix models usually consider the impact of repeated harvesting on the population size without considering the change in population structures and their consequences for resources availability (Peters 1990, Pinard 1993, Olmsted and Alvarez-Buylla 1995, Zuidema 2000). In this study, the impact of harvesting was evaluated for the population growth rate, the population structure and the availability of stems. This method allows to simulate harvest regimes and judge the sustainability based on the available future resources, and not only on a stable population size (Zuidema 2000). We used matrix (**C**) (undisturbed population) to describe population dynamics during

the forth year after harvesting, as no data were available on vital rates for that year and based on vital rates of the 1st, 2nd and 3rd year after harvesting it was expected that the vital rates of harvested populations would not differ from those in control populations.

Simulations of population size (Figure 2) showed that population recoveries were different for harvest regimes among the two study species. However, repeated short harvest cycles strongly reduced population sizes in both study species. In *C. rhabdocladus* the population did not recover to initial size even with a harvest cycle of 15 years. In *D. cf. poilanei* the population recovered to initial size with a 15 year harvest cycle. The difference in population recoverage of the two study species is probably caused by the higher population growth rate of the control population of *D. cf. poilanei* (λ = 1.068) than that of *C. rhabdocladus* (λ = 1.013, see Chapter 4).

Sustainable rattan harvesting

The results from simulations showed that the abundance of harvestable stems (Figure 3) rapidly declined when short harvest cycles were used. Annual rattan cutting resulted in a low cumulative amount of rattan harvested during a period of 30 years (Table 5). However, short harvest cycles are common practice in Vietnam and in other Southeast Asian countries (Nghia et al. 2000, Siebert 2004). The number of harvestable stems was recovered to the initial number only in the 15 year harvest cycle for *C. rhabdocladus* and in 10 and 15 year harvest cycles for *D. cf. poilanei*.

Both *C. rhabdocladus* and *D. cf. poilanei* present some characteristics that make them potentially suitable for sustained-yield harvest if long harvest cycles are applied (15 years). This also was suggested for *Calamus zollingeri* (Siebert 2004). These three species are widely distributed in tropical forests in the Southeast Asia, with fast-growing stems emerging from a clump and continuous production new shoots after harvesting. These characters make our study species different from many other highly-valued palms like *Iriartea deltoidea* (Pinard 1993, Anderson and Putz 2002), *Thrinax radiata* and *Coccothrinax readii* (Olmsted and Alvarez-Buylla 1995), *Euterpe precatoria* (Zuidema 2000), and the premier rattan species *Calamus manan* (Siebert 2004) that have proved difficult to harvest on a sustainable-yield basis. All these species are single-stemmed which severely limits the potential for sustainable stem harvesting.

The sustained-yield harvest potential of our study species could be achieved in a shorter harvest cycles if some silvicultural treatment would be applied to the harvested clumps. For example, the creation of artificial gaps by girdling techniques as the growth of stems increases with light intensity, or by fertilizing the managed area. Up to date, fertilizing was applied only in rattan plantations (DST 1991), but fertilizer requirements, spacing and line maintenance are not yet fully understood (Dransfield and Manokaran 1994). Yet, very little is known about the effectiveness of applying silvicultural treatments, and trial studies are needed before such treatments are applied at a large scale.

The maximum intensity harvesting in the big clump species *D. cf. poilanei* had a negative effect on growth and survival of the remaining stems after one year. In traditional management systems as in the Bahau area (East Kalimantan), where other rattan species are protected for 10 years after a harvest (Van Valkenburg 1997), such negative effects on growth and survival may be overcome. The method of limited but continuous harvesting is applied by people in Johore, Malaysia (cf. Van Valkenburg 1997) for *Calamus caesius* in primary forests. This species is harvested on a 4-5 month rotation and each time only a small number of stems are cut. However, as a high frequency of stem harvesting will cause much damage to the remaining stems, it is suggested that intervals between harvests should be several years.

The challenge is how to manage rattan extraction in a sustainable way. Without any silvicultural application, periods of undisturbed regrowth between years of harvesting in wild rattan should be not shorter than 15 years for *C. rhabdocladus* and *D. cf. poilanei* in order to maintain long-term harvests of these species. Recent extraction rates of *C. rhabdocladus* and *D. cf. poilanei* have exceeded the growth rates and resulted in the depletion of the rattans. The declining availability of rattan canes was evident to collectors, who collected in more distant areas and shifted collection to less valuable rattan species (Siebert 2004, personal observation). Our harvest experiments are based on the study of a particular population in a particular period, and should be interpreted carefully when applied to other sites. The effect of repeated stem harvesting on vital rates of clumps and stems requires a long-term monitoring and at different harvest intensity and regimes to evaluate potential sustainability and suitable silviculture application. The design of sustainable rattan management systems in wild populations requires more attention from research institutes, conservation organizations and policy makers.

Acknowledgements

We would like to thank Marinus Werger and Francis Putz for valuable information and discussion on the sustainable management on rattans and NTFP. We would like to thank Tropenbos International Vietnam and the Netherlands Fellowship Programme (Nuffic) for their financial support to this study.

Appendix 1. Values of vital rates used in the ramet-within-genet transition models for two rattan species in Central Vietnam. Numbers refer to genet (clump) categories and letters to ramet (stem) categories. σ = survival probability; g = growth rate (in shoot height or stem length); n = number of measured individuals at the start of the study.

One year after harvest

Calamus rhabdocladus

Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infructescence	σ	n
4a	< 0.5	1-3	0.1895	0	0	0	0.7079	12
4b	< 0.15	1-3	0.0071	0	0	0	0.7486	42
4c	0.15-0.3	1-3	0.0310	0	0	0	0.8024	33
4d	0.3-0.5	1-3	0.0670	0	0	0	0.8625	24
4e	0.5-1	1-3	0.1551	0	0	0	0.9642	15
4f	1-3	1-3	0.3932	0	0	0	0.9642	11
4g	3-6	1-3	0.6818	1	0	0	0.9642	3
4h								
5a	< 0.5	4-6	0.1895	0	0	0	0.7079	19
5b	< 0.15	4-6	0.0219	0	0	0	0.7486	39
5c	0.15-0.3	4-6	0.0458	0	0	0	0.8024	19
5d	0.3-0.5	4-6	0.0818	0	0	0	0.8625	21
5e	0.5-1	4-6	0.1699	0	0	0	0.9642	13
5f	1-3	4-6	0.4080	0	0	0	0.9642	17
5g	3-6	4-6	0.6927	1	0	0	0.9642	7
5h								
5i								
6a	< 0.5	≥ 7	0.1895	0	0	0	0.7079	19
6b	< 0.15	≥ 7	0.0490	0	0	0	0.7486	20
6c	0.15-0.3	≥ 7	0.0729	0	0	0	0.8024	14
6d	0.3-0.5	≥ 7	0.1089	0	0	0	0.8625	8
6e	0.5-1	≥ 7	0.1970	0	0	0	0.9642	7
6f	1-3	≥ 7	0.4351	0	0	0	0.9642	8
6g	3-6	≥ 7	0.7128	1	0	0	0.9642	3
6h								
6i								

Two years after harvest

Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infructescence	σ	n
			Calamus rhabdocladus					
4a	< 0.5	1-3	0.1841	0	0	0	0.7255	15
4b	< 0.15	1-3	0.0490	0	0	0	0.9263	19
4c	0.15-0.3	1-3	0.0747	0	0	0	0.9263	60
4d	0.3-0.5	1-3	0.1172	0	0	0	0.9263	28
4e	0.5-1	1-3	0.2447	0	0	0	0.9263	14
4f	1-3	1-3	0.5026	0	0	0	0.9608	15
4g	3-6	1-3	0.6798	1	0	0	0.9608	6
4h	6-10	1-3	1.0727	1	0.0664	0.9602	0.9608	0
5a	< 0.5	4-6	0.1889	0	0	0	0.7255	14
5b	< 0.15	4-6	0.0615	0	0	0	0.9263	15
5c	0.15-0.3	4-6	0.0872	0	0	0	0.9263	20
5d	0.3-0.5	4-6	0.1297	0	0	0	0.9263	13
5e	0.5-1	4-6	0.2572	0	0	0	0.9263	7
5f	1-3	4-6	0.5152	0	0	0	0.9608	13
5g	3-6	4-6	0.6881	1	0	0	0.9608	7
5h	6-10	4-6	1.0810	1	0.0664	0.9602	0.9608	0
5i								
6a	< 0.5	≥ 7	0.1961	0	0	0	0.7255	22
6b	< 0.15	≥ 7	0.0803	0	0	0	0.9263	7
6c	0.15-0.3	≥ 7	0.1060	0	0	0	0.9263	8
6d	0.3-0.5	≥ 7	0.1485	0	0	0	0.9263	12
6e	0.5-1	≥ 7	0.2760	0	0	0	0.9263	14
6f	1-3	≥ 7	0.5339	0	0	0	0.9608	6
6g	3-6	≥ 7	0.7005	1	0	0	0.9608	3
6h	6-10	≥ 7	1.0934	1	0.0664	0.9602	0.9608	1
6i								

Three years after harvest

Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infructescence	σ	n
			Calamus rhabdocladus					
4a	< 0.5	1-3	0.1830	0	0	0	0.7353	6
4b	< 0.15	1-3	0.0539	0	0	0	0.9365	14
4c	0.15-0.3	1-3	0.0849	0	0	0	0.9365	40
4d	0.3-0.5	1-3	0.1330	0	0	0	0.9365	41
4e	0.5-1	1-3	0.2603	0	0	0	0.9365	17

4f	1-3	1-3	0.5664	0	0	0	0.9800	18
4g	3-6	1-3	0.7605	1	0	0	0.9800	7
4h	6-10	1-3	1.1519	1	0.0664	0.9602	0.9800	0
5a	< 0.5	4-6	0.1891	0	0	0	0.7353	16
5b	< 0.15	4-6	0.0665	0	0	0	0.9365	10
5c	0.15-0.3	4-6	0.0974	0	0	0	0.9365	12
5d	0.3-0.5	4-6	0.1455	0	0	0	0.9365	20
5e	0.5-1	4-6	0.2729	0	0	0	0.9365	9
5f	1-3	4-6	0.5790	0	0	0	0.9800	14
5g	3-6	4-6	0.7712	1	0	0	0.9800	10
5h	6-10	4-6	1.1626	1	0.0664	0.9602	0.9800	2
5i								
6a	< 0.5	≥ 7	0.1981	0	0	0	0.7353	12
6b	< 0.15	≥ 7	0.0854	0	0	0	0.9365	12
6c	0.15-0.3	≥ 7	0.1163	0	0	0	0.9365	7
6d	0.3-0.5	≥ 7	0.1644	0	0	0	0.9365	8
6e	0.5-1	≥ 7	0.2918	0	0	0	0.9365	14
6f	1-3	≥ 7	0.5978	0	0	0	0.9800	14
6g	3-6	≥ 7	0.7873	1	0	0	0.9800	4
6h	6-10	≥ 7	1.1787	1	0.0664	0.9602	0.9800	1
6i								

One year after harvest

				Daemonorops cf. poilanei				
Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infructescence	σ	n
4a	< 0.98	1-3	0.1555	0	0	0	0.6034	20
4b	< 0.3	1-3	0.0424	0	0	0	0.8070	27
4c	0.3-1	1-3	0.2454	0	0	0	0.8425	24
4d	1-3	1-3	0.9441	0	0	0	0.9412	8
4e	3-6	1-3	1.7829	1	0	0	0.9412	0
4f								
5a	< 0.98	4-8	0.1617	0	0	0	0.6034	12
5b	< 0.3	4-8	0.0787	0	0	0	0.8070	21
5c	0.3-1	4-8	0.2816	0	0	0	0.8425	16
5d	1-3	4-8	0.9804	0	0	0	0.9412	6
5e	3-6	4-8	1.8023	1	0	0	0.9412	5
5f								
5g								
5h								
5i								
6a	< 0.98	9-15	0.1723	0	0	0	0.6034	30
6b	< 0.3	9-15	0.1421	0	0	0	0.8070	16
6c	0.3-1	9-15	0.3451	0	0	0	0.8425	34
6d	1-3	9-15	1.0438	0	0	0	0.9412	13
6e	3-6	9-15	1.8363	1	0	0	0.9412	10

6f								
6g								
6h								
6i								
7a	< 0.98	> 15	0.1777	0	0	0	0.6034	18
7b	< 0.3	> 15	0.1738	0	0	0	0.8070	12
7c	0.3-1	> 15	0.3768	0	0	0	0.8425	18
7d	1-3	> 15	1.0755	0	0	0	0.9412	14
7e	3-6	> 15	1.8533	1	0	0	0.9412	12
7f								
7g								
7h								
7i								

Two years after harvest

			Daemonorops cf. poilanei					
Cat	Height or stem length (m)	# stems per clump	g ($m\ yr^{-1}$)	Prob. clonal rep.	Prob.sex.rep. of female stem	# infruc-tescence	σ	n
4a	< 0.98	1-3	0.1575	0	0	0	0.7099	7
4b	< 0.3	1-3	0.0582	0	0	0	0.9321	23
4c	0.3-1	1-3	0.3123	0	0	0	0.9321	20
4d	1-3	1-3	1.2087	0	0	0	0.9321	6
4e	3-6	1-3	1.7125	1	0	0	0.9321	0
4f	6-10	1-3	2.0848	1	0.0493	1.7701	0.9321	0
5a	< 0.98	4-8	0.1653	0	0	0	0.7099	21
5b	< 0.3	4-8	0.0823	0	0	0	0.9321	18
5c	0.3-1	4-8	0.3364	0	0	0	0.9321	19
5d	1-3	4-8	1.2327	0	0	0	0.9321	8
5e	3-6	4-8	1.7356	1	0	0	0.9321	3
5f	6-10	4-8	2.1080	1	0.0493	1.7701	0.9321	2
5g								
5h								
5i								
6a	< 0.98	9-15	0.1790	0	0	0	0.7099	23
6b	< 0.3	9-15	0.1244	0	0	0	0.9321	6
6c	0.3-1	9-15	0.3785	0	0	0	0.9321	18
6d	1-3	9-15	1.2749	0	0	0	0.9321	14
6e	3-6	9-15	1.7761	1	0	0	0.9321	5
6f	6-10	9-15	2.1485	1	0.0493	1.7701	0.9321	2
6g								
6h								
6i								
7a	< 0.98	> 15	0.1897	0	0	0	0.7099	44
7b	< 0.3	> 15	0.1576	0	0	0	0.9321	11
7c	0.3-1	> 15	0.4117	0	0	0	0.9321	25
7d	1-3	> 15	1.3080	0	0	0	0.9321	18

7e	3-6	> 15	1.8079	1	0	0	0.9321	14
7f	6-10	> 15	2.1803	1	0.0493	1.7701	0.9321	9
7g								
7h								
7i								

Three years after harvest

Cat	Height or stem length (m)	# stems per clump	g (m yr^{-1})	Prob. clonal rep.	Prob.sex.rep. of female stem	# infructescence	σ	n
				Daemonorops cf. poilanei				
4a	< 0.98	1-3	0.1575	0	0	0	0.7099	6
4b	< 0.3	1-3	0.0912	0	0	0	0.9099	15
4c	0.3-1	1-3	0.3541	0	0	0	0.9614	25
4d	1-3	1-3	1.2882	0	0	0	0.9614	4
4e	3-6	1-3	1.9741	1	0	0	0.9614	3
4f	6-10	1-3	2.4049	1	0.0493	1.7701	0.9614	0
5a	< 0.98	4-8	0.1653	0	0	0	0.7099	12
5b	< 0.3	4-8	0.1136	0	0	0	0.9099	18
5c	0.3-1	4-8	0.3764	0	0	0	0.9614	22
5d	1-3	4-8	1.3105	0	0	0	0.9614	9
5e	3-6	4-8	1.9899	1	0	0	0.9614	3
5f	6-10	4-8	2.4207	1	0.0493	1.7701	0.9614	3
5g	10-15	4-8	2.7464	1	0.1270	2.3583	0.9614	1
5h								
5i								
6a	< 0.98	9-15	0.1790	0	0	0	0.7099	21
6b	< 0.3	9-15	0.1526	0	0	0	0.9099	8
6c	0.3-1	9-15	0.4155	0	0	0	0.9614	22
6d	1-3	9-15	1.3496	0	0	0	0.9614	13
6e	3-6	9-15	2.0175	1	0	0	0.9614	8
6f	6-10	9-15	2.4484	1	0.0493	1.7701	0.9614	4
6g	10-15	9-15	2.7464	1	0.1270	2.3583	0.9614	1
6h								
6i								
7a	< 0.98	> 15	0.1907	0	0	0	0.7099	31
7b	< 0.3	> 15	0.1861	0	0	0	0.9099	16
7c	0.3-1	> 15	0.4489	0	0	0	0.9614	22
7d	1-3	> 15	1.3830	0	0	0	0.9614	17
7e	3-6	> 15	2.0412	1	0	0	0.9614	13
7f	6-10	> 15	2.4721	1	0.0493	1.7701	0.9614	13
7g	10-15	> 15	2.7464	1	0.1270	2.3583	0.9614	3
7h								
7i								

Appendix 2. Population transition matrices for the ramet-within-genet model of two rattan species in central Vietnam.

One year after harvest (**H1**)

a. Calamus rhabdocladus

Category	Category at *t*																												
at *t*+1	1	2	3	4a	4b	4c	4d	4e	4f	4g	4h	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i
1	0.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.06	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.51	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.39	0	0	0	0	0	0.67	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.80	0.24	0.63	0	0	0	0	0	0	0.05	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.03	0.57	0	0	0	0	0	0	0.02	0.10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.15	0.51	0	0	0	0	0	0	0.04	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.26	0.59	0	0	0	0	0	0	0.06	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.27	0.69	0	0	0	0	0	0	0.06	0.14	0	0	0	0	0	0	0	0	0	0	0	0
4g	0	0	0	0	0	0	0	0	0.17	0.66	0	0	0	0	0	0	0.04	0.13	0	0	0	0	0	0	0	0	0	0	0
4h	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0	0	0	0	0	0	0	0	0.36	0	0	0	0	0	0.70	0	0	0.07	0	0	0	0	0	0	0	0
5b	0	0	0	0	0	0	0	0	0	0	0	0.22	0.52	0	0	0	0	0	0	0	0.04	0.07	0	0	0	0	0	0	0
5c	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.45	0	0	0	0	0	0	0	0.04	0.06	0	0	0	0	0	0
5d	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20	0.42	0	0	0	0	0	0	0	0.06	0.06	0	0	0	0	0
5e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.29	0.52	0	0	0	0	0	0	0	0.07	0.09	0	0	0	0
5f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.27	0.62	0	0	0	0	0	0	0	0.06	0.11	0	0	0
5g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.60	0	0	0	0	0	0	0	0.03	0.11	0	0
5h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0.03	0	0
5i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.37	0	0	0	0	0	0.70	0	0
6b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.23	0.43	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.21	0.35	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.33	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.40	0.49	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.32	0.64	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0.62	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.19	0	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Two years after harvest (**H2**)

a. Calamus rhabdocladus

Category at $t+1$	Category at t 1	2	3	4a	4b	4c	4d	4e	4f	4g	4h	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0
2	0	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.51	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.42	0	0	0	0	0	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.80	0.24	0.57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.28	0.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.42	0.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.49	0.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.41	0.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4g	0	0	0	0	0	0	0	0	0.22	0.68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4h	0	0	0	0	0	0	0	0	0	0.20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.02	0	0	0	0	0	0	0	0.40	0	0	0	0	0	0.50	0	0	0.05	0	0	0	0	0	0	0	0
5b	0	0	0	0.01	0.03	0	0	0	0	0	0	0.24	0.49	0	0	0	0	0	0	0	0.03	0.05	0	0	0	0	0	0	0
5c	0	0	0	0	0.01	0.02	0	0	0	0	0	0	0.34	0.34	0	0	0	0	0	0	0	0.06	0.03	0	0	0	0	0	0
5d	0	0	0	0	0	0.02	0.02	0	0	0	0	0	0	0.48	0.29	0	0	0	0	0	0	0	0.07	0.03	0	0	0	0	0
5e	0	0	0	0	0	0	0.02	0.02	0	0	0	0	0	0	0.53	0.40	0	0	0	0	0	0	0	0.08	0.05	0	0	0	0
5f	0	0	0	0	0	0	0	0.02	0.03	0	0	0	0	0	0	0.42	0.63	0	0	0	0	0	0	0	0.06	0.08	0	0	0
5g	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0	0	0.22	0.66	0	0	0	0	0	0	0	0.03	0.08	0	0
5h	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.20	0	0	0	0	0	0	0	0	0.03	0	0
5i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0.39	0	0	0	0	0	0.50	0.50	0
6b	0	0	0	0	0	0	0	0	0	0	0	0.03	0.06	0	0	0	0	0	0	0	0.25	0.38	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.04	0	0	0	0	0	0	0	0.44	0.24	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.03	0	0	0	0	0	0	0	0.58	0.21	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.05	0	0	0	0	0	0	0	0.61	0.37	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.08	0	0	0	0	0	0	0	0.45	0.62	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.08	0	0	0	0	0	0	0	0.23	0.65	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0.20	0.62	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.23	0

Three years after harvest (**H3**)

a. Calamus rhabdocladus

Category	Category at *t*																												
at *t*+1	1	2	3	4a	4b	4c	4d	4e	4f	4g	4h	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i
1	0.61	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0.07	0
2	0.06	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.51	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.42	0	0	0	0	0	0.52	0.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.80	0.24	0.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.30	0.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.47	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.56	0.40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.44	0.63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4g	0	0	0	0	0	0	0	0	0.25	0.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4h	0	0	0	0	0	0	0	0	0	0.22	0.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.02	0	0	0	0	0	0	0	0.41	0	0	0	0	0	0.55	0.55	0	0.05	0	0	0	0	0	0	0	0
5b	0	0	0	0.01	0.02	0	0	0	0	0	0	0.25	0.46	0	0	0	0	0	0	0	0.03	0.05	0	0	0	0	0	0	0
5c	0	0	0	0	0.01	0.02	0	0	0	0	0	0	0.37	0.29	0	0	0	0	0	0	0	0.06	0.02	0	0	0	0	0	0
5d	0	0	0	0	0	0.02	0.01	0	0	0	0	0	0	0.54	0.23	0	0	0	0	0	0	0	0.08	0.02	0	0	0	0	0
5e	0	0	0	0	0	0	0.02	0.02	0	0	0	0	0	0	0.61	0.38	0	0	0	0	0	0	0	0.09	0.04	0	0	0	0
5f	0	0	0	0	0	0	0	0.02	0.03	0	0	0	0	0	0	0.45	0.62	0	0	0	0	0	0	0	0.06	0.08	0	0	0
5g	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0	0	0.25	0.65	0	0	0	0	0	0	0	0.03	0.08	0	0
5h	0	0	0	0	0	0	0	0	0	0.01	0.03	0	0	0	0	0	0	0.22	0.62	0	0	0	0	0	0	0	0.03	0	0
5i	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0.39	0	0	0	0	0	0.55	0.55	0
6b	0	0	0	0	0	0	0	0	0	0	0	0.03	0.06	0	0	0	0	0	0	0	0.26	0.36	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.04	0	0	0	0	0	0	0	0.47	0.19	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.03	0	0	0	0	0	0	0	0.64	0.15	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.05	0	0	0	0	0	0	0	0.68	0.34	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.07	0	0	0	0	0	0	0	0.48	0.61	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.08	0	0	0	0	0	0	0	0.26	0.64	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.07	0	0	0	0	0	0	0	0.23	0.61	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0.25	0

One year after harvest (**H1**)

b. *Daemonorops cf. poilanei*

Category																		Category at *t*																	
at *t*+1	1	2	3	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i	7a	7b	7c	7d	7e	7f	7g	7h	7i
1	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.15	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.52	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.49	0	0	0	0.55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.53	0.09	0.66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.11	0.53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.28	0.48	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.43	0.37	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.54	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.02	0	0	0	0	0	0.49	0	0	0	0.55	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5b	0	0	0	0	0	0	0	0	0	0.10	0.58	0	0	0	0	0	0	0	0.04	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	0	0	0	0	0.02	0	0	0	0	0.21	0.49	0	0	0	0	0	0	0	0.16	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5d	0	0	0	0	0	0.01	0.02	0	0	0	0	0.33	0.47	0	0	0	0	0	0	0	0.15	0.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5e	0	0	0	0	0	0	0.02	0.01	0	0	0	0	0.45	0.37	0	0	0	0	0	0	0	0.18	0.13	0	0	0	0	0	0	0	0	0	0	0	0	0
5f	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0.55	0	0	0	0	0	0	0	0	0.21	0	0	0	0	0	0	0	0	0	0	0	0	0
5g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0	0	0	0.55	0	0	0	0	0.17	0	0	0	0	0	0	0	0
6b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.27	0	0	0	0	0	0	0	0.04	0.11	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24	0.27	0	0	0	0	0	0	0	0.16	0.13	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.26	0.28	0	0	0	0	0	0	0	0.15	0.15	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0.23	0	0	0	0	0	0	0	0.17	0.12	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.36	0	0	0	0	0	0	0	0	0.19	0	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0	0	0.55	0	0	0	0
7b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.22	0	0	0	0	0	0	0
7c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0.26	0	0	0	0	0	0
7d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.30	0.29	0	0	0	0	0
7e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0.24	0	0	0	0
7f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.38	0	0	0	0
7g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Two years after harvest (**H2**)

b. *Daemonorops cf. poilanei*

Category at $t+1$	1	2	3	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i	7a	7b	7c	7d	7e	7f	7g	7h	7i
	Category at t																																			
1	0	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0.15	0	0	0
2	0	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.52	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.32	0	0	0	0.28	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.53	0.06	0.40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.10	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.22	0.20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.30	0.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.29	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.27	0	0	0	0	0	0.40	0	0	0	0.29	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5b	0	0	0	0.05	0.33	0	0	0	0	0.08	0.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	0	0	0	0.08	0.23	0	0	0	0	0.17	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5d	0	0	0	0	0	0.19	0.16	0	0	0	0	0.30	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5e	0	0	0	0	0	0	0.25	0.18	0	0	0	0	0.39	0.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5f	0	0	0	0	0	0	0	0.24	0.20	0	0	0	0	0.37	0.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5g	0	0	0	0	0	0	0	0	0.22	0	0	0	0	0	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0.19	0	0	0	0	0	0	0	0	0.39	0	0	0	0.29	0.29	0	0	0	0	0	0	0	0	0	0	0	0
6b	0	0	0	0	0	0	0	0	0	0	0.21	0	0	0	0	0	0	0	0.09	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0.08	0.15	0	0	0	0	0	0	0	0.26	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0.14	0.11	0	0	0	0	0	0	0	0.34	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0.12	0	0	0	0	0	0	0	0.40	0.26	0	0	0	0	0	0	0	0	0	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.14	0	0	0	0	0	0	0	0.37	0.29	0	0	0	0	0	0	0	0	0	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0	0.34	0	0	0	0	0	0	0	0	0	0	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0.57	0	0	0	0.29	0.29	0	0	0
7b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.17	0	0	0	0	0	0	0	0.14	0.44	0	0	0	0	0	0	0
7c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.12	0.14	0	0	0	0	0	0	0	0.49	0.38	0	0	0	0	0	0
7d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.11	0	0	0	0	0	0	0	0.55	0.32	0	0	0	0	0
7e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.19	0.12	0	0	0	0	0	0	0	0.61	0.37	0	0	0	0
7f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0.14	0	0	0	0	0	0	0	0.56	0.42	0	0	0
7g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0	0.51	0	0	0
7h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Three years after harvest (**H3**)

b. *Daemonorops cf. poilanei*

Category at $t+1$	Category at t: 1	2	3	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	5e	5f	5g	5h	5i	6a	6b	6c	6d	6e	6f	6g	6h	6i	7a	7b	7c	7d	7e	7f	7g	7h	7i
1	0.17	0	0	0	0	0	0	0	0.15	0	0	0	0	0	0.15	0.53	0	0	0	0	0	0	0	0.15	0.53	0	0	0	0	0	0	0	0.15	0.53	0	0
2	0.15	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.52	0.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4a	0	0	0	0.53	0	0	0	0.36	0.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4b	0	0	0.53	0.10	0.56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4c	0	0	0	0	0.25	0.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4d	0	0	0	0	0	0.43	0.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4e	0	0	0	0	0	0	0.55	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4f	0	0	0	0	0	0	0	0.56	0.34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5a	0	0	0	0.05	0	0	0	0	0	0.50	0	0	0	0.37	0.37	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5b	0	0	0	0.01	0	0	0	0	0	0.10	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	0	0	0	0	0.04	0	0	0	0	0.29	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5d	0	0	0	0	0	0.04	0.03	0	0	0	0	0.44	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5e	0	0	0	0	0	0	0.05	0.03	0	0	0	0	0.53	0.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5f	0	0	0	0	0	0	0	0.05	0.03	0	0	0	0	0.54	0.32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5g	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0.49	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0.45	0	0	0	0.37	0.37	0.37	0	0	0	0	0	0	0	0	0	0	0
6b	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0.10	0.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6c	0	0	0	0	0	0	0	0	0	0	0.05	0.06	0	0	0	0	0	0	0	0.36	0.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6d	0	0	0	0	0	0	0	0	0	0	0	0.08	0.05	0	0	0	0	0	0	0	0.44	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6e	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.05	0	0	0	0	0	0	0	0.50	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0
6f	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.09	0	0	0	0	0	0	0	0.50	0.29	0	0	0	0	0	0	0	0	0	0	0	0
6g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.06	0	0	0	0	0	0	0	0.45	0.33	0	0	0	0	0	0	0	0	0	0	0
6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0.41	0	0	0	0	0	0	0	0	0	0	0
6i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0	0	0	0	0	0	0	0	0.57	0	0	0	0.37	0.37	0.37	0	0
7b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.10	0	0	0	0	0	0	0	0.14	0.34	0	0	0	0	0	0	0
7c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.10	0.09	0	0	0	0	0	0	0	0.56	0.34	0	0	0	0	0	0
7d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0.07	0	0	0	0	0	0	0	0.61	0.30	0	0	0	0	0
7e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0.07	0	0	0	0	0	0	0	0.66	0.31	0	0	0	0
7f	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0.08	0	0	0	0	0	0	0	0.65	0.37	0	0	0
7g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0.10	0	0	0	0	0	0	0	0.59	0.43	0	0
7h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.12	0	0	0	0	0	0	0	0	0.53	0	0
7i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All rattan stems bought by a middle man are gathered

Splitting stems into strings for weaving

6

Chapter 6

General discussion and summary

Forests, NTFP and rattans in Vietnam

In Vietnam, forest ecosystems are the most diversified systems in terms of species composition and genetic resources, both in flora and fauna. Forest types are ranging from tropical forest, mangrove, limestone and bamboo forest to conifer and subtropical forests (Chapter 2). Vietnam is located on the crossroads of three different floral regions which have their centers in China, the Himalayas and Indonesia. Due to this geographical setting Vietnam is one of the most biodiverse countries in Southeast Asia (MoF 1995).

The forests of Vietnam have considerably reduced over the last century in both quantity and quality due to many reasons, such as 30 years of wars, shifting cultivation, transformation of forests and forest land into agricultural land and other land use patterns, overexploitation and an increasing population (Chapter 2). The forest cover in the country declined from 43% of the total land area in 1943 to 27.8% in 1990 and gradually increased to 38% in 2006 (Forest Department 2007). The quality of natural forests is generally low due to a long period of degradation. The roles of forests in economic development, biodiversity and environmental protection and climate change mitigation have been increasingly acknowledged by policy makers, foresters and the Vietnamese society in general. Several re-greening, afforestation and forest protection programmes have been proposed and executed. The Five Million Hectare Reforestation Programme that was launched in 1998 by the Government was one of the most ambitious and has considerably contributed to increased reforestation and forest restoration and to improved forest management.

The concern about the rapid loss and degradation of tropical forests in general has caused recognition of the importance of non-timber forest products (NTFP) in the tropics (Myers 1984, de Beer and McDermott 1989, Peters et al. 1989). It is increasingly acknowledged that the exploitation of NTFP has played an important role in the conservation and management of tropical forests (Nepstad and Schwartzman 1992, Wegge 1993), while at the same time it contributed to the livelihood of rural people in tropical regions. An exploitation system of

NTFP is considered sustainable when it is ecologically sustainable, economically feasible and socially acceptable (Ros-Tonen et al. 1995, Peters 1996, Zuidema 2000, Ticktin 2004).

In Vietnam, the natural forests are rich in NTFP-yielding species, which have been collected and used since centuries by rural people for subsistence and trade. NTFPs are used for food, drug and medicine, handicrafts, fuel, fodder, construction materials and others (Chapter 2). Like all forest resources, NTFP resources have become scarce at the end of 20th century and some NTFP-yielding species are at their margin of extinction (FSSP 2006) due to overexploitation and increased population pressure (Chapter 2). In order to manage and conserve NTFP resources, the ongoing Five Million Hectare Reforestation Programme contained a component focusing on NTFP. In about 10% of the total reforestation area under this programme (580,000 ha) NTFP-yielding species will be planted. At present, both in-situ and ex-situ conservation for NTFP are applied in Vietnam. In-situ conservation is applied for NTFP species in protected areas, while ex-situ conservation is applied mainly with species of high economic value in both protection and production forest areas.

Rattan is the most important forest product after timber and bamboo in Vietnam. Their length, strength, durability, flexibility and uniformity make rattan stems a versatile source of raw material (Sunderland and Dransfield 2002). Vietnam harbours at least 36 species of rattans, belonging to 6 genera (Henderson 2009). Ten species of rattans are most frequently harvested; their utilization and characteristics are discussed in Chapter 2. Rural people used rattans for centuries in a many ways for subsistence and for sale. The rattan industry developed rapidly in the late 1970s, mainly involving the production of furniture and handicraft for export. The industry provides currently labour to 100,000 people in harvesting and processing (Dzung 2001, FAO 2002).

Rattans are climbing palms (Arecaceae) that grow throughout Southeast Asia, forming a characteristic component of many forest types (de Beer and McDermott 1989). Two basic growth habits can be distinguished among rattans: solitary and multi-stemmed. In single-stemmed rattans, no re-sprouting occurs after harvesting, while in clumped species the individual stems can be cut from the clumps without effect on survival of clumps (de Beer and McDermott 1989, Dransfield and Manokaran 1994, Sunderland and Dransfield 2002).

An increase in demand on rattan products for domestic consumption and for export has led to substantial overexploitation of the natural rattan resources at a large scale. In order to overcome the shortage of raw material, the Government has planned 80,000 hectares of rattan plantation under the Five Million Hectares Reforestation Programme and encouraged rattan cultivation in home gardens and enrichment planting in forests (Chapter 2). Research on rattans has been expanded in terms of propagation, seed source improvement and silvicultural techniques for plantation of some rattans.
However, in order to sustainably manage and use existing rattan resources in natural populations, harvesting guidelines should be established in Vietnam. Clearly, efforts should be paid to gather information that assists in effectively protecting and utilizing natural rattan populations. This study was therefore carried out with the goal of contributing to the basic knowledge that is required to design sustainable management systems for rattan in Vietnam. Three species: *Calamus platyacanthoides*, *C. rhabdocladus* and *Daemonorops cf. poilanei* were studied in natural populations during a period of three years.

Determinants of rattan growth, survival and reproduction

Like many other rattan species, *Calamus platyacanthoides*, *Calamus rhabdocladus* and *Daemonorops cf. poilanei* have a clustered growth form in which stems (ramets) are clustered in a clump (genet). In these clustered species, stems tend to remain connected to the rest of the clump throughout their lives and share a common root system (Eriksson 1993, Dransfield and Manokaran 1994, Araki and Ohara 2008). Characteristics of the study species are given in Table 1 and more details are provided in Chapter 3. I quantified the vital rates (growth, survival, reproduction) and evaluated the determinants of the vital rates of the three study species in natural populations. Such basic information is important to understand the functioning of the species and in addition, it is much needed for planning sustainable management and utilization of these rattans resources in wild. I analyzed data of a three censuses with intervals of one year, measuring 340-530 individuals per species. Linear, non-linear and logistic regression models to relate vital rates to total height, stem length, gender, light availability and clump size were used for these purposes (Chapter 3).
The results showed that the survival probability of shoots increased with shoot height in *C. rhabdocladus* and *D. cf. poilanei*, while no relation was found in

C. platyacanthoides. Shoot survival was unrelated to clump size or light availability for all study species. It was found that stem survival of the study species was not related to stem length, clump size or light availability (Chapter 3).

Stem growth greatly differed within and among the three study species. But the general pattern was similar in the species: growth rate increased with size up to c. 10 m and then leveled off or declined. Stem growth was affected by three factors: initial stem length, clump size and light availability. The influence of each factor changed depending on initial stem length in all study species. In short, in all species initial stem length or initial shoot height and clump size were most important for shoots and small stems (< 3 m), while light availability was most important for large stems (> 10 m). In juvenile stems (3-10 m) initial stem length and light availability were most important for stem growth. The effect of clump size on stem growth gradually declined with increasing stem length and no effects were found for stems > 10 m, while the effect of light availability gradually increased with longer stems for all three species (Chapter 3).

The study species reproduced sexually and clonally in all study years. Vegetative reproduction increased with clump size for all species. 50% of the clumps with 5 stems and almost all clumps with 10 stems produced shoots annually in the study species. The onset of sexual reproduction positively related to stem length (8-10 m for all species) and was not dependent on clump size. The flowering probability of male was higher than that of female at a given stem length in *C. rhabdocladus* and *D. cf. poilanei*, and male to female ratios were > 1 for all three study species (Chapter 3).

Using matrix models to analyse rattan demography

Matrix population models were used to analyse the population dynamics of the study species. Matrix models have a standard form which can be adjusted depending on the focal species or researcher's purposes. For the clustered rattan species, multi-state matrix models were constructed in which ramets (stems) are categorized by their own size andthat of the genet (clump) to which they belong (the same as ramet-within-genet matrix models). I quantified the vital rates (survival, growth and sexual and vegetative reproduction) for the study species and used these to estimate matrix elements (stasis, progression, retrogression and sexual and vegetative reproduction) in order to construct matrix models (Chapter 4).

Table 1. Summary of characteristics of the three rattan species studied in this PhD research. Information on habit, habitat, growth form, sizes, growth rates and harvesting impact are included. All information is taken from Chapters 3, 4 and 5. Data were collected in Bach Ma National Park, Central Vietnam. Mean values +/- standard deviation.

Species	*Calamus platyacanthoides*	*Calamus rhabdocladus*	*Daemonorops cf. poilanei*
Growth habit	Climbing with cirri, knee conspicuous	Climbing with flagella, no knee	Climbing with cirri, knee conspicuous
Habitat	Evergreen forests	Evergreen forests	Evergreen forests
Elevation	400-900 m	600-800 m	400-700 m
Max # of stems per clump	10-12	20-25	50-60
Max stem length (m)	> 30	40	50
Stem diameter (mm)	20-50	20-25	15-25
Internodes length (cm)	15-25	9-13	20-30
Max leaf length	2-3 m plus a cirrus	1-2 m	1-2.5 m plus a cirrus
Max # leaflets on one side and arrangement	30, interrupted and grouped	70, regular or interrupted	60, regular
Inflorescence	> 1.5 m, no flagellum	2-4 m plus flagellum	> 1 m, no flagellum
Max stem growth (m yr^{-1})	2.7	1.6	3.3
Max # new shoots produced per clump (yr^{-1})	2	4	13
# harvestable stems at 1st harvest (ha^{-1})	28 ± 11	38 ± 12	56 ± 22
$\sum$ stem length at 1st harvest (m ha^{-1})	313 ± 129	371 ± 109	751 ± 240
$\sum$ stem length available at 2nd harvest after 15 years	-	570	2447
Uses	Stem: handicrafts, furniture; Shoot edible	Stem: furniture, sticks; Shoot edible; Leaves used as thatch	Stem: handicrafts, furniture;Shoot edible; Leaves used as thatch

I used the output of the matrix models that indicates the population growth (λ) to project future prospects of the species: the population is growing if $\lambda > 1$ and decreasing if $\lambda < 1$. For the three species: *Calamus platyacanthoides*, *C. rhabdocladus* and *Daemonorops cf. poilanei*, evidence of increasing populations was found ($\lambda > 1$). The populations of these species are therefore expected to be increasing overtime. Especially in *D. cf. poilanei* the population grows relatively fast (λ =1.068). Many factors influence population growth rates, including uncertainties in parameter estimation, differences in growing conditions between years and recovery from previous disturbances. Although it is impossible to tell from the results which factor has been responsible for the λ values above 1, it is likely that the study populations were recovering from previous heavy exploitation. Forests resources (timber, rattans and other NTFP) in the area which is currently protected were heavily exploited until 1991 when the park was established. Since that date, no harvests were carried out in the area and the rattan populations may be recovering from the historical harvesting and disturbances of the forest.

The output of the matrix models indicated that stem survival was most important for the population growth, followed by growth and reproduction. Similar results have been found for other rattans, clonal palms and long-lived plant species (Bogh 1995, Bernal 1998, Zuidema 2000, Guedje et al. 2003, Franco and Silvertown 2004, Souza and Martins 2006, Zuidema et al. 2007, Kouassi et al. 2008). Vegetative and sexual reproduction contributed very little to the population growth rate (Chapter 4).

The model output also indicates the importance of life stages to the population growth rate (elasticity analysis), allowing for a more detailed analysis of the roles of ramets in different-sized genets. For *C. platyacanthoides*, the dynamics of stems in small and medium clumps are more important for λ than that in large clumps, while stems in big clumps are more important for λ than those in small and medium clumps in *C. rhabdocladus* and *D. cf. poilanei* (Chapter 4).

To quantify the contribution of clonal support to λ, growth elasticities were decomposed to elasticities of growth by clonal support (e_{NrSt}) and by stem length ($e_{St\ length}$). It was found that the contribution of clonal support to population growth was high for shoots and small stems in comparison with large stems in the three species (Chapter 4). Among the three species, the contribution of clonal support to λ was highest in *C. rhabdocladus*. The demographic significance of clonal support was also anlysed by setting the parameter of clump support to stem growth to zero in the regression equations that were used to construct matrix models. The results from these transition matrices showed considerably lower λ values, and λ < 1 was found for two *Calamus* species. The total elasticity of clonal support to λ is even higher than that of both vegetative and sexual reproduction in the three study species (Chapter 4). This implies that large clumps are important for the population dynamics of the clustered rattans studied in order to reach stability at a certain density.

I performed loop analysis to quantify the relative contribution of vegetative and sexual reproduction modes to the population growth rates of the three species. Although the study species have a complex life cycle graph and many loops did not have a unique loop element, by using new algorithms introduced by Guneralp (2007) it was possible to carry out loop analysis. The results showed that for *C. platyacanthoides* loop elasticity of sexual reproduction was higher than that of vegetative reproduction; thus sexual reproduction is important for λ of the species. In contrast, for *C. rhabdocladus* and *D. cf. poilanei* vegetative reproduction contributed more to λ than sexual reproduction. It was found that the largest stems within large and medium-sized clumps were the most important for reproduction in the three study species (Chapter 4).

Using matrix models to assess impacts of harvesting

NTFP harvesting affects individuals, populations, communities and ecosystems (Ros-Tonen et al. 1995, Ticktin 2004). At the level of the individual plant, the plant parts harvested, harvest pattern and intensity determine the impacts on individual plant performance. In a review on NTFP harvesting impact, Ticktin (2004) showed that there were about 70 studies dedicated to reveal the ecological impacts of NTFP harvesting. Surprisingly, just two of those studies considered the impact of rattan harvesting (Van Valkenburg 1997, Siebert 2004), in spite of the fact that rattan is one of the most important NTFP traded worldwide. So far, no study has projected future rattan availability under distinct harvesting regimes.

In this study, impacts of harvesting on *C. rhabdocladus* and *D. cf. poilanei* were studied during 3 years at individual and population levels (Chapter 5). The harvesting experiment was conducted in parallel with a demographic study in undisturbed populations. The harvesting treatment consisted of cutting all ramets ≥ 6 m stem length in the first year of this study. This treatment mimicked current harvesting practices in Vietnam.

At the individual level, the impact of the harvest on vital rates differed across the three measurement years following harvesting in both species (Chapter 5). Survival of the remaining stems was negatively affected in the first year after harvest in both species, but remained unaffected in the second and third year. Survival of the remaining stems increased strongly in the 2nd and 3rd year after harvesting, but this was less the case for shoots. This difference may be explained by the fact that during the harvesting process young stems were cut or damaged when people accessed the large stems (personal observation).

Negative effects on the growth of shoots and stems were found in the first and the second year in *C. rhabdocladus* and in the first year in *D. cf. poilanei*. No effect on growth was found in the third year in either species. Stem harvesting positively affected vegetative reproduction in the first year, while the reverse was found in the second year. In the third year no effect on vegetative reproduction was found in *C. rhabdocladus* and a negative (but smaller) effect was found in *D. cf. poilanei*. Sexual reproduction was more strongly affected by stem harvesting: during the first year, no inflorescences were produced in both species as all reproductive stems were harvested. In the 2nd and 3rd year new reproductive stems appeared, and no impact of harvesting on the relation between stem length and reproductiveness was found. It should be noted that the impact of harvesting on sexual reproduction may be underestimated as we did not include information on the impact of harvesting on seed output per infructescence. Overall, harvesting has negative impacts on the vital rates of the study species.

To assess the impacts of harvesting at population level, I also constructed multi-state matrix population models for harvested population of *C. rhabdocladus* and *D. cf. poilanei* during the first (**H1**), second (**H2**) and third (**H3**) year after harvest. Matrix models of undisturbed populations were used as a control (**C**) for the experiment (Chapter 4). Harvest simulations were carried out with the same intensities (100% of stems ≥ 6 m length were cut) at different lengths of the harvest cycle (1, 5, 10 and 15 years). Simulation always started with a harvest, which was then repeated every 1, 5, 10 and 15 years, for a period of 30 years (Chapter 5). The impact of harvest regimes was assessed both for total population size and for the abundance of harvestable stems for the four harvest regimes.

The results showed that the population growth rates of harvested populations were lower than those for an undisturbed population in the two species. The population of *C. rhabdocladus* increased during the third year after harvesting, while in *D. cf.*

poilanei the population still decreased in three years after harvesting (Chapter 5). The effects of harvesting on λ were relatively large in both species in comparison to those of defoliation treatments applied to other palm species (Pinero et al. 1984, Mendoza et al. 1987, Anten et al. 2003, Endress et al. 2004, Chazdon 1991, Zuidema et al. 2007). This is probably due to the fact that the survival probability was altered as a result of stem harvesting while the survival of defoliated palms was less affected by defoliation.

The populations of *C. rhabdocladus* and *D. cf. poilanei* decreased under all harvest regimes, except for the one that allows 15 years of recuperation between successive harvests. In that case, the *D. cf. poilanei* was projected to increase. For both species, shorter harvesting cycles caused trajectories of harvested populations to deviate more from that of an undisturbed population, indicating population declines relative to the undisturbed situation. Very strong reductions were found when harvests were repeated every year in both species (Chapter 5). This is the current status of rattan harvesting practice in Vietnam.

The impact of harvesting on the availability of rattan resources depends on harvesting regimes. Short harvest cycles (every year, or every 5 years) have severe impacts on the populations, leading to depletion of rattan resources (Chapter 5). The abundance of harvestable stems and harvestable stem length recovered to the initial sizes only under a harvesting regime of 15 years in *C. rhabdocladus* and harvesting regimes of 10 and 15 years in *D. cf. poilanei*, with even higher number of harvestable stems compared to the initial population.

Sustainable harvesting, conservation and management of rattan resources

To manage and conserve any population effectively, three main ecological questions have to be answered (in addition to political and socio-economic issues): i) what are the ecological impacts of harvest?; ii) what are the mechanisms underlying these impacts?; and iii) what kinds of management practices should be applied in order to reduce negative impacts or promote positive impacts? (Ticktin 2004). The last question can only be addressed when the first two questions have been answered. In this study, the first two questions were addressed in Chapters 3, 4 and 5 for the study species. Although the third question was not directly answered here, results from this study suggests that 1) creating artificial gaps (by girdling technique) to the increase light availability should be applied to promote rattan stem growth; 2) during harvesting care should be taken to reduce the negative impact on survival of remaining stems by protecting small stems from being cut. These shoots and stems provide the harvest of the future, and should be treated with care; 3) the remaining stems recover much better if a lower harvest intensity and longer harvest cycle are applied (not 100% stems ≥ 6 m length are to be cut and not harvest every year as presently is practice); 4) the harvest cycle for *Calamus rhabdocladus* and *Daemonorops cf. poilanei* should be 15 years in natural populations without silvicultural application after harvesting.

The harvesting techniques applied in the exploitation of rattan have an impact on the vital rates of the remaining stems within a clump, particularly for large clustering species as *D. cf. poilanei* (Siebert 2004, personal observation). In many cases, all of the stems in a clustering species may be cut in order to obtain assess to the mature stems, even those that are too young for exploitation and sale (Sunderland and Dransfield 2002). Therefore, harvesting guidelines for rattans should be issued and put into practices as a management and conservation measure for rattan resources in Vietnam.

If, in natural forests, rattans can be harvested in a careful and responsible way from natural populations rattan harvesting may be certified as sustainable forest management (Viana et al. 1996, Sunderland and Dransfield 2002). Most rattans require support and climbing opportunities for their stems. Thus, any management of rattan resources, also requires managing a multilayered forest itself (Sunderland and Dransfield 2002). Most rattans cannot grow outside such a forest system. Certification may create incentives for improved management and beneficial social practices (Shanley et al. 2002).

Sustainable harvesting is not only necessary for the conservation of the species but also for the livelihoods of the local people (Ticktin 2004). The chains of custody are complicated for rattans harvested from the wild (Belcher 1999), and in Vietnam this is dominated by a number of middle men which prevent an equitable distribution of the benefits (Dzung 2000, Sunderland and Dransfield 2002). The high demands for rattan products suggest that additional costs incurred from certification could be absorbed by consumers who pay a green premium for certified products (Shanley et al. 2002).

It is clear that the highly valued rattans are overharvested, which has resulted in serious declines of certain species (de Beer and McDermott 1989, Dransfield and Manokaran 1994, Dzung 2001, FAO 2002, Sunderland and Dransfield 2002). Thus, there is an urgent need to develop rattan management regimes that guarantee that rattan resources are sustained. However, long term in-situ management of rattans in the wild is very rare (Belcher 1999). In Southeast Asia, ex-situ management was carried out during the last decades (e.g. rattan plantations or cultivation in agroforestry systems) and proved successful when resource tenure is clear, active involved in management of local communities and their benefits are ensured (Belcher 1999, Sunderland and Dransfield 2002, Ticktin 2004). Therefore, the design of sustainable rattan management systems in wild populations requires attention not only from research institutes and conservation organizations but also from policy makers and local communities or harvesters.

Recommendations for further research

In Vietnam, for the sustainable rattan development, further research is recommended as follows:

Rattan populations in the wild:

1. An inventory in details dealt with rattan species should be made at national level, including measurement of basis parameters (e.g. number of stems per clump, number of stems and clumps per hectare, total stem length and harvestable stem length). Currently, 36 species are indentified but it is expected that about 50 rattan species occur in Vietnam (Nghia et al. 2000). Such inventories are important for conservation and development of commercial rattan species.
2. Establishing research areas for rattans in order to determine vital rates (growth, survival, fecundity and recruitment) at individual- and population-levels over time, especially for the important commercial species (Chapter 2). This will provide basic ecological information for sustainable harvesting and management.
3. Identifying and testing management techniques (including harvesting techniques and harvest regimes) for rattans in natural populations, especially the highly valued species.
4. Promoting trials on natural regeneration of rattan through enrichment planting in natural forest. This will provide technical guidelines for management and development of rattan resources in the reforestation areas under the Five Million Hectares Reforestation Programme.

Rattan cultivation

1. Promoting propagation techniques to permit large-scale production of planting material for establishing plantations. There is an urgent need to carry out seedling improvement for *Calamus tetradactylus* (in Tu Ly district, Hoa Binh province), *C. poilanei*, *C. platyacanthoides* (in Quang Tri, Thua Thien Hue and Gia Lai provinces), and *C. rudentum* (in Cat Tien National Park and Dong Nai province). If this is not established soon, there will not be enough seed sources to promote rattan plantation in the future.
2. Identifying and testing cultivation and management techniques for the economic cultivation of rattan at the village level (home gardens) and on a commercial scale.
3. Developing appropriate techniques and harvest regimes for rattan harvesting and processing including post-harvest protection, and for improving economic value of processed rattan products.

The three study species

1. It would be useful to conduct similar experiments with varying harvest intensities (e.g. 25%, 50% or 75%) in order to better understand the responses of individuals to their vital rates and population dynamics after the harvest.
2. Impact of repeated harvesting with different intensities and cycles for the three species should be carried out.
3. Impact of harvesting on *C. platyacanthoides* should be evaluated.
4. It is suggested to assess the effects of harvesting on the community and ecosystem levels for the study species as sustainability at one level may or may not be the same as sustainability at another level (e.g. effect on nutrient cycling after harvesting).
5. Identifying and testing management techniques to reduce negative impacts of harvesting on the remaining populations (e.g. fertilizer applications or opening up the canopy).

In conclusion, the three study rattan species are relatively fast growing (1.5 – 2.8 m yr^{-1} in stem length) and high yielding and can be harvested at relatively short time intervals (15 years) in comparison with timber species. This allows for relatively short to medium-scale returns for local people involved in rattan management.

Sustainable harvesting and management of rattan resources in natural populations should be considered as a measure for conservation and management of tropical forests, while at the same time contributing to the livelihood of rural people.

Acknowledgements

I would like to thank Marinus Werger, Pieter Zuidema and Ha Chu Chu for valuable comments on a draft version of this chapter.

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Samenvatting

Vietnamese Rotans: ecologie, demografie en oogst

Vietnam is het trefpunt van drie biogeografische regio's, die hun centra in respectievelijk China, de Himalaya en in Indonesië hebben. Vandaar dat Vietnam qua biodiversiteit een van de rijkste landen van Zuidoost-Azië is.

Bossen zijn de soortenrijkste ecosystemen van het land, zowel qua planten als dieren. Vietnam heeft tropische wouden, mangrovebossen, bossen op kalksteen en bamboebossen. Maar de bossen in Vietnam zijn de afgelopen eeuw hard in kwaliteit en in oppervlakte achteruit gegaan, vooral als gevolg van tientallen jaren oorlog, zwerflandbouw, het rooien van bossen om er landbouwgrond van te maken, kortom door overexploitatie en sterke bevolkingsgroei (Hoofdstuk 2). Het totale bosoppervlak nam af van 43 % van Vietnam in 1943 tot 27,8 % in 1990 en is sindsdien weer toegenomen tot 38 % in 2006. Tijdens de afgelopen decennia heeft Vietnam verscheidene herbebossingsprogramma's gestimuleerd en bosbeschermingsmaatregelen genomen. Een van de belangrijkste daarvan is het 'Vijf Miljoen Hectare Herbebossingsprogramma' dat in 1998 van start is gegaan.

Doordat men oog kreeg voor de snelle achteruitgang en vernietiging van de tropische wouden heeft men ingezien dat 'niet-hout bosprodukten' ('non-timber forest products', NTFP) een belangrijke rol in de bescherming van de wouden kunnen spelen. Tegelijkertijd zijn NTFP heel belangrijk voor het levensonderhoud van de bevolking op het platteland. NTFP hulpbronnen kunnen verantwoord geëxploiteerd worden als dat ecologisch duurzaam gebeurt, het economisch haalbaar is en het sociaal geaccepteerd wordt.

De Vietnamese bossen zijn rijk aan soorten die NTFP leveren en ze worden al eeuwenlang door de plattelandsbevolking voor voedsel, geneeskrachtige middelen, vlechtwerk, brandstof, bouwmateriaal , etc. gebruikt (Hoofdstuk 2). Maar zoals met alle bosprodukten het geval was, tegen het eind van de 20e eeuw werden de bronnen voor NTFP schaars en sommige soorten staan op uitsterven, omdat ze overbenut zijn. Om dat tegen te gaan bevat het 'Vijf Miljoen Hectare Herbebossingsprogramma' een speciaal programmapunt dat zich op NTFP richt: op 580 000 ha, dus op ongeveer 10 % van het herbebossingsareaal, worden NTFP-soorten geplant. Ook worden NTFP-soorten beschermd, zowel in situ in beschermde gebieden, als ex situ, en dat vooral voor soorten met een grote economische waarde, in beschermde bossen als wel in produktiebossen.

Rotan is het belangrijkste Vietnamese bosprodukt na hout en bamboe. Er komen op zijn minst 36 soorten rotan, behorende tot 6 genera, in Vietnam voor. Tien ervan worden het meest geoogst. Het gebruik en de kenmerken van deze soorten worden in Hoofdstuk 2 besproken.

Hoewel rotans al eeuwenlang gebruikt worden, is de rotanindustrie vooral tegen het eind van de jaren zeventig sterk gegroeid. Op het ogenblik werken er ongeveer 100 000 mensen in deze industrie in Vietnam.

Rotans zijn klimmende palmensoorten (Arecaceae). Ze zijn typisch voor de tropische wouden van Zuidoost-Azië. Men onderscheidt twee groeivormen: rotans die met een enkele stam groeien en rotans die met veel stammen in een 'pol' groeien. De rotans die met een enkele stam groeien lopen niet meer uit nadat ze geoogst zijn, maar de veelstammige soorten vormen snel nieuwe stammen als er oude stammen geoogst worden.

De toenemende vraag naar rotan, zowel in als buiten Vietnam, heeft tot een flinke over-exploitatie van de natuurlijke rotan populaties geleid. Om aan de vraag naar rotan te kunnen voldoen heeft de regering van Vietnam in totaal 80 000 ha rotanplantages binnen het 'Vijf Miljoen Hectare Herbebossingsprogramma' voorzien, stimuleert ze het verbouwen van rotansoorten op particuliere stukjes grond en bevordert ze de rotanproduktie ook door in bestaande wouden bij te planten (Hoofdstuk 2). Ook wordt er steeds meer onderzoek naar de groei en produktie van rotansoorten gedaan.

Maar er zijn oogstrichtlijnen nodig om de natuurlijke rotanpopulaties in Vietnam duurzaam te laten voortbestaan. En om die te formuleren is er meer kennis over de groei en dynamiek van rotanpopulaties nodig. Met het oog daarop is dit drie-jarig onderzoek naar drie Vietnamese rotansoorten, *Calamus platyacanthoides*, *Calamus rhabdocladus* en *Daemonorops cf. poilanei*, uitgevoerd.

Groei, overleving en reproduktie van rotans

Calamus platyacanthoides, *Calamus rhabdocladus* en *Daemonorops cf. poilanei* zijn veelstammige rotansoorten waarvan de stammen ('ramets') in een pol ('genet') groeien. In dergelijke pollen blijven de stammen steeds met elkaar verbonden en hebben ze een gezamenlijk wortelsysteem. Hoofdstuk 3 beschrijft de kenmerken van de drie soorten.

Ik onderzocht de 'vital rates' (groei, overleving, reproduktie) in natuurlijke populaties van deze drie soorten en analyseerde waardoor die bepaald worden. Ik heb de populaties drie jaar lang, steeds met een interval van 1 jaar, geinventariseerd, waarbij ik 340 – 530 individuen per soort onderzocht en ik gebruikte lineaire en non-lineaire en logistische regressiemethoden om de gegevens te analyseren.

Naarmate de jonge scheuten hoger werden nam de kans op overleven in *C. rhabdocladus* en *D. cf. poilanei* toe, maar er was niet zo'n verband in *C. platyacanthoides.* De grootte van de pol of de hoeveelheid beschikbaar licht had geen invloed op de overleving van de stammen (Hoofdstuk 3). Ondanks onderlinge verschillen nam bij alle soorten de groeisnelheid met toenemende lengte van de stam toe tot dat de stamlengte ongeveer 10 m bereikt had. Bij alle drie soorten nam de groei van erg jonge stammen (tot 3 m lengte) toe naarmate de beginlengte van de jonge scheut of stam groter was en de pol groter was, terwijl dat voor stammen die al langer dan 10 m waren gold als de lichtbeschikbaarheid beter was. Bij alle drie soorten had polgrootte geen effekt meer op stammen van meer dan 10 m, terwijl het effekt van een beter lichtklimaat steeds belangrijker werd.

Alle drie soorten maakten elk jaar zowel vegetatief als generatief nieuwe nakomelingen. De vegetatieve reproduktie nam met de polgrootte toe, de generatieve reproduktie niet; die begon aan stammen die tenminste 8 m lang waren (Hoofdstuk 3).

Rotan demografie

Met behulp van zogenaamde 'multi-state matrixmodellen' bestudeerde ik de populatiedynamica van de drie rotansoorten. Bij alle drie soorten bleken de populaties te groeien ($\lambda > 1$). Het is niet mogelijk is om nauwkeurig aan te geven welke faktoren het meest bijdragen aan deze groei van de populaties, maar het lijkt er erg op dat ze zich aan het herstellen zijn van een intensieve exploitatie in de periode voor 1991, toen het gebied waarin ze groeien nog niet beschermd werd.

De matrixmodellen gaven aan dat overleven het meest bijdroeg aan de populatiegroei, gevolgd door groei en reproduktie: zowel vegetatieve als generatieve reproduktie droegen weinig bij (Hoofdstuk 4).

Uit elasticiteitsanalysen bleek dat bij *C. platyacanthoides* de dynamica van de stammen in de kleine tot middelgrote pollen λ in belangrijker mate bepaalden dan die van de grote pollen, terwijl dat bij de beide andere soorten net andersom was. Voor de groei van de populaties bleek vooral 'clonale steun' voor jonge scheuten en nog korte stammen heel belangrijk, en dit effekt was het sterkst in

C. rhabdocladus. Op grond van de elasticiteitsanalysen concludeer ik dat voor de veelstammige rotans grote pollen belangrijk zijn om een stabiele populatie met een bepaalde dichtheid op te bouwen.

Ik onderzocht de bijdragen van vegetatieve en generatieve reproduktie aan de groei van de populaties door middel van 'loop analysis'. Het bleek dat in *C. platyacanthoides* de generatieve reproduktie belangrijk was voor de populatiegroei, maar in de beide andere soorten bleek vegetatieve reproduktie belangrijker. Bij alle drie soorten droegen de langste stammen in grote en middelgrote pollen het meest bij aan de reproduktie (Hoofdstuk 4).

Het effekt van oogsten

Het oogsten van NTFP heeft gevolgen voor individuele planten, populaties en ecosystemen. Voor individuele planten zijn de gevolgen afhankelijk van welk deel van de plant er geoogst wordt, het patroon en de intensiteit van het oogsten. Uit een overzichtsstudie naar de gevolgen van het oogsten van NTFP bleek dat er zo'n 70 studies waren die zich met de ecologische gevolgen ervan bezighielden en slechts 2 ervan behandelden de gevolgen van het oogsten van rotan, terwijl het wereldwijd een van de belangrijkste NTFP is. Er bestaat tot nog toe geen ander onderzoek dat zich richtte op de toekomstige beschikbaarheid van rotan onder verschillende oogstscenario's.

In mijn onderzoek heb ik de gevolgen van het oogsten van stammen van *C. rhabdocladus* en *D. cf. poilanei* op individueel en populatieniveau bestudeerd, waarbij ik de gevolgen van een experimentele oogst 3 jaar lang parallel aan het demografisch onderzoek in ongestoorde populaties gevolgd heb. Bij de oogst werden aan het begin van het onderzoek alle ramets van meer dan 6 m stamlengte verwijderd, net zoals dat momenteel bij commerciële oogsten in Vietnam ook gebeurt (Hoofdstuk 5).

Op individueel niveau bleek, bij beide soorten, het oogsten de overleving van de overblijvende stammen gedurende het eerste jaar na de oogst negatief te beïnvloeden, maar daarna was het effekt in sterke mate positief. Waarschijnlijk valt dit te verklaren uit het feit dat veel overblijvende stammen tijdens het oogsten van de andere stammen toch beschadigd raken.

De groei van jonge scheuten en stammen werd bij *C. rhabdocladus* tijdens de eerste 2 jaar na de oogst, en bij *D. cf. poilanei* tijdens het eerste jaar na de oogst, negatief beïnvloed, maar daarna niet meer. De vegetatieve reproduktie van *C. rhabdocladus* werd in het eerste jaar na de oogst negatief, in het tweede jaar positief en in het derde jaar in het geheel niet door het oogsten beïnvloed en bij *D. cf. poilanei* was het effekt ervan negatief. Het eerste jaar na de oogst hadden beide soorten geen generatieve reproduktie, maar daarna wel weer. Alles bij elkaar had oogsten een negatief effekt op de 'vital rates'.

Ik modelleerde de gevolgen van het oogsten van alle stammen van meer dan 6 m lang met oogstcycli van respectievelijk 1, 5,10 of 15 jaar, gedurende een periode van in totaal 30 jaar, bij beide soorten. Ik onderzocht de effekten daarvan op de populatiegrootte en op de beschikbaarheid van oogstbare stammen.

De populatiegroeisnelheden van de populaties waarin geoogst werd bleken lager dan die van de ongestoorde populaties. Tijdens het derde jaar na oogsten groeide de populatie van *C. rhabdocladus* weer, terwijl die van *D. cf. poilanei* nog steeds afnam (Hoofdstuk 5). De populatiegrootten van beide soorten namen onder alle oogstscenario's af, behalve onder het scenario van 1 oogst per 15 jaar. Vooral onder het scenario van elk jaar oogsten namen de populatiegrootten sterk af. Maar dit scenario weerspiegelt wel de huidige praktijk van het oogsten van rotans in Vietnam!

Korte oogstcycli, tot 5 jaar, hadden sterk negatieve effekten op de populaties en leidden tot een sterke afname van het aantal oogstbare stammen en van de oogstbare totale stamlengte. Slechts onder het scenario van een oogst per 15 jaar kwam dat weer op het oorspronkelijke niveau bij *C. rhabdocladus*, en oogstscenario's van eens per 10 of 15 jaar leverden zelfs meer oogstbare stammen op bij *D. cf. poilanei* (Hoofdstuk 5).

Duurzaam oogsten, beschermen en managen van rotanbestanden

De resultaten van mijn onderzoek geven aan, (1) dat het openen van het bladerdek van het bos, dat meer licht in het bos brengt, de groei van rotans kan bevorderen; (2) dat oogsten voorzichtig moet geschieden om te voorkomen dat de achterblijvende jonge scheuten en korte stammen beschadigd worden; (3) dat de rotans veel beter bijgroeien als de oogst niet te intensief is en als de tijd tussen successievelijke oogsten langer is; (4) dat de oogstcycli voor *C. rhabdocladus* en *D. cf. poilanei* 15 jaar moet bedragen, in elk geval in natuurlijke populaties zonder bosbouwkundige verbeteringsingrepen.

Oogsten heeft negatieve effekten op de 'vital rates' vooral op die van soorten met grote pollen, zoals *D. cf. poilanei*. Huidige oogsttechnieken in Vietnam houden vaak in dat alle scheuten en stammen gekapt worden om gemakkelijker de langere stammen te kunnen oogsten. Het is dus zaak dat er degelijke richtlijnen voor het oogsten van rotansoorten worden opgesteld en in praktijk worden gebracht.
Als rotan op een voorzichtige en verantwoorde manier in natuurlijk populaties in bossen kan worden geoogst kan de oogst als duurzaam gecertificeerd worden.
Verantwoord management van rotansoorten omvat het managen van een veellagig bos, want rotans hebben steun nodig om omhoog te klimmen. Certificatie kan een stimulans betekenen om zulke duurzame managementsystemen te ontwikkelen. Duurzaam oogsten is niet alleen nodig om de rotansoorten te beschermen, maar ook om de economische levensomstandigheden van de lokale bevolking in stand te houden. In Vietnam blijven de verdiensten die het oogsten van rotan genereert echter veelal hangen bij een klein groepje mensen dat een meer gelijkmatige verdeling van de opbrengsten in de weg staat. De grote vraag naar rotan doen suggereren dat de bijkomende kosten van certificatie door verbruikers, die bereid zijn een groene premie voor de certificatie te betalen, zouden kunnen worden gedragen.
Het is overduidelijk dat de waardevolle rotansoorten momenteel overgeëxploiteerd worden en sterk achteruit gaan. Er is dus dringend behoefte aan managementscenario's die garanderen dat de rotansoorten duurzaam beheerd worden. Maar langlopende in situ managementpraktijken voor wilde rotansoorten zijn uiterst zeldzaam. Ex situ managementpraktijken werden de afgelopen decennia wel in Zuidoost-Azië toegepast (bijv. rotanaanplantingen in 'agroforestry' systemen) en zijn succesrijk gebleken wanneer de eigendomsrechten duidelijk waren, de lokale gemeenschappen actief bij het management betrokken werden en hun inkomsten gegarandeerd waren. Het is dus duidelijk, dat het ontwikkelen van duurzame managementsystemen voor de exploitatie van wilde rotansoorten niet slechts de aandacht van onderzoeksinstituten en natuurbeschermingsorganisaties verdient, maar vooral ook van bestuurders en van lokale gemeenschappen en mensen, die in de rotanindustrie hun geld verdienen.

Tóm tắt kết quả nghiên cứu và thảo luận

Đề tài đã nghiên cứu, tìm hiểu những kiến thức cơ sở về sinh thái, quần thể học và tác động của khai thác cho ba loài song có giá trị kinh tế cao ở Việt Nam, với các mục tiêu:

1. Mô tả và diễn giải quá trình sinh trưởng, sức sống và sinh sản của ba loài song.
2. Tìm hiểu quần thể học của ba loài nghiên cứu, nhấn mạnh tầm quan trọng trong mối tương quan giữa quá trình sinh sản hữu tính và vô tính, và sinh trưởng dòng của các loài nghiên cứu.
3. Nghiên cứu những tác động của quá trình khai thác tới sinh trưởng, sức sống và sinh sản của cá thể, hệ quả của những tác động đó đối với quá trình sinh trưởng của quần thể cũng như tài nguyên song trong tương lai.

Luận văn gồm 6 chương, tóm tắt như sau:

Chương 1. Giới thiệu đại cương.
Chương 2. Mô tả khái quát về đặc điểm địa lý khí hậu và thổ nhưỡng Việt Nam. Cũng mô tả hiện trạng rừng, đa dạng sinh học cùng những hệ sinh thái với sự nêu bật tầm quan trọng của lâm sản ngoài gỗ nhằm bảo tồn và phát triển. Ngoài ra, có đề cập tới việc phân loại, tầm quan trọng về kinh tế và vấn đề quản lý tài nguyên song mây ở Việt Nam.
Chương 3. Trình bày kết quả nghiên cứu về sinh trưởng, tỷ lệ sống và sinh sản của ba loài song. Đánh giá những yếu tố quyết định quá trình sinh trưởng, tỷ lệ sống và sinh sản của các loài nghiên cứu. Lượng hóa vai trò hỗ trợ của dòng vô tính (clonal support) trong quá trình sinh trưởng, phát triển của chồi và thân cây, và đề xuất một số gợi ý về quản lý.
Chương 4. Phân tích quần thể học của ba loài song nghiên cứu, sử dụng mô hình quần thể "cây-trong-cụm". Áp dụng những mô hình ma trận, trong đó động thái của cây song phụ thuộc vào kích thước của bản thân nó và kích thước của cụm song sinh ra cây song đó. Dựa trên mô hình ma trận này có thể đánh giá được vai trò của sinh sản hữu tính, sinh sản vô tính và sự hỗ trợ của dòng vô tính đối với cả quần thể.
Chương 5. Phân tích tác động của việc khai thác thân cây song lên quá trình sinh trưởng, tỷ lệ sống và sức sinh sản của các cây song còn lại. Trong chương này mô hình quần thể "cây-trong-cụm" được mở rộng bao gồm cả tác động do quá trình

khai thác thân cây lên các động thái quần thể của hai loài nghiên cứu. Theo đó, các mô hình ma trận quần thể với 4 kịch bản khai thác khác nhau được sử dụng để xác định những quần thể song tương lai và tài nguyên song trong vòng 30 năm tới.
Chương 6. Tóm tắt những kết quả chủ yếu của luận văn, thảo luận và kiến nghị. Những kết quả chủ yếu được tóm tắt dưới đây:

Rừng, Lâm sản ngoài gỗ và song mây ở Việt Nam

Ở Việt Nam, các hệ sinh thái rừng rất phong phú về thành phần loài và nguồn gen thực vật và động vật. Có các kiểu rừng khác nhau từ rừng nhiệt đới, rừng ngập mặn, rừng núi đá vôi, rừng tre nứa đến các kiểu rừng lá kim và á nhiệt đới (Chương 2). Việt Nam là nằm trên giao lộ của 3 vùng có những hệ thực vật khác nhau là Trung Hoa, Himalaya và Indonesia. Do vị trí địa lý đó Việt Nam là một trong những nước có đa dạng sinh học phong phú vào bậc nhất ở Đông Nam Á (Bộ Lâm nghiệp 1995).
Rừng Việt Nam, trong Thế kỷ qua đã bị suy giảm nhiều cả về lượng và chất do nhiều nguyên nhân như 30 năm chiến tranh, canh tác du canh, chuyển đổi đất rừng sang đất canh tác nông nghiệp cùng các phương thức sử dụng đất khác, khai thác quá mức và tăng dân số (Chương 2). Diện tích rừng đã bị giảm từ 43% lãnh thổ, năm 1943 xuống còn 27,8%, năm 1990, nhưng năm 2006 đã tăng lên đến 38% (Cục Lâm nghiệp, 2007). Chất lượng của rừng tự nhiên nói chung thấp do giai đoạn suy thoái rừng kéo dài. Nhận thức của các nhà hoạch định chính sách, những người làm lâm nghiệp và đa số người dân về vai trò của rừng trong phát triển kinh tế, bảo vệ môi trường và đa dạng sinh học và làm giảm tác hại của biến đổi khí hậu đã được tăng lên. Nhiều chương trình phủ xanh, trồng rừng và bảo vệ rừng đã được thực hiện. Chương trình trồng mới 5 triệu ha rừng do Chính phủ phát động từ 1998 là một trong những chương trình có tham vọng lớn nhất, đã đóng góp vào trồng rừng, phục hồi rừng và quản lý rừng.
Mối lo ngại về việc mất rừng và suy thoái rừng nhiệt đới nhanh chóng đã làm nổi lên vai trò quan trọng của lâm sản ngoài gỗ (LSNG) ở rừng nhiệt đới (Myers 1984, de Beer và McDermott 1989, Peters et al. 1989). Ngày càng rõ hơn việc khai thác lâm sản ngoài gỗ có vai trò quan trọng trong bảo tồn và quản lý rừng nhiệt đới (Nepstad và Schwartzman 1992, Wegge 1993) đồng thời đóng góp vào sinh kế của cư dân nông thôn. Phương thức khai thác LSNG chỉ được coi là bền vững khi bền vững về sinh thái được đảm bảo, khả thi về kinh tế và được xã hội chấp nhận (Ros-Tonen et al. 1995, Peters 1996, Zuidema 2000, Tictin 2004).

Ở Việt Nam, rừng tự nhiên có nhiều loài LSNG. Từ nhiều thế kỷ, LSNG được khai thác để dùng làm thức ăn, dược liệu, hàng thủ công, chất đốt, thức ăn gia súc, vật liệu xây dựng và nhiều công dụng khác (Chương 2). Giống như tất cả các lâm sản khác, LSNG đã trở nên khan hiếm vào cuối thế kỉ 20 và những loài LSNG có giá trị đang có nguy cơ tuyệt chủng (FSSP 2006) do sự khai thác quá mức và áp lực của tăng dân số (Chương 2). Để quản lý và bảo tồn LSNG, chương trình quốc gia trồng mới 5 triệu ha rừng đã có kế hoạch dành 10% diện tích trồng rừng (580.000 ha) để trồng LSNG. Hiện nay, cả hai phương thức nội vi và ngoại vi đều được áp dụng để bảo tồn LSNG. Phương thức nội vi áp dụng cho LSNG ở trong rừng đặc dụng còn ngoại vi cho các LSNG có giá trị kinh tế ở cả trong rừng đặc dụng và rừng sản xuất.

Song là một trong những lâm sản quan trọng nhất sau gỗ và tre nứa ở Việt Nam. Nhờ có độ dài, cường lực, độ bền, tính dẻo dai cao cùng với sự đồng nhất song được đánh giá là vật liệu đa dụng (Sunderland và Dransfield 2000). Việt Nam sở hữu ít nhất là 36 loài song, thuộc 6 chi (Henderson 2009). Mười loài song được khai thác nhiều cùng những đặc tính của chúng được trình bày trong Chương 2 của bản luận văn này. Người Việt Nam ở nông thôn đã dùng song từ lâu đời, họ khai thác để dùng và để bán trên thị trường. Công nghiệp gia công song mây được phát triển mạnh từ cuối những năm 1970, chủ yếu làm đồ nội thất và hàng mỹ nghệ xuất khẩu. Ngành công nghiệp song mây tạo công việc cho khoảng 100.000 lao động thu hoạch và gia công chế biến (Dũng 2001, FAO 2002).

Song là loài cây leo họ Cau dừa (*Arecaceae*) mọc ở Đông Nam Á, là một thành phần đặc trưng của nhiều kiểu rừng (de Beer và McDermott 1989). Hai tập tính sinh trưởng cơ bản có thể phân biệt giữa các loài song: mọc đơn độc và mọc cụm. Trong những loài song thân đơn không có tái sinh chồi sau khi cây bị khai thác, còn ở loài mọc cụm việc khai thác từng cây không tác động tới sự sống còn của cụm (de Beer và McDermott 1989, Dransfield và Manokaran 1994, Sunderland và Dransfield 2002). Nhu cầu tăng cao đối với các sản phẩm song mây trên thị trường nội địa cũng như xuất khẩu đã dẫn tới tình trạng khai thác song mây quá mức trên qui mô lớn. Để khắc phục sự thiếu hụt nguyên liệu Chính phủ đã qui hoạch 80.000 ha trong Chương trình quốc gia trồng mới 5 triệu ha rừng và khuyến khích nông dân trồng song mây trong vườn nhà và làm giầu rừng bằng song mây (Chương 2). Đã có một số công trình nghiên cứu về nhân giống, cải thiện hạt giống và kỹ thuật trồng một số loài song mây. Tuy nhiên, để quản lý và sử dụng bền vững nguồn song hiện còn trong những quần thể tự nhiên cần phải có những tài liệu hướng dẫn khai thác và quản lý nguồn tài nguyên này. Công trình nghiên cứu này có mục đích góp phần vào sự hiểu biết cần thiết để xây dựng phương thức quản lý bền vững song ở Việt Nam.

Đề tài đã nghiên cứu ba loài song *Calamus platyacanthoides* (song mật), *C.rhabdocladus* (hèo) và *Daemonorops cf. poilanei* (mây nước) trong thời gian 3 năm ở Vườn Quốc gia Bạch Mã, tỉnh Thừa Thiên Huế.

Những yếu tố quyết định đến tăng trưởng, sức sống và sinh sản

Giống như những loài song khác, *C.platyacanthoides*, *C.rhabdocladus*, và *Daemonorops cf. poilanei* có dạng sinh trưởng cụm trong đó nhiều thân cây mọc từ gốc chung tạo thành khóm. Trong những loài mọc cụm đó các thân cây gắn liền với khóm trong suốt quá trình sinh sống và liên hệ với các cây khác trong cụm thông qua hệ rễ chung (Erikson 1993, Dransfield và Manokaran1994, Araki và Ohara 2008). Đặc tính của những loài nghiên cứu được mô tả chi tiết trong Chương 3. Những trị số sinh lực (tăng trưởng, sức sống, và sinh sản) được lượng hóa và những yếu tố quyết định các trị số đó của ba loài song nghiên cứu cũng được đánh giá. Trị số sinh lực là những thông tin cơ bản để hiểu biết về quá trình sinh sống của song; mặt khác, cũng rất cần cho việc quy hoạch, quản lý và sử dụng bền vững tài nguyên song mây tự nhiên. Số liệu của 3 lần điều tra, đo đếm 340-530 cá thể cho mỗi loài, với khoảng cách 1 năm đã được sử dụng để phân tích. Những mô hình tương quan hồi qui tuyến tính hoặc không tuyến tính được sử dụng để phân tích mối liên hệ giữa trị số sinh lực với chiều cao, chiều dài thân cây, giới tính, khả năng nhận được ánh sáng và kích thước của cụm (Chương 3).

Kết quả cho thấy rằng tỷ lệ sống của chồi song tăng lên cùng với chiều cao của chồi ở loài *C. rhabdocladus* và *D. cf. poilanei*, trong khi đó không thấy mối liên hệ nào ở loài *C. platyacanthoides.* Sự sống sót của chồi không phụ thuộc vào kích thước của cụm hoặc khả năng nhận được ánh sáng ở cả ba loài nghiên cứu. Tỷ lệ sống của thân cây song của các loài nghiên cứu cũng không phụ thuộc vào chiều dài thân, kích thước của cụm hoặc khả năng nhận được ánh sáng (Chương 3).

Sức sinh trưởng của thân cây khác biệt nhau khá lớn giữa các loài song nghiên cứu nhưng diễn thế chung lại tương tự trong cả 3 loài: tốc độ sinh trưởng tăng lên tỷ lệ thuận với chiều dài thân tới 10m, sau đó ổn định hoặc giảm đi. Tăng trưởng của thân cây song chịu tác động bởi 3 yếu tố: chiều dài ban đầu của thân cây, kích thước của cụm và khả năng nhận ánh sáng. Ảnh hưởng của mỗi yếu tố biến đổi phụ thuộc vào chiều dài ban đầu của thân. Nhận xét này đúng với cả ba loài nghiên cứu. Tóm lại, chiều dài ban đầu của thân hay chiều cao ban đầu của chồi và kích thước của cụm là quan trọng nhất đối với chồi và thân cây nhỏ (< 3 m), trong khi đó khả năng nhận được ánh sáng lại là quan trọng nhất đối với thân cây lớn (>10 m). Ở

những thân cây chưa thành thục (3-10 m) độ dài thân ban đầu và khả năng nhận được ánh sáng là quan trọng nhất đối với sự sinh trưởng. Ảnh hưởng của kích thước cụm tới sức sinh trưởng của thân cây giảm dần khi chiều dài thân tăng lên và hoàn toàn không có ảnh hưởng khi thân cây đạt tới chiều dài > 10 m, trong khi tác động của khả năng nhận ánh sáng lại tăng dần ở cả ba loài song (Chương 3).
Cả ba loài song đều sinh sản hữu tính và vô tính trong suốt thời gian nghiên cứu. Sinh sản vô tính tăng tỷ lệ thuận với kích thước bụi trong cả ba loài nghiên cứu. 50% số bụi có 5 thân và hầu hết số bụi có 10 thân đều sinh chồi hàng năm. Quá trình sinh sản hữu tính bắt đầu từ những thân cây có độ dài 8-10 m (cả ba loài) và không phụ thuộc vào kích thước của bụi cây. Xác suất ra hoa đực lớn hơn hoa cái khi thân cây ở cùng một độ dài của hai loài *C. rhabdocladus* và *D. cf. poilanei,* tỷ lệ giữa cây đực và cái đều > 1 ở cả ba loài.

Dùng mô hình ma trận để phân tích quần thể học

Mô hình ma trận của quần thể được sử dụng để phân tích động thái quần thể các loài nghiên cứu. Đối với những loài song mọc cụm mô hình ma trận đa nhóm được sử dụng, trong đó cá thể cây được phân hạng theo kích thước của bản thân cá thể đó và của cụm (tương tự như mô hình ma trận "cây-trong-cụm"). Những trị số sinh lực (tỷ lệ sống, sinh trưởng, sinh sản hữu tính và vô tính) được xử lý, tính toán và sử dụng để xây dựng mô hình ma trận (Chương 4).

Tốc độ tăng trưởng của quần thể (λ) là một trong số các kết quả thu được từ mô hình ma trận, được sử dụng để dự đoán tương lai cho quần thể: quần thể đang sinh trưởng và phát triển tốt nếu λ > 1 và quần thể bị suy thoái nếu λ < 1. Kết quả thu được đối với cả ba loài *C. platyacanthoides*, *C. rhadocladus* và *D. cf. poilanei* là các quần thể đang phát triển tốt (λ > 1). Đặc biệt là quần thể của loài *D. cf. poilanei* phát triển khá nhanh (λ = 1,068). Có nhiều yếu tố ảnh hưởng tới tốc độ tăng trưởng của quần thể, bao gồm những sự bất định trong các thông số đánh giá, những khác biệt về các điều kiện sinh trưởng giữa các năm và sự phục hồi sau quá trình tác động trước đây. Mặc dù, không thể nói chắc chắn yếu tố nào có ảnh hưởng nhất đối với tốc độ tăng trưởng của quần thể, nhưng các quần thể đang phục hồi tốt sau một thời gian bị khai thác nặng nề. Tài nguyên rừng (gỗ, song mây, và các LSNG khác) trên diện tích mà bây giờ được bảo vệ đã bị khai thác nặng nề đến tận năm 1991 khi vườn Quốc gia Bạch Mã thành lập. Từ thời điểm đó, việc thu hái chấm dứt trên diện tích này và các quần thể song mây có thể đã được phục hồi trên cơ sở của sự khai thác và các tác động trong quá khứ.

Kết quả thu được từ các mô hình ma trận chỉ ra rằng tỷ lệ sống của các cá thể là quan trọng nhất cho sự tồn tại và phát triển của quần thể. Đối với *C. platyacanthoides* các cá thể trong những cụm nhỏ và trung bình đóng vai trò quan trọng hơn các cá thể ở cụm lớn đối với sự sinh trưởng và phát triển của quần thể, trong khi đó những cá thể ở cụm lớn quan trọng hơn những cá thể trong cụm nhỏ và trung bình ở các loài *C. rhabdocladus* và *D. cf. poilanei*. Sinh sản hữu tính và vô tính có tác động ít nhất tới quá trình sinh trưởng và phát triển của quần thể (Chương 4).
Để lượng hoá vai trò đóng góp của dòng vô tính vào giá trị của λ, tốc độ sinh trưởng được phân tách thành sinh trưởng do hỗ trợ của dòng vô tính (e_{NrSt}) và do chiều dài thân ($e_{St\ length}$). Kết quả cho thấy rằng sự hỗ trợ của dòng vô tính cho tốc độ tăng trưởng của quần thể là cao đối với chồi và cá thể nhỏ so với cá thể lớn ở cả ba loài nghiên cứu (Chương 4). Trong ba loài thì sự đóng góp của dòng vô tính vào λ là cao nhất ở loài *C. rhabdocladus*. Tầm quan trọng của hỗ trợ từ dòng vô tính cũng được đánh giá bằng cách đưa thông số hỗ trợ của cụm đối với tốc độ sinh trưởng của cá thể bằng trị số 0 trong phương trình hồi qui, mà phương trình này được dùng để xây dựng mô hình ma trận. Kết quả từ những ma trận chuyển dịch này đã cho những trị số λ thấp hơn, và $\lambda < 1$ được thấy ở hai loài *Calamus*. Đóng góp của dòng vô tính vào giá trị λ là cao hơn so với đóng góp của cả sinh sản hữu tính và vô tính ở cả ba loài nghiên cứu (Chương 4). Điều đó hàm ý rằng những cụm song lớn có vai trò quan trọng cho sự tồn tại, sinh trưởng và phát triển của quần thể để đạt tới sự ổn định với mật độ nào đó.
Việc phân tích các nhóm khép kín trong biểu đồ chu trình sống của cây (loop analysis) đã được sử dụng để lượng hoá sự đóng góp của sinh sản hữu tính và vô tính vào tốc độ tăng trưởng của quần thể. Mặc dù những loài được nghiên cứu có một biểu đồ chu trình sống phức tạp, bằng cách dùng thuật toán mới do Guneralp (2007) giới thiệu, sự đóng góp của từng loại hình sinh sản vào trị số λ đã tính toán được. Đối với loài *C. platyacanthoides*, sinh sản hữu tính có vai trò quan trọng hơn đối với tốc độ tăng trưởng của quần thể, trong khi sinh sản vô tính lại quan trọng hơn ở hai loài còn lại. Kết quả cho thấy những cá thể lớn nhất trong các cụm có kích thước lớn và trung bình có vai trò quan trọng nhất đối với sinh sản của các loài song nghiên cứu trong đề tài này (Chương 4).

Sử dụng mô hình ma trận để đánh giá tác động của khai thác

Việc khai thác LSNG có tác động lên các cá thể, quần thể, cộng đồng và hệ sinh thái (Ros-Tonen et al. 1995, Tickin 2004). Ở cấp độ cá thể cây, những bộ phận của cây bị thu hái, cách thức và cường độ thu hái là những yếu tố quyết định tác động lên cây. Trong một tạp chí viết về tác động của khai thác LSNG, Tickin (2004) đã cho biết có khoảng 70 công trình nghiên cứu để phát hiện những tác động về mặt sinh thái của việc khai thác LSNG. Tuy nhiên, chỉ có hai công trình dành cho khai thác song mây (Van Valkenburg 1997, Siebert 2004), mặc dù song được coi là một trong những LSNG quan trọng nhất trên thị trường thế giới. Cho đến nay, chưa có nghiên cứu nào đề cập tới việc duy trì nguồn tài nguyên song mây dưới các chế độ khai thác khác nhau.

Trong đề tài nghiên cứu này những tác động của khai thác lên loài *C. rhabdocladus* và *D. cf. poilanei* đã được nghiên cứu trong 3 năm ở cấp độ cá thể và quần thể (Chương 5). Thực nghiệm khai thác đã được tiến hành song song với nghiên cứu quần thể học trong những quần thể không bị tác động. Tại các quần thể thử nghiệm khai thác, toàn bộ thân cây ≥ 6 m bị khai thác trong năm đầu tiên khi bắt đầu nghiên cứu. Cách khai thác này giống như cách khai thác song hiện hành ở Việt Nam.

Ở cấp độ cá thể, tác động của khai thác lên những trị số sinh lực được theo dõi, đo đếm trong 3 năm sau khai thác ở cả hai loài. Kết quả cho thấy, tỷ lệ sống của những cá thể còn lại bị giảm xuống trong năm đầu sau khai thác, nhưng không bị tác động trong năm thứ hai và thứ ba. Tốc độ sinh trưởng của chồi và thân song giảm đi trong hai năm đầu tiên ở loài *C. rhabdocladus* và chỉ giảm trong năm đầu đối với loài D. *cf. poilanei.* Tốc độ sinh trưởng ở năm thứ ba không bị tác động ở cả hai loài. Khai thác thân cây tác động tích cực lên quá trình sinh sản vô tính trong năm đầu tiên nhưng có xấu đi trong năm thứ hai. Trong năm thứ ba thì những tác động xấu lên sinh sản vô tính không còn thấy đối với C. *rhabdocladus* nhưng vẫn còn, dù ít hơn trước, đối với loài D. *cf. poilanei.* Sinh sản hữu tính bị tác động mạnh hơn do khai thác: trong năm đầu ở cả hai loài đều không thấy ra hoa bởi vì tất cả thân cây sinh sản đều đã bị cắt. Trong hai năm sau những thân song sinh sản xuất hiện, và không có tác động nào của quá trình khai thác ảnh hưởng tới mối quan hệ giữa chiều dài của thân cây và khả năng sinh sản. Cũng cần ghi nhận rằng tác động của khai thác lên sinh sản hữu tính có thể chưa được đánh giá đúng mức vì những thông tin về tác động của khai thác lên đầu ra của hạt ứng với một cụm hoa không được đưa vào xem xét. Nhìn chung, khai thác có tác động xấu lên những trị số sinh lực của các loài nghiên cứu.

Để đánh giá tác động của khai thác ở cấp độ quần thể những mô hình ma trận đa nhóm cũng đã được xây dựng cho các quần thể khai thác của loài *C. rhabdocladus* và D. *cf. poilanei* trong năm đầu (**H1**), năm thứ hai (**H2**) và năm thứ ba (**H3**) sau khai thác. Những mô hình ma trận xây dựng cho các quần thể không khai thác được dùng làm đối chứng (**C**). Việc mô phỏng quá trình khai thác được tiến hành với cùng cường độ (khai thác 100% thân cây có chiều dài ≥ 6 m) trong những chu kỳ khai thác khác nhau (1, 5, 10, 15 năm). Sự mô phỏng bao giờ cũng được bắt đầu bằng việc khai thác mà sau đó cứ 1, 5, 10 và 15 năm được lặp lại trong giai đoạn 30 năm (Chương 5). Tác động của chế độ khai thác được đánh giá cả về tổng kích thước của quần thể và về số lượng các thân cây đủ tiêu chuẩn khai thác cho 4 chế độ khai thác đã nói trên.

Kết quả cho thấy rằng tốc độ tăng trưởng của quần thể khai thác thấp hơn so với quần thể không bị khai thác đối với cả hai loài. Quần thể *C. rhabdocladus* tăng lên trong năm thứ ba sau khai thác, trong khi đó quần thể loài *D. cf. poilanei* còn tiếp tục giảm trong 3 năm sau khai thác (Chương 5). Kích thước quần thể của loài *C. rhabdocladus* và *D. cf. poilanei* đều giảm đi trong tất cả các chế độ khai thác, trừ một trường hợp, đó là sự phục hồi của quần thể loài *D. cf. poilanei* giữa hai lần khai thác với chu kỳ 15 năm. Những chu kì khai thác ngắn hơn làm cho quỹ đạo các quần thể khai thác càng khác biệt nhiều hơn so với các quần thể không bị khai thác. Với chu kỳ khai thác hàng năm, kích thước các quần thể này bị giảm đi nhanh chóng đối với cả hai loài (Chương 5). Đó chính là hiện trạng của phương thức khai thác song ở Việt Nam.

Tác động của khai thác lên tài nguyên song mây phụ thuộc vào chế độ khai thác. Những chu kỳ khai thác ngắn (liên tục hàng năm hoặc 5 năm một lần) làm giảm nghiêm trọng kích thước quần thể, dẫn tới suy giảm nguồn tài nguyên. Sự phong phú của những thân cây đủ chiều dài để khai thác chỉ có thể có khi khai thác với chu kỳ 15 năm với loài *C. rhabdocladus* và chu kỳ 10 và 15 năm với loài *D. cf. poilanei*, số lượng thân cây có thể khai thác thậm chí lớn hơn số cây được khai thác trong quần thể ở lần đầu.

Khai thác, bảo tồn và quản lý bền vững tài nguyên song mây

Để quản lý và bảo tồn một quần thể nào đó một cách có hiệu quả, ba câu hỏi về sinh thái phải được giải đáp (cùng với những vấn đề chính trị và kinh tế xã hội): i) những tác động về sinh thái của khai thác là gì? ii) những tác động đó theo cơ chế nào? và iii) phương thức quản lý nào cần được áp dụng để giảm những tác động tiêu cực hay phát huy tác động tích cực? (Ticktin 2004). Câu hỏi sau cùng chỉ có thể trả lời được khi hai câu hỏi đầu tiên đã được giải đáp. Trong đề tài nghiên cứu này, hai câu hỏi đầu đã được đề cập trong các Chương 3, 4 và 5 đối với các loài song nghiên cứu. Mặc dù câu hỏi thứ ba không được trực tiếp giải đáp ở đây nhưng những kết quả nghiên cứu đưa ra những gợi ý sau: 1) tạo ra những khoảng trống nhân tạo bằng girdling technique (mở tán rừng bằng kỹ thuật cắt vỏ xung quanh thân cây gỗ để cây vẫn đứng nhưng sẽ chết dần) để tăng khả năng nhận được ánh sáng cho các quần thể song, thúc đẩy tốc độ tăng trưởng; 2) trong khi khai thác cần phải chú ý để làm giảm những tác động tiêu cực đến tỷ lệ sống của những thân song còn lại, tránh để những thân cây nhỏ bị cắt theo. Những cây nhỏ và chồi sẽ là nguồn cho lần khai thác sau; 3) những thân cây còn lại phục hồi tốt hơn nếu khai thác với cường độ thấp và chu kì dài (không khai thác 100% thân cây có chiều dài ≥ 6 m và không khai thác hàng năm ở một quần thể như hiện nay); 4) chu kì khai thác đối với *C.rhabdocladus* và *D. cf. poilanei* phải là 15 năm trong những quần thể tự nhiên nếu không áp dụng biện pháp lâm sinh gì sau khai thác.

Kỹ thuật khai thác song mây có tác động lên các trị số sinh lực của những thân cây còn lại trong khóm, đặc biệt là những loài mọc cụm lớn như *D. cf. poilanei* (Siebert 2004, quan sát thực địa). Trong nhiều trường hợp tất cả thân cây của loài mọc cụm đều bị cắt để lấy được những thân trưởng thành mặc dù những thân song khác trong cụm còn quá non để khai thác và để bán được (Sunderland và Dransfield 2002). Do vậy, phải ban hành bản hướng dẫn khai thác song và đưa vào thực hiện như một biện pháp bảo tồn nguồn tài nguyên song mây ở Việt Nam.

Nếu trong rừng tự nhiên song được khai thác một cách cẩn thận và có trách nhiệm thì việc khai thác song từ những quần thể tự nhiên có thể phải được cấp chứng chỉ như quản lý rừng bền vững (Viana et al. 1996, Sunderland và Dransfield 2002). Hầu hết các loài song mọc trong rừng và cần hỗ trợ của cây khác để thân cây leo và tua bám vào. Do đó, bất kỳ cách quản lý nào đối với tài nguyên song mây cũng đòi hỏi việc quản lý rừng có nhiều tầng (Sunderland và Dransfield 2002). Cấp chứng chỉ có thể khuyến khích việc quản lý được tốt hơn và thực hành phúc lợi xã hội (Shanley et al. 2002).

Rõ ràng là những loại song có giá trị cao đều bị khai thác quá mức, kết cục là sự suy thoái của nhiều loài song. Do đó, việc cấp bách là phải xây dựng các phương thức quản lý nhằm đảm bảo tài nguyên song mây được duy trì bền vững. Tuy nhiên, việc quản lý song nội vi lâu dài ở nơi hoang dã là rất hiếm (Belcher 1999). Ở Đông Nam Á, trong những thập niên gần đây quản lý ngoại vi được tiến hành và đã có kết quả thành công khi quyền sở hữu tài nguyên được rõ ràng, có sự tham gia tích cực vào quản lý của các cộng đồng địa phương và khi lợi ích của họ được đảm bảo (Belcher 1999, Sunderland và Dransfield 2002, Ticktin 2004). Vì vậy, phương thức quản lý bền vững đối với những quần thể song mây hoang dã đòi hỏi sự quan tâm, chú ý không chỉ của các Viện nghiên cứu, các Tổ chức bảo tồn mà còn của các nhà làm chính sách và các cộng đồng địa phương hoặc những người chuyên khai thác.

Những kiến nghị về nghiên cứu

Ở Việt Nam, để phát triển bền vững nguồn song mây cần tiếp tục nghiên cứu theo hướng sau đây:

Những quần thể song mây trong rừng tự nhiên:

1. Cần tiến hành điều tra chi tiết ở cấp quốc gia, bao gồm việc đo đếm các thông số cơ bản (ví dụ: số thân trong cụm, số thân và cụm trên một hecta, chiều dài thân và số thân song mây có thể khai thác). Những số liệu điều tra đó rất quan trọng đối với công tác bảo tồn và sự phát triển các loài song mây có giá trị thương mại. Hiện nay, 36 loài song mây đã được xác định nhưng theo nhiều nhà nghiên cứu có thể có tới 50 loài ở Việt Nam (Nghĩa et al. 2000).
2. Thiết lập những diện tích dành cho công tác nghiên cứu song mây để xác định các trị số sinh lực (tốc độ sinh trưởng, tỷ lệ sống, khả năng tái sinh từ hạt, từ chồi) ở cấp độ cá thể, quần thể qua thời gian, đặc biệt là đối với những loài có giá trị thương mại. Việc này sẽ cung cấp những thông tin sinh thái cơ bản để khai thác và quản lý tài nguyên song mây bền vững.
3. Xác định và khảo nghiệm những biện pháp kỹ thuật (bao gồm cả kỹ thuật và chế độ khai thác) để quản lý song mây trong các quần thể tự nhiên, đặc biệt là các loài có giá trị kinh tế cao.
4. Xúc tiến các khảo nghiệm tái sinh tự nhiên các loài song mây thông qua trồng làm giầu trong rừng tự nhiên. Việc này sẽ làm cơ sở để xây dựng hướng dẫn kỹ thuật cho quản lý và phát triển tài nguyên song mây trên các diện tích rừng phục hồi thuộc Chương trình trồng mới 5 triệu hecta rừng.

Trồng song mây

1. Xúc tiến các kỹ thuật nhân giống cho phép sản xuất cây con trên qui mô lớn. Việc cấp thiết là cải thiện giống cho loài *Calamus tetradactylus* (ở huyện Tu Lý, tỉnh Hòa Bình), *C. platyacanthoides* (ở tỉnh Quảng Trị, Thừa Thiên Huế và Gia Lai), *C. rudentum* (ở Vườn Quốc gia Cát Tiên, tỉnh Đồng Nai). Nếu việc này không xúc tiến sớm thì sẽ không có đủ nguồn giống để trồng trong thời gian tới.
2. Xác định và khảo nghiệm kỹ thuật trồng và quản lý song mây ở quy mô nhỏ (cấp độ thôn bản, hộ gia đình) và ở qui mô thương mại.

3. Xây dựng những kỹ thuật và chế độ khai thác thích hợp để khai thác và chế biến song mây kể cả sơ chế, bảo quản sau khai thác và để nâng cao giá trị kinh tế của nhưng sản phẩm được chế biến từ song mây.

Đối với ba loài song nghiên cứu

1. Sẽ rất bổ ích nếu những thử nghiệm tương tự như đã tiến hành trong đề tài này được tiếp tục nhưng với cường độ khai thác khác nhau (25%, 50% hoặc 75%) để có thể hiểu thấu đáo hơn khả năng phục hồi của cá thể về những trị số sinh lực và động thái của quần thể sau khai thác.
2. Tác động của quá trình khai thác lặp lại với những cường độ và chu kỳ khác nhau cho cả ba loài cũng nên được tiến hành tiếp.
3. Tác động của khai thác lên loài *C. platyacanthoides* cần phải được đánh giá.
4. Cần đánh giá tác động của khai thác ở cấp độ cộng đồng và cấp độ hệ sinh thái đối với các loài nghiên cứu. Ở cấp độ này có thể là bền vững nhưng có thể là không bền vững ở cấp độ khác (ví dụ: tác động lên chu kỳ chuyển chất dinh dưỡng sau khai thác).
5. Xác định và khảo nghiệm những kỹ thuật quản lý nhằm giảm tác động tiêu cực của khai thác lên những cá thể còn lại của quần thể (ví dụ: bón phân hoặc mở tán).

Tóm lại, ba loài song nghiên cứu đều tương đối mọc nhanh và năng suất khá cao nên có thể khai thác với chu kỳ tương đối ngắn so với cây gỗ (15 năm). Điều đó cho phép đem lại lợi nhuận trong thời hạn từ tương đối ngắn đến trung bình cho người dân tham gia quản lý. Việc quản lý và khai thác bền vững tài nguyên song mây trong các quần thể tự nhiên cần phải được coi như một biện pháp bảo tồn và quản lý rừng nhiệt đới, đồng thời giải quyết sinh kế của người dân.

Tũn visited me in Bach Ma during the field work (2006)

Acknowledgements

During my study, many persons and institutions have contributed to the preparation, conduct and completion of this study. In a limited space I would like to mention some persons here and I sincerely thank all of them for their contribution.

Firstly, I would like to express my sincere thanks to my promotor and supervisor, Prof. Dr. Marinus Werger, for accepting me as a Ph.D student of the Plant Ecology and Biodiversity Group at Utrecht University, his positive encouragement, wise instructions, and invaluable comments on my manuscripts that made that other people could also understand what I wanted to say. I have greatly appreciated the guidance and support by Dr. Pieter Zuidema, my co-promotor and daily supervisor, in providing continuous assistance during all stages of this undertaking and his precious comments and suggestions for improvement. Thank you very much for your great help and all things you have done for me.

I owe a debt of gratitude to the staff members of the Plant Ecology and Biodiversity Group, Utrecht University, especially to Dr. Heinjo During, Dr. Feike Schieving, Dr. Niels Anten and Dr. Hans ter Steege for the fruitful discussions, advice and enjoyable lunches, and to Sander van Hal for computer software assistance. During my stay at Utrecht University for more than one year, my knowledge has improved, not only on my study subject but also my views on social and cultural matters are broadened. I have received a lot of enthusiastic help and encouragement from many people in the Group. I want to thank all of you, Peter, Baocheng, Shouli, Zhengwen, Liang, Danae, Arjen, Claudia, Juliana, Sylvia, Maria, Huy, Paddy, Roy, Henri, Betty, Yusuke, Galia, Yun, Marijke, Chien, Toshihiro and Sonja. Many thanks also to Martie, Piet, Bertus, Maaike, Geert, Anneke and Natasja for their help in administrative affairs.

I would like to express my gratitude to my local promoter and supervisor, Prof. Dr. Trieu Van Hung, who was ready to help me whenever I needed, especially for creating excellent working conditions for me, both at the office and in the field during the early stages of this study. I am deeply indebted to Prof. Dr. Ha Chu Chu for his invaluable advise, provision of valuable documents, and willingness to take care of me since the beginning of my Ph.D programme. Without the inspiration and encouragement of these two persons, this study could not have been carried out.

I would like to thank all of my colleagues in the International Cooperation Department of the Ministry of Agriculture and Rural Development, who took over my job while I was studying in the Netherlands. In particular, I want to thank Dr. Le Van Minh for his consistent support and encouragement throughout my study, Mrs. Hoang Thi Dzung for her helpful assistance and suggestions in applying for the scholarship, Mrs. Nguyen Thi Tuyet Hoa for making all the documentation available to me, and MSc. Tran Kim Long for constructive discussions and support during the field work.

The field work would have been impossible without the support of the people of Bach Ma National Park, Thua Thien Hue province. I especially appreciated the support provided by Dr. Huynh Van Keo for his permission and help during the field work. Special gratitude is expressed to Mr. Nguyen Le Tho, Mr. Le Quoc Khanh, Mr. Nguyen Van Vong, Mr. Nguyen Quang, and Mr. Nguyen Hoang Trung for their assistance with the field work. I also am very grateful to Mr. Nguyen Van Quyet and his family for his indispensable support concerning the field work, his helpful information on the rattans of Bach Ma area in the past, and for giving me all logistical support I needed.

I am also grateful to other scientists from different Institutions, especially Prof. Dr. Francis E. Putz (University of Florida, USA) for his fruitful discussions, advice and helpful information on the rattans, Dr. John Dransfield (the Royal Botanic Gardens, Kew, UK) and Dr. Ninh Khac Ban and Dr. Tran Phuong Anh (Institute of Ecology and Biological Resources) for helping me to identify the scientific names of my rattan species, Prof. Dr. Nguyen Hai Tuat and Miss Nguyen Thi Thin (Vietnam Forestry University) for their help with statistical analyses, assistance with SPSS and MapInfo programmes, Dr. Nguyen Phu Hung, Dr. Vu Van Dzung (Forest Inventory and Planning Institute) and Dr. Le Thanh Chien (Forest Science Institute of Vietnam), who sacrificed their time to share information and give me practical hints.

I extend my words of thanks to Tropenbos International Vietnam and the Netherlands Fellowship Programme (Nuffic) for their financial contribution to the field work in Vietnam and my study in the Netherlands. Special thanks are extended to Prof. Dr. Rene Boot and MSc. Tran Huu Nghi, who were always willing to help with administration procedures and gave me encouragement during the entire study.

Finally and particularly, my deepest gratitude is extended to my family in Hanoi, especially my parents-in-law and my parents, for taking care of my children and giving me support and encouragement in difficult situations. Special persons to be thanked are Tun (my son) and Bong (my little daughter), they sacrificed a lot during my study period. Last but not least, I am much indebted to my husband Tuan Minh, for his patience and understanding, his continuous and unconditional support in all possible ways during the past years, and his love over the years.

Curriculum vitae

Bui My Binh was born on 17 February 1973 in Thai Nguyen, Vietnam. In 1988, she started her studies at the Forestry University of Vietnam in Xuan Mai, Ha Tay. During this study she specialized in wood technology and non-timber forest products. In 1993, she graduated from the University with a Bachelor degree of Science. In 1994, she started working for the Forest Science Institute of Vietnam as an officer of the International Cooperation Division. She participated in several (inter)national projects related to forest land allocation, watershed protection, agro-forestry and sustainable forest management, mainly in the mountainous areas of North Vietnam.

In 1999, she continued her study at the Technical University of Dresden in Germany, where she specially focused on forest policy, conservation and management of tropical forestry. She obtained her Master degree in Tropical Forestry and Management at the Technical University of Dresden in 2001. After returning from Germany, she continued working at the Forest Science Institute of Vietnam. In 2003, she worked in the Sustainable Utilisation of Non-timber Forest Products Project Vietnam (phase 2). This project became incorporated in the cooperation with Tropenbos International Vietnam and Utrecht University. Her Ph.D study programme was one of the results of this cooperation.

In 2004 she was admitted as a Ph.D student at the Plant Ecology and Biodiversity Group, Biology Department, Faculty of Science, Utrecht University. Within the 'sandwich' study programme, she investigated the ecology, demography and the effects of harvesting of three rattan species in Central Vietnam. She was able to pursue this study programme also when, from 2005 onwards, she has employed at the International Cooperation Department under the Ministry of Agriculture and Rural Development. After completion of her Ph.D in October 2009, she returns to Vietnam and continues her career at the Ministry of Agriculture and Rural Development.

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