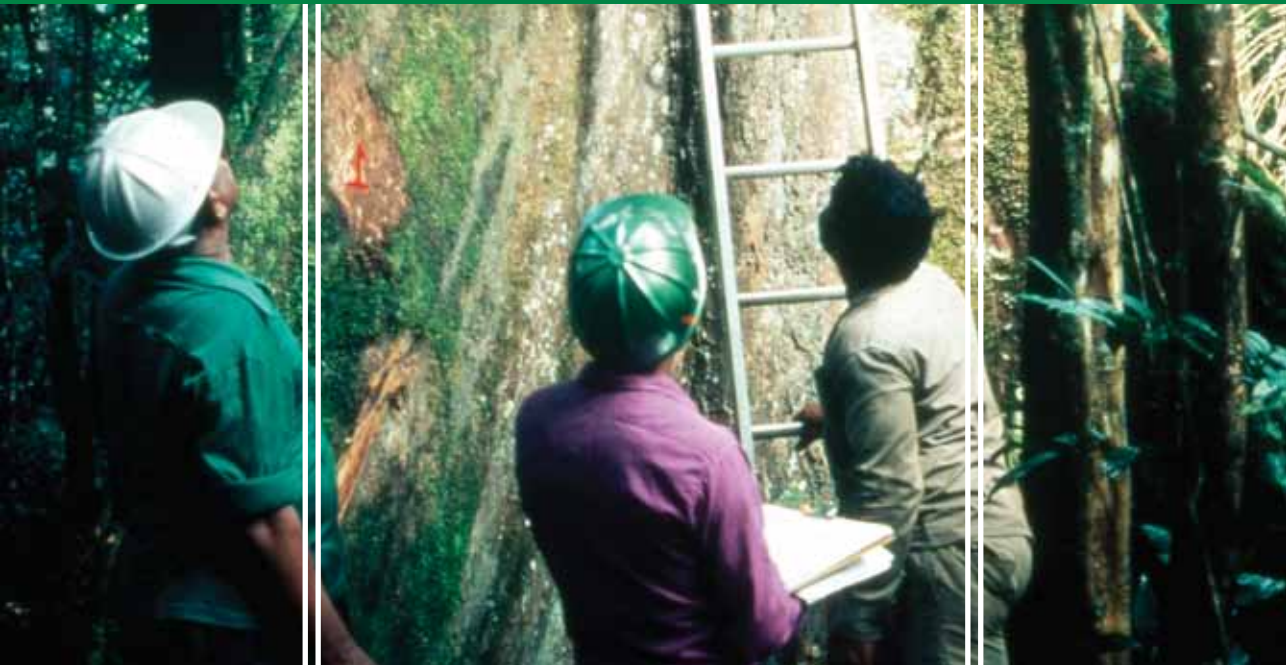# Sustainable Management of Tropical Rainforests
The CELOS Management System

Marinus J.A. Werger (ed.)

Sustainable Management of Tropical Rainforests

The CELOS Management System

Edited by
Marinus J.A. Werger

This book is based on the initiatives of Frits (G.M.J.) Mohren, Rick O. van Ravenswaay, and Rudi F. van Kanten

Contents

Preface

Suriname is one of the most forested tropical countries. So far, deforestation has not been severe, probably because of the relatively small population, lack or inadequacy of a road infrastructure in the hinterlands, and low pressure for converting the forest into agricultural land. Moreover, harvestable commercial volumes in its forests are rather low as compared to some other tropical forest areas.

Nevertheless, the timber value of these forests has long been recognized, and after the Second World War it was decided to develop a logging industry in the so-called Forest Belt, a 50 – 200 kilometers wide, accessible zone of lowland rainforests across the northern part of the country. The Suriname Forest Service ('s Lands Bosbeheer, LBB) developed and for some time stood as a model forestry institution in the region. It aimed at the application of evidence-based silvicultural systems for the management of the permanent forest estate and at raising its production of useful timber. To achieve this, the Suriname Forest Service closely cooperated with forestry experts. Joop Schulz, Jan Boerboom and Reitze de Graaf played pioneering roles in developing forest management systems in which natural regeneration of commercial timber trees was an important feature, and forestry experiments were set up and monitored.

After the independence of Suriname, in 1975, the involvement of Wageningen forestry experts in Surinamese forestry initially stayed firm, and in 1978 a new cooperation agreement was signed between the Anton de Kom University of Suriname and Wageningen University (then Wageningen Agricultural University – Landbouwhogeschool Wageningen) to further develop a forest management system for the sustainable production of timber (Project LH/UvS 01 also registered as MAB project 949). New experiments were set up at the field stations of the Centre for Agricultural Research in Suriname (CELOS) at Mapane and Kabo in the district of Para. LBB (Kenneth Tjon and Jaap de Vletter) initiated some experiments in the Mapane area too.

Reitze de Graaf advocated the development of a polycyclic silvicultural system in Suriname, as against the earlier experiments with monocyclic approaches. Soon Reitze de Graaf, Wyb Jonkers and John Hendrison developed the theory, designed the experiments and collected the necessary experimental data on the basis of which the CELOS Silvicultural System (CSS) and the CELOS Harvesting System (CHS) were formulated and integrated into the CELOS Management System (CMS) for sustained forest exploitation and timber production. They formed a team with Onno Boxman, Jan Consen, Rein Poels (†2007), John Procter (†1979), Pieter Schmidt, Renate Tjon Lim Sang and Frank Vreden at CELOS, and this core of CMS-researchers attracted, stimulated and supervised other researchers, including many Surinamese and Dutch students in their practical training phase, to study various aspects of the natural and treated forests in the experimental plots at Mapane and Kabo and elsewhere in Suriname. Many inventories, measurements, monitoring censuses and a great deal of supplementary research were done, and a wealth of important data was gathered. In 1983 political developments caused the interruption of these research activities for a considerable number of years. In

subsequent years Gerold Zondervan, then at CELOS, later at WWF Guianas, played a very significant role in preserving the experimental plots at Mapane and Kabo, emphasized their importance for forestry research, and encouraged re-starting the investigations.

The results of these research projects in the tropical forest of Suriname have been reported in four Ph.D.-dissertations (issued in the series Ecology and Management of the Tropical Rain Forest in Suriname), many M.Sc.-theses, a number of publications in professional journals and books, and many internal reports (see Annex 1). But they have never been integrated in a comprehensive publication, evaluating the results so far obtained.

In recent decades the interest in and importance of reduced impact logging and sustainable forest management strongly increased, and the interest in the CMS also grew, in Suriname and in other Latin American countries. As the documentation on this system was so widely scattered, it has proved difficult to readily gather an adequate account of the usefulness of the system. There was a clear need for a synthesis, bringing together a description of the CMS principles, its underlying yield model, its associated silvicultural treatments, as well as a balanced assessment of its long-term effects on the silvicultural and ecological dynamics and biological value of the managed forests, as apparent from the various studies carried out in the experimental stands. Such a synthesis would show the potential of the CMS to serve as a proper guide for forestry management in the region and beyond.

At long last, the decision to produce such an integrated account was taken at the occasion of the farewell meeting for Reitze de Graaf, in 2005, when he retired from Wageningen University. The result is this book. It was initiated by Frits (G.M.J.) Mohren, and enthusiastically supported by CELOS (Rick O. van Ravenswaay, Rudi F. van Kanten), Tropenbos International Suriname and WWF Guianas. They encouraged the authors, including the core researchers who had worked in project LH/UvS 01 during 1977 to 1983 that directly led to the CELOS Management System, to embark on writing the chapters. They accessed relevant information and documentation from the CELOS archives and elsewhere, and recent information that had become available from re-measurements of the CELOS plots. It was decided to not just restrict the book to the CMS-related work in Suriname, but to also briefly assess the experiences with other forestry systems aimed at reduced impact logging or sustainable forest management in the tropics.

This book, with contributions from 25 authors, tells in brief the history of forestry in Suriname and some other tropical countries. It reveals how the work on forestry in Suriname led to the development of a potentially sustainable forest management system, integrating a harvesting and a silvicultural system. And it documents the long-term effects of applying this system as apparent from a great deal of research in experimental forest stands of CELOS in Suriname. This information holds the evidence to determine the potential of the CELOS Management System to serve as a model for other systems of sustainable management of tropical forests in Suriname and beyond, particularly in other Latin American countries in the region with similar forests.

This book makes the theoretical basis of the system, and the practical results as apparent from extensive and long-term experimental work in forest plots, readily available for a large readership, for those working in tropical forestry and forestry policy, as well as for those with just a general interest in tropical forests. This ecological, silvicultural and practical knowledge allows evaluation of the CMS in terms of present concepts and policies on tropical forests and tropical forestry, including the important developments in these fields since the Conference of Rio de Janeiro (1992), the introduction of forest certification standards and the developments around REDD(+). Is the CMS suitable as a source of inspiration, and a model that can be adapted for further development into a full-scale, practical and feasible silvicultural management system for tropical forests?

I congratulate the 25 authors with this book, and I thank them sincerely for the pleasant and efficient cooperation towards its completion. I trust that it will be well received.

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Part I

The CELOS Management System as an option for sustainable forest management in Suriname

1   Introduction

G.M.J. Mohren & R.F. van Kanten

1.1   Sustainable management of tropical lowland rainforest

The use of tropical forests, as in forests everywhere in the world, started with hunters and gatherers cutting down trees and extracting timber, fruits, honey and other forest products. That led to small scale clear-cutting, removing patches of forest trees, and substituting these with crop plants, grown and harvested over the short period that nutrient availability was sufficient. This shifting cultivation still exists today in many tropical regions, and can be sustainable as long as the fallow period is sufficient for soil fertility to recover, and in practice this means as long as population density is sufficiently low to have long enough fallows to allow soil fertility recovery. When population density increased, and forest use started to be more systematic, early silvicultural systems were developed and forest use became more and more regulated.

From mere simple exploitation and shifting cultivation, essentially two types of silvicultural systems have developed: an intensive silviculture in which productivity is optimized in a manner that corresponds to agricultural cropping (plantation silviculture), and an extensive silviculture in which individual trees are harvested from a forest ecosystem that otherwise remains intact, thus resembling the undisturbed forest ecosystem occurring naturally at a given site (see Fig. 1.1).

Plantation silviculture may develop when conditions for industrial forestry, i.e. means for mechanization and investment, rational planning and stable land use apply. However, plantation forestry in combination with clear-cutting leads to soil exposure and, under conditions of high temperatures and high rainfall, may lead to soil degradation and site impoverishment. Low-impact silviculture, as in the case of selective logging, with long intervals between logging operations of relatively low intensity, may develop where the need for soil protection prevents clear-cut (as in steep mountain terrain), or where soil exposure would otherwise lead to loss of nutrients and thus of productive capacity of

Photo credits page 1
1. Logging technique: applying a wedge in directional felling. (Photo J. Hendrison)
2. Logging technique: using choker cables for winch extraction. (Photo J. Hendrison)
3. Directional felling. (Photo J. Hendrison)
4. Silvicultural treatment. (Photo P. Schmidt)
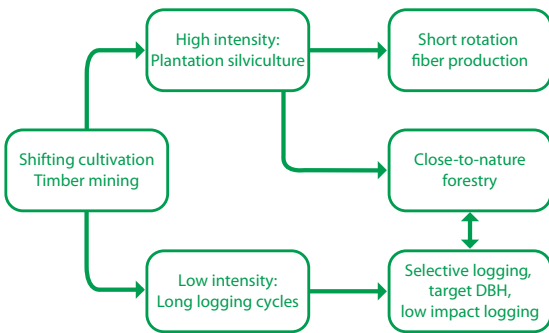5. An open canopy one year after refinement. (Photo P. Schmidt)

Figure 1.1. Development of selective logging systems from initial simple exploitation. Shifting cultivation and timber mining develop either into plantation silviculture (via intensification comparable to agricultural cropping) or into low intensity individual-tree harvesting with long intervals between logging operations. In the low intensity case, features of the original ecosystem are maintained to a large extent.

the site, as on many tropical soils. In general, selective logging with limited timber extraction per unit area enables maintenance of other forest functions such as protection of water and soil, maintenance of biodiversity, carbon sequestration, and erosion control. Selective logging may also be required in the case where the desired tree species do not regenerate on exposed sites and bare soil, but require a forest microclimate to germinate and establish. This is the case with many of the valuable tropical timber species, particularly late successional species that normally develop under a closed canopy.

With increased pressure on forests, there is the need to safeguard the scarce resources.
In the case of low-intensity selective logging systems, it may become desirable to increase the number of trees to be harvested, either by increasing the number of species harvested or by increasing the proportion of valuable species by silvicultural measures in between logging events. Silvicultural stand treatment also may allow improvement of timber quality of the remaining trees, thereby increasing economic yield. Such selective logging systems have developed in many places, sometimes as a by-product of farm forestry, e.g. in the Alps in Europe, where elaborate selection forests developed by long-term low-intensity use by farmers that were in need of many different sizes of timber and poles (De Graaf 2000; Reininger 2000).

In the tropics, notably in tropical rainforests, high-impact logging and intensive forest exploitation may lead to serious damage to the soil (e.g. loss of nutrients, soil compaction). Also, the remaining stand structure may take very long to recover and this seriously limits future forest use for a long period of time. In such cases, low-impact logging and intermediate silvicultural treatment may ensure long-term sustainability of forest use when conditions are favorable. There, depending on forest composition and site conditions, a maximum logging intensity is allowed to guarantee recovery of the forest over time. But the intensity of low-impact logging and intermediate silvicultural treatment is also influenced by the need for timber and other forest products.

Suriname, with its low population pressure and high forest cover (see Fig. 1.2), provides an excellent opportunity for development of sustainable forest management on the

Photo 1.1.   CELOS office in Paramaribo 1983.
(Photo K.E. Neering)

basis of close-to-nature selection forests with cycles of low-impact logging combined with silvicultural treatments in between logging cycles. For the development of such a management system research projects were started in experimental plots in lowland rainforest in the 1960s and 1970s, in a collaboration between the Centre for Agricultural Research in Suriname (CELOS, nowadays part of the Anton de Kom University of Suriname), and Wageningen University in the Netherlands. This research collaboration ran until 1983 and has resulted in a large number of reports, papers and PhD dissertations. The experimental plots are still intact and offer the opportunity for further research. Even though the system has not yet been tested on a commercial scale in Suriname, forest logging companies with more advanced management apply the principles of the system in their operations.
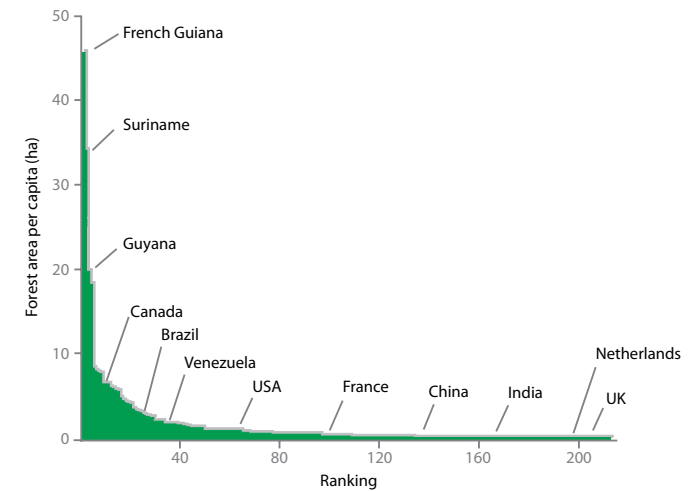
Figure 1.2.   Forest area per capita for selected countries, indicating the pressure on forest land for agricultural use. (Source Hammond, 2005)

1.2   Forest cover in Suriname

Suriname, located between Guyana in the west and French Guiana in the east, and bordering on the Atlantic Ocean in the north and Brazil in the south, lies just above the equator between 2° and 6° N and 54° and 58° W. The country has a typical tropical moist climate with a daily average temperature of 27.5 °C, and an annual range of only 3 °C. Mean annual rainfall varies between 1500 mm on the coast to 2500 mm in the higher areas in the central and southern parts of the country.

The country is divided into a mountainous region and a coastal zone. The mountainous region covers roughly 80 % of the country, consists of pre-Cambrian rock and is part of the Guiana shield, the world's oldest rock formation. The highest point is Juliana-top at 1230 m above sea level. The coastal zone consists of the young coastal plain, the old coastal plain, and the Zanderij formation or cover landscape. The young and old coastal plains are almost flat or only elevated a few meters, and generally have heavily textured and badly drained marine clay soils interspersed with sandy areas. The Zanderij formation tapers from about 100 km wide in the west to about 40 km wide in the east (Fig. 1.3).
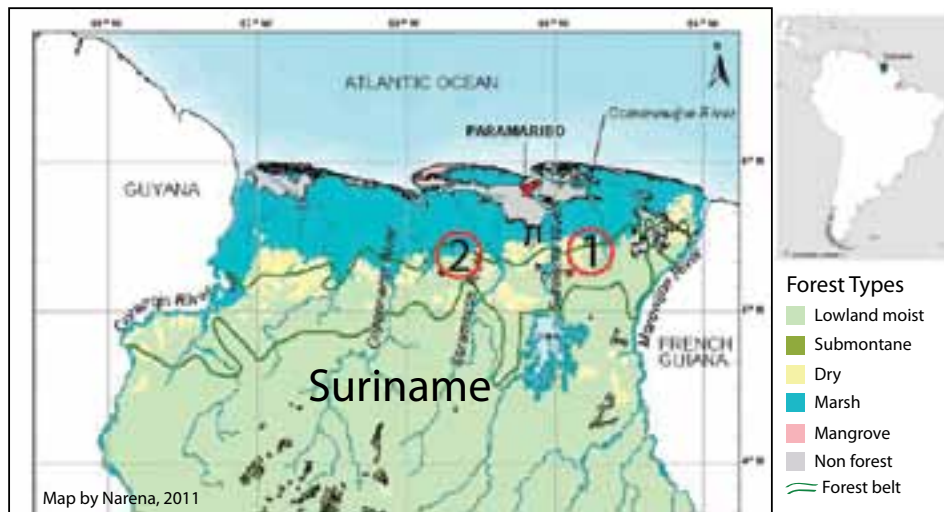
Figure 1.3. Map of the northern part of Suriname, with indication of the Forestry belt. Locations of the experimental sites: 1 Mapane; 2 Kabo.

The average population density is low with about three inhabitants per square km, and around 60 % of the population is concentrated in and around the capital city, Paramaribo, in the north of the country. Large parts of the interior are virtually uninhabited.

Forests on the young coastal plains consist of low swamp forests, covering about 3 % of the land area. They consist mainly of the following species: *Mauritia flexuosa* L., *Chrysobalanus icaco* L., *Annona glabra* L., *Erythrina glauca* Willd., *Triplaris surinamensis* Cham., *Pterocarpus officinalis* Jacq. and *Tabebuia insignis* (Miq.) Sandwith (see Annex 1 for common names). Tall swamp forest mainly occurs on the old coastal plain and covers about 2 % of the country. In the final stages of succession, this forest consists of mixed *Virola surinamensis* Warb., *Symphonia globulifera* L. and *Euterpe oleracea* Mart. stands, with occasional dominance of *Hura crepitans* L.. In the central part of the old coastal plain, a species-poor *Crudia glaberrima* (Steudel) J.F. Macbr. – *Macrolobium acaciifolium* Benth. forest may occur. Tall seasonal swamp forests occur on poorly drained soils, low ridges and plateaus of the coastal plain, as well as along creeks and rivers in the Savanna Belt and in the interior. Many of these forests are dominated by a single species, e.g. the palm *E. oleracea* L. (this entire section is largely based on Werkhoven 1996).

The tall dryland forest of the interior is described as seasonal evergreen forests by Lindeman & Mori (1988). A description of this forest type is given by Schulz (1960). It covers approximately 80 % of Suriname. These forests occur on the well-drained soils of the higher ridges in the interior, on the plateaus of the coastal plains, and on the loamy sands of the Savanna belt, provided seasonal desiccation does not occur. These forests can vary in species composition, with occasional dominance of single species such as *Mora gonggrijpii* (Kleinhoonte) Sandwith, *Aspidosperma excelsa* Kuntze, *Vouacapoua americana* Aubl., or *Bertholletia excelsa* Humb. & Bonpl.

The Exploitable Forest Belt, totally located above 4 º N latitude, is defined as a 40 to 100 km wide forest zone, south of the Zanderij Belt with its low-value forest, and north of the rugged hill country and the rapids. The forest belt comprises some 2.5 M ha (Nationaal Bosbeleid van Suriname 2005), but in view of topography and stand composition only some 600 000 ha are considered (potentially) productive, including some xerophytic forest north of the forest belt itself (Werkhoven 1996).

The landscape of the exploitable forest belt is level to undulating, with sandy and loamy deposits of coarse brown and white sands, subordinate gravels and kaolinite clays (Boxma et al. 1987), which rest on weathered basement. The deposits are up to 25 m thick in the north, and become shallower towards the south. Some of the deposits, especially the white sands after which the Zanderij area is named, are covered with savanna vegetation. This forms the most conspicuous feature of the Zanderij area, even though it covers only a small proportion of the area: about 40 % of the area has bleached soils (white sands) but only about 7 % is covered with savanna vegetation of grasses and low shrubs. The remainder of the white sands is covered with high savanna shrubs or savanna forest. The brown sands and loams in this landscape are covered with mesophytic high forest. The landscape is generally well drained by many creeks in a dendrite pattern. These mesophytic high forests are included in the evergreen seasonal forests. The height of the forest varies from 25-38 m with an occasional tree reaching more than 50 m.

1.3   Research for forest management

The historical development of forest management in Suriname will be described in more detail in Chapter 2. Early research for high forest management in tropical countries generally consisted of inventory studies (e.g. Schulz 1960, for Suriname), combined with studies on the regeneration processes in natural forests (e.g. Boerboom 1964). In Suriname, the Centre for Agricultural Research in Suriname (CELOS) was established as a foundation in 1967, originally linked to the former Landbouwhogeschool Wageningen (now Wageningen University) and after the independence of Suriname in 1975 to the Anton de Kom University of Suriname. The centre focuses on sustainable management and utilization of renewable natural resources, with the purpose to provide a scientific basis for long-term strategic decisions on land use in the country. As part of this research strategy, projects on forest management systems were started already since the establishment of the institute, partly building onto earlier research into silvicultural methods that were started in the beginning of the 20th century with the establishment of the forest service. From these efforts, the CELOS Management System (CMS) for lowland rainforest in Suriname developed in the 1980s.

This book brings together the main results of this research, with the aim to synthesize the existing information, to document and provide reference to results and data stored in technical reports, and to provide a state-of-the art for further research and application, both in Suriname and elsewhere, with the purpose to contribute to the development of sustainable forest management in the tropics in general, and in Suriname in particular. The book describes the experiences with the CELOS management system as an outstanding example of a management system for tropical lowland rainforest, and contains a synthesis of experiences and knowledge on the CMS system.

The majority of the results summarized here are based on long-term collaboration between the Anton de Kom University of Suriname (formerly University of Suriname) and the Centre for Agricultural Research in Suriname (CELOS), the Suriname Forest Service, and Wageningen University (formerly Landbouwhogeschool Wageningen) in the Netherlands. This collaboration started in the 1960s, and ran until 1983. The detailed project reports and related scientific publications related to the CMS system are included in Annex 2. The book aims at a readership of academics and professionals, involved in research and the development of sustainable forest management systems in rainforests in the tropics, and thus hopes to make a contribution to conservation and wise use of this precious resource.

References

Boerboom, J.H.A. 1964. De natuurlijke regeneratie van het Surinaamse mesofytische bos na uitkap. Wageningen, Nederland, Landbouwhogeschool.

Boxman, O., de Graaf, N.R., Hendrison, J., Jonkers, W.B.J., Poels, R.L.H.,Schmidt, P. & Tjon Lim Sang, R. 1987. Forest land use in Suriname. Tropenbos Scientific Series 1, 119-129.

De Graaf, N.R. 2000. Reduced impact logging as part of the domestication of neotropical rainforest. International Forestry Review 2, 40-44.

Hammond, D.S. (ed.) 2005. Tropical forests of the Guiana shield: ancient forests of the modern world. Oxford, CABI Publishing.

Lindeman, J.C. & Mori, S.A. 1988. The Guianas. In: D.G. Campbell & H.D. Hammond (eds.). Floristic inventory of tropical countries: the status of plant systematics, collections and vegetation, plus recommendations for the future. New York Botanical Garden, pp. 375-390.

Nationaal Bosbeleid van Suriname. 2005. Ministry of Natural Resources & the Foundation for Forest Management and Production Control, Paramaribo.

Reininger, H. 2000. Das Plenterprinzip. Graz, Stuttgart, Leopold Stocker Verlag, pp. 59-62.

Schulz, J.P. 1960. Ecological studies on rain forest in northern Suriname. Verhandelingen der Koninklijke Akademie van Wetenschappen Afdeling Natuurkunde Tweede Reeks 53, 1-267.

Werkhoven, M. 1996. Chapter 32: Suriname. In: C.S. Harcourt, J.A. Sayer & C. Billington (eds.). The conservation atlas of tropical forests: the Americas. New York, Simon & Schuster, pp. 303-311.

2   History of use and management of forests in Suriname

J. Hendrison & N.R. de Graaf

2.1   Introduction

Suriname became a colony of the Netherlands in the second half of the 17th Century with the main objective to develop a settlement of Dutch planters. Until the end of the 18th century, the colony was prosperous and able to produce cotton, coffee, and especially sugar for the European markets (Buddingh 1995). As in most Caribbean countries, the agricultural system was based on the labour of African Slaves, employed on large plantations along the navigable sections of the Suriname River, the Commewijne River, and the Marowijne River (Fig 1.3). The colony ruled itself without much input of the mother country. Actually, most of the plantation owners were living in The Netherlands and could afford to employ estate managers to run their possessions in Suriname.

Exports of agricultural products, generating essential revenues for the colonial government, decreased substantially even before the abolition of slavery in 1863. Before the turn of the 18th century the mother country had to finance the budget deficits of the local government. After 1863 the plantation system could only temporarily survive with contract labour from India, and a few decades later from Indonesia. The colony remained agrarian, but no longer was a significant exporter of selected products. The Asian immigrants changed the pattern towards a more diverse production system with rice as the main crop. With the decline of the plantation economy, a more stable local market was developed with a higher level of self sufficiency for food crops.

Suriname's economy made a remarkable move when bauxite became the main export commodity during and after the Second World War. The mining industry became the corner stone of the economy, especially after the construction of a hydropower plant and an aluminium factory in 1959-1960. The second source of revenues for the government was the development aid from The Netherlands that increased impressively after Suriname's independence in 1975. Until 1984 the substantial amount of approximately

one billion USD had been invested in the development of infrastructure, agriculture and forestry. Since the early 1990s oil exploration and processing, and gold mining became two new sources of revenue for the country. During the last two decades the trade and industrial activities increased and became more diverse and this can be considered a moderate achievement of the development aims of 1975.

Since the first attempts of the government around 1904 to regulate the forest sector, it progressed with ups and downs. Until the 1940s the forest sector was weakly developed, but grew since 1947, after the re-establishment of the Forest Service and the founding of the Bruynzeel Wood Company, but far less than was aimed at. The present contribution of the forest-based industry to export, gross domestic products and employment is less than 3 %.

Forest management development in Suriname can be characterized by five periods, which are not sharply and somewhat arbitrarily marked (Table 2.1). The transfer from one period to the next was mainly determined by initiatives of the forest management and research organisations, and not by a change of government policy or by the implementation of new strategies. The development plans since 1950 were predominantly influenced by the views of forestry experts from The Netherlands and from international agencies such as FAO, but also often substantially modified by governmental policy makers and politicians. Professional foresters in civil service, such as the academic staff of the Surinam Forest Service, were often key innovators while the government itself remained for a long time an observer who set the constraints for forest legislation.

Table 2.1. Review of the development of use and management of forests in Suriname

No	Period	Management concept	Main forestry activities
1	Before 1900	selective unmanaged forest use	collecting non-timber forest products; logging in private timber estates
2	1904-1947	conversion of natural forest to uneven-aged stands; plantations of indigenous tree species	first Forest Service establishing experimental plantations and testing timber harvesting; private logging along navigable rivers; boom in the balata trade
3	1948-1977	selective logging with management plans; monocyclic regeneration and open as well as strip planting	new Forest Service starting forest inventories, opening up the Forest Belt, and establishing Caribbean pine plantations and natural regeneration experiments; extension of private logging to the Forest Belt; establishing of the BSH integrated forest industry; mechanisation of timber harvesting
4	1978-1990	sustainable forest management based on ongoing CELOS forest management research (four publications on CMS)	forest management research; private logging in managed concessions; further progress in forestry training on operational, college, and academic level
5	1990-present	ecologically based forest management with RIL; polycyclic harvesting and natural regeneration based on CMS; certified forest operations and products	enforcement of the Forest Management Act; establishing SBB; formulating a National Forest Policy; introducing RIL and forest certification; international timber companies starting logging and wood processing

2.2 Selective unmanaged forest use (before 1900)

Early records on forest exploitation in Suriname refer to the harvesting of "Letterhout" by Amerindians who used it as currency in trade with colonists from Europe. It was reported that already in 1650 Letterwood (or Captain's Letterwood, *Brosimum guianense* (Aubl.) Huber, basionym *Piratinera guianensis* Aubl.) was purchased by sailors from the Dutch Province of Zeeland (Photo 2.1). This valuable commodity was very much in demand for the manufacturing of letterheads for printing offices (Gordijn 1977). Not much else is known about these early days of forest exploitation.

For about two centuries (1700-1900) the vast forestland of Suriname merely was used for selectively harvesting marketable non-timber products, while some timber was harvested in accessible forests, usually located along navigable rivers.

A number of planters were also harvesting timber on the so called 'Houtplantages' in addition to their main tasks on the agricultural plantations. These timber estates were private enterprises often close to the agricultural plantations and also based on slave labour (Kappler 1883). Their number decreased rapidly after the abolition of slavery in 1863, but a few remained until the turn of the century (Plasschaert 1910). The average size of a timber estate was around 3000 ha. All labour, including the sawing of logs into boards, was done manually. The capacity of the timber estates could hardly meet the demand for construction timber in the capital town of Paramaribo and on the agricultural settlements. Due to lack of animal and machine power for log transport, the sites closest to the river were rapidly depleted and, already in that period, the colony was confronted with deficits of desired timber species for construction wood. Berkhout (1917) reported heavily exploited forests adjacent to the agricultural estates along the main rivers. But replanting of logged-over areas was not practised.

Photo 2.1. Sometimes a keen observer sees an apparently rotten stem on the forest floor, lying there for perhaps half a century or more, which upon inspection proves to be a piece of core-wood of Letterwood, hidden in a mantle of decayed sapwood. Letterwood *Brosimum guianense,* Moraceae, is a very durable, dense and heavy wood. Local varieties show an attractive pattern of blots. It was one of the first export products of Suriname and it was gathered by hand. (Photo J.Franco)

The demand for wood products was, for a substantial part, satisfied by timber imports from the USA. Sailing ships sent to Suriname to collect agricultural products carried sawn wood as ballast; that was cheaper than locally processed boards. Buildings in the old residential quarters of Paramaribo were partly constructed from American pitch-pine lumber (*Pinus palustris* and *P. elliottii*, mainly).

2.3 Introduction of forest management (1904 – 1947)

Already before the turn of the century the most important forest product was balata or bullet-wood gum, from the bolletri (*Manilkara bidentata*). The collecting of balata was more profitable than timber exploitation and could be done with far lower investments than those required for logging. The Balata Ordinance of 1914 included prescriptions for tree tapping and gum preparation, and stipulations to maintain the required harvesting cycle, in order to protect the bolletri from overexploitation. With the continued recession of the plantation agriculture, the balata business offered jobs to thousands of workers ("balata bleeders") in the first two decades of the 20th century. After a peak export in 1913 the significance of the balata industry gradually declined until it ceased to exist in the early 1970s, but the bullet-tree is still protected and its restricted felling is subjected to special regulations in the Forest Management Act of 1992.

The colonial government had been neglecting the extensive forest land of Suriname as a sustainable source of income for a long time. The focus was too much on plantation agriculture, while forests were considered as an obstacle that had to be cleared for agrarian development. Even after the re-establishment of the Forest Service in 1947, it took almost half a century to change this approach and to gain public awareness for sustainable forest use and biodiversity conservation. After the first attempt, in 1905 (Berkhout 1917), to make the tropical rain forest of Suriname more productive as a source of quality timber, forest management concepts changed, but were not based on national forest policy objectives. Just recently, in 2003, the government of Suriname has formulated for the first time a consistent forest land use policy (see Section 2.5.2).

The colonial government in Suriname had the idea that forest plantations could be established in the same way as teak plantations on the island of Java in the Dutch East Indies (Indonesia). Teak (*Tectona grandis*) stands had already established semi-naturally before the time of the Dutch colonization of Java. An area of nearly a million hectares of teak stands were successfully brought under permanent management in the nineteenth and twentieth centuries (Dawkins & Philip 1998). This plantation management concept, so successful on Java, was adapted for Suriname.

The starting point was the visit by Prof. Berkhout to the country, in 1903, to advise the government on developing a productive forest sector. As a result, a few years later a forest management department was founded and named 'Boschwezen'(Forest Service). Berkhout (1903) opposed the idea that the tropical rain forest has the potential to regenerate rapidly without human interference. In his opinion the significance of maintaining a cutting cycle was vital in order to develop a sustainable forest management system. He proposed a cutting cycle of 50 years in combination with replanting schemes in the logged-over forests.

In 1905 the pristine forest along the railway to the Lawa goldfields was selected for timber production. This was the first time in Suriname that a forest management unit was established. The system of Berkhout was tested on a practical scale in an experimental area of 10 000 ha, divided in annual coupes of 200 ha compartments to attain a felling rotation of 50 years. A gradual conversion to a two-storey forest was envisaged with an age difference of 50 years between the upper and middle storey. Natural regeneration was to be stimulated by manual liberation of commercial trees, while additional planting was considered to fill gaps in the forest cover (Berkhout 1917; Gonggrijp 1925).

The proposed management system was inspired by the selection forest concept, developed by the forestry schools of Switzerland (Knuchel 1947) as an alternative for clear felling. Yet, Berkhout regarded clear felling of the natural forest and conversion to forest plantations of commercial timber species the best option for Suriname. A parallel might be seen in the management of the production forests on the heavily populated island of Java, where the teak was nearly all planted with a taungya agroforestry system. In scarcely populated Suriname, however, the taungya system was not suitable, because it brought no tangible incentives for local farmers as they did not need to compete for forestland. Thus, in Suriname, additional funds were needed to establish timber stands by planting. Hence, a natural regeneration system was thought to be cheaper, but the first timber harvest (logging) could only be profitable if this could be done in a rational way so that the silvicultural measures could be paid from the revenues of logging.

This forest exploitation experiment was unsuccessful for reasons of mismanagement and wrong estimates of logging costs, as was reported by Plasschaert (1910). The experiments were suspended because of lack of funds to proceed. The expected revenues from the model forest exploitation were never made and around 1926 the Forest Service was disbanded for financial reasons. A remedy could have been, according to Plasschaert (1910), to switch to machine skidding. Pfeiffer (1929), however, rejected that option, because a far higher volume of at least 60 $m^3.ha^{-1}$ was considered essential for an economic harvest with machine skidding. Such volumes were commonly harvested in the Philippines and the Dutch East Indies, where the experiences with mechanised logging originated from, but the forest in Suriname was much poorer in commercial volume.

Photo 2.2. *Virola* spp. (Baboen) stems are pulled over a little dam, which separates two water basins with permanent different water levels. Coesewijne, Suriname, 1982. (Photo P. Schmidt)

Photo 2.3. *Virola* spp. (Baboen) stems are selected and combined into a raft for transport to the sawmil. Coesewijne, Suriname, 1982. (Photo P. Schmidt)

2.4   The activities of the Suriname Forest Service (1947 - 1977)

When the Suriname Forest Service (LBB) was re-established in 1947 there was high expectation regarding the possibilities of expanding forest production and creating a forest-based industry. The key to success would be the introduction of wise forest management accompanied by public investments in forest infrastructure. In spite of a promising start and dynamic initiatives of the Forest Service for a period of approximately 30 years, the results were not very impressive. The only forest industry that could meet international standards was that of the Bruynzeel Wood Company Inc (BSH) that was established around 1947. BSH grew rapidly and became for years the local market leader and the most important supplier of plywood and quality hardwood lumber to Caribbean countries. The local forest and sawmill business expanded in the wake of BSH, but was not able to establish a modern logging and wood-processing industry, until recently when a few new companies entered the forest sector (see section 2.5).

The re-established Forest Service had to start all over again, after a period of 22 years of unsupervised forest use. Most of the forest infrastructure was gone and field personnel such as forest guards were employed elsewhere. The forestry experiments from the previous period had not been maintained and were not measured or guarded anymore. One of the oldest plantations (the 'Gonggrijp Forest') was largely occupied by local people and converted to agricultural land. Gonggrijp, who worked in Suriname as Conservator of Forests from 1907 to 1923, returned to the country in 1947 to assist the colonial government to prepare a forest policy and to help with the re-establishment of the Forest Service. His findings were published in a comprehensive handbook on post-war forestry in Suriname (Gonggrijp & Burger 1948). The envisaged forest management system was in fact a modification of the system that was earlier proposed by Berkhout (1917) comprising replanting of exploited forest with valuable tree species. Emphasis was put on the planting of the well-known commercial hardwoods in open areas or logged-over stands.

Gonggrijp's concept of replanting has never been applied on a practical scale, because experiments with small plantations of commercial hardwood had indicated, already in an early stage, the slow juvenile growth of most indigenous tree species. His predictions on future yields were far too optimistic and were not supported by convincing field research.

At that time the idea arose to develop the most accessible pristine forest region as a forestry zone. Heinsdijk (1950) used the term Forest Belt, referring to the economically accessible dry land forests of Suriname behind the wide old coastal plain (Fig. 1.3). The hinterland further south was seen as inaccessible for sustainable forest use, because of terrain difficulties, extremely poor soils, and lower stocks of commercial species. According to professional foresters it would be better to develop a forest management system that could sustain the production of useful timber from the relatively restricted (1.5 million hectares) Forest Belt.

At that time the Suriname Forest Service had not yet made a choice for a specific forest management system, but opted for a more flexible strategy involving a number of forest use and regeneration schemes. The most important activities and achievements of the Forest Service were:

- The Forest Belt of Suriname was opened up by a network of sandy and gravelled roads, which were first constructed from the Suriname River in eastern direction to the Commewijne River, to compensate for the depleted areas along these navigable rivers.
- An extensive forest inventory was carried out in the Forest Belt and part of that area was allocated for managed timber concessions.
- Enrichment planting experiments were continued on a small scale as a means to recover logged-over stands.
- Forest research was carried out, including experiments with monocyclic natural regeneration of logged-over forest as a means to recover the stock of commercial hardwood species.
- Pine (*Pinus caribaea*) plantations were established on cleared forest land to supply the local market with utility and industrial wood.
- Forest guards, rangers and technicians were educated successfully in an own training centre.
- Two governmental mills were established, one in Central Suriname at the Saramacca River (Photo 2.4), and one in Western Suriname at the Corantijn River, in 1973 and 1975, respectively. The first one had to test modern processing techniques and the second to produce sleepers for the new railway and construction timber for the developments in Western Suriname.

The exploration and subsequent layout of the Forest Belt formed the basis for the development of a local forest and wood-processing industry. The Forest Belt became the major region for timber harvesting and forestry in general, including the establishment of tree plantations. A system for managing forest concessions was introduced and legally enforced by the Timber Ordinance and the Special Concession Ordinance of 1947. The Forest Service was given responsibility for implementing the Ordinances. A substantial number of concessions were granted as forest units subjected to regular management. The regular management concept (Bhadran 1965) comprised the use of a management plan designed by the Forest Service, including a manual for road construction, inventory, harvesting and recording of timber production. A forest unit was divided into cutting compartments in anticipation of a felling cycle of 30-35 years, as a rotation cut was considered achievable in less than 40 years.
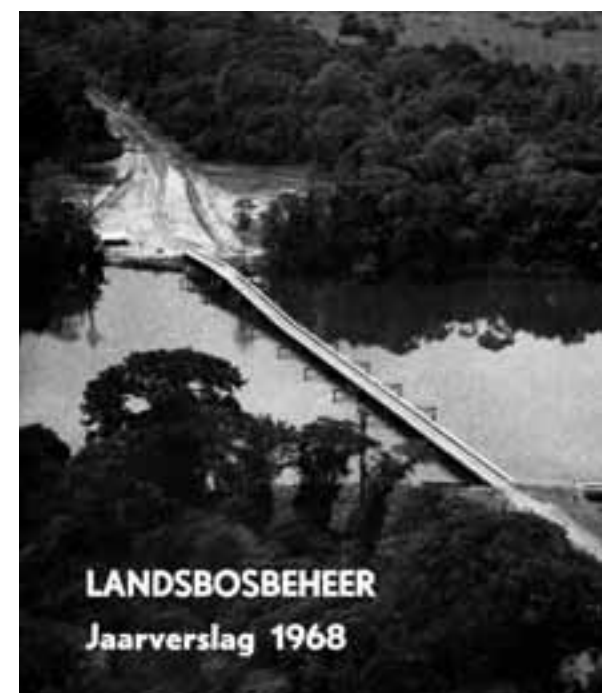

Photo 2.4. The wooden bridge over the Saramacca river, completed in 1968. (Photo Dienst's Lands Bosbeheer)

The extensive swamp forests along the coast of Suriname contained a considerable volume of plywood logs of *Virola surinamensis* Warb. (Myristicaceae). Due to a very dry year (1964) large parts of these swamp forests were destroyed by fire, often inclusive of the peat layer. This was a great set-back for the forest industry that had developed systems for exploiting the swamp forests (see Photos 2.5 & 2.6).

2.5 Further developments in forest use and management after 1977

2.5.1 The deterioration of the forest sector and the Suriname Forest Service

When Suriname became independent in 1975 the Forest Service was still an active organization and a role model for the Caribbean region. But the brain drain of the early 1970s had also affected the forest sector. Already at that time there were problems in recruiting managerial and skilled staff at all levels and, as a consequence, the Forest Service had to end or suspend a number of its activities. The situation worsened the next decade after a military coup in 1980 that had its impact on the stability and democratic status of the country. A complete decline of the Forest Service and the logging industry resulted from the inland war that started in 1986.

Around 1977 the Forest Service stopped with the expansion of the Caribbean pine plantations, because of disappointing growth results and the excessive costs of stand management and weed control (Fraser et al. 1977). Tree plantation establishment on the poor tropical soils turned out to be very unattractive both in an economical and ecological sense. The objective now became to maintain the existing estates of almost 9000 ha and to search for a more efficient management system focusing more and more on the natural regeneration of logged-over forests. A governmental firm, the BOSMIJ, was set up to manage and utilise the pine stands.

Photo 2.5. and Photo 2.6. Extensive stands of *Virola surinamensis* (Roland.) Warb. (Myristicaceae), in the coastal swamps were opened up by small canals. In the early days these canals were sprung with dynamite, but later they were dug out with machines. (Photo J.H.A. Boerboom)

Already before the 1977 the road building activities had been assigned to private contractors, while the training of rangers had been transferred to the Institute for Natural Resource and Engineering Studies (NATIN). Research activities were suspended and only the main tasks of forest management, production control and timber inspection were still carried out.

The inland war in the late 1980s heavily hit both public institutions and private logging enterprises, which lost a considerable amount of equipment and almost their complete infrastructure. The Forest Service lost practically all the 24 forest guard stations and related assets and became almost non-existent in the early 1990s. Various attempts to reanimate the Forest Service failed, mainly because of the weakness of governmental departments at that time. A radical solution was the establishment of a new forestry venture in 1999, the Foundation for Forest Management and Production Control (SBB), which took over the management and inspection tasks from the Forest Service.

The wood-processing industry was directly impacted by the corrosion of the logging ventures and the chaos in accessible production forests. Especially the larger companies, such as the Bruynzeel Wood Company, came into great troubles not only because of the reduced supply of raw material, but also due to the financial crisis in the country and therefore the lack of funds to reconstruct the damaged infrastructure. Further decline of Bruynzeel was also due to weakness of the management and the inability to renovate the company so that it could compete with other ventures from the region. Slowly, but steadily, BSH was moving towards bankruptcy.

2.5.2 Developments in forest policy and management control

The promulgation in 1992 of the Forest Management Act (FMA), which had been strongly modified since the first draft of 1974, gave the government a more powerful tool than the Timber Ordinance of 1947 to manage Suriname's forests and to supervise forest use and nature conservation. But even after a period of almost 20 years of preparation, successive governments failed to effectuate the FMA and to reorganise the Suriname Forest Service.

The FMA stipulates that timber concessions larger than 5000 ha should be managed according to a management plan designed by the concessionaire. The management plan has to be submitted to the forest authority (at that time the Forest Service) for approval. The FMA includes stipulations regarding the layout of a forest management unit, the felling cycle, the allowable annual coupe, and the maximal per ha harvest of commercial species. Yet, it took another decade before forest production could be controlled effectively by the newly assigned governmental foundation SBB.

Another major achievement was the increase of the royalty on timber harvesting from USD 50 cents to USD 6.00 per m³. As a result of the development of SBB, the forest sector could finally again contribute to the government's budget, something that had not happened since the balata boom of 70 years earlier. In addition, concessionaires were better guided and controlled and new actions were taken to improve forest management. Furthermore, the new organisation took initiatives to promote forest and

timber certification. The first company (Suma Lumber Inc.) was certified in 2008 while presently two other ventures are in a preparatory stage for certification (Houtwereld 2008).

The Forest Service had not only survived, but got new drive after the inspection tasks had been delegated to SBB, and it reorganised the nature conservation and training departments. Further developments could lead to an integration of SBB and the Forest Service in a new forest and nature conservation authority 'BOSNAS', similar to that of Guyana. A concept to adjust the FMA has meanwhile been presented to the government. This recent initiative from SBB got support from international agencies as FAO and ITTO, who have also sponsored capacity building projects for the forest sector of Suriname.

A milestone in Suriname's forestry history was the formulation of a national forest policy (NFP) that addresses modern forest management subjects as well as community forestry and gender issues (SBB 2003). Moreover, the NFP was a backing for the new SBB and a firm commitment of the government to proceed with policy reforms.
Meanwhile a new institute, The National Institute for Environment and Development in Suriname (NIMOS), was established and also statutory involved in the forest environment. A forest sector impact assessment was conducted in 2003, including a sector study and a design of guidelines for forest land assessments (NIMOS 2003).

2.5.3 International companies

Three Asian companies got huge timber concessions in 1994 under the conditions that they would establish modern logging and wood-processing industries. These ventures went bankrupt within a few years leaving behind one middle-sized sawmill and a number of badly managed forest units with a poor infrastructure.

Currently six Chinese companies are active in Suriname's forest sector, mainly in sawmilling and small-scale traditional logging. One wood-manufacturing firm, and one plywood mill are relatively successful on the local market, but the foreign companies have contributed little to modern forest management in Suriname, accept one that has employed a trained unit to perform reduced-impact logging with the intention to prepare forest and timber certification.

2.5.4 State of the art in 2009

The activities of the successive forest management organisations ("Forest Services") were decisive for forestry development in Suriname: A century of governmental ruling of the forest sector has been followed up in the past decade by a transitional phase, in which other interest groups got involved in the management of forests.

The forest sector of Suriname is clearly in an advanced state of recovery and improvement. Most important is that public as well as private organisations are taking their responsibility to further developing the sector and its supporting institutions. Almost all interest groups and stakeholders are organised in one way or another and structural consultations have been accepted as an effective tool to rule the forest sector.

The private sector is represented by the General Suriname Timber Association (ASHU) and by the Timber Sector Platform (Platform Houtsector Suriname, PHS), which have regular meetings with SBB and private organisations from the sector. This new phenomenon of consultation has also to do with public awareness on issues of sustainable forest management, biodiversity conservation, and management of natural resources. It is an encouraging development and the first time in Suriname's history that the government gets effective feedback from the society through its representing bodies.

The Foundation for Forest management and Production Control (SBB) has become a respected organisation, which has reached remarkable achievements with regard to the quality of its inspection and extension tasks. It presently employs about 130 persons, including academic, college and lower technical staff. SBB promotes sustainable forest management, not only by implementing regulations and control, but also by guiding and training logging operators including those from forest communities.

Forest legislation is in need of revision, because since the enforcement of the Forest Management Act of 1992 social-economic circumstances and forest management practices changed substantially. The concession stipulations need to be reviewed and a project is in preparation to adapt the forest charges system in such a way that the revenues for the government are increased and at the same time incentives are introduced for sustainable and efficient forest operations.

In spite of the promising projected policy, forest legislation and forest management reforms, the logging and wood-processing industries are yet far from modern. The only integrated forest industry, BSH, has disappeared again, while little improvements were achieved in the sawmilling sector. Since the financial crises of 2008, export of timber declined by approximately 20 % and investments in new ventures came almost to a complete stop. Yet, in the last quarter of 2009 there were indications that this negative trend started to recover. A number of temporarily closed forest enterprises started again with logging and timber trade, while local lumber prices increased with a mere 5 %.

2.6 Research developments since 1950

The history of forest management and forest research is strongly linked with the development of the Suriname Forest Service, which once was a role-model institution in the region, able to execute a variety of tasks and activities. Already in the 1950s it understood the importance of having reliable silvicultural systems available in order to manage permanent forest estates. Various experiments were started on the soils of the wet coastal zone (Photo 2.5 & 2.6) as well as on the soils more inland under high-dryland tropical rain forest. Both plantations (open planting as well as enrichment planting) and natural regeneration were tried. The goal was to raise the volume production per hectare of useful timber. Logically, the natural forest types with a relatively high proportion of usable timber volumes got early attention. Schulz, Boerboom and De Graaf played pioneer roles in developing a forest management system adapted to the special features of the tropical rain forest of Suriname. Their research contributed to the design of the CELOS Management System (CMS).

2.6.1 The ecological studies of Schulz

The investigations of Schulz (1960) largely concentrated on forest ecology with due attention to forest regeneration. One of his conclusions was that the ecology of tropical rain forest is probably too complex to allow a reliable prediction of effects of regeneration treatments, even after extensive research. Schulz was strongly influenced by the research of Dawkins (1958) in Uganda, who recommended a monocyclic regeneration system to transform the uneven-aged mixed tropical rainforest into an even-aged stand, largely consisting of valuable tree species. The aim was to increase not only the increment, but also the number of the current commercial timber species. This commercialisation of lesser known species became a hot issue in wood technology research (Japing & Japing 1960; Vink 1965).

Schulz stated that most species regenerate regularly in the high-dryland forest of Suriname, and that this uneven-aged forest has more or less an exponential diameter distribution for a great number of species, with a decreasing number of the large-diameter trees. It was already clear that regeneration takes place mainly in (natural) gaps caused by falling trees, with a dynamic equilibrium between recruitment and mortality of trees.

In his first publication Schulz (1960) did not opt for one specific silvicultural system for Suriname. He made reservations in a later paper about introducing a monocyclic system as designed for Africa (Schulz 1967). However, the risk of excessive logging damage in a polycyclic system is less in Suriname. This is, amongst others, because of the relatively small tree crowns, a factor in favour of polycyclic management systems.

2.6.2 Silvicultural research of Boerboom

The concept of the accessible and manageable Forest Belt had been introduced already in the 1950s, with the idea to establish a sustainable and productive forest management zone. It was already known at that time that after harvesting the relatively small volume of valuable timber per ha, the extremely slow re-growth of these attractive species would not generate a next comparable harvest within a few decades. The required felling cycle of probably 80 years or more would imply a costly maintenance of the forest infrastructure and would require the allocation of a relative vast area of forestland to harvest sufficient volume. Tree planting systems turned out to be uneconomical, while controlled natural regeneration could be an option.

The need for a higher number of trees of valuable species meant that a drastic change in the volume composition (species abundance) of the forest stands had to be achieved, promoting the valuable species from a mere 10 % towards a multiple value of that original percentage. This seemed to be possible, from early interpretations of the first experiments, and was considered as ecologically acceptable. A lower final stand volume than originally present was seen as acceptable in this system. New methods to remove trees of non-commercial species had become available during World War II by means of synthetically produced arboricides which fatally disturbed (especially) root growth already at very low concentrations. Removing in this way nearly all of the dominant canopy trees proved to be very effective and relatively cheap. Also the ravage from falling branches and stems of treated trees was considerably less than from felled trees (Boerboom 1964).

Dawkins visited the Suriname Forest Service in 1955 (LBB 1956) and recommended as best practice a shelterwood system with clear felling after establishment of sufficient regeneration, because a polycyclic systems was considered to be very damaging to the residual forest. The shelter wood approach was followed in Trinidad with apparently good results in similar forests as in Suriname (Boerboom 1965). There was, however, a good market for firewood in Trinidad at that time, allowing revenues to compensate for the labour-intensive clearing, but that was not the case in Suriname. Here, the researchers thus had to use arboricides to remove the canopy.

Results obtained in these first regenerating experiments were encouraging enough to continue with research, but the high costs of tending the young stands were a drawback. Early assumptions (Schulz 1960) that once established stands (cohorts) of saplings of a few meters tall could keep sufficient dominance over the abundantly regenerating pioneer and secondary species proved to be over-optimistic (Photo 2.7). The stands were swamped with pioneer trees and other undesirable vegetation, which made increment of desirable species often very slow (Boerboom 1964; Schulz 1967). Nevertheless, Boerboom intensively tested the monocyclic regeneration system and tried to formulate the goals. Furthermore, he proposed new experiments to clear up the then vague perceptions on forest regeneration.

2.6.3 Silvicultural research of De Graaf

A few decades later De Graaf (1982, 1986), concluding from Boerboom's studies on forest succession after clearing, opposed a monocyclic system with the argument that a final clear felling, even under a reasonably successful shelterwood regeneration system, would lead to an interim dominance of invading pioneer and early secondary tree species as well as climbers. This dominant layer would suppress the valuable species for several decades or would have to be removed by costly and repeated interferences. It seemed that the early researchers repeatedly underestimated the overpowering vitality of the pioneer and early secondary vegetation after intensive refining in this forest ecosystem. As most of these fast-growing species are not marketable, much unlike the situation in Southeast Asia, in Suriname this interim dominance had to be avoided by allowing only a reduced opening of the canopy.

Photo 2.7. Early treatment schedules were very intensive, with stand basal area reductions from an original 28 m^2.ha^{-1} of the logged forest to a mere 4 m^2.ha^{-1}. Regrowth after such treatment was very dense, and several secondary species strongly dominated. The person in the bush is Dr Jan Boerboom. (Photo J.P. Schulz)

New field experiments to test the monocyclic system were started by Boerboom at the field stations of the Centre of Agricultural Research

in Suriname (CELOS) and were continued by De Graaf as from 1970, with logistic support of LBB. This research is discussed in detail by De Graaf (1986), who compared the results of these quite diverging experiments by using the same parameters and methods to analyse the records. Previous conclusions were confirmed after renewed inventories of the experimental plots (De Graaf et al. 1999; Poels et al. 1998). These field experiments, some of them dating from about 40 years ago, still exist in the Mapane research area.

The oldest experiment was set up in an area of 20 ha in 1965 to study the effects of delayed liberation treatments on populations of young trees of valuable species in heavily refined stands. Another field experiment in two blocks of 5 ha, started in 1967, aimed at studying developments in a forest that was lightly logged without post-harvesting silvicultural treatment. A third experiment on 25 ha, also started in 1967, was to test a series of silvicultural liberation techniques after refinement, each technique with various liberation schedules. Finally, a 25-ha extension of this third experiment was established in 1975, to test the best technique and schedule so far found, but now on a practical scale. Even an assessment of the treatment costs was possible, as the plot size was large enough to allow regular manual operations. The data would be compared with those from the Forest Service's experiments. In all these trials the refinement and liberation was done using the arboricide 2, 4, 5-T solved in diesel oil.

The experiments have been intensively recorded the first years, some even annually (De Graaf 1986), but after 1982 the recording and monitoring stopped, because of the instable political situation in Suriname. Only one occasional observation by Van Rompaey took place in a selection of experimental sites in 1987 (De Graaf et al. 1999). The next opportunity for measurements in the experimental plots came eight years later, in 1995. The absence of data in the time gap of 13 years could partly be compensated by the long period of annual recordings from 1965/1967 up to 1982, so that De Graaf was able to process and analyse the data (De Graaf et al. 1999).

Already in 1978 De Graaf proposed to test his findings on a practical scale. He designed a large-scale experiment in the Kabo area named "Experiment 78/5 - Mortality, Natural Regeneration and Increment" to study the effects of logging and refinement on the residual forest, and conducted the logging operations as a first treatment of a pristine forest (De Graaf 1986). In the follow-up research carried out by Jonkers (1987) the experiment was revised and coded as "MAIN experiment". A few years later De Graaf proposed that a more in-depth study should be undertaken on the various impacts of timber harvesting and terrain transport of timber, because the way in which this first human interference is carried out is decisive for the regeneration ability of the forest. Both extensions of the original research programme took place within a new university cooperation structure (Section 2.6.4).

2.6.4 Research at the Centre for Agricultural Research in Suriname

After the independence of Suriname in 1975 the previously discussed silvicultural research was continued within the framework of a project named "Human interference in the tropical rain forest ecosystem" (LH-UvS01 Project, registered as MAB Project 94). This project, a cooperative effort of Wageningen University and the University of Suriname,

started in 1978 and was suspended in 1983. Its overall objective was: "An evaluation of the consequences of interference on the potential productivity of the ecosystem, on its environment and on its capacity for sustained timber production."

The specific research objectives were formulated as:
- Analysing the effects of management and operational practices on the forest ecosystem;
- Investigating ecological processes, particularly those related to production, and the effects of stand treatments on neighbouring systems (e.g. aquatic systems);
- Developing principles on which to base the planned management of tropical rain forest.

The field research of the project was facilitated by the Centre of Agricultural Research in Suriname (CELOS). Two field stations were established, one near the bridge over the Mapane River and another in yet unexploited forest at Kabo, near the Tibiti River. A total of 60 field plots, including plots from older experiments, were laid out. Most of the experimental plots are today still detectable at the research sites. They were all marked and coded, mapped, and described in a manual that is still in use. Around 1982, six scientists and 30 field assistants were employed in the project.

The Silvicultural experiments. The largest silvicultural experiment, the MAIN experiment at Kabo, aimed at determining which combination of logging intensity and silvicultural treatment would result in optimal development of the commercial stand. The scheduled silvicultural treatments were two varieties of CSS (CELOS Silvicultural System, see Chapter 3) and a control treatment, and the logging treatments were tree levels of semi-controlled selective felling. This completely factorial block experiment originally consisted of three randomized blocks (replications), each of nine treatment plots, and tree virgin plots which were added in 1981.

Photo 2.8. The encampment at Tonka site, near the MAIN Experiment. Such traditional huts are comparatively cool and comfortable for those accustomed to sleep in a hammock. (Photo N.R. De Graaf)

The MAIN experiment was revised by Jonkers who applied the silvicultural treatments and observed both the refining and logging impacts for three years (Jonkers 1987). The impacts on three growth, recruitment and mortality, as well as the findings which contributed to the design for CMS, are discussed in Chapter 4.

The ecological studies. Under all circumstances the envisaged forest management system should be developed within the ecological constraints of the ecosystem, including the question to what extent one can interfere in the tropical rain forest ecosystem without jeopardizing its capacity to recover and to maintain its biological productivity. The ecological research was carried out at both research sites simultaneously with the silvicultural studies (Schmidt 1981, 1982). The observed impacts on forest structure and

plant species composition are discussed in Chapter 5, the impacts on animal species in Chapter 7, while a number of related ecological aspects are highlighted in Chapter 6.

The hydrological and nutrient studies. Silvicultural and logging treatments can also impact the hydrological system and the nutrient balance of the forest. Hydrological aspects included observations and measurements of rainfall, discharge (runoff), evaporation and groundwater levels. A computer model (WOFOST4) was used for simulating water flow and forest growth in the research area. The nutrient balances of undisturbed and treated forest were compared to determine the effects of refining and logging. The findings from this research are discussed in Chapter 6.

The timber harvesting experiments. The first efforts to reduce logging damage in tropical rain forest date from the 1950s, when directional felling was introduced in the Philippines as a means to avoid damage to potential crop trees (Reyes 1968). In the same period, the first publications on logging damage in Malaysia appeared (Nicholson 1958; Wyatt-Smith & Foenander 1962) and this led to the introduction of pre-felling climber cutting in the late 1960s (Fox 1968). However, serious efforts to modify the complete logging operation with the dual aim to reduce damage and to improve efficiency were not undertaken in South East Asia until the late 1970s, and even later in Latin America and Africa.

In addition to the study of logging damage in the MAIN experiment, a more specific research on various aspects of logging impacts was carried out by Hendrison (1990) in the Mapane area in 1981. The best management practices to reduce damage (then defined as damage-controlled logging) were investigated in the context of sustainable forest management. Further observations of logging impacts were made in the concession area of BSH at Patamaka. The background of this study, including the formulation of a controlled harvesting system, called the CELOS Harvesting System (CHS), are discussed in Chapter 3.

Suspension of fieldwork. In fact the CMS fieldwork was already suspended by Wageningen University in December 1983 after the serious political problems involving developmental cooperation between Suriname and The Netherlands emerged. This was very unfortunate, especially with respect to the planned observations in the experiments at Kabo and Mapane. The first phase of development of the CMS was ended after processing and analyses of field data and the publications of the results (De Graaf 1986; Poels 1987; Jonkers 1987; Hendrison 1990).

2.6.5 The design of the CELOS Management System

Development of a sustainable forest management system such as the CMS was somewhat complex and it took quite a number of years before a polycyclic management system was finally considered most suitable for the tropical rain forest of Suriname. Such a system can restrict the invasion of woody weed species, in contrast to the heavy disturbance caused by application of a monocyclic system, as was concluded from the Mapane and Kabo field experiments.

The relatively small volume of projected harvests of 20 to 30 $m^3.ha^{-1}$ in polycyclic systems is economically a disadvantage, but restricts disturbance of the ecosystem, which is very important for tree regeneration and continuity of other ecosystem processes. Furthermore, no intensive (and thus expensive) silviculture, such as clearing, planting and weed-control, appears to be needed to create large standing volumes over long periods. These and a number of other aspects were essential for the development of the CELOS Silvicultural System (CSS) and the CELOS Harvesting System (CHS), and finally for their integration in the CELOS Management System (CMS) as is explained in Chapter 3.

Societal acceptance of the CMS was thought to be gained when jobs would be created, sustainable production achieved, and the forest ecosystem would not unduly change so that other functions would be maintained, such as water and erosion control and provision of non-timber forest products. These aspects later became more complex and sensitive to trends in the perception of issues, such as needs for nature conservation and respect for indigenous people's rights, while the use of arboricide in forest management turned out to be questionable. However, these issues were not included in the original research programme.

The findings of the various specialists in the LH-UvS01 Project were finally integrated into the CELOS Management System. De Graaf & Hendrison (1987) presented a preliminary version of the CMS at a seminar in Honduras followed by another description by De Graaf (1987). A comprehensive description of the system, including previously formulated elements, is found in Hendrison (1990). Since then a few more aspects were elaborated, which could be considered as CMS-related research, such as the further development of methods to reduce impacts of logging (RIL).

RIL research really gained momentum in the 1990s. Many studies were initiated, e.g. in the Malaysian state of Sabah (Pinard et al. 1995), Indonesia (Bertault & Sist 1995), Brazil (Johns et al. 1996), Guyana (Van der Hout 1999, 2000) and Cameroon (Jonkers & Van Leersum 2000). Furthermore, a code of practice for forest operations (COP) was formulated by FAO, which applies worldwide (Dykstra & Heinrich 1996). Meanwhile, a number of countries, including Brazil and Guyana, have adapted the COP to their specific requirements, in close cooperation with stakeholders from the forest sector. Recently, Suriname has requested FAO assistance to design a COP of its own.

Probably the first true Reduced Impact Logging System was already developed in the late 1970s in Sarawak, Malaysia (Mattson Marn & Jonkers 1981). In the 1980s, another RIL system was developed in Australia (Ward & Kanowski 1985), followed by the CELOS Harvesting System (CHS) as proposed for Suriname (Hendrison 1990; Jonkers & Hendrison 1987). Hence, CHS is the oldest RIL method developed in South America.

References

Berkhout, A.H. 1903. Rapport over de Surinaamse bossen. Mouton, The Hague, The Netherlands.

Berkhout, A.H. 1917. Rapport over het Surinaamse Boschwezen. Mouton, The Hague, The Netherlands.

Bhadran, C.A.R. 1965. The introduction of regular forest management. Report to the Government of Suriname, FAO, Rome, Italy.

Boerboom, J.H.A. 1964. De natuurlijke regeneratie van het Surinaamse mesofytische bos na uitkap (The natural regeneration of the mesophytic forest of Surinam after logging). Wageningen University, Wageningen, The Netherlands

Boerboom, J.H.A. 1965. Some remarks on the natural regeneration of tropical rain forest, with special reference to a method newly applied in Suriname. Proceedings 6th World Forestry Congress, Madrid, Spain.

Budding, J. 1995. Geschiedenis van Suriname. Het Spectrum, Utrecht, The Netherlands.

Dawkins, H.C. 1958. The management of natural tropical high forest with special reference to Uganda. (IFI Paper 34). Imperial Forestry Institute, Oxford, U. K.

Dawkins, H.C. & Philip, M.S. 1998. Tropical moist forest silviculture and management: a history of success and failure. CAB International, Wallingford, U. K.

Dykstra, D. & Heinrich, R. 1996. FAO model code of forest harvesting practices. FAO, Rome, Italy.

De Graaf, N.R. 1982. Sustained timber production in the tropical rainforest of Suriname. In: Wienk, J.F. & Wit, H.A. de (eds.), Proceedings of the joint workshop on 'Management of the low fertility acid soils of the American humid tropics'. San José, Costa Rica, pp. 175-190.

De Graaf, N.R. 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Management of Tropical Rain Forest in Suriname 1. Wageningen Agricultural University, Wageningen, The Netherlands.

De Graaf, N.R. 1987. Tropical lowland rain forest management for sustained timber production in Suriname moulded in the CELOS management system. In: Cardozo, R. & Solano, J.F. (eds.), Memorias Reunion Nacional de Silvicultura, Bogotá (Columbia). CONIF, Serie de Documentacion 9, pp. 67-80.

De Graaf, N.R. & Hendrison, J. 1987. Algunas notas sobre el manejo del bosque tropical humedo en Surinam. Revised edition of the paper in Actas del primer seminario internacional sobre manejo de bosque tropical humedo de la region de Centro America (SEMBOTH), Esnacifor, Siguatepeque, Honduras, Noviembre 1986. Internal report, CATIE, Turrialba, Costa Rica.

De Graaf, N.R., Poels, R.L.H. & van Rompaey, R.S.A.R. 1999. Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. Forest Ecology and Management 124, 123-135.

Fox, J.E.D. 1968. Logging damage and the influence of climber cutting prior to logging in the lowland Dipterocarp forest in Sabah. Malaysian Forester 31, 326-347.

Gonggrijp, J.W. & Burger, D. 1948. Bosbouwkundige Studiën over Suriname. Veenman, Wageningen, The Netherlands.

Gonggrijp, L. 1925. Bosexploitatie in Suriname. (Bulletin 48). Departement van Landbouw, Nijverheid en Handel, Paramaribo, Suriname.

Gordijn, W. 1977. Encyclopedie van Suriname. pp. 85-86. Argus Elsevier, Amsterdam, The Netherlands.

Fraser, A.I., Busby, R.J.N. & Paul, D.K. 1977. Forest Regeneration Suriname. International Forest Consultancy, Edinburg & Suriname Forest Service, Paramaribo, Suriname.

Heinsdijk, D., de Hulster, I.A. & Snijders, W.J.J. 1950. De inschakeling van het bos voor de economische opbouw van Suriname (Employing the forest for the economic advancement of Suriname). Surinam Forest Service, Paramaribo, Suriname.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 4. Agricultural University, Wageningen, the Netherlands.

Houtwereld 2008. SUMA haalt FSC binnen in Suriname. Houtwereld 61(16), 14 -17.

Japing, C.H. & Japing, H.W. 1960. Houthandboek Surinamaamse Houtsoorten. Surinam Forest Service, 1960. Paramaribo, Suriname.

Johns, J.S., Barreto, P. & Uhl, C. 1996. Logging damage during planned and unplanned logging operations in the eastern Amazon. Forest Ecology and Management 89, 59-78.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 3. Wageningen Agricultural University, Wageningen, The Netherlands.

Jonkers, W.B.J. (ed.) 2000. Logging, damage and efficiency: a study on the feasibility of Reduced Impact Logging in Cameroon. Tropenbos-Cameroon Reports 00-3. The Tropenbos-Cameroon Programme, Kribi, Cameroon.

Jonkers, W.B.J. & Hendrison, J. 1987. Prospects for sustained yield management of tropical rain forest in Suriname. In Figueroa Colon, J.C. et al. (eds.). Management of the forests of tropical America: prospects and technologies. Institute of Tropical Forestry, USDA Forest Service, San Juan, Puerto Rico, USA.

Jonkers, W.B.J. & van Leersum, G.J.R. 2000. Logging in south Cameroon: current methods and opportunities for improvement. International Forestry Review 2, 11-16.

Kappler, A. 1883. Zes jaren in Suriname 1863-1842. De Walburg Pers, Zutphen, The Netherlands

Knuchel, H. 1947. Management control in selection forest. Imperial Forestry Bureau, Oxford, U. K.

Mattson Marn, H. & Jonkers, W.B.J. 1981. Logging damage in tropical high forest. In Srivastava, P.B.L. et al. (eds.). Tropical forests, source of energy through optimisation and diversification. Penerbit Universiti Pertanian Malaysia, Serdang, Malaysia.

Nicholson, D.I. 1958. Analysis of logging damage in tropical rain forests, North Borneo. Malayan Forester 21, 235-245.

NIMOS 20003. Environmental Impact Assessment in the forest sector of Suriname. National Institute for Environment and Development in Suriname, Paramaribo, Suriname.

Pfeiffer, J.Ph. 1929. Rapport aangaande de wijze waarop de Regering in Nederland en het Gouvernement in Suriname in de toekomst werkzaam zullen kunnen zijn ter bevordering van de houtuitvoer in Suriname. Algemene Landsdrukkerij, The Hague, The Netherlands.

Pinard, M.A., Putz, F.E., Tay, J. & Sullivan, T.E. 1995. Creating timber harvest guidelines for a reduced-impact logging project in Malaysia. Journal of Forestry 93 (10), 41-45.

Plasschaert, E.K. 1910. Der Forstbetrieb in Suriname. Kastner & Callwey, München, Germany.

Poels, R.L.H. 1987. Soils, water and nutrients in a forest ecosystem in Suriname.Ecology and Management of Tropical Rain Forest in Suriname 2. Agricultural University, Wageningen, the Netherlands.

Poels, R.L.H., N.R. de Graaf & Wirjosentono, J. 1998. Growth and mortality of trees after various experimental silvicultural treatments for natural regeneration in Suriname. A. Silvicultural experiment Mapanebrug (1967); B. Extended silvicultural experiment Akintosoela (1975). Hinkeloord Reports no 25. Sub-Department of Forestry, Agricultural University Wageningen, The Netherlands.

Reyes, M.R. 1968. Selective logging, a must tool for continuous production of Philippine mahogany in the Philippines. Philippine Forests 2 (2), 14-21.

SBB 2003. National Forest Policy. Foundation for Forest Management and Production Control, Paramaribo, Suriname.

Schmidt, P. 1981. Productie ecologie. Pp 11-16 in CELOS kwartaalverslag 59 (1981-III). CELOS, Paramaribo, Suriname.

Schmidt, P. 1982. Production ecology. Pp 30-43 in Annual report, Project no. LH/UvS 01 Human interference in the tropical rainforest ecosystem. CELOS, Paramaribo, Suriname.

Schulz, J.P. 1960. Ecological studies on rain forest in northern Suriname. The vegetation of Suriname, vol. II. Van Eedenfonds, Amsterdam, the Netherlands.

Schulz, J.P. 1967. La regeneracion natural de la selva mesofitica tropical de Surinam despues de su aprovechamiento (The natural regeneration of the mesophtyc forest of Surinam after exploitation). CELOS bulletins 3, CELOS, Paramaribo, Suriname.

Van der Hout, P. 1999. Reduced impact logging in the tropical rain forest of Guyana. Tropenbos-Guyana Series 6. Tropenbos-Guyana Programme, Tropenbos Foundation, Wageningen, The Netherlands.

Van der Hout, P. 2000. Testing the applicability of reduced impact logging in Greenheart forest in Guyana. International Forestry Review 2, 24-32.

Van der Hout, P. & van Leersum, G.J.R. 1998. Reduced impact logging: a global panacea? in Tropenbos research in tropical rain forests: its challenges for the future: 185-203. The Tropenbos Foundation, Wageningen, The Netherlands.

Vink, A.T. 1965. Surinam Timber. Surinam Forest Service, Paramaribo, Suriname.

Ward, J.P. & Kanowski, P.J. 1985. Implementing control of harvesting operations in north Queensland rainforests. In: Shepherd, K. & Richter, H.V. (eds.). Managing the tropical forest. Australian National University, Canberra, Australia.

Wyatt-Smith, J. & Foenander, E.C. 1962. Damage to regeneration as a result of logging. Malayan Forester 25, 40-44.

3 The CELOS Management System: concept, treatments and costs

W.B.J. Jonkers & J. Hendrison

3.1 The concept

Modern management of tropical rainforest, when aimed at sustainable production of high quality timber, is generally based on low impact intervention, harvesting of single, large stems of valuable timber species, and sufficient restoration time after logging to allow forest recovery. Various detailed sets of criteria and indicators exist which serve to guide the management approach adopted and to verify its application (e.g. ITTO 1998; see also Chapter 8).

When the CELOS Management System (CMS) was formally proposed in the 1980s, standards for sustainability were less precisely defined. Still, CMS is based on similar principles: the management should not only result in an attractive, sustained yield; it also had to be ecologically justifiable, economically viable, technically feasible and socially acceptable. Furthermore, the system is flexible in the sense that it can be adjusted on the basis of future scientific and technical findings as well as to economic and social developments.

The main objective of the CELOS Management System (CMS) is to produce quality tropical hardwoods on a sustainable basis in the tropical rain forests of Suriname. The system was designed in the 1970s and 1980s, and reflects the conditions which then prevailed in that country and largely still apply to date (see also Chapter 1):
- Most of Suriname was – and still is – covered with tropical rain forest;
- Timber from the rain forest was – and still is – an important economic commodity for the country, although the forest is generally not particularly rich in commercial timber species and the forest-based industry was - and still is - weakly developed.
- The density of the human population in rain forest areas was – and still is – very low, with human settlements almost confined to the vicinity of the main rivers;

- Timber extraction per hectare was low, seldom exceeding 20 m^3.ha^{-1}, and still is modest;
- Rain forest areas in the country are generally poorly suited for conversion to permanent agriculture.

Based on these conditions, a forest management system, which requires little capital and labour input per hectare and results in an attractive return on investment, was called for. Since rain forests designated for timber production were scarcely inhabited or uninhabited, there was little need to consider social aspects other than the perceived need to create jobs for the inhabitants of forest villages. As timber yields were low, there was also no urgent need to reduce harvest intensity to sustainable levels. CMS research therefore focused rather on silvicultural treatments to stimulate the growth of timber species in their natural environment, on what is now called Reduced Impact Logging (RIL)[1], and on the ecological effects and economic costs and benefits of the methods proposed.

Thus, the CMS is a polycyclic system, in which some of the largest commercial trees are harvested while smaller trees are retained. The growth of the remaining commercial trees is stimulated through silvicultural interventions, so that a yield similar or larger than the first one can be obtained after a few decades. There is a distinct focus on silvicultural and logging methods, which are referred to as the CELOS Silvicultural System (CSS) and the CELOS Harvesting System (CHS). These are embedded in a rather conventional management planning procedure that can be summarized as follows. For each management unit of at least 25,000 ha, a management plan is prepared based on reconnaissance mapping of forest composition and terrain characteristics. The areas allocated as production forest are divided into compartments of about 200 ha and a network of roads is planned to allow timber transport by truck from the compartments to the processing plant. In a standard unit of 250 km^2, five compartments are logged annually, giving a felling cycle of 25 years[2].

The CMS mimics natural forest dynamics. In tropical rain forest, very little light penetrates through the forest canopy, and seedlings only have a chance to grow and survive where the forest canopy has been opened up, that is, where a large tree has fallen. Such spurts of fast growth in the improved light conditions of canopy gaps are called 'releases' (Brienen & Zuidema 2006). Harvesting mature trees before they deteriorate and collapse creates similar gaps where regeneration can develop. Initial growth in gaps is rather rapid, but soon increment rates drop because the young trees increasingly compete with one another when they grow bigger, and because the trees surrounding such openings tend to expand their crowns laterally and close the gap.

Deteriorating light conditions make that small individuals of canopy species are forced to grow mainly in height, which often gives them a slender appearance with a narrow oblong crown and a tall straight stem. Lack of light and severe root competition make that most of them slowly perish, and those that survive often need several 'releases',

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1   The term Reduced Impact Logging (RIL) was first used by Pinard et al. (1995). It stands for efficient timber harvesting, which is executed in such a way that damage to the forest ecosystem is minimised.
2   Earlier publications mentioned cutting cycles of 15, 20, 25 and 30 years. The cycle of 25 years is based on evidence presented in this book (see Chapter 4).

resulting from the death of other trees in their vicinity, to reach the canopy. It may take a century or longer before they reach the canopy. When they become finally exposed to direct overhead light, the survivors respond to the improved light conditions by modifying their growth pattern: large, often cauliflower-shaped crowns are formed, diameter growth of stems increases, and the height increment of the trunks decreases and finally stops. However, although stem diameter increment may double or triple, competition for light and nutrients remain severe and growth therefore remains modest and mortality remains substantial (see Chapter 4 for details). The CMS silvicultural treatments reduce the competition in the canopy, but not among trees growing in the understorey, thus stimulating diameter growth of medium sized and large trees while small individuals receive more overhead light to accelerate their height increment.

The CELOS Harvesting System (CHS; Hendrison 1990) aims to diminish logging damage and to improve the efficiency of the logging operation. The operation is based on an inventory and mapping of harvestable trees and terrain characteristics. The information gathered is used for production planning, for designing an efficient network of main skid trails and for marketing purposes. The logging method prescribes directional felling; winching of the logs to the main trails, and other measures which are described in further detail in Section 3.2. Another important aspect of the CHS is that the attention to long-term aspects of forest management goes beyond efforts to minimise damage to vegetation and soil: the entire infrastructure, including the main skid trails, is designed in such a way that it can be utilised again in future harvests.

The CELOS Silvicultural System (CSS; De Graaf 1986; Jonkers 1987) aims to promote the growth of timber trees rather than to stimulate regeneration of commercial species, as logging supposedly creates sufficient openings in the canopy to secure adequate recruitment. The focus is on medium-sized and large trees, which are to be logged during the next timber harvest, but smaller trees are also meant to benefit. The favoured species include not only the currently marketable timbers, but also species, which are likely to become marketable within a few decades.

Silvicultural operations start one to two years after logging has been completed. The treatments are referred to as refinements and consist of favouring future crop trees by reducing competition through killing specific categories of trees without commercial value and by cutting lianas. The methods applied are discussed in more detail in Section 3.3. The result of such an intervention is that light conditions for the remaining vegetation are improved and that the nutrients released from the decomposing trees left on site become available for tree growth. As the effect of an individual treatment lasts eight to ten years, three refinements were foreseen during one cutting cycle.

The CMS operations indicated above are only part of the process: most of the work is done by nature itself. The system depends heavily on ecological processes such as litter decomposition, seed dispersal and pollination and it is crucial that human interventions do not jeopardise these critical processes. In other words, organisms involved in these processes need to be preserved. As scientific knowledge to date is insufficient to determine which species are essential, this can only be achieved by maintaining a high level of biodiversity.

Another critical aspect is nutrient preservation. Most rain forests grow on chemically poor soils, and nutrients are stored mainly in the living and dead biomass. Intricate nutrient cycling mechanisms exist, which need to be maintained within CMS production forest, that is, nutrients released from decomposing plant material should not be lost through leaching but should remain in the ecosystem. These aspects are discussed in more detail in Chapters 5 and 6.

The CMS is flexible in the sense that it allows future modifications resulting from technical and scientific progress or changing economic and social conditions. The CMS alters the ecosystem, but these changes are reversible in the long term, thus allowing future changes in management objectives and methods. Application of the CMS outside Suriname will generally also require adaptation of the system, depending on local conditions. For instance, where timber yields are likely to exceed sustainable levels, the sustainable cut will have to be quantified and adhered to. This implies that regeneration, growth and mortality should be monitored on the basis of permanent sample plots. In populated areas, the rights and needs of the local population will have to be taken into account. Furthermore, there may be considerations not to apply the CSS as a method to improve growth conditions of future crop trees, for instance where local site conditions seem to be adverse to treatment, such as in Suriname's savannah forests (see also Chapter 9), or if there are other options for sustainable management.

3.2 The CELOS Harvesting System

In Suriname and many other tropical countries, most forest land is state-owned, while timber is harvested by private companies, which obtain logging concessions from the government. Given the limited duration of such logging licenses, these companies do not have a long term interest in the forests they exploit, and this is reflected in their operations. Logging is often done with little concern for the forest, leading to considerably more damage to vegetation and soil than strictly necessary (see e.g. Boxman et al. 1985; Hendrison 1990). Logging damage affects the ecosystem and the environment and reduces the economic value of the residual forest and should therefore be avoided. Changes in harvesting methods cannot be achieved if they are not in the interest of the ones who have to implement them. In other words, logging methods aimed at damage reduction should be economically beneficial to the logging industry.

The CHS is essentially a reduced impact logging method (RIL) as has been stated in Section 2.6.5. It includes the following elements:
- In felling and skidding, the same machines were used as in conventional logging. The method is based on improved working methods rather than on technical

Photo 3.1. Logging technique: applying a wedge in directional felling. (Photo J. Hendrison)

innovations, so it can be implemented without major investments in equipment and training.
- Logging was preceded by surveying and mapping of terrain conditions and of harvestable trees.
- These maps were used to align the main skid trails, which were 100 – 150 m apart, approximately perpendicular to the logging road and as straight as possible. These trails were as close as possible to trees to be felled, and passing watercourses was avoided or, if inevitable, a creek crossing was provisionally bridged. Given the low yield per hectare, relatively few landings were required: one landing per three to six main trails was sufficient. This led to a dendritic skid trail pattern. The main trails were opened prior to felling.
- Directional felling was applied to facilitate skidding. Trees could be felled in any direction, as long as the angle with the main skid trail was approximately 40°, and definitely not less than 10° and not more than 60°. Where necessary, wedges were used to direct the tree in an appropriate direction. Improvements in felling techniques also included safety features and measures to avoid wastage of timber.
- Winching was prescribed, mainly to reduce damage to regeneration in felling gaps. In principle, the skidders should not leave the main trails and logs should be winched to the trails whenever possible. Secondary trails were made as skidding progressed to reach logs, which could not be winched directly from the main trail.
- Frequently used skid trails were considered part of the permanent infrastructure. Studies had shown that using a trail for more than two loads led to such severe compaction that establishment of tree seedlings was prohibited for at least some decades[3]. Old trails were re-used whenever possible and were therefore mapped during the pre-harvest survey. Also, the trail network was planned in such a way, that secondary trails were used for not more than two loads.

Photo 3.2. Directional felling. (Photo J. Hendrison)

Photo 3.3. Logging technique: using choker cables for winch extraction. (Photo J. Hendrison)

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3 This phenomenon is not unique for Suriname. Jonkers (unpublished results) also observed it in Peninsular Malaysia, when re-measuring the logging experiment of Wyatt-Smith & Foenander (1962) in 1977.

The results can be summarised as follows (Hendrison 1990): extra expenditures on surveys, planning and pre-harvesting operations were more than compensated by cuts in skidding costs and improved efficiency. The CHS also led to considerable reductions in logging damage: for instance, the area under skid trails was reduced by half to a mere 5 % of the total area.

Some innovations in harvesting technology were developed to improve forest surveying and operational efficiency in the last two decades. The progressive application of Geographic Positioning Systems (GPS) in fieldwork has led to better and cheaper methods for forest inventory and operational planning. The track skidder, which is equipped with a special winch, is better suited for pulling out logs from the stump area to the trail, but is substantially more expensive in use than the traditional wheeled skidder. Efficient and low-impact terrain transport can still better be achieved by improved planning and work preparation than by advanced technology.

Photo 3.4. Logging technique: winch extraction , Mapane 1983. (Photo P. Schmidt)

3.3 The CELOS Silvicultural System

The CELOS Silvicultural System is meant to stimulate the growth of the timber trees which remain after logging. Immediately after logging, working in the forest is difficult because of the logging debris. The first treatment is therefore scheduled at least one year after logging. In the CELOS silvicultural experiments, this first refinement consisted of eliminating trees without commercial value, which exceeded specified stem diameter limits, and lianas with a diameter of 2 cm and more. Although a diameter limit for trees of 20 cm dbh invariably gave the most promising results (see Chapter 4), it was not recommended to use this limit as a fixed standard for the first refinement. This is because in parts of the forest where trees without commercial value are comparatively few, a lower diameter limit is needed than in parts with more non-commercial trees if one wants to obtain the same treatment intensity and growth response. Furthermore, applying a 20-cm limit in parts of the forest where commercial trees are scarce leads to an almost complete eradication of medium-sized and large trees, resulting in a proliferation of pioneer species, lianas and weeds and possibly also in a considerable loss of nutrients through leaching. In other words: the composition of the stand should determine the diameter limits to be applied.

De Graaf (1986) therefore proposed to reduce the average stand density in a compartment to a predetermined level, leaving a basal area of about 12 m^2.ha^{-1}. This means that the

basal area is reduced to approximately 40 % of the pre-felling value. The diameter limit is then based on a post-felling inventory. Jonkers (1987) presented another, somewhat less drastic approach, using two fixed diameter limits: a limit of 20 cm that applies within a radius of 10 m around a commercial stem of 20 cm dbh or larger, and a higher limit of 40 cm that applies elsewhere. In practice, the 40-cm limit will mainly be used in parts of the forest where commercial species are very scarce, e.g. due to unfavourable soil conditions. An additional advantage of this approach is that an inventory to determine the diameter limit is not required.

Trees to be killed should preferably die slowly and should remain standing in order to:
- reduce the speed of decomposition of the killed biomass, thus minimizing the loss of nutrients through leaching,
- avoid damage by falling trees and
- prevent an excessive change in microclimatic conditions at the forest floor.

In the CELOS experiments, an arboricide (2,4,5-T) was used for this purpose. The arboricide was administered to the lower stem in order to create a ring of dead phloem all around the trunk, thus permanently disrupting the flow of photosynthetic products from the crown to the roots. The techniques used were simple. Trees to be killed were marked by an experienced tree spotter, who was accompanied by a labourer who cut all large lianas with a machete (Figure 3.1). These two men were followed by a gang of three to four labourers, who frill-girdled marked trees at a convenient height with a small axe and administered the arboricide. Frill-girdling was done by making overlapping cuts over the whole circumference of the tree, forming a kind of channel. The cuts should extend just into the sapwood and make an angle with the vertical of about 45°. Next, this channel was

Photo 3.5 and 3.6. Arboricide is administered to kill the bark near the frill, thus interrupting the phloem transport from the crown to the roots. The poisoned trees die slowly, but remain standing, thus causing minimal damage to the remaining vegetation. (Photo P. Schmidt.)

Step 1: The trees to be poison-girdled are marked

Step 2: Lianas are cut

Step 3: The frill-girdle is made

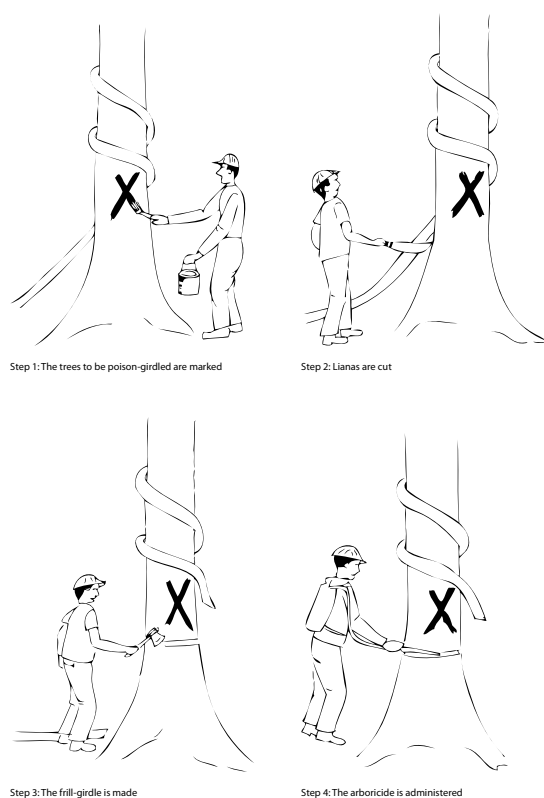Step 4: The arboricide is administered

Figure 3.1. Refinement technique (source Jonkers & Schmidt 1984)

filled carefully with the arboricide solution and thereafter 10 cm of bark immediately above it was coated with a film of arboricide (Jonkers & Schmidt 1984; Jonkers 1987). This leads to a slow death of the trees, although virtually all die within one year. Ringing the stems at two or three heights may be an inexpensive and environmentally friendly alternative to the use of arboricide. Regular stems can be ringed with a small axe, but for buttressed trees and fluted stems special tools are required.

The second refinement is scheduled eight to ten years after the first one, when the diameter growth of commercial trees starts to decline. Again, trees are killed to stimulate the growth of the commercial stand. Its scientific basis is weaker, however, as such a second refinement has been applied only in two plots of 0.64 ha each. This treatment consisted of killing virtually all non-commercial trees larger than 3 cm in diameter. Based on the results, De Graaf (1986) proposed a second treatment in which the basal area was reduced to approximately 10 m².ha^{-1} by eliminating all non-commercial trees larger than 5 or 10 cm dbh. Jonkers (1987), however, pointed out that this would lead to the eradication of most non-commercial species. He considered that undesirable for a variety of reasons and preferred a kind of thinning, that is, a refinement similar to the first one, except that trees to be killed are selected on the basis of defects, stem form and crown form rather than on the market potential of the species. More recent findings indicate that in many cases a second silvicultural treatment is not required (see Chapter 4).

A third refinement is scheduled about five to eight years before the second harvest. Treatment prescriptions have not yet been formulated and the usefulness of this treatment still has to be shown.

3.4 Significance of operational and training aspects of the CMS

In previously executed research in Suriname and elsewhere in the tropics, the condition of the forest after timber harvesting was accepted as a starting point for silvicultural treatment. The prevailing view was that a logged-over forest should be repaired (by silvicultural interference) to regain its productivity and to yield a next timber crop, while timber harvesting could essentially be considered as the first silvicultural treatment with a strong impact on soil and vegetation. The intensity of this impact is decisive for

the recuperation process. Consequently, logging and silviculture treatments have to be integrated, at least at the operational level. That means that, already at the start of the 100 % inventory, data are recorded for both logging and post-harvesting treatments. Furthermore, it is recommendable to assign the same field workers for both operational activities.

It is of utmost importance that forest managers should have a proper understanding of the operational aspects of the CMS. Both logging (CHS) and silviculture (CSS) operations should be under the responsibility of one management as was already indicated in the first provisional manual of the CMS (Van Beusekom & De Graaf 1991). A new manual for the CMS should be more in line with the FAO Code of Practices (Dykstra & Heinrich 1996), and with the requirements for certification, as explained in Section 2.6, but the emphasis will remain on the reduction of logging damage, the training of operational staff, and on the operational efficiency, as is highlighted in the following text.

Forest inventory. A pre-harvesting inventory could also serve the post-harvesting treatments provided that not only data from harvestable trees are collected, but also from future crop trees. The survey could then already produce a good picture of the post-harvesting conditions under which the refinement has to be carried out. Recording of terrain characteristics are important for both interferences. An inventory crew should be thoroughly trained for such a multifunctional survey.

Felling. Directional felling became in an encouraging way more and more accepted as a means to control vegetation damage, to recover more wood from the felled tree, and to reduce the risks of accidents. Nevertheless, fellers should be better trained and better rewarded to perform this responsible and dangerous work. They should have sufficient understanding of the consequences of tree felling for the follow-up operations, notably skidding. The extra costs of planned and careful felling are very largely recovered by a more effective lay of the logs for the consecutive skidding.

A CMS felling crew should also be able to mark or tack the logs and to record them in a form or by aid of a field scanner. Timber fellers in tropical countries are not yet appreciated as operational specialists, as is the case with their colleagues from the temperate zones of the western hemisphere, who are sometimes better rewarded than machine operators (Conway 1982).

Planning and construction of skidding trails. Actually, the planning of skidding trails is a management as well as an operational obligation. The main (primary) trails are part of the permanent forest infrastructure, because they are planned to be re-used in the next felling cycles. It means that the main trail system has to be carefully designed in accordance with terrain and hydrographical features. This trail system is constructed before felling and as a result pre-compacted before logs are transported. Finally, it is mapped and attached to the (long-term) management plan.

A permanent main trail network results not only in a substantial reduction of the affected forest area, but also in a reduction of costs in the next felling cycle when the same trails are re-opened. It is both cost effective and in harmony with the RIL approach and it can

also be used to facilitate post-harvesting operations (Hendrison 1990; FAO 1997; Durrieu de Madron et al. 1998).

Skidding equipment. It is still not generally acknowledged that the articulated wheeled skidder ("skidder") is comparatively cheaper to operate and environmentally better adapted than, for instance, crawler tractors or track forwarders. There are however a few prerequisites for a proper use of this machinery. The skidder should operate on pre-designed trails, which are constructed before felling. These trails should be constructed by a crawler tractor with blade (bulldozer), and not by the skidder itself, because it is not designed for that purpose and could therefore damage (rut-up) the trail surface. Best results are obtained in flat to undulating terrain and in steep terrain if down-slope skidding is possible. In practise it

Photo 3.7. Preparing a felled log for winch extraction. (Photo P. van der Hout)

means that the crawler tractor, which is needed for road and trail construction, should always be available as a standby machine in steep terrain. Skidders can also successfully be used to winch the logs from the stump area to the main trails, while for heavy logs the machine can travel directly to the stump, which demonstrates its versatility as a terrain transporter.

Landing operations. The selection, crosscutting, measurement, grading, and storing of logs at a forest landing are operations which could save timber loss and therefore indirectly forest damage. In traditional operations a wood waste of 10 % of the logs on the landing is not uncommon. This waste could be restricted by training the scaling and inspecting crew, and by designing the log yard properly along the forest road.

Post-harvesting operations. Shortly after logging in a compartment has been completed the main obstacles that could hamper the recovery of the forest should be removed. Especially watercourses should be cleaned from logs and provisional culverts which were constructed to cross creeks. Landings, which are heavily tracked or rutted or even partly swamped, should be drained in one way or another. Temporary camps or living quarters have to be dismantled and the site should be left behind without garbage. In other words, the forest environment should be recovered where possible to get back as close as possible to its original state.

Silvicultural operations, such as refining and the cutting of lianas as explained in Section 3.3, should be carried out with great care. Although this treatment is basically simple to apply, the method described in Section 3.3 should be performed accurately and safely by skilled workers. The responsibilities of the workers should be well defined: the tree spotter solely should be responsible for the selection of trees to be killed, and the worker who administers the arboricide should be responsible for the quality of the poison-girdling operation.

Job rotation. Considering the problems to recruit and to maintain operational staff in a forest environment, it is advisable to train surveyors and operators for more than one skill. All-round workers can replace each other and will be more motivated to run the logging effectively. In this way more work satisfaction could be gained and it would be easier to integrate surveying, logging and silvicultural operations.

Operational efficiency. In the CMS operational efficiency means more than organisational and costs effectiveness. It also refers to a working method that could help achieving RIL. The benefits of operational planning for costs and damage reduction have been emphasised by Hendrison (1990), Van der Hout (1999) and others. Well planned and efficiently executed logging causes far less damage to vegetation and soil than traditional logging.

The benefits of training as a means to improving operational performance are obvious. Training staff is a modest investment in human resource development that easily pays off. It also seems crucial to have skilled personal on all levels if forest and timber certification are aimed at. Although the human resource issues in forest management were not explicitly included in the original research programme, the CMS system was developed with due attention for the training of staff as a major precondition to obtain the best results.

A feed back for operational efficiency is the recording of the timber flow from the forest to the wood processing industry ("log tracking"). All operations, including inventory and long-distance transportation, should be tracked by tagging and recording the dimensions of logs from felled trees that were spotted and mapped in the forest inventory. The subsequent movement of the logs (terrain, road and river transportation) is to be followed (tracked) by recording or scanning the numbers on the tags. Log tracking is a powerful tool to get insight in the production performance and the efficiency of the forest operations.

Finally, operational efficiency is also achieved by acquiring the most suitable equipment and by operating it properly. The considerable investments which have to be made in logging machines and transport vehicles should encourage forest companies to take good care of their equipment, which has to be handled by skilled operators who are reasonably paid.

3.5   The costs of the CMS

The financial input required for the practical application of the CMS was already assessed in an early stage of its development both for silvicultural treatment (De Graaf 1986; Jonkers 1987) and for controlled logging (Hendrison 1990). Emphasis was put on the additional costs of using the CMS system when compared with traditional timber harvesting, which is carried out without planning and without post-harvesting treatments. The two major cost calculations thus refer to the implementation of the CSS and CHS, comprising the costs of growing the next crop and the costs of harvesting that crop, respectively.

3.5.1 Harvesting costs

An unambiguous assessment of logging costs is complicated and time consuming, because quite a number of preparatory activities and sub-operations should be observed to collect statistically reliable data. Hendrison (1990) calculated that additional logging costs for applying the CHS are partly compensated by increased operational efficiency. Yet, an increase of the total costs of 10-20 % was expected if the traditional system was replaced by this early low-impact logging method.

The cost perception as from the 1980s is presently outdated by new developments in forest and nature conservation management and the introduction of forest certification. The assessment of logging costs is more geared towards calculating real costs of efficient logging and additional costs for RIL-related to forest certification. There is no need anymore to compare logging costs of a conventional and a controlled system, because in the last decade quite a number of countries have enforced forest management and timber harvesting regulations, while gradually abolishing destructive logging methods. The FAO model code of forest harvesting practices (Dykstra & Heinrich 1996; FAO 1997) has meanwhile been adopted as guideline for forest operations in tropical countries, such as Guyana and Brazil. The present aim is to assess the costs of controlled logging as a required standard method to achieve sustainable forest management.

Essentially, it is not possible to provide information on logging costs with a wide range of applicability, because of the great variability in cost conditioning factors, such as forest composition and terrain characteristics. These factors vary too much from region to region and even from site to site, to develop overall standards. In addition, logging costs are often company specific in terms of production objectives, operational methods and personnel skills. Therefore, cost assessments should not be made occasionally, but regularly as an instrument of management.

The most recent updating of controlled logging costs was obtained from a field study in Suriname's Tibiti area in three forest management units (FMU1, FMU2 and FMU3) in 2005-2006 (Tropenbos 2006). The choice of these enterprises as study objects was primarily justified by the quality of their management practises. All of them are switching from conventional to reduced impact logging. The study aimed at getting insight in the cost of RIL according to modern standards.

The results of this study were updated with an inflation correction for 2010 and a sensitivity analysis was carried out to match the cost components (Table 3.1). It points out that cost variables are site specific. When compared with a similar study in Guyana (Van der Hout 1999), it is obvious that, apart from the sensitiveness of costs to site characteristics, logging costs in Suriname are structurally higher than in Guyana. The fixed costs of machinery play an important role in this respect. The prices of logging equipment are 25-60 % higher in Suriname than in Guyana and Brazil (Pokorny & Steinbrenner 2005), countries which employ the same logging methods in tropical rainforests.

Table 3.1. The costs of timber harvesting (US $ per m^3) 2010

Forest management units Logging operations	FMU1	FMU2	FMU3	Guyana
Management/planning	3.00	5.10	5.50	3.90
Inventory	0.30	1.50	1.90	0.60
Road construction	o	o	4.40	2.70
Felling	1	3.80	1.40	1.50
Skid trail opening	o	2.20	o	o
Skidding	16.50	5.20	10.30	5.50
Loading	2.80	3.40	3.30	4.70
Housing	1.00	1.50	o	2.50
Others	o	o	1.70 [2]	o
Total logging	23.60	22.70	28.20	21.40

o = data not available
[1] = felling and skidding are contracted as one operation
[2] = mainly maintenance of machinery
[4] = inflation correction (22%)

The cost studies were used to derive a standard cost price for sustainable forest management and timber harvesting that could meet the standards for FSC certification, by calculating the costs of the sub-operations more carefully. This exercise was carried out with the participation of five selected logging companies, who were all applying RIL in their harvesting operations (FAO in press). Two companies had recently obtained an FSC certificate for timber harvesting (Houtwereld 2008). The assessment of the cost components on basis of the price level of 2010 is explained below (Table 3.2)

Table 3.2. Estimated cost price for RIL in Suriname (US $) 2010

Logging operations	Costs per m^3
Management/planning	6.50
Inventory	2.60
Road construction	4.60
Felling	2.30
Skid trail opening	2.80
Skidding	12.40
Loading	3.10
Housing	3.00
Others	2.10
Total logging	39.40

Costs of management and planning. The costs of management were relatively high with a standard of US $ 7.50 per m^3. Management and planning involve an important cost factor, because a price has to be paid for the benefits of RIL and sustainable forest use.

It is expected however, that these costs will decrease after more experience has been obtained with the new management systems and when more staff have been trained to support the certification process.

Inventory costs. The updated inventory costs are derived from the fee that forest inventory and surveying firms have charged forest operators to prospecting their forest management unit. The price in 2010 was US $ 2600 for a block of 100 ha, hence approximately US $ 2.60 per m³. Inventory costs are comparatively high (6.0 % of the total cost price), but the results of a forest and terrain survey could have a strong positive impact on logging efficiency and indirectly on profits. Spending in inventory training is quickly paid back and the operational advantages are visible within a few months.

Road construction costs. Costs of road construction were not separately recorded by the concessionaries and could also not be assessed from the collected field data. The standard for Suriname for secondary roads (within a logging compartment) is tentatively set at US $ 4.60 per m³, as could be concluded from local forest management and operational plans. In general these roads need not to be gravelled, because of their short service life.

Costs of felling. The felling costs in FMU 3 are based on RIL methods as developed by Van der Hout (1999) for Guyana. Discounted for the price level in 2010, the standard for felling costs in Suriname could be estimated at US $ 2.30 per m³. Costs of controlled felling are not low (5.8 % of the total logging costs), but it pays to invest in proper felling methods to create favourable preconditions for the subsequent expensive terrain transport.

Costs of skid trail construction. Two FSC certified companies could provide the cost data for opening of skid trails prior to logging at US $ 2.00 per m³. The establishment of a well-designed skid trail system is one of the cornerstones of the RIL method.

Costs of skidding. Closest to RIL are the skidding methods of the two certified companies, and as such considered representative for assessing the standard skidding costs at US $ 12.40 per m³. Skidding takes approximately 31 % of the cost price, and even 39 % if the cost of trail opening is included. This means that emphasis should be put on operational planning and logging efficiency to reduce the skidding costs.

Costs of loading. Costs of loading are reasonably consistent in all five study objects, although the most efficient loading operations were met in FMU1 (US $ 2.80 per m³). This is an acceptable standard for RIL.

General costs. A contingency of 10 % is included in the cost price for RIL to cover costs such as housing, communication, health care and recreation.

Summarising, the cumulative cost price for RIL operations is set at US $ 39.40 per m³ (Table 3.2). Not included are timber royalties and concession area fees, which are fixed components, imposed by the Forest Management Act. RIL costs also do not include the costs of access forest roads and the costs of timber transportation on roads and rivers.

3.5.2 Silvicultural costs

A first indication of costs of the CSS was given by De Graaf (1986). To carry out one refinement and two liberation treatments during a 20 years management cycle, with a target harvest of 20 m³.ha⁻¹, 10 man-days and 40 litres of arboricide mixture are required per hectare. This is an input of 0.5 man-day and 2 litres arboricide mix to grow 0.9 m³ of commercial timber annually. On basis of these figures and taking into account a compound interest factor of 4 %, the discounted cost price for silvicultural interference was assessed to be 25 % of the sales price of logs delivered at a mill yard in Paramaribo. This means for the present price level (2010) about US $ 15 per m³ round wood product, which is already substantial without the additional cost of RIL.

However, the costs of silvicultural treatment turned out to be somewhat lower when the uniform scheme was adapted towards a system of liberating future crop trees on basis of their stocking pattern (see Section 3.3). This led to a slight reduction of refinement intensity and savings on inventory costs. Furthermore, evidence presented in Chapter 4 will show that follow-up treatments may not be necessary in many cases. Thus, the projected personnel and arboricide input can often be decreased to 3 man-days and 17 litres of arboricide mixture per ha. Where one follow-up treatment is required, an additional 3 man-days and 13 litres of arboricide will be needed. On basis of these findings the costs of the CSS could be updated as follows.

The two main cost factors of applying the CSS refer to field labour and arboricide inputs. The labour costs include all sub-operations of refinement, such as spotting and marking of future crop trees, liana cutting, frilling and administering arboricide to competing trees (see Section 3.3). If the mean labour (man-day) cost is set at US $ 20.00, the labour input is US $ 60 per ha. The cost for the solution of arboricide (for instance 5 % 2, 4 D in diesel fuel) delivered at the forest site is approximately US $ 5 per ha based on the unit prices of the concentrate of US $ 6.50 per litre and of the solvent of US $ 1.00 per litre. Hence, the total costs of refinement are US $ 65 per ha (2010 price level). However, if these costs are up-rated for a period of 25 years and an interest rate of 4 %, the real costs of silvicultural intervention are close to US $ 170 per ha. The costs for growing the next crop (the second harvest) of 20 m³ (mean yield) or 30 m³ (high yield) would then be US $ 8.50 per m³ or US $ 5.6 per m³ respectively. If a second refinement is necessary after 10 or 15 years the CSS costs could exceed US $ 10.0 per m³.

Although the costs of silvicultural interventions are not immaterial, the CSS treatment is justifiable when the reduction of the felling cycle to 25 years is taken into account. If a forest management unit can sustainably be harvested each 25 years, it would give clear economic advantages, in the first place because the same forest infrastructure can be re-used in following felling cycles. Furthermore, the FMU has already been laid out for permanent use with monitoring and research plots. Finally, less area could be allocated for timber production and more for conservational purposes. Thus, intensive forest management such as the CMS is aiming at has both ecological and economical advantages. And the aim of sustainability is best achieved when more than one harvest can be realised within the boundaries of one forest management unit.

Finally, CSS costs, which are basically the additional costs of growing timber, can partly be financed by an increased stumpage fee imposed to forestland under sustained management. On the other hand, concessionaries who have the courage to invest in forest improvement can be compensated by reducing the royalty that they have to pay for the next timber harvest.

References

Armstrong, S. 2000. RIL for real: introducing reduced impact logging into a commercial forestry operation in Guyana. International Forestry Review 2, 17-23.

Bertault, J. G. & Sist, P. 1995. Impact de l'exploitation en forêt naturelle. Bois et Forêts des Tropiques 245, 15-20.

Blate, G. 1997. Sustainable forest management in Brazil. Tropical Forestry Update 7(3), 14-15.

Boxman, O., De Graaf, N.R., Hendrison, J., Jonkers, W.B.J., Poels, R.L.H., Schmidt, P. & Tjon Lim Sang, R. 1985. Towards sustained timber production from tropical rain forests in Suriname. Netherlands Journal of Agricultural Science 33, 125-132.

Brienen, R.W.J. & Zuidema, P.A. 2006. Life time growth patterns and ages of Bolivian rain forest trees obtained by tree ring analysis. Journal of Ecology 94, 481-493.

Cedergren, J, Falck, J, Garcia, A, Goh, F. & Hagner, M. 1994. Reducing impact without reducing yield. Tropical Forestry Update 4 (3), 9-10.

Durrieu de Madron, L., Forni, E. & Mekok, M. 1998. Les techniques d'exploitation à faible impact en forêt dense humide camerounaise. Série Forafri Document 17, CIRAD-Forêt, Montpellier, France.

De Graaf, N.R. 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Management of Tropical Rain Forest in Suriname 1. Wageningen Agricultural University, Wageningen, The Netherlands.

Dykstra, D. & Heinrich, R. 1996. FAO model code of forest harvesting practices. FAO, Rome, Italy.

FAO 1997. Environmentally sound forest harvesting: testing the applicability of the FAO model code in the Amazon in Brazil. Forest harvesting case-study 8. FAO, Rome, Italy.

FAO in press. Revision of the forest charges system in Suriname. FAO, Rome, Italy.

Fox, J.E.D. 1968. Logging damage and the influence of climber cutting prior to logging in the lowland Dipterocarp forest in Sabah. Malaysian Forester 31, 326-347.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 4. Agricultural University, Wageningen, the Netherlands.

Houtwereld 2008. Suma haalt FSC binnen in Suriname. Houtwereld 61(16), 14 -17.

ITTO 1998. Criteria and Indicators for Sustainable Management of Natural Tropical Forests. ITTO Policy Development Series No.7, Yokohama, Japan.

Johns, J.S., Barreto, P. & Uhl, C. 1996. Logging damage during planned and unplanned logging operations in the eastern Amazon. Forest Ecology and Management 89, 59-78.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 3. Wageningen Agricultural University, Wageningen, The Netherlands.

Jonkers, W.B.J. (ed.) 2000. Logging, damage and efficiency: a study on the feasibility of Reduced Impact Logging in Cameroon. Tropenbos-Cameroon Reports 00-3. The Tropenbos-Cameroon Programme, Kribi, Cameroon.

Jonkers, W.B.J. & Hendrison, J. 1987. Prospects for sustained yield management of tropical rain forest in Suriname. In: Figueroa Colon, J.C. et al. (eds.). Management of the forests of tropical America: prospects and technologies. Institute of Tropical Forestry, USDA Forest Service, San Juan, Puerto Rico, USA.

Jonkers, W.B.J. & van Leersum, G.J.R. 2000. Logging in south Cameroon: current methods and opportunities for improvement. International Forestry Review 2(1), 11-16.

Jonkers, W.B.J. & Schmidt, P. 1984. Ecology and timber production in tropical rain forest in Suriname. Interciencia 9, 290-298.

Mattson Marn, H. & Jonkers, W.B.J. 1981. Logging damage in tropical high forest. In: Srivastava, P.B.L. et al. (eds.). Tropical forests, source of energy through optimisation and diversification. Penerbit Universiti Pertanian Malaysia, Serdang, Malaysia.

Nicholson, D.I. 1958. Analysis of logging damage in tropical rain forests, North Borneo. Malayan Forester 21, 235-245.

Pinard, M.A., Putz, F.E., Tay, J. & Sullivan, T.E. 1995. Creating timber harvest guidelines for a reduced-impact logging project in Malaysia. Journal of Forestry 93 (10), 41-45.

Pokorny, B. & Steinbrenner, M. 2005. Collaborative monitoring of production and costs of timber harvest operations in the Brazilian Amazon. Ecology and Society 10 (1), 3.

Putz, F.E., Dykstra, D.P. & Heinrich, R. 2000. Why poor logging practices persists in the tropics. Conservation Biology 14, 951-956.

Reyes, M.R. 1968. Selective logging, a must tool for continuous production of Philippine mahogany in the Philippines. Philippine Forests 2 (2), 14-21.

Tropenbos 2006. Preparing the study on practical scale operations of CMS. Final project document. Tropenbos-Suriname Programme, Paramaribo, Suriname.

Van der Hout, P. 1999. Reduced impact logging in the tropical rain forest of Guyana. Tropenbos-Guyana Series 6. Tropenbos-Guyana Programme, Georgetown, Guyana.

Van der Hout, P. 2000. Testing the applicability of reduced impact logging in Greenheart forest in Guyana. International Forestry Review 2 (1), 24-32.

Van der Hout, P. & van Leersum, G.J.R. 1998. Reduced impact logging: a global panacea? Tropenbos research in tropical rain forests: its challenges for the future, pp 185-203. The Tropenbos Foundation, Wageningen, the Netherlands.

Ward, J.P. & Kanowski, P.J. 1985. Implementing control of harvesting operations in north Queensland rainforests. In Shepherd, K. and Richter, H.V. (eds.). Managing the tropical forest. Australian National University, Canberra, Australia.

Wyatt-Smith, J. & Foenander, E.C. 1962. Damage to regeneration as a result of logging. Malayan Forester 25, 40-44.

4 Tree growth, recruitment and mortality after logging and refinement

W.B.J. Jonkers

4.1 Introduction

The CELOS Management System should, among others, result in an attractive sustained yield (see Chapter 3). Evidence presented by De Graaf (1986) indicates that forest recovery after selective logging is too slow for this purpose, and that silvicultural interventions are needed (see Chapter 2). The CELOS Silvicultural System (CSS; De Graaf 1986; Jonkers 1987) was primarily meant to speed up the volume increment of the commercial stand, so that the desired sustained yield could be achieved.

This chapter deals with long-term impacts of logging and refinement on the stem diameter increment, mortality and ingrowth[1] of commercial and non-commercial tree species, and on the volume increment of the commercial stand. It is based on the large-scale MAIN experiment at Kabo, supplemented by information from the older CELOS silvicultural experiments Mapanebrug and Akintosoela1 and the Akintosoela2 experiment of the State Forest Service. The CELOS experiments have been established between 1967 and 1978. Until 1983 they were re-measured frequently. Akintosoela2 was created in 1984 in an area which Hendrison (1990) had used earlier for testing the CELOS Harvesting System. Since 1984, each of the experiments has been assessed once between 1995 and 2000. The growth, recruitment and mortality data thus obtained allow a review of the CSS based on the long-term response of the forest to the logging and silvicultural treatments applied.

This chapter provides answers to the following question: how do logging and silvicultural treatments influence tree growth, mortality and recruitment? Or, more specifically:

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1 Ingrowth: trees, which had not been included in previous enumerations because they had not yet reached the minimum diameter applied in enumerations. In the MAIN experiment, this minimum size was 15 cm dbh, although smaller trees where recorded in subsamples.

- What is the commercial volume increment resulting from these logging and silvicultural treatments?
- Is the growth of the timber stand such that all timber harvested or killed by logging can be substituted within one cutting cycle of 25-30 years?
- To what extent do trees damaged by logging recover from injury?
- Do non-commercial tree species recover after logging and silvicultural interventions?

4.2 Regeneration, growth and mortality patterns in pristine forest

Light conditions at the forest floor are poor, except where a fallen tree has formed an opening in the canopy. Most tree species depend on such gaps for their regeneration. Seeds of most pioneer species and a few other trees, such as *Goupia glabra*, only germinate in gaps. Other species produce seedlings underneath a closed canopy, most of which die soon after germination. Those which remain may survive for years in dense shade without noticeable growth. When a tree-fall gap is formed, seedlings within the gap start to grow. The response of a given seedling depends on its vitality, the ecological requirements of the species concerned and on local microclimatic conditions. The least vital individuals hardly respond to the changed light conditions. Some tree species develop best in the full sun, but most grow better under more moderate microclimatic conditions. There is considerable variation in light, temperature and humidity between gaps of different sizes and shapes, and also between the edges and the centre of a gap. Chances for growth and survival of a given seedling therefore depend on its ecological requirements, the dimensions of a gap, and its location within the gap.

When a gap newly forms, most of the existing vegetation in the gap area is destroyed by the impact of the falling material. It decays together with the remains of the fallen tree, thus providing nutrients to the seedlings inside the gap as well as to the surrounding trees. Most natural gaps are small, and although light conditions in such gaps are more favourable than under a closed canopy, only a fraction of the sunlight reaches the forest floor. Light and nutrient conditions generally deteriorate with time, because the seedlings increasingly compete with one another and because crowns of surrounding trees gradually close the opening in the canopy. Under such conditions, regenerating trees have to grow as rapidly as possible towards the light in order to ultimately reach the canopy. Thus, seedlings and saplings grow in length rather than in width, which leads to slender stems and narrow and oblong crowns. The growth release usually lasts not longer than a few years as growth is increasingly impeded by suboptimal light conditions in the closing gap, and virtually all small trees will become suppressed sooner or later. Most surviving small trees need a sequence of growth releases to reach the canopy.

Understorey species adapt to the shady conditions in the forest by slowly expanding their branches in lateral directions to reduce self-shading and to capture more light. Canopy and emergent species respond by reducing their physiological activity until light conditions become more favourable for further height increment, that is, until an adjacent small tree perishes or until a new gap is formed near the tree. Most trees die before there is such an opportunity. This pattern of slow but highly variable growth is

reflected in the diameter growth of small commercial trees in the MAIN experiment: the mean value was just 0.31 cm.y^{-1} with a standard deviation (S.D.) as high as 0.28 (Jonkers et al. 2005).

When a tree ultimately reaches the canopy, it starts to expand its crown laterally, and the height increment of the stem comes to a halt. At this point, the tree generally attains sexual maturity (Jonkers 1987). Emergent species also start forming large oblique-oriented branches, which allow the tree to grow further in height and to form their characteristic wide-spreading crowns. The diameter growth of the stems increases, but remains highly variable. This is again evident from the results of the MAIN experiment: the mean increment of medium-sized and large commercial trees was just 0.39 cm.y^{-1} with a S.D. as high as 0.29 (Jonkers et al. 2005).

In large gaps, the pattern is slightly different. In the central part of the gap, light-demanding pioneer trees emerge. These species grow fast and can be so abundant that they effectively suppress regeneration of other trees for decades. Because of their fast growth, some pioneer trees may reach the canopy before the gap is closed. Although their live span tends to be shorter than that of most other tree species, pioneer trees such as *Inga* and *Cecropia* spp. can live longer than half a century (see Section 4.5).

4.3 Impact of logging on growth and mortality within the commercial stand

Logging affects tree growth and mortality in various ways. The most obvious direct impact is that trees are killed during the harvest operation: a certain number of large trees are harvested and other trees are destroyed by falling trees or during skidding. In the MAIN experiment, logging was carefully planned

Photo 4.1. Fish-eye lens photos of forest gaps in Guyana. (Photo H. ter Steege)

and controlled, and unintended logging damage was therefore low. Between 6.8 % and 20.3 % of the commercial trees larger than 5 cm dbh (including harvested trees) died during the logging operation, depending on the logging intensity which varied from 15 to 46 m^3.ha^{-1} (Jonkers 1987). Table 4.1 summarizes how many commercial trees were killed during the logging operation, and gives the stem volumes felled[2] and destroyed.

Table 4.1. Trees felled or destroyed during logging in the MAIN experiment: numbers, basal areas and volumes*

Logging treat-ment **	Felled trees			Destroyed trees***			Total killed***		
	N.ha^{-1}	Basal area (m^2.ha^{-1})	Volume (m^3.ha^{-1})	N.ha^{-1}	Basal area (m^2.ha^{-1})	Volume (m^3.ha^{-1})	N.ha^{-1}	Basal area (m^2.ha^{-1})	Volume (m^3.ha^{-1})
E15	3.36	1.38	19.04	2.76	0.26	3.05	6.12	1.64	22.09
E23	6.08	2.31	31.66	3.51	0.33	3.96	9.59	2.64	35.62
E46	11.49	3.87	52.68	5.48	0.52	6.22	16.97	4.39	58.90

* Volume equation: V = -0.2335 + 0.001125D2 (Jonkers 1987); V = volume in m^3 and D = dbh in cm
** The treatment codes reflect the volumes extracted per ha (E15: 15 m^3.ha^{-1} extracted, etc.)
*** Trees > 15 cm dbh, commercial species only

In addition, 8.9 to 15.0 % of the trees were damaged, but survived (Jonkers 1987). Jonkers (1987) showed that small trees are more vulnerable to destruction and severe damage than large individuals, while minor injury is more common among large trees. The status of the surviving damaged trees was assessed 19 years after logging for those parts of the MAIN experiment which did not receive any silvicultural treatment (Table 4.2). The results showed that trees with mild forms of injury mostly recovered, but trees with severe logging injury had almost twice as much chance either to die within 19 years or to develop a defective stem as compared to trees with minor or no damage. However, the data indicated also that even trees with severe crown or stem injury often developed into good-quality timber trees, although some of these stems may be hollow or decayed inside. So, injured trees apparently have the potential to contribute to future harvests and can be considered as part of the timber resource.

In theory, the growth of the commercial stand should be such, that the stem volume lost during the logging operation is replaced within one cutting cycle. This loss is more than the volume extracted, as the stump, the top end and defective parts of the felled stems are not hauled out and remain in the forest to rot. In addition, some trees of commercial species die during the logging operation due to felling damage. Table 4.1 summarises the main statistics regarding trees felled or destroyed during logging in the MAIN experiment. The commercial volumes to be replaced ranged from approximately 22 m^3.ha^{-1} for the lowest felling intensity to 59 m^3.ha^{-1} for the highest felling intensity. Assuming a 25-year cutting cycle, this would mean that the required annual volume growth should be almost 1 m^3.ha^{-1}.y^{-1} for the lowest logging intensity (E15) and almost 2.4 m^3.ha^{-1}.y^{-1} for the highest one (E46).

2   The volumes felled were considerably larger than the volumes extracted. This is because parts of the felled trees were left in the forest (stumps, top ends and defective parts).

Table 4.2. Recovery and mortality among trees with various degrees of logging damage (MAIN experiment, plots without silvicultural treatment, commercial species; trees >15 cm dbh)

Logging damage (1981)		Number of trees (=100%)	Tree condition in 1999-2000				
Stem injury*	% of crown broken off		Stem quality (%)				Dead / not found (%)
			Good	Adequate	Poor	Broken	
None	0%	1360	12.2	60.9	3.8	3.1	20.0
	1-50%	120	9.2	55.8	8.3	6.7	20.0
	50-99%	48	8.3	43.8	4.2	16.7	27.1
	100%	42	4.8	35.7	0.0	14.3	45.2
	All	1570	11.7	59.3	4.1	4.1	20.9
Minor	0%	58	12.1	62.1	10.3	1.7	13.8
	1-50%	11	9.1	54.5	9.1	27.3	0.0
	50-99%	7	42.9	28.6	0.0	14.3	14.3
	100%	5	0.0	40.0	20.0	0.0	40.0
	All	81	13.6	56.8	9.9	6.2	13.6
Major	0%	25	4.0	44.0	24.0	4.0	24.0
	1-50%	6	0.0	33.3	33.3	16.7	16.7
	50-99%	4	0.0	0.0	25.0	0.0	75.0
	100%	1	0.0	0.0	0.0	0.0	100.0
	All	36	2.8	36.1	25.0	5.6	33.3
All	0%	1443	12.1	60.6	4.4	3.0	19.8
	1-50%	137	8.8	54.7	9.5	8.8	18.2
	50-99%	59	11.9	39.0	5.1	15.3	28.8
	100%	48	4.2	35.4	2.1	12.5	45.8
	All	1687	11.6	58.7	4.8	4.2	20.8

* Major stem injury means that the stem has split, or that the bark has been ripped off over either at least one third of the circumference of the stem or over more than 20 cm of the stem circumference or over a length of at least 2 meters. Minor stem injury means that a smaller piece of the bark has been ripped off. Source: Jonkers et al. (2003)

Volume growth in virgin forest and after logging was investigated in the MAIN experiment. The growth of the commercial volume in a given forest is mainly determined by diameter growth and mortality; volume increment as result of recruitment is so little that it does not merit a separate analysis. Furthermore, volume growth is partially determined by the richness in commercial species, as each commercial tree contributes to volume increment. The forest of the MAIN experiment was - and still is - richer than most forests in Suriname.

Average diameter growth rates per logging intensity and their standard deviations are shown in Table 4.3. The data suggest a positive correlation between logging intensity and tree growth. The differences between the means were rather small and standard deviations were high, however. The evidence is not fully convincing, but it is plausible that logging enhances the growth of commercial trees (see also Section 4.4.1).

Table 4.3. Diameter growth of commercial trees > 15 cm dbh (between the 1982-1983 and 1999-2000 enumerations; MAIN experiment, plots without silvicultural treatment)

Logging treatment	Number of trees	Diameter growth (cm.y^{-1})	
		Mean	Standard deviation
Untouched	452	0.39	0.29
E15	528	0.42	0.33
E23	400	0.44	0.29
E46	484	0.46	0.30

Source: Jonkers et al. (2003)

As trees with severe logging damage are more likely to die within one cutting cycle than other trees, one would expect a positive relation between logging intensity and mortality in the first decades after logging. However, such an impact was not evident and could not be proven. The average mortality for all logging treatments combined was modest; about 21 % over a 17 year period (see Table 4.2), but the differences in mortality between individual plots were enormous (see Table 4.4). Two plots in the intermediate logging intensity (E23) had very high death rates, while mortality in two plots with the highest logging intensity (E46) was negligible. It is unlikely that these differences were due to the harvesting regimes applied, and further statistical analysis was therefore considered redundant. The mortality rates recorded in virgin forest plots were comparable to the average value for logged forest.

Table 4.4. Mortality among commercial trees > 15 cm dbh (between the 1982-1983 and 1999-2000 enumerations; 1-ha plots)

Logging intensity	Replication						Mean	
	1		2		3		Number of trees per ha	Volume (m^3.ha^{-1})
	N.ha^{-1}	m^3.ha^{-1}	N.ha^{-1}	m^3.ha^{-1}	N.ha^{-1}	m^3.ha^{-1}		
Untouched*	13	31.96	16	45.59	18	38.02	15.67	38.52
E15	9	16.84	17	12.17	19	24.31	15.00	17.78
E23	30	55.24	24	66.64	15	22.38	23.00	48.09
E46	9	4.92	17	31.72	8	3.89	11.33	13.51

* Plot 41: Replication 1; Plot 42: Replication 2; Plot 43: Replication 3
Source: Jonkers et al. (2003)

Due to the high variation in mortality, volume growth differed much from plot to plot (Table 4.5). In the virgin forest plots, there was on average hardly any change in commercial volume, as one would expect, although volume increment varied considerably between plots. Volume increment after logging varied even more, from – 36 m^3.ha^{-1} (–2.1 m^3.ha^{-1}.y^{-1}) to +78 m^3.ha^{-1} (+ 4.6 m^3.ha^{-1}.y^{-1}). On average, the volume increment in logged plots amounted to + 1.7 m^3.ha^{-1}.y^{-1}, indicating that the commercial stand recovers after logging.

Table 4.5. Volume increment* of commercial species (change in volume of trees > 15 cm dbh between the 1982-1983 and 1999-2000 enumerations; no silvicultural treatment)

Logging intensity	Replication			Mean
	1	2	3	
	Volume increment in 17 years (m³.ha⁻¹)			
Untouched**	15.49	9.16	-15.72	2.98
E15	34.65	47.92	46.22	42.93
E23	-24.50	-36.19	34.82	-8.62
E46	44.68	40.38	78.10	54.39

* Volume equation: $V = -0.2335 + 0.001125D2$ (Jonkers, 1987); V = volume in m³ and D = dbh in cm ** Plot 41: Replication 1; Plot 42: Replication 2; Plot 43: Replication 3 Source: Jonkers et al. (2003)

These mean values suggest that a sustained yield of about 20 m³.ha⁻¹ once every 25 years can be achieved without any silvicultural treatment in this particular forest, but the variation in mortality was such, that this cannot be proven. Moreover, because the MAIN experiment is a lot richer in commercial species than most forests in Suriname, it is likely that 25 years is generally insufficient to sustain such a yield without additional measures such as silvicultural treatment.

Actions to reduce logging damage in addition to the measures already applied in the MAIN experiment may also lead to higher sustained yields, although Table 4.1 shows that the potential for further damage reduction is limited. The CELOS Harvesting System (Hendrison, 1990) and other RIL methods are not meant to enhance the growth of individual trees, but should have a beneficial effect on the volume growth of the entire commercial stand as more trees, seedlings and saplings survive logging to form the growing stock. Evidence from the Akintosoela2 experiment showed indeed that the CHS resulted in significantly more new, young timber trees in the 5-15 cm diameter class than conventional logging (Jansen et al., 2005), but this experiment had been subject to too much unscheduled disturbance to prove an eventual effect on the volume increment of the entire commercial stand.

4.4 Impact of silvicultural treatment on growth and mortality of commercial species

The CELOS Silvicultural System is meant to enhance the growth of commercial timber species by eliminating part of the competing vegetation (see Chapter 3). In this section, the impact of silvicultural treatment on increment and mortality is elaborated.

Treatment intensities varied not only within the experiments because different diameter limits were tested, but also between experiments because of differences in forest composition (see Chapter 5) and in criteria for trees to be eliminated. In all experiments, not only trees of non-commercial species were killed, but also trees of commercial species which did not meet certain standards. These standards differed from one experiment to another. When the oldest pilot experiment (Mapanebrug) was established in 1967,

the idea was that the research would lead to a monocyclic management system. Hence, all trees above the refinement limit were killed, except trees of commercial species which were likely to be still in good condition at the end of the rotation of 60-80 years, that is, good quality stems which were less than 50 cm in diameter (Boerboom 1965, appendix 32). In experiment Akintosoela1, which was established in 1975, this 50 cm upper diameter limit for commercial species was not applied, but poor stem form and other defects remained reasons to reject and eliminate timber trees (Staudt 1977). In the MAIN experiment, all trees of commercial species were retained, except for a few visibly hollow or extensively decayed stems and split or broken trunks (Jonkers 1983, 1987). Furthermore, when the Mapanebrug experiment was established, there were only 31 entries on the commercial species list, while a list of 58 species was applied in the other experiments. Hence, in refinements with a 20 cm diameter limit, basal area was reduced to about 7 m².ha⁻¹ in Mapanebrug, to 9.8 m².ha⁻¹ in Akintosoela1 (De Graaf 1986) and to about 14 m².ha⁻¹ in the MAIN experiment (Jonkers 1983)[3]. For comparison: the basal area in undisturbed forest is about 30 m².ha⁻¹.

Photo 4.2. Measuring a stem diameter above the buttresses. (Photo K.E. Neering)

The treatments applied in the State Forest Service's experiment Akintosoela2 were less rigorous than in the 20-cm diameter limit refinements in other experiments. Diameter limits of the five most intensive treatments were meant to be in accordance with De Graaf's CSS prescriptions, that is, a basal area of 12.5 – 15 m².ha⁻¹ should remain after refinement. However, the basal area calculations were based on trees larger than 25 cm in diameter only, and not on all trees exceeding 10 cm in diameter as was meant by De Graaf (see Van Bodegom & De Graaf 1991). Hence, diameter limits applied ranged from 25 cm to 50 cm (Jansen et al. 2005). In addition, the experiment included a refinement with a diameter limit of 65 cm and a control treatment.

4.4.1 Growth of medium-sized and large trees

The bulk of the commercial volume increment has to be brought about by the diameter growth of medium-sized and large commercial trees, that is, stems exceeding 15 cm in diameter. In Mapanebrug and Akintosoela1, the refinements with a 20-cm diameter

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3 The true difference in treatment intensity between the Mapane experiments and the MAIN experiment is even larger, as De Graaf based his basal area calculations on all trees larger than 5 cm in diameter, while Jonkers' estimate is based on trees exceeding 15 cm in diameter.

limit, or rather, the drastic reductions in biomass resulting from these treatments, led initially to average diameter growth rates of about 0.9 cm.y^{-1} for such medium-sized and large stems (see De Graaf 1986; Jonkers 1987). However, after about eight years, diameter increment rates dropped rapidly to pre-refinement levels and basal area growth of commercial species fell to a mere 2 % of the pre-treatment basal area (Poels et al. 1995; De Graaf et al. 1999, see Figure 4.1). But in those Mapanebrug plots where a second refinement had been applied, diameter growth remained high for another 8 years, as predicted by De Graaf (1986). In the absence of such a second treatment, the forest in Akintosoela1 produced a sufficient volume of marketable timber for the next harvest, but only marginally so: 19 years after refinement, there was about 40 m³.ha^{-1} of harvestable timber in the stand, assuming a low minimum felling diameter of 45 cm (De Graaf et al. 1999). De Graaf et al. (1999) therefore concluded that "a treatment scheme as prescribed in the CSS should not be abandoned after one treatment if a sustained yield is to be implemented".
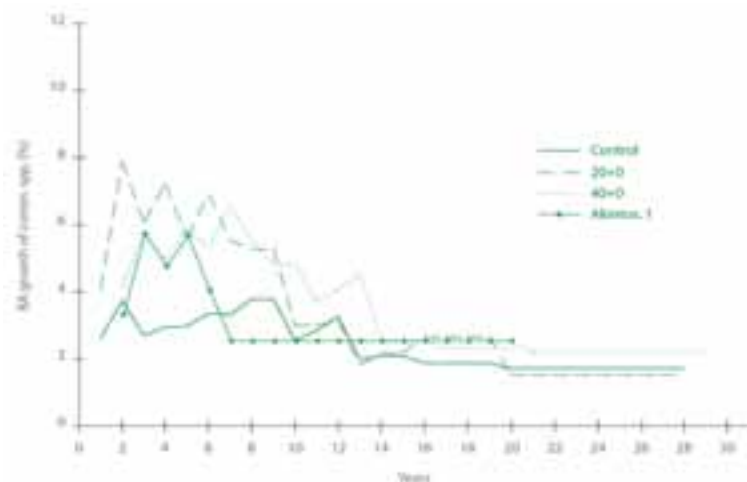
Note: Treatments presented are the control treatment (no refinement after logging) and refinements with 20 and 40 cm diameter limits without follow-up.

Figure 4.1.   Basal area growth of commercial species in Mapanebrug and Akintosoela1: changes in time, expressed as percentage of the basal area in year 1 (source: Poels et al. 1995).

The much milder treatments applied in Akintosoela2 also stimulated diameter growth, but the response was substantially less than in Mapanebrug and Akintosoela1. In order to get statistically meaningful results, Jansen et al. (2005) lumped the seven treatments in two classes: all refinements with diameter limits of 25 to 40 cm together in class I, and the control treatment and refinements with higher diameter limits in class II. The difference in diameter growth between these two classes was small but statistically significant for all species groups, and the mean diameter increment of all species combined was just 0.038 cm.y^{-1} faster after the heavier refinements. This treatment effect may seem negligible, but in relative terms it is an increase by 16 %. According to Schneider's law, this is equivalent to a 33 % increase in volume growth (Jansen et al. 2005). The annual volume increment of surviving commercial trees was about 1.4 m³.ha^{-1} in untreated plots and 1.9 m³.ha^{-1} in plots with relatively heavy refinements (Jansen et al. 2005).

In the MAIN experiment, temporal changes in growth could not be investigated, as there were only two enumerations after silvicultural treatment: one about 1 year after the treatment and one 17 years later, but the experiment allowed a more detailed analysis of long-term impacts of a first refinement than the other trials, also because three levels of silvicultural treatment had been combined with three logging intensities. The levels of silvicultural treatment applied were a control treatment (no refinement, code S0) and refinements with diameter limits of 20 cm (code SR14) and 30 cm (code SR18). The SR codes reflect the basal areas which were expected to remain after application of the treatments (Jonkers 1983). The logging intensities are indicated by the codes E15, E23 and E46, which reflect the average harvested timber volumes (15, 23 and 46 m³.ha^{-1} respectively).

Average growth rates per combination of logging intensity and silvicultural treatment (Table 4.6) suggest that higher intensities of logging and refinement lead to faster diameter growth of the remaining trees, and that refinement has more impact than logging. All mean growth rates were substantially higher than the mean rate recorded in the virgin forest plots, which amounted to 0.39 cm.y^{-1} (S.D. = 0.29) (see previous section) and slightly inferior to the average growth rates recorded in Akintosoela1 over a 19-year period. Because differences in growth rate between the logging intensities were small and standard deviations were high, the overall impact of logging on diameter growth could not be proven with Analysis Of Variance (ANOVA, p = 0.08). Differences between the lowest logging intensity (E15) on the one hand and the intermediate and the highest logging intensities (E23 and E46) on the other hand were substantial, but the differences between the growth rates of the two highest logging intensities were small. The conclusion is the same as the one presented in Section 4.3: the evidence is not statistically proven, but it is likely that logging enhances the growth of commercial trees.

Table 4.6. Diameter growth of commercial trees > 15 cm dbh in cm.y^{-1} (between the 1982-1983 and 1999-2000 enumerations; 2.25-ha plots of the MAIN experiment)

Refinement	Logging intensity											
	E15			E23			E46			All		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
S0	528	0.42	0.33	400	0.44	0.29	484	0.46	0.30	1412	0.44	0.31
SR18	560	0.51	0.33	498	0.55	0.30	453	0.56	0.34	1511	0.54	0.32
SR14	516	0.55	0.40	467	0.60	0.34	420	0.60	0.35	1403	0.58	0.37
All	1604	0.49	0.36	1365	0.53	0.32	1357	0.54	0.33	4326	0.52	0.34

N: number of trees
Source: Jonkers et al. (2005)

Refinement resulted in mean growth rates of 0.5 – 0.6 cm.y^{-1}. The differences between treatments proved statistically significant when tested with ANOVA (p = 0.008). The t-tests showed that especially the differences between the untreated plots (S0) on the one hand and each of the refinement treatments on the other hand were highly significant (p = 0.000), but the difference between both refinements (SR14 and SR18) was highly significant as well (p = 0.001). This result confirms earlier claims (De Graaf

1986; Jonkers 1987) that the diameter growth of medium-sized and large commercial trees is stimulated by refinement, and that a 20-cm diameter limit refinement leads to faster growth than a 30-cm diameter limit treatment.

Remarkable are the high standard deviations (0.3 – 0.4 cm.y^{-1}) found for each combination of logging intensity and silvicultural treatment and also for the virgin forest plots. This means that the growth rates of individual trees were often substantially higher or lower than the mean. A closer examination of the data revealed, that 5 – 10 % of the trees had grown less than 0.1 cm.y^{-1} while the fastest growing individuals had an increment of about 2 cm.y^{-1}. An effort was made to find explanations for these differences in growth rate. One obvious explanation is that some species grow faster than others. This was indeed the case, and variation in growth rate within species was generally somewhat less

Photo 4.3. Numbering the tree and marking the point at which the diameter is measured. Mapane, 1982. (Photo P. Schmidt)

than for all species combined (Table 4.7). However, the diameter increment of the two most common species, *Qualea rosea* and *Dicorynia guianensis*, was more variable than the growth of all commercial trees. These species were also the common commercial species with the fastest average growth[4].

Table 4.7.   Diameter growth rates of common commercial species (trees > 15 cm dbh; MAIN experiment).

Scientific name	Vernacular name	Treatment	N*	Mean dbh growth (cm.y^{-1})	Standard Deviation (cm.y^{-1})
Manilkara bidentata	Bolletri	virgin forest plots	47	0.27	0.16
		logged, no refinement	202	0.30	0.16
		logged, refinement SR18	157	0.42	0.18
		logged, refinement SR14	153	0.44	0.20
Goupia glabra	Kopi	virgin forest plots	24	0.36	0.17
		logged, no refinement	6	0.38	0.26
		logged, refinement SR18	72	0.46	0.30
		logged, refinement SR14	53	0.49	0.27
Virola michelli	Hoogland baboen	virgin forest plots	34	0.33	0.18
		logged, no refinement	86	0.37	0.22
		logged, refinement SR18	84	0.51	0.27
		logged, refinement SR14	109	0.52	0.25

Scientific name	Vernacular name	Treatment	N*	Mean dbh growth (cm.y^{-1})	Standard Deviation (cm.y^{-1})
Tetragastris altissima	Rode sali	virgin forest plots	36	0.42	0.24
		logged, no refinement	69	0.40	0.22
		logged, refinement SR18	111	0.48	0.21
		logged, refinement SR14	88	0.55	0.27
Dicorynia guianensis	Basralokus	virgin forest plots	84	0.44	0.29
		logged, no refinement	287	0.51	0.32
		logged, refinement SR18	348	0.50	0.32
		logged, refinement SR14	267	0.62	0.48
Qualea rosea	Bergi gronfolo	virgin forest plots	40	0.53	0.38
		logged, no refinement	300	0.57	0.36
		logged, refinement SR18	350	0.69	0.35
		logged, refinement SR14	358	0.71	0.37

* N: number of trees
Source: Jonkers et al. (2005)

Variation in diameter increment is apparently mostly due to other factors, such as the vitality of individual trees and competition from neighbouring trees, lianas and other plants. The impact of competition from neighbouring trees is reflected in the following regression equation:

$$\delta dbh = 0.657 - 0.201\ BA_{0-5} - 0.069\ BA_{5-10} - 0.104\ BA_{10-15} \qquad p = 0.000 \qquad \text{(Eq. 4.1)}$$

where δdbh = diameter increment in cm.y^{-1}, BA_{0-5} = competing basal area (in m^2) within 5 m distance from the stem, BA_{5-10} = basal area (in m^2) at 5-10 m distance and BA_{10-15} = basal area (in m^2) at 10-15 m distance (BA derived from 1982-1983 data).

This equation shows indeed that diameter growth is negatively correlated to the density of the surrounding vegetation. The impact of competition is substantial and is not confined to the immediate vicinity of the tree. This applies both to light and root competition. Jonkers (1987) analyzed crown dimensions and reported that considerable light competition over distances exceeding 10 m may be expected from trees of approximately 50 cm dbh and larger and evidence presented in Section 5.5.2 indicates that root systems can extend to at least 30 m from the stem. Because of this, and because competition changed considerably over the 17 years recording period during which competing trees either grew larger or died, equation 4.1. explains only a small part of the variation in tree growth (R^2=0.05).

Diameter growth also depends on tree size. Relatively small trees are generally shaded by larger trees and are therefore likely to suffer more from competition than large individuals. On the other hand, large trees may grow less fast in diameter than smaller individuals because they may become less vital with increasing age and also because a

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4   Higher average growth rates were recorded for some less common species, such as *Parkia nitida* and *Simarouba amara*.

tree has to increase its annual volume growth substantially when it gets larger if it is to maintain the same diameter increment.

Regression analyses were conducted for each silvicultural treatment to analyse the relation between diameter increment on the one hand and the stem diameter and the square of the stem diameter on the other hand. This led to the following equations:

For logged forest, no refinement:
$\delta dbh = 0.2485719 + 0.0089114\ dbh - 0.0000767\ dbh^2$ $p = 0.000$ (Eq. 4.2)

For logged forest, after refinement SR18:
$\delta dbh = 0.3868536 + 0.0075807\ dbh - 0.0000757\ dbh^2$ $p = 0.000$ (Eq. 4.3)

For logged forest, after refinement SR14:
$\delta dbh = 0.4338468 + 0.0076187\ dbh - 0.0000775\ dbh^2$ $p = 0.004$ (Eq. 4.4)

where δdbh = diameter increment in cm.y^{-1} and dbh = stem diameter in cm (1982-1983 data).

These equations are all statistically significant and show indeed a relation between diameter growth and tree size. The curves are rather flat, however, with slight peaks between 40 – 60 cm dbh, and explain only a small part of the variation ($R^2 < 0.10$). Trees in the 40 – 60 cm diameter class grew on average about 0.1 cm.y^{-1} faster than trees of 15-20 cm dbh. A similar analysis of the Akintosoela1 data gave comparable results (see De Graaf et al. 1999).

4.4.2 Growth of small trees

The diameter increment of small commercial trees (5-15 cm dbh) shows trends comparable to those found for larger ones. In Mapanebrug and Akintosoela1, the drastic reductions in living biomass led initially to average diameter growth rates of commercial trees of about 0.7 cm.y^{-1} (see De Graaf 1986; Jonkers 1987). After about eight years, diameter increment rates dropped fast to pre-refinement levels. Where a second refinement had been applied, however, diameter growth remained high for another 8 years (Poels et al. 1995; De Graaf et al. 1999).

Data from the MAIN experiment again suggest that higher intensities of logging and refinement lead to faster growth, and that refinement has a larger impact than logging (see Table 4.8). All mean growth rates except one were higher than the average rate recorded in the virgin forest plots, which amounted to 0.31 cm.y^{-1}. The differences in growth rate between the logging intensities were small and standard deviations were high. Again, the impact of logging on diameter growth could not be proven with ANOVA ($p = 0.68$). The differences between the lowest logging intensity (E15) on the one hand and the intermediate and the highest logging intensities (E23 and E46) on the other hand were again substantial, while the differences between the growth rates of the two highest logging intensities were once more very small.

Table 4.8. Diameter growth of commercial trees 5-15 cm dbh in cm.y^{-1} (between the 1982-1983 and 1999-2000 enumerations)

Refinement	Logging intensity											
	E15			E23			E46			All		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
S0	170	0.31	0.28	138	0.33	0.23	145	0.36	0.28	453	0.33	0.28
SR18	185	0.42	0.31	185	0.45	0.30	156	0.48	0.33	526	0.45	0.31
SR14	171	0.42	0.29	167	0.52	0.31	140	0.54	0.32	478	0.49	0.31
All	526	0.38	0.30	490	0.44	0.32	441	0.46	0.32	1457	0.43	0.30

N: number of trees
Source: Jonkers et al. (2005)

Refinement resulted in mean growth rates of 0.42 – 0.54 cm.y^{-1}. The differences between treatments proved statistically significant when tested with ANOVA ($p = 0.038$). The t-tests conducted showed that especially the differences between the untreated plots (S0) on the one hand and each of the refinement treatments on the other hand were highly significant ($p = 0.000$), as was the difference between both refinements (SR14 and SR18) ($p = 0.011$).

Standard deviations were again very high (0.3 – 0.5 cm.y^{-1}) for all combinations of logging intensity and silvicultural treatment and also for the virgin forest plots (0.28 cm.y^{-1}). Growth rates of individual trees varied from 0.0 cm.y^{-1} to 1.4 cm.y^{-1}. Regression analyses showed a significant correlation between diameter growth and tree size; trees of 14 - 15 cm dbh grew on average about twice as fast as the ones of 5 - 6 cm dbh. Once more, this explained the variation in growth only partially.

4.4.3 Mortality

Mortality in undisturbed tropical rain forest is modest: on average 1 % of the trees are dying annually (see e.g. Swaine et al. 1987), but higher values of 2-3 % have also been reported (e.g. Condit et al. 1995). Expressed in terms of wood volume or biomass, losses due to mortality are in the same order of magnitude as gains due to growth of surviving trees and this makes mortality a crucial parameter for sustainability. The CELOS Silvicultural System does not include specific measures to reduce mortality and is in fact based on the assumption that mortality of commercial trees does not increase substantially after silvicultural treatment. However, logging and silvicultural treatment influence the chances of trees to survive in various ways; they lead for instance to less competition among trees but also to increased exposure to adverse weather condition, and this may lead to an increase or a decrease in mortality.

Because of the low incidence of mortality, it is hard to soundly quantify it; one needs a long period and large numbers of trees to obtain statistically sound results, especially when the spatial and temporal variation in mortality is considerable. This is often the case: extreme weather conditions may generate temporal peaks in mortality, and the fall of a large tree usually destroys several other trees, thus causing a local increase in death rate. The recording period of the MAIN experiment is adequate for a reliable assessment,

but the numbers of trees may be somewhat meagre for analyses per combination of treatments and per species category.

Mortality among the species, which were considered commercial in 1978, is summarised in Tables 4.9 and 4.10. In the replications, about one out of the 95 trees per hectare died annually during the 17-year recording period. Variation between plots was large, but differences between the means for treatments were modest, and there was not the slightest sign of a correlation between mortality on the one hand and logging or refinement intensity on the other hand. Mortality in the virgin forest plots was slightly less than in the logged and refined plots, 15.67 trees.ha^{-1} in 17 years, due to the somewhat lower stocking in these plots (87 trees.ha^{-1}).

Table 4.9. Mortality among commercial species (1978 list) between the 1982-1983 and 1999-2000 enumerations (1-ha plots); number of trees > 15 cm dbh

Refinement	Logging intensity							
	E15		E23		E46		All	
	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.
S0	15.00	5.29	23.00	7.55	11.33	4.93	16.44	7.35
SR18	20.00	3.61	21.33	8.96	15.67	6.43	19.00	6.34
SR14	20.00	6.00	16.67	5.69	18.33	6.03	18.33	5.32
All	18.33	5.05	20.33	7.11	15.11	5.90	17.93	6.24

N.ha^{-1}: number of trees per hectare
Source: Jonkers et al. (2005)

Mortality was also expressed as stem volume loss per annum. This led to substantial differences between means per treatment and between means per combination of treatments (Table 4.10), although there was again no indication of a correlation between mortality on the one hand and logging or refinement intensity on the other. The average loss in the three replications was 2.13 $m^3.ha^{-1}.y^{-1}$; in virgin forest plots the loss was even higher: 2.53 $m^3.ha^{-1}.y^{-1}$ (standard deviation 0.43 $m^3.ha^{-1}.y^{-1}$). Differences between treatments could not be proven with ANOVA ($p > 0.05$) and are probably mostly due to chance.

Table 4.10. Mortality among commercial species (1978 list) between the 1982-1983 and 1999-2000 enumerations (1-ha plots), expressed as stem volume growth. Trees > 15 cm dbh

Refinement	Logging intensity							
	E15		E23		E46		All	
	dV	S.D.	dV	S.D.	dV	S.D.	dV	S.D.
S0	-1.26	0.37	-3.19	1.48	-0.96	1.01	-1.80	1.39
SR18	-2.20	0.22	-3.36	1.92	-1.63	0.25	-2.40	1.24
SR14	-2.60	0.66	-2.38	1.04	-1.61	0.60	-2.20	0.82
All	-2.02	0.72	-2.98	1.39	-1.40	0.69	-2.13	1.16

dV: volume growth in m^3 per hectare per year. Source: Jonkers et al. (2005)

4.4.4 Ingrowth and regeneration

Sustainable rainforest management means, among others, that mortality among species of commercial value should be compensated by ingrowth, that is, trees reaching a size of 15 cm dbh, to secure future harvests. Furthermore, there should remain sufficient advance regeneration (trees smaller than 15 cm diameter). During one cutting cycle of 25 years, those trees of commercial species which were felled or killed during logging operations should be replaced by ingrowth of the same group of species. Furthermore, commercial trees, which died during the recording period, should also be replaced by ingrowth. The required ingrowth can thus be estimated as follows:

- The numbers of commercial trees > 15 cm dbh, which died during logging, were estimated by Jonkers (1987) at 7.1 trees.ha^{-1} for exploitation level E15, at 11.9 trees.ha^{-1} for exploitation level E23 and at 19.1 trees.ha^{-1} for exploitation level E46. As the period between the 1982-1983 and 1999-2000 enumerations covers 67 % of the 25-year cutting cycle, at least two-third of this loss due to felling has to be replaced by ingrowth during this period.
- One can assume the same mortality for all treatments, that is 18 trees.ha^{-1} during the 17 years recording period.
- This means that the ingrowth should be at least 22.8 trees.ha^{-1} for exploitation level E15, 26.1 trees.ha^{-1} for exploitation level E23 and 31.1 trees.ha^{-1} for exploitation level E46.

Photo 4.4. A new sprout helped a poison- girdled tree to survive. (Photo J. Wirjosentono)

The recorded ingrowth in undisturbed forest amounted to just 14.67 trees.ha^{-1} in 17 years. Hence, ingrowth after logging should be much more than in untouched forest.

In the MAIN experiment, the minimum amounts for ingrowth were met where silvicultural treatment had been applied, but logging without silvicultural treatment resulted often in inadequate ingrowth (see Table 4.11). The impact of logging intensity on ingrowth could not be proven, but the positive effect of silvicultural treatment could be shown with ANOVA ($p = 0.046$). The differences between both refinement treatments (SR18 and SR14) on the one hand and the control treatment (S0) on the other hand were also significant when tested with Fisher's t-test ($p = 0.03$ and $p = 0.04$ respectively). However, the difference between the effects of both refinement treatments was not evident ($p = 0.69$).

Table 4.11. Ingrowth of commercial species (1978 list) between the 1982-1983 and 1999-2000 enumerations (1-ha plots; ingrowth > 15 cm dbh)

Refinement	Logging intensity							
	E15		E23		E46		All	
	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.
S0	21.33	13.50	32.00	7.21	28.67	13.80	27.33	11.34
SR18	41.33	18.50	42.33	20.21	42.67	17.04	42.11	16.14
SR14	36.67	10.50	51.00	28.51	49.00	20.52	45.56	19.53
All	33.11	15.52	41.78	19.65	40.11	17.51	38.33	17.38

N.ha^{-1}: number of trees per hectare
Source: Jonkers et al. (2005)

This leads to the conclusion that in a 25-year cutting cycle logging without silvicultural treatment often led to ingrowth levels insufficient to compensate losses incurred due to logging and mortality, while the significantly higher ingrowth after both refinement treatments was more than adequate. Apparently, silvicultural treatment is required to ascertain an adequate amount of ingrowth.

The advanced regeneration (saplings) of commercial species, recorded in 1982-1983 and 1999-2000, is given in Table 4.12. Apparently, sapling densities increased considerably in the silviculturally treated plots. The changes in sapling densities in plots without silvicultural treatment was also positive, but distinctly less spectacular. This indicates that silvicultural treatment has a strong beneficial effect on the regeneration, but that adequate sapling densities can also be obtained without such treatment.

Table 4.12. Number of saplings of commercial species in relation to logging intensity and silvicultural treatment. MAIN experiment, replications 2 and 3 only. Sample size: 0.08 ha per combination of treatments.

Logging intensity	Silvicultural treatment	N.ha^{-1}		Change
		1999-2000	1982-1983	
E15	S0	412.5	275.0	137.5
	SR18	700.0	587.5	112.5
	SR14	650.0	362.5	287.5
	All	587.5	408.3	179.2
E23	S0	687.5	387.5	300.0
	SR18	875.0	425.0	450.0
	SR14	837.5	362.5	475.0
	All	800.0	391.7	408.3
E46	S0	537.5	425.0	112.5
	SR18	787.5	412.5	375.0
	SR14	900.0	462.5	437.5
	All	741.7	433.3	308.3
All	S0	545.8	362.5	183.3
	SR18	787.5	475.0	312.5
	SR14	795.8	395.8	400.0

N.ha^{-1}: number of saplings per hectare
Source: Jonkers et al. (2005)

4.4.5 Volume increment

An important objective of sustainable forest management is to achieve a volume increment of commercial species sufficient to compensate losses incurred during logging. These losses are more than the volumes extracted, as the stumps, the top ends and defective parts of the felled stems are not hauled out and remain in the forest to rot. In addition, some trees of commercial species die during the logging operation due to felling damage. The volumes to be replaced add up to about 23.5 m^3.ha^{-1} for the lowest felling intensity and to 58.7 m^3.ha^{-1} for the highest felling intensity. Assuming a 25-year cutting cycle, this would mean that the required annual volume growth amounts to 0.9 m^3.ha^{-1} for the lowest logging intensity (E15), 1.4 m^3.ha^{-1} for the intermediate intensity (E23) and 2.4 m^3.ha^{-1} for the highest one (E46).

Volume growth depends not only on diameter growth, mortality and ingrowth, but also on the density and the size class distribution of the commercial stand[5]. When a variable is determined by such a variety of parameters, of which some have little or no relation to the treatments applied, one may expect a large amount of unexplained variation. This makes volume increment less fit for statistical testing than diameter growth. Mortality and the original composition of the forest determine volume increment to a large extent, and are major sources of unexplained variation.

Logging affects volume increment in various ways. On the one hand, it opens up the canopy and may therefore stimulate the growth and survival of the remaining commercial trees. On the other hand, it reduces the number of commercial trees and therefore the growth potential of the commercial stand. The effect of logging intensity on volume increment may therefore be either positive or negative.

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[5] The volume increment per unit area is the sum of the volume increments of individual trees and therefore dependent on the number of trees per unit area. Individual large trees contribute substantially more than small trees. This can be explained as follows:
- The volume equation for the MAIN experiment is: $V = -0.2335 + 0.001125D^2$ (Jonkers 1987); where V = volume in m^3 and D = dbh in cm.
- This means that the relation between volume increment (dV), the stem diameter and diameter growth (dD) is: $dV = 0.001125 * dD * (2D + dD)$.
- As dD << D as a rule and as dD changes only slightly with increasing D, volume increment dV increases almost proportionally with D.

Silvicultural treatment stimulates volume increment through increased diameter growth and recruitment. The impact of refinement on mortality was less evident and rather erratic, however, and this will partially blur the overall effect on volume growth.

Volume increment in relation to the treatments is summarised in Table 4.13. The increment in the virgin forest plots was negligible, as expected. In plots where logging was not followed by silvicultural treatment, volume increment was mostly positive, although the relation between harvest intensity and volume increment remained unclear. It seems that a modest sustained yield can be achieved without any silvicultural treatment, but this could not be proven (see also Section 4.3).

Table 4.13. Volume increment* among commercial trees > 15 cm dbh (between the 1982-1983 and 1999-2000 enumerations; 1-ha plots of the MAIN experiment)

Logging intensity	Silvicultural treatment	Volume increment (m³.ha⁻¹.y⁻¹) due to		
		Tree growth and ingrowth	Mortality	Total
Untouched	None	2.55	-2.54	0.01
E15		3.61	-1.26	2.35
E23		2.30	-3.20	-0.90
E46		3.89	-0.96	2.93
E15	SR18	4.21	-2.20	2.01
E23		3.56	-3.36	0.20
E46		3.56	-1.62	1.94
E15	SR14	4.47	-2.60	1.87
E23		4.61	-2.38	2.23
E46		3.47	-1.61	1.86
All	None**	3.27	-1.81	1.46
	SR18	3.78	-2.40	1.38
	SR14	4.19	-2.21	1.98

* Volume equation: $V = -0.2335 + 0.001125D^2$ (Jonkers, 1987); V = volume in m³ and D = dbh in cm
** Except untouched plots
Source: adapted from Jonkers et al. (2005)

There is a positive relation between refinement intensity and the volume gains due to tree increment and ingrowth. Volume losses due to mortality were somewhat higher in the silviculturally treated plots than in plots without silvicultural treatment, but there is no indication that these losses are treatment-related. Mortality was indeed a major source of unexplained variation: average volume loss due to mortality amounted to 2.1 m³.ha⁻¹.y⁻¹, but losses in individual plots ranged from 0.37 to 4.32 m³.ha⁻¹.y⁻¹. The evidence indicates that one refinement with a 20-cm diameter limit is sufficient to secure a second yield of at least 25 m³.ha⁻¹ after 25 years.

Photo 4.5. Stereoscopic photo of an untreated forest in Mapane region about 20 years after logging. (Photo N.R. De Graaf)

Photo 4.6. Stereoscopic photo of a forest in Mapane region 7 years after refinement. (Photo N.R. De Graaf)

4.5   Impact of silvicultural treatment on other tree species

Species, which were not on the list of commercial species in the 1970s, can be grouped into four categories:

- Timber species, which were not on the original list but which are currently on the market. This category is referred to below as "Commercial B";
- Potentially commercial species ("Commercial P"), that is, other species which are included in the CELOS list of commercial species (CELOS 2002) because they may become marketable in the future;
- Non-commercial pioneer species; and
- Other non-commercial species.

Trees of these species were supposed to be killed during refinement if they exceeded the diameter limit. In the MAIN experiment, the numbers of poison-girdled "Commercial B" trees were rather modest, 2.1 and 7.2 trees.ha^{-1} in refinements SR18 and SR14, respectively. Some of those were still alive in 1999-2000 (1.0 trees.ha^{-1} in each treatment). The numbers of poison-girdled "Commercial P" trees were much higher, 9.1 and 17.9 trees.ha^{-1}. Again, a few of those survived until 1999-2000 (1.3 and 1.4 trees.ha^{-1}). "Non-commercial pioneer species" were less common; 1.9 and 10.2 trees.ha^{-1} were poison-girdled in refinements SR18 and SR14, respectively. Relatively many of them were still alive in 1999-2000 (1.0 trees.ha^{-1} in refinement SR18 and 3.2 trees.ha^{-1} in refinement SR14). The numbers of poison-girdled "Other non-commercial species" trees were much higher (19.7 and 36.2 trees.ha^{-1}), and only few of them were found alive in 1999-2000 (1.7 and 1.4 trees.ha^{-1}).

Table 4.14.   Mortality among other currently commercial species (not on the 1978 list) and species with commercial potential between the 1982-1983 and 1999-2000 enumerations (1-ha plots; trees > 15 cm dbh)

Refinement	Logging intensity							
	E15		E23		E46		All	
	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.
Other currently commercial species								
S0	3.00	2.00	2.00	0.00	5.00	2.83	3.29	2.06
SR18	2.50	2.12	1.50	0.71	4.00	2.83	2.67	1.97
SR14	3.00	0.00	2.00	1.41	2.33	0.58	2.43	0.79
All	2.86	1.46	1.83	0.75	3.57	2.07	2.80	1.64
Potentially commercial species								
S0	5.00	2.65	9.00	1.73	3.00	1.00	5.67	3.12
SR18	9.33	4.16	10.33	7.09	5.33	3.06	8.33	4.95
SR14	7.33	0.58	5.67	1.53	10.67	1.15	7.89	2.42
All	7.22	3.11	8.33	4.27	6.33	3.81	7.30	3.71

N.ha^{-1}: number of trees per hectare
Source: Jonkers et al. (2005)

Mortality of "Commercial B" and "Commercial P" species after the 1982-1983 enumeration is summarised in Table 4.14. The loss in the "Commercial B" category was somewhat lower in the silviculturally treated plots than in the untreated plots. This was expected, since many trees had been poison-girdled and were already dead before the 1982-1983 enumeration. Mortality among "Commercial P" species, however, was higher in silviculturally treated forest, because most poison-girdled trees died after the 1982-1983 enumeration. Mortality in the virgin forest plots (4.33 and 6.67 trees.ha^{-1} for "Commercial B" and "Commercial P", respectively) was slightly higher than in untreated logged forest, which was probably due to a difference in initial stocking. There was no clear relation between logging intensity and mortality.

The losses in the category "Commercial B" were also expressed in volume terms, as the species concerned are at present of commercial value. Between the refinement and the 1982-1983 enumeration, mortality amounted to 4.0 and 7.6 m^3.ha^{-1} for refinements SR18 and SR14, respectively. Thereafter, losses in the silviculturally treated plots were modest (Table 4.15), amounting to 1.8 and 3.4 m^3.ha^{-1} in 17 years. This adds up to 5.8 m^3.ha^{-1} for refinement SR18 and 11.0 m^3.ha^{-1} for refinement SR14. The volume lost in the control treatment (S0) amounted to 6.8 m^3.ha^{-1} and therefore exceeded the losses during and after refinement in treatment SR18, but not those incurred in refinement SR14.

Table 4.15.   Mortality among other currently commercial species (not on the 1978 list) between the 1982-1983 and 1999-2000 enumerations (1-ha plots), expressed as stem volume growth. Trees > 15 cm dbh

Refinement	Logging intensity							
	E15		E23		E46		All	
	dV	S.D.	dV	S.D.	dV	S.D.	dV	S.D.
S0	-0.51	0.46	-0.13	0.12	-0.51	0.30	-0.40	0.35
SR18	-0.09	0.05	-0.05	0.03	-0.18	0.17	-0.11	0.10
SR14	-0.15	0.12	-0.07	0.07	-0.31	0.36	-0.20	0.24
All	-0.29	0.34	-0.08	0.07	-0.33	0.28	-0.24	0.28

dV: volume growth in m^3 per hectare per year

Mortality of "Non-commercial pioneer" and "Other non-commercial" species after the 1982-1983 enumeration is summarised in Table 4.16. The losses in these categories were somewhat lower in the silviculturally treated plots than in the untreated plots, in spite of the high number of poison-girdled trees still alive during the 1982-1983 enumeration. It seems that in silviculturally treated forest mortality among "Other non-commercial species" was mainly a delayed effect of poison girdling, as relatively few trees which had not been poison-girdled died. Mortality in the virgin forest plots was comparable to rates in untreated logged forest (5.56 and 21.33 trees.ha^{-1} for "Non-commercial pioneer species" and "Other non-commercial species", respectively), and there was again no clear relation between logging intensity and mortality. It is remarkable that more than 50 % of the trees of pioneer species, which were larger than 15 cm dbh in 1982, were still alive in 2000. These species apparently are not as short-lived as is often thought.

Table 4.16. Mortality among species without commercial potential in the period between the 1982-1983 and 1999-2000 enumerations (1-ha plots); number per hectare of trees > 15 cm dbh

Refinement	Logging intensity							
	E15		E23		E46		All	
	N.ha⁻¹	S.D.	N.ha⁻¹	S.D.	N.ha⁻¹	S.D.	N.ha⁻¹	S.D.
Non-commercial pioneer species								
S0	8.67	2.52	6.00	2.65	9.00	0.00	7.89	2.32
SR18	4.00	1.73	5.00	1.73	8.00	4.58	5.67	3.16
SR14	4.00	2.65	6.50	3.54	7.67	4.73	6.00	3.63
All	5.56	3.09	5.75	2.25	8.22	3.35	6.54	3.10
Other non-commercial species								
S0	15.00	5.57	31.00	11.53	20.33	4.93	22.11	9.84
SR18	15.00	6.00	22.33	6.03	23.67	12.50	20.33	8.57
SR14	21.00	8.72	22.33	9.29	18.33	4.16	20.56	6.93
All	17.00	6.69	25.22	9.09	20.78	7.41	21.00	8.24

N.ha⁻¹: number of trees per hectare. Source: Jonkers et al. (2005)

The average growth rates of trees in category "Commercial B" were low, ranging from 0.17 cm.y⁻¹ in logged forest without silvicultural treatment to 0.27 cm.y⁻¹ after refinement (SR14). Most species in this category were rather rare (fewer than 1.5 trees.ha⁻¹ > 15 cm dbh prior to silvicultural treatment). The only common one, *Lecythis corrugata*, was also the slowest grower with mean rates ranging from 0.12 cm.y⁻¹ in the virgin forest plots to 0.22 cm.y⁻¹ after refinement (SR14). The average growth rates of trees in category "Commercial P" were substantially higher, ranging from 0.30 cm.y⁻¹ in the virgin forest plots to 0.43 cm.y⁻¹ after refinement (SR14). The mean increments varied considerably among species. Most common species were slow growers. By far the fastest growing species was Sclerolobium albiflorum with mean growth rates as high as 1.3 – 1.9 cm.y⁻¹.

The mean increments in the category "Non-commercial pioneer species" deviated very little from the rates in the "Commercial P" category and ranged from 0.30 cm.y⁻¹ in the virgin forest plots to 0.46 cm.y⁻¹ after refinement (SR14). Average growth rates of individual pioneer species were mostly close to these mean values, except for Pourouma spp., which grew faster.

The mean increments in the category "Other non-commercial species" ranged from 0.20 cm.y⁻¹ in the virgin forest plots to 0.27 cm.y⁻¹ after refinement (SR14). Most species in this rest category are understorey species with mean growth rates of 0.1 - 0.2 cm.y⁻¹. The fastest growing species was again a *Sclerolobium* species: the canopy tree *S. melinonii* with rates of 0.7 – 0.9 cm.y⁻¹.

In all categories and in most individual species diameter growth was highly variable with standard deviations in the order of magnitude of 80 % of the mean values. Furthermore, the growth rates of individual species indicate that virtually all species respond to logging and silvicultural treatment with increased diameter growth.

Trees of "Commercial B" species, which died during or after logging and silvicultural treatment, should preferably be replaced by ingrowth within one cutting cycle. The average ingrowth figures for the various combinations of logging and refinement intensities are given in Table 4.17, together with their standard deviations. Ingrowth generally did not reach the desired levels in plots where no silvicultural treatment had been applied. This may indicate slow recovery, but it may also be due to long-term variation in ingrowth; ingrowth in virgin forest plots, which in 17 years amounted to 3.00 trees.ha⁻¹ (S.D. = 1.73), was also less than the mortality in the same period (4.33 trees ha⁻¹). Ingrowth after silvicultural treatment was generally adequate.

Table 4.17. Ingrowth of other currently and potentially commercial species (not on the 1978 list) between the 1982-1983 and 1999-2000 enumerations (1-ha plots; ingrowth > 15 cm dbh)

Refinement	Logging intensity							
	E15		E23		E46		All	
	N.ha⁻¹	S.D.	N.ha⁻¹	S.D.	N.ha⁻¹	S.D.	N.ha⁻¹	S.D.
Currently commercial species (not on the 1978 list)								
S0	3.00	1.00	4.33	1.53	3.33	1.53	3.56	1.33
SR18	4.00	1.73	9.00	2.00	7.67	4.93	6.89	3.59
SR14	6.67	2.89	7.67	2.52	9.67	2.89	8.00	2.74
All	4.56	2.40	7.00	2.74	6.89	4.08	6.15	3.24
Other species with commercial potential								
S0	5.00	2.00	10.00	6.56	6.33	2.08	7.11	4.23
SR18	9.00	3.00	15.67	5.51	9.00	7.94	11.22	6.06
SR14	11.67	8.02	12.67	0.58	13.00	1.73	12.44	4.16
All	8.56	5.27	12.78	4.94	9.44	5.10	10.26	5.24

N.ha⁻¹: number of trees per hectare
Source: Jonkers et al. (2005)

The category "species with commercial potential" ("Commercial P") includes a wide variety of timber species, which are not harvested presently but which may become marketable in the future (see Comvalius 2001; CELOS 2002). Therefore, forest management should preferably allow the option to restore the pre-felling stocking of such species before the end of the second cutting cycle. The average ingrowth figures for the various combinations of logging and refinement intensities are given in Table 4.17, together with their standard deviations. Ingrowth was very variable, but it generally reached the desired levels. "Commercial P" trees lost due to logging, refinement and natural mortality will probably be compensated by ingrowth within one cutting cycle where no silvicultural treatment had been applied and within two cutting cycles in silviculturally treated forest. Ingrowth in virgin forest plots, which in 17 years amounted to 6.33 trees.ha⁻¹ (S.D. = 2.89), was slightly less than the mortality in the same period (6.67 trees.ha⁻¹).

Shortly before refinement, there were on average 18.3 trees.ha⁻¹ of "Non-commercial pioneer species" in the three replications. Most of these species are rather short-lived,

so mortality was high: 40 % died in 17 years in plots where no silvicultural treatment had been applied while in silviculturally treated forest, some 40-50 % died between 1982 and 2000, depending on the treatment. Furthermore, one may assume that 1-2 trees.ha^{-1} were destroyed during logging operations, depending on felling intensity. So, an ingrowth level of 8-11 trees.ha^{-1} would fully compensate mortality plus losses due to logging.

It was expected that ingrowth in the replications would be more than sufficient to compensate mortality and that it would exceed the ingrowth in the virgin forest plots, which amounted to 6.67 trees.ha^{-1} (S.D. = 3.06). This certainly was the case; ingrowth was usually abundant, but varied considerably between plots with the same treatments (Table 4.18). Furthermore, the means suggest a sharp rise in ingrowth with increasing exploitation and refinement intensity. Effects of logging intensity and silvicultural treatments on ingrowth proved indeed significant when tested with ANOVA ($p < 0.05$), and the t-tests showed significant differences between refinement treatment SR14 and the silvicultural control treatment S0 ($p = 0.03$) and also between logging intensities E15 and E46 ($p = 0.003$). Differences between logging intensity E23 on the one hand and E15 and E46 on the other hand, and between refinement treatment SR18 on the one hand and treatments S0 and SR14 on the other could not be proven with the t-test ($p > 0.05$).

Table 4.18. Ingrowth of species without commercial potential between the 1982-1983 and 1999-2000 enumerations (1-ha plots; ingrowth > 15 cm dbh)

Refinement	Logging intensity							
	E15		E23		E46		All	
	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.	N.ha^{-1}	S.D.
Non-commercial pioneer species								
S0	13.33	14.57	29.00	13.00	58.00	30.79	33.44	26.79
SR18	37.00	20.22	55.33	16.50	72.67	22.48	55.00	23.14
SR14	40.33	15.95	69.67	37.00	111.33	44.11	73.78	42.98
All	30.22	19.53	51.33	27.78	80.67	37.67	54.07	35.15
Other non-commercial species								
S0	20.33	13.65	25.67	2.08	22.33	8.50	22.78	8.44
SR18	29.67	3.21	31.00	7.94	34.00	7.00	31.56	5.85
SR14	48.00	9.64	30.00	1.73	24.00	5.57	34.00	12.20
All	32.67	14.87	28.89	4.86	26.78	8.24	29.44	10.12

N.ha^{-1}: number of trees per hectare. Source: Jonkers et al. (2005)

Shortly before refinement, there were on average 79.5 trees.ha^{-1} of "Other non-commercial species" in the three replications. Mortality was not high where no silvicultural treatment had been applied, 22 trees.ha^{-1} died in 17 years, while in silviculturally treated forest, some 33-44 trees.ha^{-1} died between 1982 and 2000, depending on the treatment. Furthermore, one may assume that 3-7 trees.ha^{-1} were killed during logging operations, depending on felling intensity. So, ingrowth levels in the order of 27 trees.ha^{-1} (no silvicultural treatment), 38 trees.ha^{-1} (refinement SR18) and 49 trees.ha^{-1} (refinement SR14) would fully compensate both mortality and fatal logging damage.

Here, it was expected that ingrowth in the replications would compensate only part of the mortality and logging damage, especially in silviculturally treated forest, and that it would exceed the ingrowth in the virgin forest plots, which amounted to 18.33 trees.ha^{-1} (S.D. = 5.51). This was to some extent true; it takes the "Other non-commercial species" apparently more than 17 years to recover from losses due to logging and refinement (see Table 4.18), but tree densities at the end of the 25-year cutting cycle will probably be comparable to pre-felling densities.

Table 4.18 suggests that logging intensity hardly had any impact on ingrowth of these species and that silvicultural treatment had a stimulating effect. An influence of logging intensity on ingrowth could indeed not be proven ($p \gg 0.05$), while the effect of silvicultural treatment could be shown with ANOVA ($p = 0.025$). Also, the differences between both refinement treatments (SR18 and SR14) on the one hand and the control treatment (S0) on the other were significant when tested with Fisher's t-test ($p = 0.02$ and $p = 0.04$, respectively). A difference between the effects of refinement treatments SR14 and SR18 could not be proven ($p = 0.60$).

4.6   Consequences for the CELOS Management System

The experimental results show that both logging and silvicultural treatment stimulate the diameter growth and recruitment of tree species and that tree growth increases with logging and refinement intensities. This applies for both commercial and non-commercial tree species. The relation between logging and refinement on the one hand and mortality on the other hand is less straightforward: during timber harvesting and silvicultural treatment, many trees are killed, but in the years thereafter, mortality is rather erratic. Still, volume increment of commercial species is generally positive, indicating a recovery of the commercial stand.

In the MAIN experiment, the forest is richer in commercial timber than most natural forests in Suriname. Under these conditions, the rate of recovery is such that:
 • A modest sustained yield of about 15 m^3.ha^{-1} once every 25 years can probably be achieved without silvicultural intervention;
 • A higher production level of approximately 25 m^3.ha^{-1} once every 25 years will require one refinement with a diameter limit of 20 cm; and
 • If one wants to achieve a sustained yield of about 40 m^3.ha^{-1} in a 25-years' cutting cycle, one refinement is not sufficient and at least one follow-up treatment will be needed.

In poorer stands, diameter growth rates after logging will be similar as in better stocked stands, but volume increment will be less as there is less growing stock. Hence, silvicultural treatment will be necessary in such forest if one wants to produce sustainably. Such stands will generally contain more non-commercial trees than richer forest, and the intensity of the 20-cm diameter limit refinement will therefore be higher. The Mapane experiments show that this may result in a dramatic increase in the growth of individual trees and to a volume increment comparable to the rate obtained in the MAIN experiment, and also that a second treatment is required after eight years to maintain growth at this level.

First refinements with a 20-cm diameter limit yielded good results in all experiments. The evidence presented gives no reason for major changes, in spite of the considerable proliferation of pioneer species. Applying a lower diameter limit will result in even larger numbers of pioneer trees and is therefore undesirable, and higher diameter limits did not adequately stimulate the growth of the commercial stand. However, Jonkers' (1987) suggestion to use a limit of 20 cm in the vicinity of commercial stems and a higher limit elsewhere (see Section 3.3) may be considered as protection measure for very poorly stocked parts of the forest. Commercial trees with logging damage should be preserved during the first refinement: most of them will either die or recover, and it is therefore not advisable to kill them.

Furthermore, the findings suggest that the second refinement should focus on reducing competition from pioneer species and a few other fast growing non-commercial species rather than on eliminating slow growing understorey trees. In addition, trees with very serious defects can be eliminated.

References

Boerboom, J.H.A. 1965. De natuurlijke verjonging van het Surinaamse mesofytische bos na uitkap. Landbouwhogeschool Wageningen, Afdeling voor Houtmeetkunde, Bosbedrijfsregeling en Houtteelt en Bosbescherming in de Tropen, Wageningen, The Netherlands.

CELOS 2002. CELOS-list of commercial tree species 2000. CELOS, Paramaribo, Suriname.

Comvalius, L.B. 2001. Surinamese timber species: characteristics and utilization. CELOS, Paramaribo, Suriname.

Condit, R., Hubbell, S.P. & Foster, R.B. 1995. Mortality rates of 205 Neotropical tree and shrub species and the impact of a severe drought. Ecological Monographs 65, 419-439

De Graaf, N.R. 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Management of Tropical Rain Forest in Suriname 1. Wageningen Agricultural University, Wageningen, The Netherlands.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 4. Wageningen Agricultural University, Wageningen, the Netherlands.

Jansen, J.J., Bongers, F., De Graaf, N.R., Jonkers, W.B.J., Sterck, F.J., Stuiver, B.M. & Wirjosentono, J. 2005. Secondary data analysis Mapane plots 1981-1997. Internal report. CELOS, Paramaribo, Suriname and Wageningen University, Wageningen, The Netherlands.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 3. Wageningen Agricultural University, Wageningen, The Netherlands.

Jonkers, W.B.J., Tjon, K. & Wirjosentono, J. 2003. Long-term effects of logging in a Neotropical rain forest in Suriname. In: International expert meeting on the development and implementation of national codes of practice for forest harvesting: issues and options. International Forestry Cooperation Office, Forestry agency, Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan, pp. 157-166.

Jonkers, W.B.J., Tjon, K. & Wirjosentono, J. 2005. Long-term changes in selectively logged and silviculturally treated tropical rain forest in Suriname: analysis of the 1978-2000 data of Experiment 78/5. Internal report. CELOS, Paramaribo, Suriname and Wageningen University, Wageningen, The Netherlands.

Poels, R.L.H., De Graaf, N.R. & Wirjosentono, J. 1998. Growth and mortality of trees after various experimental silvicultural treatments for natural regeneration in Suriname. Hinkeloord reports 25. Wageningen Agricultural University, Wageningen, The Netherlands.

Staudt, F.J. 1977. Arbeidskundig onderzoek van werkzaamheden t.b.v. natuurlijke verjonging van het drooglandbos (zuiveringsarbeid). Vakgroep Bosbouwtechniek, Landbouwhogeschool, Wageningen, The Netherlands.

Swaine, M.D., Lieberman, D. & Putz, F.E. 1987. The dynamics of tree populations in tropical forests, a review. Journal of tropical ecology 3, 359-366.

Van Bodegom, A.J. & De Graaf, N.R. 1991. The CELOS Management System: a provisional manual. IKC-NBLF-LNV, Wageningen University and Foundation BOS. Wageningen, The Netherlands.

5 Impacts on forest structure and plant species diversity

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Table 5.1. An overview of the forest stands discussed in this chapter.

Stand name	Phytomass Forest	MAIN*	Van Leeuwen transect	Procter's Forest	Mapanebrug	Akintosoela1	Weyerhäuser
Region	Kabo	Kabo	Kabo	Mapane	Mapane	Mapane	Mapane
Treatment	Undisturbed	Selective cutting, refined	Undisturbed	Selective cutting	Selective cutting, refined	Selective cutting, refined	Nearly total clear cut
Year harvest	n.a.	1978	n.a.	1966, 1974	1966	1966, 1974	1969
Harvest intensity	n.a.	Four levels, 0, 1, 2, 4 m².ha⁻¹	n.a.	Light	Light	Light	All trees > 27 cm dbh removed, ± 200 m³.ha⁻¹
Year refined	n.a.	1982/3	n.a.	n.a.	1967	1975	n.a.
Refinement intensity	n.a.	Three levels: no, > 30cm, > 20 cm dbh	n.a.	n.a.	20+D8 **	20+ **	n.a.
Remarks	Reference plot	Test plot CSS	Reference plot	Reference plot	Test plot CSS	Test plot CSS	Secondary forest
Abbreviation	Phy Fo	MAIN	Van Leeuwen transect	Pro Fo	Ma Br	Akin	Weye

* Of the total of 30 plots, 9 were used in the experiments discussed here. See Section 5.4 for more details.

** Deviating from the normal prescriptions, large commercial trees have been poisoned too. See Section 5.4.

5.1 Introduction

Forest management systems such as the CMS need to be firmly based on ecological principles. In tropical rainforest ecosystems, sustainable use is intimately linked to ecology, as each management system interferes with the forest structures and processes. The question is whether or not these interferences have such a strong impact that key features of the forest, such as its structure and its species composition (and biodiversity), will change in such a way that the sustenance of the forest and forest use become problematic. When the first concepts of the CSS were formulated and tested around 1980 research was undertaken to address this question to a certain extent. These initial studies ran more or less parallel in time with the experimental application of CSS treatments, or shortly after. Longer-term effects were studied about two decades later, when old and new data were analysed to arrive at a more comprehensive understanding of the impact of the CMS.

Six forest stands, representing different intensities of human interferences related to the CMS, were studied. These interferences ranged from selective logging, to refining, to cutting nearly all trees. Table 5.1 shows that the treatments in the six forests stands varied from 'undisturbed' (Phytomass Forest), via selective cutting (Procter's Forest), selective cutting and refinement (MAIN, Mapanebrug and Akintosoela) to intensive clear cutting (Weyerhäuser). In Mapanebrug a first and a second refinement were carried out. In the Kabo region the Phytomass Forest and the untreated plots of the MAIN experiment served as reference plots; for Mapane this is Procter's Forest. Not all features were studied in all forest stands, as some stands were too small or too unique for destructive experiments.

5.2 Forest structure

5.2.1 Introduction

Main variables of the spatial structure of a tropical rain forest include patchiness and gaps, dead wood laying on the forest floor, basal area, stratification, crown density, stem and crown dimensions. Roots make up the belowground structure. The physical structure of the forest is of importance for its plants, most obviously so for epiphytes, climbers and lianas, which all require the support provided by the stems and branches of self-supporting woody plants. For herbs, shrubs and immature trees in the understorey, the structure of the forest canopy above them determines the light regime to which they are exposed, and thus their development (see Hartshorn 1990 for the Neotropics).

5.2.2 Diameter class distribution, basal area and standing volume

An important general feature of the tropical rain forest is that it has a well balanced tree diameter class distribution, with numbers of trees per diameter class diminishing almost geometrically with increasing tree size (Rollet 1978). This results from the dynamic pattern of growth to maturity of the trees, during which seedlings and small trees struggle to grow and survive, and, while individuals die, only some trees reach adult stages, produce flowers and seeds. Ultimately relatively few large trees are available for harvesting. A second feature is that individual tree species, both commercial and non-commercial ones, may deviate substantially from this general pattern. Schulz (1960) described this for the Mapane forest and Jonkers (1987) for the MAIN experiment.
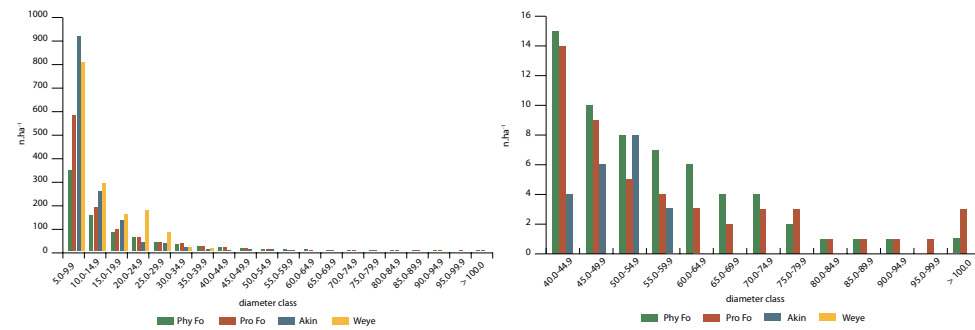
Figure 5.1.   Diameter distribution (cm) in trees (standardized per ha) in four differently treated (see Table 5.1) forest stands. Surface of inventory Phytomass Forest 5 ha; Procter's Forest 5 ha, Akintosoela1 1 ha; Weyerhäuser 0.25 ha.

It can be expected that both logging and refinement will change the diameter class distribution, the basal area and the standing volume of the forest. Figure 5.1 shows that both Phytomass Forest and Procter's Forest have a fairly normal, reversed-J shaped stem diameter distribution. In Akintosoela1 all large trees had been killed (even more than prescribed in the normal CSS procedure, see Section 4.4) and seven years after treatment no new large trees had replaced them yet, resulting in only a few trees > 40 cm dbh. In Weyerhäuser trees in the smaller dbh classes dominate. Here severe logging had completely removed the larger diameter classes and subsequent rejuvenation resulted in many young individuals. Weyerhäuser had no trees with dbh > 40 cm due to the short recovery time (about 13 years) after heavy exploitation.
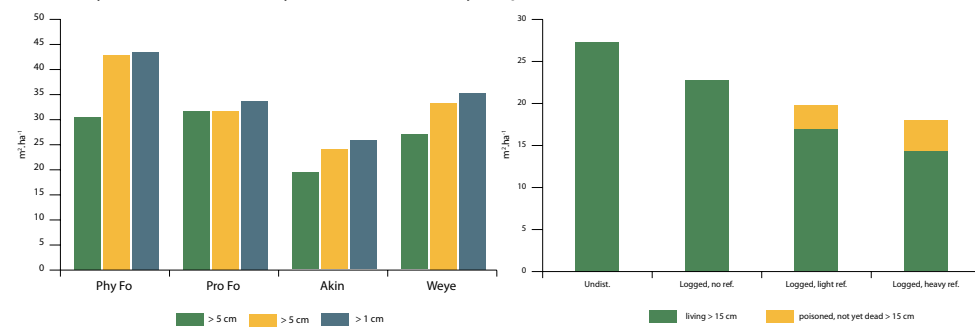

Figure 5.2.   Left: Basal area of all tree species in four differently treated (see Table 5.1) forest stands as assessed in a forest inventory (green, 5 ha in Phytomass Forest and Procter's Forest and 1 ha in Akintosoela1 and Weyerhäuser) and in phytomass plots (yellow and blue, 0.12 ha in Phytomass Forest, 0.14 ha in Procter's Forest, 0.12 ha in Akintosoela1 and 0.025 ha in Weyerhäuser). Right: Basal area in MAIN five years after logging and one year after refinement, assessed on 9 ha.

The basal areas in both control forests (Phytomass Forest and Procter's Forest) did not differ much from each other (Figure 5.2). These values were higher than those given by Schulz (1960). His value of 17.2 m².ha⁻¹ for the Mapane forest was based on trees > 24.5 cm dbh. As expected, logging and refinement had reduced the basal area. The heavier the intervention, the more the basal area was reduced. From our inventories it is clear that it will take many years to reach the pre-intervention value again. In Akintosoela1 the basal area before refinement was 28.3 m².ha⁻¹. In refinements with a 20 cm diameter

limit basal area was reduced to about 9.8 m².ha⁻¹ (De Graaf 1986). Seven years later the basal area reached 19.2 m².ha⁻¹. The secondary forest of Weyerhäuser had grown, in 13 years, to a basal area of 27 m².ha⁻¹. This high value is the result of the large number of fast growing trees of pioneer species in the secondary vegetation (see below). It is not known how much the initial basal area of this forest stand was immediately after the cutting of all trees > 23 cm dbh in 1969.

No assessment of the standing volume of all trees in treated forest stands was carried out. However, assuming an average specific gravity[1] of 0.72 g.cm⁻³, an estimate can be made based on the phytomass of tree stems. It is difficult, however, to compare these data with bole volumes, because in this phytomass study the continuing part of the stem above the first major branch was considered as stem, whereas usually this part is not considered as being part of the bole. Standing volumes in Phytomass Forest and in Procter's Forest were similar (see Figure 5.3) and somewhat lower than the 426 m³.ha⁻¹ (dbh > 24.5 cm) mentioned by Schulz (1960). Striking, however, is the very low standing volume of trees > 5 cm dbh in Akintosoela1 and Weyerhäuser. Even when including trees between 1 and 5 cm volume value remained low. This is evidence that the harvest and refinement in Akintosoela1 had reduced the growing stock of large trees enormously. The large number of young trees indicated a good restoration potential, mainly with non-commercial trees, but also a sufficient amount of commercial trees (Jonkers pers. obs.).
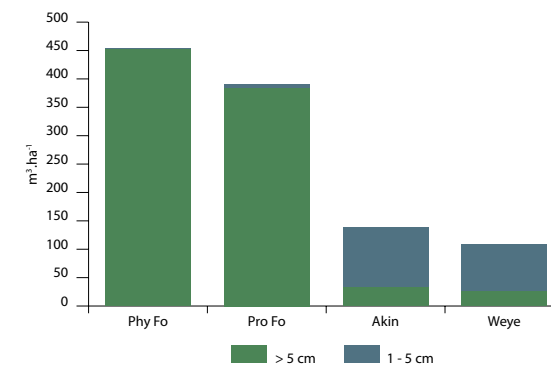
Figure 5.3.   Standing volume of all trees in four differently treated (see Table 5.1) forest stands, estimated on the basis of phytomass data

5.2.3 Foliage distribution and light

The vertical distribution of the leaf mass influences the light conditions and affects the conditions for photosynthesis, and thus growth and regeneration to maturity. Nevertheless, data on the distribution of leaf mass in tropical rain forest are scarce. Odum et al. (1963, Puerto Rico) thought the existence of strata in rain forest was doubtful, whereas Rollet (1974, Venezuela) showed that leaf mass has a roughly bell shaped distribution with a maximum density at around half the maximum tree height. Logging and refinement as carried out in the CMS experiments in Mapane undoubtedly changed

the distribution. Logging had probably only limited impact on the overall structure of the forest stands, as the exploitation carried out was light. A few gaps and skid trails (see below) were created. Refinement, however, changed the structure considerably. Trees died and if they collapsed, additional gaps were created and the height of the canopy became probably lower, more open and more uniform (compare in Figure 5.4 the canopy in the lightly exploited Procter's Forest with the lightly exploited and refined Akintosoela1). In the gaps, dense secondary vegetation developed with fast growing pioneer species (*Inga, Pourouma, Cecropia* spp.). In Kabo, however, where large commercial trees were retained during refinement, such lowering of the canopy did not occur (Jonkers, pers. obs.) and proliferation of pioneer species was less pronounced (see Section 4.5). In general, the vegetation density in the lower strata increased.
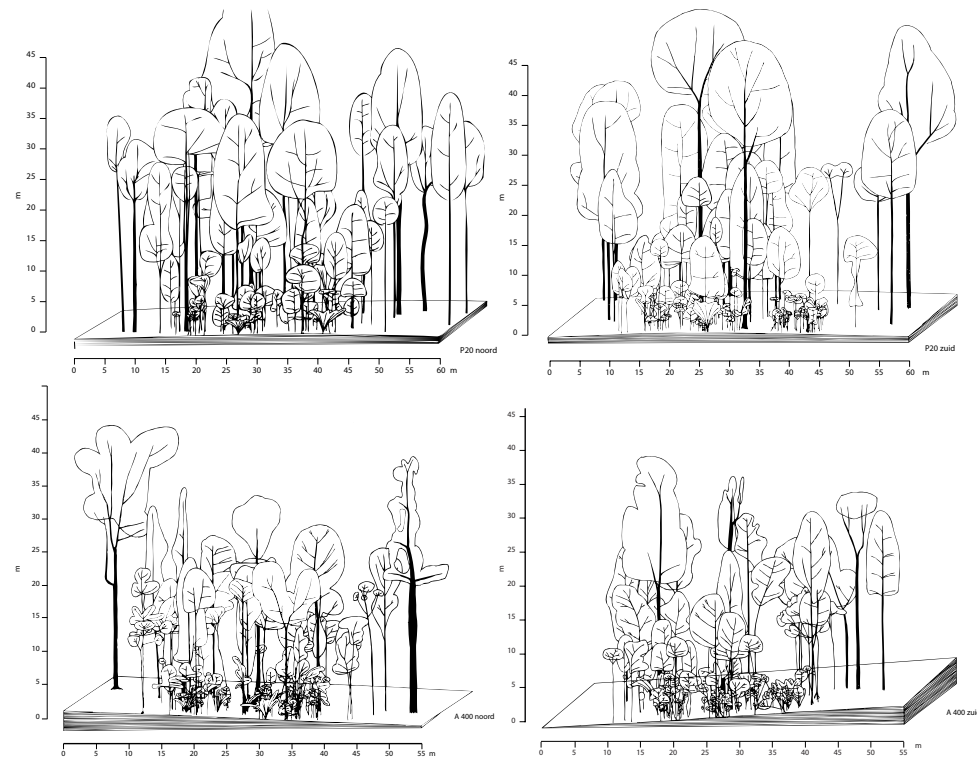

Figure 5.4. Profile diagrams in Procter's Forest (P20) and Akintosoela1 (A400). Profiles were drawn in 1983 along an East-West running straight central line. In the profiles only those smaller trees (> 2 m height) were drawn that grew close to the central line. (Source Voordouw 1985). On this central line birds were sampled in 1982 (see Chapter 7) and light distribution was measured in 1983 (see section 5.2.3).

Depending on the treatment, the total height of the leaf mass and its vertical distribution differed. Treatments, such as selective cutting, refinement and nearly clear cutting, reduced the leaf mass (Phytomass Forest 8.5 t.ha^{-1}; Procter's Forest 7.9 t.ha^{-1}; Akintosoela1 7.2 t.ha^{-1} and Weyerhäuser 3.7 t.ha^{-1}, see Chapter 6), and thus reduced the photosynthetic capacity of the forest. This reduction was probably stronger than the increase in photosynthesis resulting from the higher light availability deeper into the forest structure as a result of those treatments.
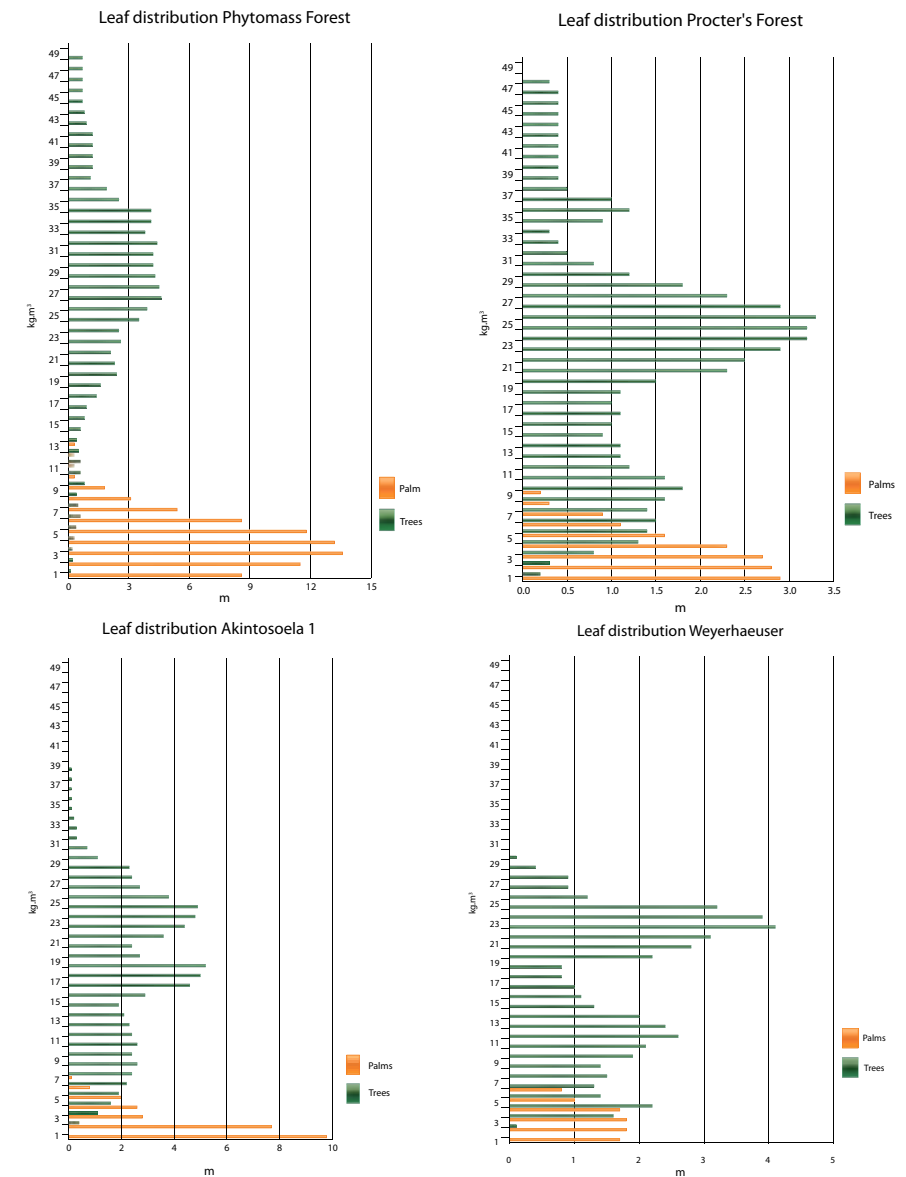
Figure 5.5. Distribution of tree and palm leaves (kg.m[3], X-axis) along tree height (m, Y-axis) in Phytomass Forest (not treated, above left), Procter's Forest (lightly exploited, above right), Akintosoela1 (exploited and refined, below, left) and Weyerhäuser (clear cut, below, right). For more details of the treatments see Table 5.1.

Light conditions in treated forest stands differed from those in non-treated stands. Cumulative photochemical (uranyl-oxalate) assessment of UV light over longer periods on different heights on three plots in two differently treated stands confirmed this: seven years after refinement the light climate in the exploited and refined stand Akintosoela1 resembled that in an artificial plantation, while the non-refined Procter's Forest retained a light climate similar to an undisturbed natural forest (Voordouw, 1985). Fig. 5.4 gives an impression of these two forest stands.

The effects of treatments on leaf mass distribution were studied in the Phytomass Forest (12 plots), Procter's Forest (14 plots), Akintosoela1 (12 plots), and Weyerhäuser (2.5 plots). These plots were 100 m² each. The following features were measured: of all felled trees (> 1 cm dbh) and palms (> 1.5 m high) the total height, the stem length (until the lower end of the crown), the greatest diameter of the crown and the dry weight of the leaf mass were measured on the lying tree. Subtraction of stem length from total height gives crown depth, and multiplying that value by crown diameter gives the volume of each crown calculated as a cylinder. The distribution of the leaf mass over each crown was calculated on the assumptions that the leaf distribution over the crown was diffuse over the whole crown volume for trees less than 18 m high, and diffuse over the upper half of the crown for trees of more than 18 m in height. These assumptions were based on observations on the profile diagrams of these forests. Of course, these assumptions are rough approximations and do not take into account differences based on species, position and age. Based on the figures for each crown, the leaf distribution in an air volume of 10x10x1=100 m³ was calculated for every meter of crown height (see also Chapter 6 and Schmidt 1981, 1982).

Photo 5.1. Secondary forest, Mapane 1983. (Photo P. Schmidt)

When the crowns of the poisoned and dying trees collapsed, average height of the strata decreased, and the distribution of the leaf mass along the tree's height changed. Keeping in mind that in the untreated Phytomass Forest an over-sampling of tree phytomass had occurred, and in the lightly exploited Procter's Forest an under-sampling (see Chapter 6), and that the ecological conditions in these two stands are not the same, we nevertheless observe that (see Figure 5.5):
- A bell-shaped distribution as described by Rollet (1974) was found in Phytomass Forest and Procter's Forest, but the latter shows some irregularities along the height profile, having more strata. Noteworthy is the dense layer of palm leaves in the understorey.
- In both Phytomass Forest and Procter's Forest, emergent trees built an open canopy above 36 m. The density here will be very variable: from open space without any leaves to dense crowns of the emergent trees. This layer was denser in Phytomass Forest than in Procter's Forest, which could be the result of differences in growth conditions between the forests, of selective cutting in Procter's Forest, or of the sampling methods.
- In Phytomass Forest, the next layer, between 20 and 36 m, formed the densest layer in the canopy. In Procter's Forest this height interval was less dense and split into three layers: two more or less dense layers around 32-36 m and 20-28

m separated by a layer with few leaves. Perhaps there was an earlier exploitation of some trees whose crowns filled these layers. Below 20 m, there was not much leaf mass, though slightly more in Procter's Forest than in Phytomass Forest. Two factors could play a role here: the abundance of palm leaves in Phytomass Forest, intercepting light, and the stimulus given to regeneration and leaf production of trees in the understorey of Procter's Forest due to selective cutting.
- Fifteen years after selective cutting in Procter's Forest the forest floor was shaded.

Comparing the three forests in Mapane, with similar ecological conditions but quite different treatments (Procter's Forest: selective cutting, about 15 years before assessment; Akintosoela1 selective cutting and refinement about 15 and 7 years before assessment; Weyerhäuser: regrowth after nearly complete clear cut 13 years before assessment), we observe that (see Figure 5.5 and Schmidt 1981; 1982):
- Both Procter's Forest and Akintosoela1 had an upper layer of emergent trees. This layer did not form a closed canopy. In the former stand this layer stretched between 35 and 47 m. In Akintosoela1 the upper layer was lower, between 29 and 37 m, a consequence of the refinement, and probably consisting mainly of valuable trees. In Weyerhäuser, no such layer was found: the highest trees were predominantly secondary trees (such as *Cecropia* and *Pourouma*) and similar in height.
- In all three stands other leaf mass layers could be distinguished.
- In Akintosoela1 two dense layers occurred, at 20 to 25 m and at 14 to 18 m. The higher one corresponded with the closed canopy layer in Procter's Forest, the lower one with the top of the understorey in Procter's Forest. Below 12 m more leaves were present than in Procter's Forest, possible caused by extensive regrowth as more light was available after the refinement.
- In Weyerhäuser leaf mass was concentrated in three layers, one between 19 and 24 m, one between 8 and 12 m and one between 2 and 4 m.

5.2.4 Long-term changes in forest structure

In 2000-2001 forest structure was measured in the MAIN experiment, about two decades after logging and refinement (De Dijn 2001b, c). Measurements took place in one-hectare core plots:
- three logged and silviculturally treated plots with treatment code E23–SR18 (the plots that were individually numbered 15, 27 and 36 when the MAIN experiment was set up);
- three logged plots with treatment code E23-S0 (plots numbers 14, 26 and 38);
- two undisturbed control plots, one (number 41) in the MAIN experiment and one chosen in 2000 in an adjacent experiment, the Van Leeuwen transect (number 51).

The forest structure was assessed horizontally – parallel to the soil surface – in the low understorey, and vertically – straight up from soil surface into forest canopy – at nine point locations in each 1-ha plot (De Dijn 2001a, b). The horizontal measurements involved the inventory of vegetation structures along and beneath a rope tied at 1 m above the soil surface. Structures inventoried were the live stems and crowns or twigs of tree seedlings, palms, and climbers/lianas touching the rope or between the rope and the forest floor, as well as individual terrestrial and epiphytic herbs, ferns, moss clusters and

macro-fungi; small pieces of fallen (dead) wood were also noted. Vertical measurements involved counting the number of 1 m sections of a flagged rope (shot up by a catapult and hanging down from the canopy) that touched these same types of structures. The horizontal counts were regarded as measures of the abundance or density of structures in the lower understorey, the vertical counts as measures of the extent or density of structures along the vertical axis of the forest. Large fallen (dead) stems, branches and stumps (diameter > 10 cm) were counted in three 20 × 50 m subplots per ha.

In these horizontal and vertical inventories a total of 17 structure variables were recorded. To evaluate how much these structure variables contributed to the overall forest structure the data were analysed by a Non-Metric Multidimensional Scaling (NMS) procedure (De Dijn 2001a, b).

The results of this NMS analysis suggested that most of the variation in the Kabo forest structure data set was associated with the abundance of large palm crowns (mostly of boegroemaka, *Astrocaryum sciophilum*, one of the locally dominant palms at Kabo; see Raghoenandan 2001). This agrees with findings of Schulz (1960) who reported that *A. sciophilum* can form a closed layer below the tree canopy that impedes plant growth in the lower understorey (see also Section 5.3.3 and Figure 5.5).

In addition, the results of the NMS analysis suggested that forest disturbance is associated with much of the remaining variability in the Kabo data set, but not in a simple manner (De Dijn 2001a, b). Disturbances due to logging and refinements seemed to manifest itself at many point locations in the plots in the form of low forest with less extensive crowns and much old debris (dead wood, probably mainly originating from the high post-treatment mortality, see also Sections 4.4.3 and 4.5). Similar features were reported from recovering, secondary forest (De Graaf 1986; Jonkers 1987). Disturbance, however, also appeared to manifest itself as forest with an open lower understorey and extensive tree crowns overhead. This may be forest that has developed in gaps resulting from severe disturbance. The development of such forest in CMS-treated plots has been discussed by De Graaf (1986). Altogether the NMS analysis suggested that logged and logged and refined forest plots developed a more heterogeneous pattern in the forest structure, ranging from apparently undisturbed to severely disturbed patches. It is important to emphasize that even in the disturbed forest plots at Kabo there were many point locations where the forest was structurally similar to that of undisturbed plots.

The same data were further analyzed by ANOVA, using the vertical extent of palm crowns as a covariate (an inventory-based variable), in an attempt to assess the impact of large palms on the forest structure (De Dijn 2001a, b). The primary purpose of these analyses was to assess the significance of differences in forest structure between disturbed and undisturbed plots. No across-the-board significant differences between disturbed and undisturbed plots were detected, as was to be expected given the fact that the NMS analysis had already indicated a distinct overlap in structural features between the disturbed and undisturbed plots. However, significant differences were found between logged plots and logged and refined plots. The logged plots had significantly more liana stems and epiphytic mosses in the lower understorey, but less old, heavily decomposed tree stumps than the logged and refined plots. The abundance of old tree stumps in the

logged and refined plots is undoubtedly a legacy of the extensive poison-girdling of trees. Lower numbers of lianas in the refined forest may represent a persistent effect of liana cutting as part of the CMS treatment.

5.2.5 Roots

Since roots are situated belowground, it is difficult to investigate their spatial distribution in large patches of the tropical rainforest. In Proctor's Forest we washed away the soil in a patch of 10×10 m, till a depth of about 90 cm, using a fire hose. This revealed that:

- No individual root space exists in the soil and the roots of different trees intermingle (see photos 5.2, 5.3, 5.4, 5.5, 5.10). This can be seen for fine roots as well as for coarse roots (> 10 mm). Even inside the very crowded, shaving-brush-like root system of a *Oenocarpus bacaba* palm, fine and coarse roots of other trees could be found. Strangling other roots was a fairly common phenomenon (photo 5.10). Some parts of the washed-out plot seemed overcrowded by roots, while others were almost devoid of roots.
- At various places roots grew upwards (see photo 5.6). For instance, one root of about 2 cm thick had grown upwards for about 20 cm and had developed there various smaller horizontal branches. These were probably feeder roots growing along the gradient of increasing nutrients near the litter layer.
- Roots could extend over substantial distances: a couple of roots (about 8 cm in diameter) grew into the 10×10 m plot and left the plot on the other side (photo 5.4). One of those could be traced back to a tree 10 m south of the plot. At the north side of the plot it continued for at least 8 m without any visible reduction in diameter.
- It is tempting to say that fine roots stayed near the surface, whereas larger roots grew deeper. Often this seems to be the case. But the buttresses of the large *Sclerolobium micropetalum* dissolved just below the soil surface in thick (5 cm) roots spreading horizontally and many small roots growing downwards (photo 5.9).
- The variation in root system architecture was large. Nevertheless, most trees had developed a pen root. Root systems of palms varied too, with extremes like the shaving-brush-like system of *Oenocarpus bacaba* (photo 5.7) and the more haphazard system of the stemless *Astrocaryum paramaca* (photo 5.8).

In the context of our study the main question is, of course, how roots and root growth may be affected by treatments used in the CMS. Killing trees, as done during logging and refinement, will cause a die back of roots, reducing the uptake capacity but also reducing the competition for nutrients and water. But, as a result of the enhanced growth of the remaining trees and the regeneration of new trees, the uptake capacity will be restored. Nevertheless, leaching of nutrients from decomposing plant material may occur due to a treatment (see Chapter 6). Killing trees did not, or not noticeably, affect the anchoring capacity of the remaining trees.

Root growth can seriously be impeded by logging operations. Transportation of logs from the forest to the road landing is commonly carried out by means of heavy tractors or wheeled skidding machines, which can severely damage the soil structure. When logs

are skidded on the forest floor, the soil is moved aside by the logs and by the wheels of the skidder – this is called rut or track formation – and at the same time the subsoil is compacted by the weight of the skidder and its load. Compacted soils have a reduced water infiltration capacity and an increased resistance for root penetration. Both are adverse conditions for plant growth. These effects, although not irreversible, need a long time to recover.

Photo 5.2. Overview root systems in Procter's Forest, area 1×1 m, 0.1 m depth. (Photo P. Schmidt)

Photo 5.3. Overview root systems in Procter's Forest, area 2×3 m 0.1-0.2 m depth (Photo P. Schmidt)

Photo 5.4. Overview root systems in Procter's Forest, area 5×5 m, 0.4 -0.6 m depth (Photo K.E. Neering)

Photo 5.5. Root of *Eschweilera poiteaui* (Berg) Ndz. penetrates through the root system of *Sclerolobium micropetalum* (Ducke) (Photo P. Schmidt)

Photo 5.6. Root of *Sclerolobium micropetalum* (Ducke) grows upwards (Photo P. Schmidt)

Photo 5.7. Root system of *Oenocarpus bacaba* Mart. (Photo P. Schmidt)

Photo 5.8. Root system of *Astrocaryum paramaca* Mart. (Photo P. Schmidt)

Photo 5.9. Root system of *Sclerolobium micropetalum* (Ducke) (Photo P. Schmidt)

Long-term changes in the soil structure were studied in Procter's Forest by Zwetsloot (1982). Compaction was analysed by determining the bulk density in wheel ruts and between the (two) ruts of skid trails, as well as in undisturbed forest soils. Less than 2 % of the area was occupied by skid trails. In the trails the bulk density had increased significantly, even in trails with a low travelling intensity. Re-invasion by tree seedlings and young trees in and between the tracks occurred, but their growth was visibly hampered, due to the impacted subsoil. Only a few pioneer species, such as *Inga* spp. (tree), *Selaginella pedata* and *Adiantum latifolium* (herbs), regenerated well on disturbed soil near the ruts.

Photo 5.10. Roots strangling the pen root of *Eschweilera corrugata* (Poit.) Miers (Photo P. Schmidt)

Hendrison (1990) carried out soil-impact studies in the Mapane research forest, measuring bulk density in soil samples and using a penetrometer. A significant relationship was found between the degree of soil compaction and the travelling intensity of the tractor or wheeled skidder. Primary skid trails, which enclosed a logging compartment, were maximally compacted, because they were frequently used by the skidding machines, while branch trails showed far less compaction because of a lower travelling intensity.

Keeping in mind those soil disturbances and the long period needed to recover from that, as described above, from the beginning the CELOS Harvesting System aimed at minimizing the number and length of the skid trails along which logs are to be extracted from the forest.

Table 5.2. Bulk density (0-20 cm), non-capillary pore volume, root dry weight (0-20 cm), and dry weight of tree seedlings and herbs as percentage of the value outside the trail

	Forest outside trails	Shallow trail		Deep trail	
		Between tracks	In tracks	Between tracks	In tracks
Bulk density	100	100	105	113	112
Non-capillary pore volume	100	98	67	55	60
Root dry weight	100	96	94	39	52
Tree seedling dry weight	100	150	3	23	5
Herb dry weight	100	343	267	115	204

Source: Zwetsloot (1982).

5.2.6 Observations regarding the impact of the CMS on the forest structure

Based on the findings of the studies of 1977 – 1983 (in Kabo and Mapane, see above) and 2000-2001 (in Kabo, see De Dijn 2001a and above) into the forest structure, we observe the following:

- An important structural aspect of the forest is the gap, an "opening" in the canopy that allows direct sunlight to penetrate into the understorey. Gaps are seen as a result of a disturbance event, such as a tree bole or branch snapping, or an entire tree falling or being felled (Hartshorn 1990; Van der Meer et al. 1994). These events create openings in the canopy, resulting in changes in light distribution. Ecologically natural tree fall due to strong winds and tree felling are comparable, except that the stems are extracted after felling, which creates extra damage to the vegetation and soil. In any case, this is the starting point for natural forest regeneration and associated changes in forest structure. As gaps age and progressively disappear, gradual changes take place in the density of the understorey vegetation, in tree growth and, depending on the size of the gap, in forest composition (see e.g. Van der Meer & Bongers 1996). These slow changes, leading to the repair of the forest canopy, are initiated by the sudden change in forest structure and light regime at the time of new gap formation.

- Logging will cause a minimal change in diameter distribution, as only a few large diameter trees per hectare will be harvested and some smaller trees will be destroyed (see also Section 4.3).

- Felling reduces basal area and standing volume per hectare only slightly, depending on the number of trees and volume felled and/or damaged (see also Section 4.3).

- Extraction of logs results in soil compaction in the skid trails, which has a negative impact on regeneration and thus may indirectly affect the future forest structure.

- Logging followed by refinement can be considered as a shock effect on the forest structure. This combination severely disturbs the relatively stable conditions (long lasting conditions in a constant biotope) of the forest, for
  - ∞ Dying and breaking of branches cause changes in the vertical structure of the forest and an increase of dead wood on the forest floor (see also Chapter 6).
  - ∞ Collapsing stems create gaps and cause even more dead wood on the floor (see also Chapter 6).
  - ∞ Basal area and standing volume initially are considerably decreased, but (in Akintosoela1) increase rapidly again as the growth of remaining (commercial) trees continues and is stimulated.
  - ∞ Dying of leaves causes a change in canopy cover and foliage distribution, resulting in changes in light climate, humidity and temperature (the latter two not having been studied).

- The cutting of mature lianas in early stages of forest management seems to lead to the observed long-term (20+ years) reduction in liana abundance. A possible explanation is that the canopy openings created during refinement are generally too small to allow light-demanding liana regeneration to compete effectively with trees and palms. If so, it would mean that one can expect repeated CMS treatments to reduce the abundance of lianas. This would be in line with the silvicultural targets of the CMS, and would imply that the forest will become structurally different from untouched forest, at least as regards the density of lianas.

- The impact of the CMS on the overall forest structure lasts for at least two decades, as can be observed in the MAIN experiment: 20 years after treatments, which means disturbance of forest due to selective logging and refinement (at low intensities, including liana cutting), the forest still is structurally more heterogeneous but encompasses patches that are structurally similar to undisturbed forest. As time goes by, one would expect the impacted forest to recover and become structurally more similar to untouched forest, that is, if it is left undisturbed after initial logging and refinement. The latter, however, is not what is envisaged under the CMS, and one can expect that repeated logging and silvicultural treatments will stop the process whereby the impacted forest becomes structurally more similar to untouched forest. It remains uncertain whether the strict application of the CMS will succeed in creating a mature forest which is dominated by commercial tree species, but is otherwise, e.g. structurally, similar to untouched forest.

A note of caution regarding the last two points must be added: these generalizations are based on the investigations in the experimental plots at Mapane and Kabo, which are the first small and medium-scale CMS try-outs (see Chapters 2, 3 and 4). Furthermore, the plots studied in Kabo had been treated rather mildly (in terms of logging and silvicultural treatment intensity; see Jonkers 1987, De Graaf 1986, and Chapter 4). Our observations should thus, at least partly, be regarded as hypotheses that require further testing, e.g. during a rigorous, large-scale application of the CMS to be monitored during decades.

5.3 Plant diversity

Much attention was paid to the effects of interferences on the biodiversity and species conservation in tropical rain forests. Already during the conceptual phase of the CMS it was realised that refinement in particular might have a severe impact on plant diversity. Selective refinement of non-commercial tree species might eventually lead to their extinction. Within the framework of the CMS some aspects concerning the diversity of trees and other plant species were studied, first between 1978 and 1983, followed up with broader studies about two decades later.

5.3.1 Trees

The mesophytic tropical lowland rain forest harbours many tree species and generally no species predominate, although patches of forest exist in which certain species occur in high frequency. This is also the case in Suriname, where about 500 tree species have been identified and 100-150 species are usually found per hectare (Schulz 1960). Jonkers (1987) recorded about 75 species per ha for the Kabo region. By far not all these tree species have an economic value, but all have an ecological value. Applying the CSS it is attempted to diminish the number of non-commercial trees in favour of the commercial (timber) trees in a stand. Obviously, the group of commercial species, identified as such on the so-called CELOS list, is not stable over time. Due to advances in timber technology, reduced availability of some species and changing market conditions it increased in number: the 1978 CELOS-list, used by De Graaf (1986) and somewhat adapted by Jonkers (1987), comprised about 50 actual and potential commercial tree species, whereas the most recent list of the year 2000 (see CELOS 2002) comprises about 100 vernacular species names.

Photo 5.11 Lightly exploited forest, Procter's Forest Mapane, 1983. (Photo A.L.C. Schmidt)

Between 1980 and 1983 floristic tree inventories were made in six forest stands to estimate the consequences of interventions according to the CSS. Unfortunately, however, with an exception for the MAIN experiment (see below), no inventories were made within one year before and after a treatment in the same forest stand. Hence, these inventories allow no conclusion about eventual real disappearances of species due to treatments. Table 5.3 presents the floristic composition at family level and the number of species per family, demonstrating the impressive species richness of the Suriname tropical forest. The dominant families in Phytomass Forest and Procter's Forest (i.e. the reference forests) are Burseraceae, Dichapetalaceae, Euphorbiaceae, Lecythidaceae, Leguminosae, Sapotaceae and Violaceae.

Differences between the two forest stands in the Kabo region (Phytomass Forest and MAIN 21) are probably due to soil conditions, as a light harvest will hardly affect the species composition of trees > 5 cm dbh within three years. Noteworthy is the large number of Apocynaceae and Vochysiaceae in MAIN 21. In the Mapane region the treatments seem to have an effect: in Akintosoela1, six years after refinement (see Table 5.1) the number of individuals of Burseraceae, Lauraceae, Meliaceae and Sapotaceae had increased (Table 5.3). These families all contain a high number of commercial species. On the other hand the number of species and individuals of the Moraceae (such as *Cecropia* and *Pourouma*

spp.), Rubiaceae, Sapindaceae, Solanaceae (*Solanum* spp.) and Violaceae had increased too, indicating some secondary succession as a result of refinement. The increase of *Inga* spp. (Leguminosae) emphasizes this development. However, it is not fully sure that these differences are solely due to refinement; local variability in floristic composition may have played a role too. Dekker & De Graaf (2003) found 20 years after harvest and 19 years after refinement in the MAIN experiment a similar development: regeneration of both pioneer and climax species is stimulated by treatments but the ratio of climax to pioneer species seems to be acceptable in the low impact interferences as applied in the CMS (refinement). In Weyerhäuser the situation is different. The original forest was largely destroyed. Trees > 27 cm dbh were removed and the crowns of the felled trees were left on site. Thirteen years after the exploitation the resulting secondary forest was still poor in commercial trees and the vegetation was heavily infested with lianas.

Table 5.3. Floristic composition of trees > 5 cm dbh, of six differently treated (see Table 5.1) forest stands. Data are given as number of species (sp.) and number of individuals (ind.). Note different sizes of inventory areas and different units.

Region	Kabo				Mapane							
Forest stand	Phy Fo		MAIN21[1]		Pro Fo		Ma Br[2]		Akin[2]		Weye	
Year of inventory	1979		1981		1980		1981		1981		1981	
area	4*0.25 ha		1*0.25 ha		4*0.25 ha		1*0.25 ha		4*0.25 ha		1*0.25 ha	
Data	n/ha		n/0.25ha		n/ha		n/0.25ha		n/ha		n/0.25ha	
	sp.	ind.	sp.	ind.	sp.	ind.	sp.	ind.	sp.	ind.	sp.	ind.
Anacardiaceae	1	2	1	1	1	6	1	4	1	6	1	22
Annonaceae	3	24	1	1	3	38	3	5	4	28	1	3
Apocynaceae	6	32	3	23	3	35	1	1	4	40	2	5
Araliaceae	1	2										
Bignoniaceae	2	11	1	6	2	10	1	2	2	18	1	4
Bixaceae					1	6	1	1	1	8		
Bombacaceae	1	10	1	4	1	2			1	2		
Boraginaceae	3	6	1	2	2	26	1	11	2	45	1	22
Burseraceae	3	35	3	15	9	140	5	41	7	154	4	8
Caricaceae			1	1					1	5	1	1
Caryocaraceae					1	1						
Celastraceae	1	6	1	2	1	1	1	1			1	4
Combretaceae			1	1	1	1			1	1		
Dichapetalaceae	1	75	1	12	1	4			1	4		
Ebenaceae					2	12			2	30	1	2
Elaeocarpaceae	1	4			1	7			1	9		
Euphorbiaceae	5	47	2	8	3	37	3	6	5	28	6	17
Flacourtiaceae	2	10	1	6	5	10	1	1	3	11	2	11
Guttiferae	2	3			2	11			4	19		
Humiriaceae	1	3							1	1	2	1

Table 5.3. (continued)

Region	Kabo				Mapane							
Forest stand	Phy Fo		MAIN21[1]		Pro Fo		Ma Br[2]		Akin[2]		Weye	
Year of inventory	1979		1981		1980		1981		1981		1981	
area	4*0.25 ha		1*0.25 ha		4*0.25 ha		1*0.25 ha		4*0.25 ha		1*0.25 ha	
Data	n/ha		n/0.25ha		n/ha		n/0.25ha		n/ha		n/0.25ha	
	sp.	ind.	sp.	ind.	sp.	ind.	sp.	ind.	sp.	ind.	sp.	ind.
Icacinaceae	3	45	2	22	2	16	1	3	2	12	1	4
Lauraceae	7	22	2	3	7	26	3	6	7	38	4	7
Lecythidaceae	7	91	6	22	6	150	4	12	6	72	6	31
Leguminosae[3]	18	88	9	23	16	82	8	72	12	275	8	75
Linaceae					1	1						
Loganiaceae	1	2	1	1	1	6			1	3		
Melastomataceae	2	5	1	1	2	4			2	12	1	4
Meliaceae	2	30	1	4	4	102	4	31	6	138	2	4
Monimiaceae	3	7			1	1	1	3	1	1		
Moraceae[4]	4	15	1	2	4	23	1	5	7	125	5	119
Myristicaceae	2	19	2	6	2	45	2	5	2	28	3	10
Myrtaceae	3	6			2	45			2	28	1	1
Nyctaginaceae					1	18			2	22	1	1
Olacaceae			1	4					1	3	1	1
Polygonaceae	1	2										
Rosaceae	5	32	2	13	3	28			5	10		
Rubiaceae	2	3	2	2	2	4	1	1	4	12		
Sapindaceae	1	6	2	3					3	20	1	1
Sapotaceae	8	48	6	9	3	29			6	37	1	2
Simaroubaceae	1	1	1	1	1	1			1	1		
Solanaceae							1	1	1	41		
Sterculiaceae	1	8	1	3	1	7	1	12	1	13	1	12
Tiliaceae	1	1	1	1	1	2			2	11	1	2
Ulmaceae	2	4			1	2			1	5	1	1
Violaceae	1	12	3	9	2	68	1	19	2	96	2	9
Vochysiaceae	3	26	2	41	1	4	1	1	2	5	1	1
non det.	n.a.	2							n.a.	3		
TOTAL	111	745	64	252	103	1011	47	244	120	1420	64	385

1: Inventory after harvest but before refinement. 2: Large commercial trees killed during refinement. 3: *Inga* spp.: 13, 6, 41, 57, 230 and 47 individuals, respectively. 4: *Pouruma* and *Cecropia* spp combined.: 8, 0, 7, 4, 99 and 103 individuals, respectively.

5.3.2 Spatial and temporal variation in tree species composition

Maintaining a high level of biodiversity is important if one wants to manage rain forests for sustained timber production (see Chapter 3). Hence, spatial variation and temporal changes in biodiversity after logging and silvicultural treatment were studied in the MAIN experiment. A total of 259 tree species were recorded before the silvicultural treatments were conducted (Jonkers et al. 2005). Many of those occurred in frequencies of less than one individual per ha, and one may therefore expect that after a few decades, some species may have disappeared. Indeed, after 18 years four species were no longer present in the plots that had been logged but had not received silvicultural treatment (nine ha). As one might also expect, species losses in the silviculturally treated plots were higher: both refinements lost 15 species in 9 ha. But these vanished species were replaced by larger numbers of new tree species; 19 to 24 per 9 ha. Apparently, both logging and refinement led to a net increase in the number of tree species within this 18-year period, and not to a reduction as one might have expected.

Before refinement, spatial variation in species composition within the MAIN experiment was rather low for a tropical rain forest, but there was nevertheless a clear north-south gradient (Jonkers 1987). Correspondence analyses, reflecting the situation before, immediately after and 18 years after silvicultural treatment, also showed clear north-south gradients but no evidence of a pronounced impact of logging intensity or refinement (Jonkers et al. 2005).

The impact of silvicultural treatment on species composition was nevertheless substantial. This is illustrated in Table 5.4 which shows temporal changes in stocking for a number of common species. The species on the 1978 commercial species list obviously benefited from silvicultural treatment and also from logging, with *Dicorynia guianensis* as a notable exception. *Dicorynia guianensis* densities dropped slightly throughout the experiment and the reason for this decline remains unclear.

Table 5.4. Impact of silvicultural treatment on densities of common species and species categories.

Species	Number of trees > 15 cm dbh per hectare								
	No refinement			Refinement SR18			Refinement SR14		
	1981–1982	1982–1983	1999–2000	1981–1982	1982–1983	1999–2000	1981–1982	1982–1983	1999–2000
Commercial species (1978 list)									
Qualea rosea	19.6	18.7	23.1	20.4	19.3	31.8	20.7	20.2	35.3
Dicorynia guianensis	21.7	20.9	19.6	25.6	24.1	22.2	20.8	20.1	18.7
Virola michelli	6.3	6.0	7.4	7.3	6.9	7.9	8.0	7.0	9.4
Jacaranda copaia	3.9	3.4	4.9	4.1	3.6	8.1	4.4	4.1	8.4
Tetragastris altissima	6.2	6.0	7.2	8.0	7.7	9.2	7.1	7.1	8.4
Manilkara bidentata	11.3	11.2	11.0	8.8	8.4	9.0	8.0	7.4	7.2
Others	50.0	47.6	55.3	51.5	49.0	53.7	54.9	50.4	54.2
Subtotal	119.0	113.8	128.5	125.7	119.0	141.9	123.9	117.3	141.6

Table 5.4. (continued)

Species	Number of trees > 15 cm dbh per hectare								
	No refinement			Refinement SR18			Refinement SR14		
	1981-1982	1982-1983	1999-2000	1981-1982	1982-1983	1999-2000	1981-1982	1982-1983	1999-2000
Species, added to the CELOS commercial species list in 2000									
Lecythis corrugata	12.1	12.1	12.7	10.9	10.2	14.4	12.9	8.4	13.9
Protium polybotryum	2.3	2.3	2.4	1.7	1.7	1.6	4.3	3.7	4.7
Couepia caryophylloides	6.0	6.0	6.1	4.3	3.4	4.9	6.3	3.8	5.7
Others	41.8	41.8	40.0	43.1	37.8	39.2	44.9	33.8	36.6
Subtotal	62.2	62.2	61.2	60.0	53.1	60.1	68.4	49.7	60.9
Secondary species									
Inga spp.	7.4	7.0	12.8	8.1	7.1	28.4	8.1	4.6	39.3
Pourouma spp.	9.5	8.3	13.8	2.8	2.3	9.0	7.5	3.5	22.0
Palicourea guianensis	1.0	1.0	14.0	2.0	2.0	23.0	1.7	1.7	15.3
Cecropia sciadophylla	1.7	1.7	2.7	3.5	1.5	2.5	1.0	1.0	11.0
Cecropia peltata	2.0	2.0	4.0	1.0	1.0	1.0	7.5	4.0	8.5
Others	9.7	9.5	14.3	7.8	7.3	12.5	9.3	8.4	13.0
Subtotal	31.3	29.5	61.6	25.2	21.2	76.4	35.1	23.2	109.1
Non-commercial primary species									
Dendrobangia boliviana	20.9	20.8	17.3	22.0	18.7	16.4	18.3	11.4	9.3
Sclerolobium melinonii	6.0	6.0	6.8	7.7	3.0	3.5	6.6	3.0	7.1
Mabea piriri	1.5	1.5	2.5	3.0	3.0	5.0	2.0	2.0	7.0
Bixa orellana	4.1	3.6	3.9	2.7	2.3	4.8	4.4	3.4	6.0
Chaetocarpus schomburgkianus	7.7	7.6	5.7	8.9	6.9	5.6	8.0	5.3	5.0
Swartzia benthamiana	6.1	6.1	5.4	5.7	5.0	4.8	5.8	3.8	4.0
Others	58.6	58.2	58.7	58.2	55.2	64.3	63.9	53.9	55.5
Subtotal	104.9	103.8	100.3	108.2	94.1	104.0	109.0	82.9	93.9
All species	**319.4**	**311.3**	**352.6**	**320.1**	**288.4**	**383.2**	**338.4**	**274.2**	**406.5**

Source: Jonkers et al. (2005)

During refinement most species not included in the 1978-CELOS-list of commercial species were reduced in numbers of trees, as one might expect. Such reductions were quite substantial for canopy species such as *Sclerolobium melinonii*, but modest for most other species. Species which are characteristically small in stature, such as *Palicourea guianensis* and *Mabea piriri*, were not at all affected during the refinements. In the years after refinement, most non-commercial species increased substantially in numbers within the silviculturally treated plots, often to more than 90 % of the pre-refinement density, while species densities generally remained fairly stable in the plots where no refinement had been applied. The densities of secondary species, however, increased sharply in response to both logging and silvicultural treatment and especially in plots where the highest harvest and refinement intensities had been combined.

A different approach to study the effects of treatments on species composition was used by Ter Steege et al. (2003). They compared the results of three different tree inventories in 1954, 1981 and 1997 in the same forest area in Mapane. Comparison was made between 15 treated and untreated plots. Treatments consisted of highly selective logging (1960s, again 1980s) in combination with (in the 1980s) no poison-girdling, uniform poison-girdling (to a basal area of 12.5 m².ha⁻¹) or selective poison-girdling.

The repeated inventories were carried out along 11 lines that were recovered in block 840 at Mapane. In total 6130 trees of 182 species were scored. In 1954, the ten most abundant tree taxa in the forest comprised 39 % of all trees > 25 cm dbh. The general composition in 1981, after some rounds of selective cuttings in the years in between, differed only little from the one in 1954. The ten most abundant species together comprised 50 % of all trees > 25 cm dbh. Overall composition in 1997 again was almost similar to the previous censuses, except that now *Cecropia obtusa* and *C. sciadophylla* were amongst the ten most abundant species, while Inga moved from position eight (1954) to position four (1981) and then to position two (1997)! Two *Pourouma* spp. also increased substantially and ranked 11 and 15 in 1997.

Pioneer species, such as *Cecropia* and *Pourouma* spp., not only increased in numbers but also in the frequency with which they occurred in the plots. This resulted from new establishment from the seed bank (cf. Holthuijzen & Boerboom 1982) as well as from input of seeds from outside. Overall density of large trees was not significantly different between treatments due to high variation in the census data. Density of smaller trees increased significantly from 1981 to 1997, as a result of changes in the light conditions in the forest following the logging and poison-girdling activities. In terms of diversity slight but significant differences over time were found. In 1954 Fisher's α (average of the lines in the inventory block) was 33.7. In 1981 the average for 5 one-ha plots was 27.3 for non-treated plots and 25.7 for the treated plots. In 1997 these figures were 28.1, respectively 20.3 (Ter Steege et al. 2003). There were no differences in diversity between the treatments in 1981, but they differed significantly in 1997.

Ter Steege et al. (2003) also found that a total of 19 species among the large trees and 18 species among the small trees disappeared. In Mapane, among the lost species of large trees, only two were commercial species (*Virola surinamensis*, *Vochysia guianensis*). For all 15 plots an average of twelve species of large trees disappeared per plot, whereas on average eight newly appeared, resulting in a net loss of four. Of the smaller trees an average of eight species were lost, but 12 newly appeared, thus there was a net gain of four species.

5.3.3 Palms

Palms are of interest to the silviculturist, among others because they actively compete with tree species for light, above- and below ground space, water and nutrients. Palms are abundant in many Neotropical rainforests. For instance, in the MAIN experiment at Kabo, more than 750 individuals of palms of at least 1.5 m in height (of the highest leaf) were counted per hectare (Jonkers 1987). Most of them belonged to boegroemaka (*Astrocaryum sciophilum*), which was almost confined to the northern part of the

experimental area, and paramaka (*Astrocaryum paramacca*), which was found mainly in the southern part. Both are understorey species which grow very slowly in the shade. The configuration of the leaves makes both palms very effective in intercepting falling litter, and they are likely to derive most nutrients from decaying debris accumulated at the crown base and around their stem foot (De Granville 1977).

Boegroemaka has large leaves and a short stem, is often gregarious and tends to form a dense canopy at 5 - 12 m height. In Phytomass Forest, the dry weight of its leaves was estimated at 8 t.ha^{-1}; that amounts to about half the total leaf phytomass there (see Chapter 6). Where the species was present in the MAIN experiment, the number of mature boegroemaka individuals often exceeded 1000 per hectare. The boundary of the boegroemaka population was remarkably sharp, a phenomenon which was also observed in French Guiana (Charles-Dominique et al. 2003). Evidence reported by Jonkers (1987) indicates that boegroemaka effectively suppresses the regeneration of trees, other palms and lianas, not only because little light penetrates through the palm canopy, but also because the dense boegroemaka crowns intercept falling fruits. Jonkers (1987) therefore suggested that reducing boegroemaka densities should be considered part of the CSS, but the evidence presented in Chapter 4 does not indicate the need for such an intervention.

Paramaka is a stemless palm with large leaves which may reach heights of about 3 m. Although there were up to 435 mature individuals per one-hectare plot in the MAIN experiment, this palm seldom dominated the understorey and seems less of a problem than boegroemaka (Jonkers 1987). Still, it may suppress regeneration of tree species locally. Paramaka was notably scarce in forest where boegroemaka was present. Paramaka is the dominant palm species in the Mapane region, but palms are considerably less frequent there than in Kabo.
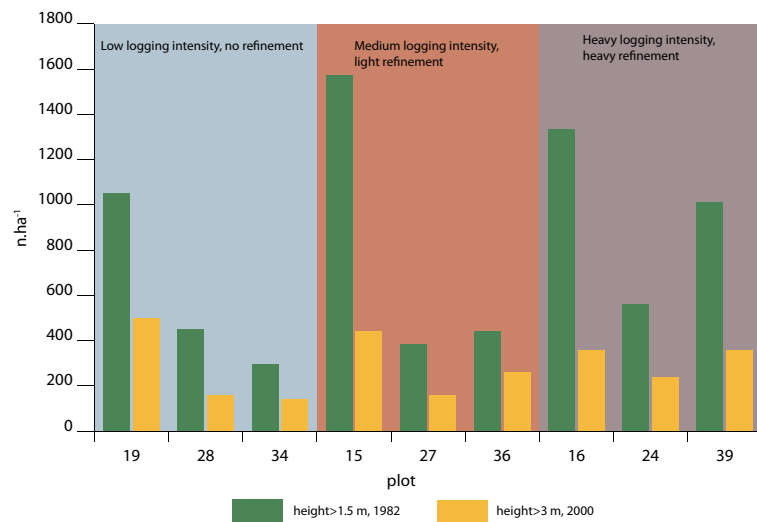

Figure 5.6.   Palm densities in nine plots of the MAIN experiment. Treatments applied: plots 19, 28 and 34: low logging intensity, no refinement; plots 15, 27 and 36: medium logging intensity, light refinement; plots 16, 24 and 39: high logging intensity, heavy refinement. Adapted from Jonkers (1987) and Dekker & De Graaf (2003).

In 2000, palms were enumerated once again in part of the MAIN experiment (Dekker & De Graaf 2003). Only individuals exceeding 3 m in height were tallied, which makes a direct comparison with the older data difficult. However, there was an obvious correlation between palm densities recorded in 1982 and 2000 and there was no clear impact of the treatments applied (see Figure 5.6).

5.3.4 Lianas

Lianas are a characteristic component of the tropical rain forest. To reduce felling damage and competition after felling and refinement, cutting of thick lianas is included in the CSS prescription. In 2000, 22 years after logging and 19 years after refinement, Dekker & De Graaf (2003) assessed liana density in the layer between 3 and 10 m height in the MAIN experiment. No unambiguous impact of treatment was found, possibly due to an interaction with the presence of palms. De Dijn (2001a, b; see also Section 5.2.4), however, detected significant differences between logged plots and logged and refined plots. The former had significantly more liana stems than the latter. Lower numbers of lianas in the refined forest may represent a persistent effect of liana cutting as part of the CMS treatment.

Photo 5.12.   A giant liana (*Bauhinia* sp.) named "sekrepatoe trappoe"(turtle stairs) in Suriname. (Photo Ivan Torres)

5.3.5 Observations regarding the impact of the CMS on the floristic composition

A high diversity in plant species is inherent to tropical rain forest. To preserve such a high diversity, not only in conservation areas but also in production forests under the CMS, is necessary, because many of the relations and cycles in CMS-forests should continue to function to guarantee a sustainable production and permanent forest cover. Floristic composition is important here, not only because young commercial trees compose the future production, but also because tree species that have no commercial value at the moment may be marketable in the future, and because plant functions in many cycles and interactions are not yet completely known.

The CMS comprises two treatments, selective logging and poison-girdling. Both can change the species composition. During logging a small number of trees per hectare are felled and extracted, killing and damaging some other trees and plants in the process. During poison-girdling lianas are cut (not poisoned) and the non-commercial trees above a certain diameter are killed by poison-girdling. The number of trees killed during this action is much larger than during logging. The cutting of lianas may have a negative effect on the number of liana species.

Selective logging in Kabo did not have a clear impact on tree diversity at family level (Table 5.3). Ter Steege et al. (2003) found comparable results for Mapane. Considering that the intervention implies that only a small number of large trees at the end of their life cycle are killed and removed and some smaller ones are damaged and killed, this does not come as a surprise. Apparently, the species composition remained largely determined by factors other than logging and an impact of the intervention on diversity at family level was not apparent.

On the other hand, selective logging and heavy refinement in Mapane (Table 5.3, compare Procter's Forest with Mapanebrug and specially Akintosoela1), resulted in an increase in the density of Leguminosae (mainly *Inga* spp.), Moraceae (mainly *Cecropia* spp. and *Pourouma* spp.) and Solanaceae seven years after treatment. The genera mentioned comprise pioneer species. Noteworthy is the decrease in density of Lecythidaceae, with mainly non-commercial species. The refinement intervention in Akintosoela1 was heavier than the ones in the MAIN experiment, where Jonkers et al. (2005), using correspondence analyses to compare the situation before, immediately after and 18 years after poison-girdling, found no evidence of a pronounced impact of logging intensity or refinement. Further analyses showed, however, that the species on the 1978-list of commercial species obviously benefited from silvicultural treatment and also from logging. Ter Steege et al. (2003), for the Mapane area, reported an increase in pioneer species due to refinement, about 15 years after treatment, comparable to the shift in species composition in Akintosoela1.

Photo 5.13.   Stereophoto of a forest in Mapane 7 years after the second refinement. (Photo N.R. De Graaf)

Both Jonkers et al. (2005) and Ter Steege et al. (2003) found a small loss of species and a small gain of species due to refinement, both mainly among the rare species. This may result in a net gain.

One may therefore conclude that the refinements ultimately led to a moderate shift in species composition, that is, to slightly more commercial trees, to slightly less non-commercial primary trees and to a proliferation of secondary species. Moreover, in our experiment poison-girdling is a more severe intervention than selective logging, and it provides better possibilities for pioneer species to invade the forest than under natural circumstances. Hence this intervention should be planned with utmost care. It should be as heavy as needed, just enough to stimulate the growth of the remaining commercial trees, and as light as possible, to minimize the stimulation of pioneer species to invade. One can envisage here a variable treatment in patches, more heavy where commercial trees of the right dimension are available and less heavy or even no treatment at all where no such commercials are present.

5.4   Discussion and conclusions

It is quite obvious from the above that the structure and the species composition of the tropical rainforest will change due to treatments involved in the CMS. It is also evident that not all aspects have been studied and that not all the studied aspects have been studied as thoroughly as they should have been. Moreover, it should be noted that adequate baseline data were not always available for Mapane as well as for Kabo. Zero-treatment control plots were available for Kabo only, and to a limited extent. Choices which had to be made regarding funding and personnel played a role here. Furthermore, determining the impact of human activities on biodiversity in tropical forests is a very complex task due to the interaction of numerous factors, including micro- and macro-scale variation in topography and associated variables, and spatial and temporal variation in the intensity of the activities.

Most data so far collected about the impact of CMS interferences on structure and species composition/biodiversity are related to one single harvest followed by one refinement. It looks as if one (light) harvest plus one (light) refinement do not have a severe negative effect on structure and species diversity. However what will happen after a second refinement and eventually a second harvest? In Chapter 4 it is shown that timber volume growth (commercial species) in forest under the CMS may be enough for a second harvest 20 - 25 years after the first one, even if the total (i.e. commercial and non-commercial) timber volume does not yet reach the former level. Will the results found so far and assumptions made still stand after that second harvest?

Two harvests in relatively rich forest in Mapane have not led to large changes in species composition and tree diversity (Ter Steege et al. 2003). In logged forests species richness and diversity was higher than in non-logged forests, but the changes were small, if the natural variation in the forest is taken into account. Too heavy or further treatment may increase the abundance of pioneer species, such as *Cecropia* spp. and *Pourouma* spp., as

was observed in Mapane. Rare tree species and lianas may become extinct as a result of refinements when too often these species are eliminated. It is clear that forest changes are slow.

A light harvest followed by a light refinement increases patchiness. However, a variation in phases in space (size and distribution) and time (age) should be guaranteed to maintain biodiversity (Scherzinger 1999). Sufficient vertical and horizontal structural variation, including large parts of undisturbed forest, should be present in the forest at all times.

References

Charles-Dominique, P., Chave, J., Dubois, M.A., De Granville, J.J., Riéra, B. & Vezzoli, V. 2003. Colonization front of the understorey palm Astrocaryum sciophilum in a pristine rain forest of French Guiana. Global Ecology and Biogeography 12, 237-248.

De Dijn, B.P.E. 2001a. Habitat diversity assessment at Tonka. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 12-32.

De Dijn, B.P.E. 2001b. Sampling and data analysis. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 10-12.

De Dijn, B.P.E. 2001c. Tonka. the study site at Kabo, Suriname. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 3-9.

De Graaf, N.R. 1986. A silvicultural system for natural of tropical rain forest in Suriname. Ecology and management of tropical rain forest in Suriname, I. Thesis Landbouwhogeschool Wageningen, The Netherlands. 250 pp.

De Granville, J.J. 1977. Notes biologiques sur quelques palmiers guyanais. Cahiers ORSTOM, Série Biologique 12, 347-353.

Dekker, M. & De Graaf, N.R. 2003. Pioneer and climax tree regeneration following selective logging with silviculture in Suriname. Forest ecology and management 172, 183-190.

Hartshorn, G.S. 1990. An Overview of Neotropical Forest Dynamics. In: Gentry, A. (ed.). Four Neotropical Rainforests. Yale University Press, pp. 585-599.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Thesis Landbouwhogeschool, Wageningen, The Netherlands. 204 pp.

Holthuyzen, A.M.A. & Boerboom, J.H.A. 1982. The Cecropia seedbank in the Suriname lowland rainforest. Biotropica 14, 62-68.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in a tropical rain forest in Suriname. Thesis Landbouwhogeschool, Wageningen, The Netherlands. 172 pp.

Jonkers, W.B.J., Tjon, K. & Wirjosentono, J. 2005. Long-term changes in selectively logged and silviculturally treated tropical rain forest in Suriname: analysis of the 1978-2000 data of Experiment 78/5. Internal report. CELOS, Paramaribo, Suriname and Wageningen University, Wageningen, The Netherlands.

Odum, H.T., Copeland, B.J. & Brown, R.Z. 1963. Direct and optical assay of leaf mass of lower montane rain forest of Puerto Rico. Proceedings National Academy of Sciences 49, 429-434.

Rahgoenandan, U.P. 2001. Plant diversity assessment at Tonka. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 32-50.

Rollet, B. 1974. L'architecture des forêts denses humides sempervirentes de plaine. CTFT, Nogent-sur-Marne, France.

Rollet, B. 1978. Organization. In: UNESCO, Tropical forest ecosystems. (Natural resources research XIV). United Nations Educational, Scientific and Cultural Organization, Paris, France.

Scherzinger, W. 1999. Importance of Vertical Stratification and Horizontal Patchiness Concerning Species-Diversity in Managed Forests - A Comparison. NINA-Reports. Vol. 12 Special Issue No.2, 83-84.

Schmidt, P. 1981. Productie ecologie. In: CELOS kwartaalverslag 59 (1981-III). CELOS, Paramaribo, Suriname, pp. 11-16.

Schmidt, P. 1982. Production ecology. In: Annual report, Project no. LH/UvS 01 Human interference in the tropical rainforest ecosystem. CELOS, Paramaribo, Suriname, pp. 30-43.

Schulz, J.P. 1960. Ecological studies on rain forest in Northern Suriname. (The vegetation of Suriname, II). Van Eedenfonds, Amsterdam, The Netherlands. 267 pp.

Ter Steege, H. Laumans, B., Laumans-Bus, D., Zondervan, G. & Bongers, F. 2003. Long-term effect of timber harvesting in north Suriname. In: Ter Steege, H. (ed.). Long-term changes in tropical tree diversity: Studies form the Guiana Shield, Africa, Borneo and Melanesia. Tropenbos series 22. Tropenbos International, Wageningen, the Netherlands, pp. 79-94.

Van der Meer, P.J. & Bongers, F. 1996. Formation and closure of canopy gaps in the rain forest at Nouragues, French Guiana. Vegetatio 126, 167-179.

Van der Meer, P.J., Bongers, F., Chatrou, I. & Riera, B. 1994. Defining canopy gaps in a tropical rain forest: effects on gap size and turnover time. Acta Oecologica 15, 701-714.

Voordouw, J.J., 1985. Vertical distribution of light intensity in tropical rainforest in Suriname with relation to silvicultural treatment. MSc Thesis VPO-LH Wageningen, The Netherlands and CELOS, Paramaribo, Suriname.

Zwetsloot, R. 1982. Skidtrails, een inleidend onderzoek, Internal report, CELOS, Paramaribo, Suriname. 65 pp.

6 Impacts on biomass, nutrients and water

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6.1 Introduction

Tropical lowland rain forest growing on deeply weathered soils of low fertility, as the mesophytic forest in Suriname, is characterised by a huge standing phytomass. The nutrient capital is mainly stored in the phytomass, nitrogen quite often being an exception (Golley et al. 1975). High annual rainfall, tropical temperatures, a high leaf production, high litterfall and rapid decomposition of the litter at the forest floor, all contribute to a relatively quick cycling of water and nutrients. The dense mat of roots, generally in symbiosis with mycorrhiza fungi growing in the litter layer, recaptures much of the nutrients and thus reduces their loss from the system by leaching.

Such semi-closed cycling systems are considered characteristic for tropical lowland rainforests and it may be expected that they are sensitive to management interferences in the forest such as inherent to the CMS. In order to assess this quantitatively a number of key processes were studied in forests stands subjected to different management interventions and in undisturbed forest (see Table 5.1). We also provide here an overview of the amounts and fluxes of phytomass and nutrients and the flux of water in forest stands treated according to the CMS. In addition, we discuss the results of a computer simulation for the Kabo forest, modelling the input and output of phytomass, nutrients and water.

6.2 Phytomass and nutrients

6.2.1 Methods

In four of the seven forests mentioned in Table 5.1 phytomass was measured. The undisturbed Phytomass Forest in Kabo and the lightly exploited Procter's Forest in Mapane (no unexploited forest is available there) were taken as the controls; the lightly

exploited and refined stand Akintosoela1 and the heavily exploited stand Weyerhäuser (both in Mapane) as treated forests.

In a variable number of 10×10 m plots, the total amounts of phytomass and nutrients were determined by harvesting all above ground phytomass. Fresh and dry weights (subsamples dried at 70 ^{0}C for 24 hours) and nutrient concentrations of (samples of) all compartments (leaves, branches, stems) of all individual trees and palms rooting in the plot were measured.

The following parameters were measured on each individual tree (including palms): total tree height, stem height (height till the first major branch), diameter at reference height (DBH or above buttresses), crown length and crown width.

Tree phytomass in each stand was estimated based on relations between stem diameter and dry weight totals of leaves, branches and stems (see below). Most other compartments, such as fine (leaves, flowers, fruits and twigs) and coarse litter (wood > 2 cm diameter), lianas, small trees of < 1 cm dbh, and herbs, were bulked, sampled and analysed for mass and nutrients.

Where relevant, the results based on harvest measurements were compared to those based on regression analysis.

Roots were sampled as bulk in a 50×50×50 cm monolith in the middle of the plot or in a randomly chosen locality just outside the plot. The total soil volume studied in each of the four forest stands did not exceed 3.5 m^2 surface area against 1500 m^2 for the assessment of the aboveground phytomass. To improve the root mass estimates based on these small pits, in one large 0.9 m deep pit of 10×10 m in Procter's Forest, all root phytomass > 1 cm diameter was collected, traced to individual trees, and analysed, while smaller roots were bulked and analysed. Roots of all trees in the pit were pooled to establish a relation between dbh and root dry weight. Regressions found here were extrapolated to the other stands.

Amounts of phytomass and concentrations and amounts of nutrients were calculated per compartment, per tree and per plot. Tree phytomass was estimated on basis of the relations between the diameter at reference height of individual stems and the dry weights of the compartments (leaves, branches stem) of these trees. For tree leaves, branches and stems, the best fit, with very high correlation coefficients (see Table 6.1), was found with the function:

$$W = k * d^{2b} \qquad\qquad (Eq. 6.1)$$
in which $k = 10a * EXP (0.5*S^2 ln^2 10)$.
For roots the best fit was:
$$W = c + e.d^2 \qquad\qquad (Eq. 6.2)$$

In both formulas W = dry weight in kg, d = dbh in mm, a, b, c, e, S and k are constants (see Table 6.1). Total tree dry weight (leaves, branches, stems, roots) per stand was recalculated using these correlations and the inventory data from the forest stands.

Table 6.1. Correlations between dry weight of tree parts and stem diameter for four differently treated (see Table 5.1) forest stands. For explanation of formulas see text.

	Phytomass Forest	Procter's Forest	Akintosoela1	Weyerhäuser
Leaves: formula used $W = k * d^{2b}$ with $k = 10a * EXP(0.5*S^2 \ln^2 10)$.				
N	177	499	476	117
a	-3.764	-3.759	-3.680	-2.828
b	0.998	0.964	0.959	0.681
S2	0.087251	0.177532	0.251879	0.219533
R	0.956	0.839	0.778	0.744
Branches: formula used $W = k * d^{2b}$ with $k = 10a * EXP(0.5*S^2 \ln^2 10)$.				
N	133	285	432	113
a	-4.852	-4.338	-4.076	-3.580
b	1.418	1.280	1.242	1.051
S2	0.138294	0.169339	0.196403	0.254048
R	0.966	0.917	0.88	0.846
Stems: formula used $W = k * d^{2b}$ with $k = 10a * EXP(0.5*S^2 \ln^2 10)$.				
N	177	497	476	117
a	-3.485	-3.615	-3.797	-3.261
b	1.257	1.258	1.272	1.125
S2	0.042209	0.053816	0.073722	0.076163
R	0.986	0.964	0.950	0.953
Roots: formula used $\log W = c + e.d^2$				
N		22		
c		-5.944		
e		0.0012		
R		0.999		

In each stand plots were selected randomly. Due to the small number of plots, the basal area measured in all harvested plots in a stand did not compare well with the basal area found after inventories of larger areas. In the Phytomass Forest a basal area of 42.8 m².ha⁻¹ was harvested, whereas in a forest inventory of 5 ha (in 1981) a basal area of 30.5 m².ha⁻¹ was found. For the other stands values were: Procter's Forest (31.6 and again 31.6 m².ha⁻¹ on five hectare), Akintosoela (23.8 and 19.2 m².ha⁻¹ on one hectare) and Weyerhäuser (33.2 and 26.9 m².ha⁻¹ on one hectare). These differences explain why the tree phytomass data (stems, branches, leaves and roots) differ so much between the two estimation methods. Hence, the correlation method was used for the estimation of tree phytomass (stem, branches, leaves and roots). This is in line with commonly applied methods. A correction simply based on basal area (not shown here) was rejected.

Nutrient concentrations in each sample were analysed and nutrient amounts calculated for each compartment of each tree and for the other bulked samples and compartments. Next, mean concentrations were calculated per compartment (tree leaves, etc.) and nutrient amounts were calculated for each plot and averaged for each stand. The tree data given here are based on regression analysis; those for the other compartments are based on harvesting totals.

Soil nutrient content was studied in soil pits, but not in all four stands. Soils and the nutrient amounts in the Kabo region and the Mapane region differed (see Table 6.2), and this is reflected in different growth patterns, structures and species compositions of the forest vegetation in the two regions (see Chapter 5).

Table 6.2. Soil nutrient contents in Kabo and Mapane regions, based on soil pits 1.2 m deep.

Region		Kabo	Mapane
Location*		Kabo, Eastern Creek**	Procter's Forest
Number of pits		5	1
Soil organic matter	t.ha⁻¹	99.5	113.1
N	kg.ha⁻¹	8816	9602
P (P-Bray)	kg.ha⁻¹	33.0	10.3
K	kg.ha⁻¹	93.9	183.4
Ca	kg.ha⁻¹	377.7	564.9
Mg	kg.ha⁻¹	226.2	77.7
Source		Poels (1987)	Boxman (unpublished)

* Identical methods used at both locations. * *Located about 1 km east of the MAIN experiment and about 10 km west of Phytomass Forest.

We assume that the soils under Procter's Forest, Akintosoela1 and Weyerhäuser are similar, because these stands are located within 1 km from each other. Even though Procter's Forest is located down the slope, near the Mapane Creek, Weyerhäuser is at the top of the slope, and Akintosoela1 in between, differences in altitude are less than 10 m. With this assumption the effects of treatments (see Table 5.1) on phytomass can be studied by comparing these three forest stands. Procter's Forest and Akintosoela1 were selectively cut in 1966 (about 20 m³.ha⁻¹ removed, De Graaf 1986). Akintosoela1 was refined in 1975; all unwanted trees above 20 cm dbh were poison-girdled, thus reducing the basal area of living trees from 28.3 to 9.8 m².ha⁻¹. Dead phytomass was left in the stand. Hence, the exploitation and refinement in Akintosoela1 were somewhat heavier than the normal CMS prescriptions, as carried out in the MAIN experiment (see Section 4.4). In Weyerhäuser, virtually all wood was harvested in 1969, removing 194 m³.ha⁻¹ and there was no follow-up treatment (see 's Landsbosbeheer 1971). This resulted in a residual basal area of 7.7 m².ha⁻¹ (Boerboom 1970). Keeping in mind that after this treatment stand growth has to start almost from scratch, this stand can be considered as a secondary forest. Thus, Weyerhäuser is taken to indicate what will happen after very severe interferences. In the Mapane region, no untreated forest was available for phytomass assessment. Phytomass assessments were carried out between 1980 and 1982 (see Table 5.1), thus allowing for different regrowth periods after treatment.

6.2.2 Phytomass in undisturbed and lightly exploited forest

With about 574 t.ha^{-1} the total amount of phytomass in Phytomass Forest in the Kabo region was some 15 % larger than that of Procter's Forest (about 492 t.ha^{-1}) in the Mapane region (see Table 6.3, values estimated by regression, and Figure 6.1). Phytomass Forest had a considerable amount of palms. Therefore Phytomass Forest had about 30 % more total leaf mass in comparison to Procter's Forest, although the total weights of tree leaves in these two forests were similar. Phytomass Forest also had about 20 % more fine litter than Procter's Forest, but Procter's Forest had about 40 % more coarse litter.
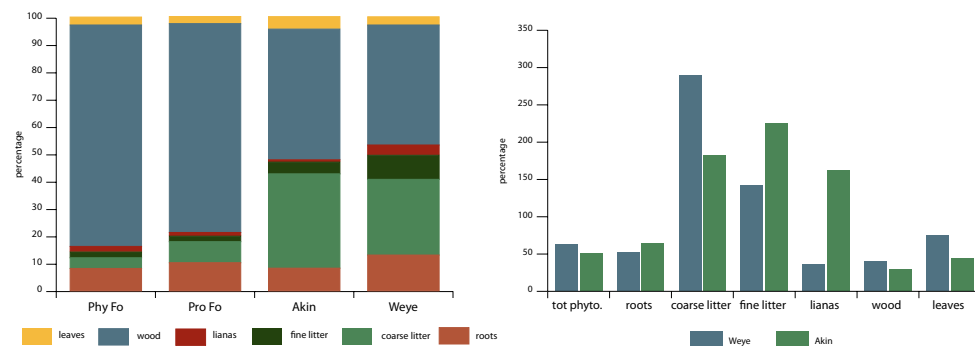

Figure 6.1. Left: Distribution of total phytomass, corrected according to regression analysis, over compartments in four differently treated (see Table 5.1) forest stands. Right: Phytomass of given compartments in Akintosoela1 and Weyerhäuser as a percentage of the same compartment in Procter's Forest. Phy Fo = Phytomass Forest, Pro Fo = Procter's Forest, Akin = Akintosoela1, Weye = Weyerhäuser; tot. phyt. = total phytomass; co. lit. = coarse litter; fi. lit. = fine litter.

The difference in total phytomass of about 82 t.ha^{-1} was mainly due to the difference in wood mass, both in branches and stems. The selective cutting of only about five trees per ha carried out in the Mapane region (De Graaf 1986) may be the main cause, whereas differences in growth and soil conditions may also have contributed. Logging probably also is the cause of the much higher percentage of coarse litter (lying dead stems) in Procter's Forest (see Figure 6.1).

Procter's Forest, while having less above-ground phytomass, had a slightly larger root phytomass than Phytomass Forest (51 respectively 47 t.ha^{-1}).

We calculated the root mass of the 10×10×0.9 m plot that we sampled in Procter's Forest using the relation we had established between dbh and dry weight of roots. We obtained a root mass value of around 161 t.ha^{-1}. This plot, however, was densely stocked compared to the surrounding forest. Therefore we applied a correction based on basal area in the plot and in the surrounding forest. That gave a total tree root mass for the stand (excluding palms) of 45 t.ha^{-1} (Table 6.4). This brings our estimates of tree root mass for both Phytomass Forest and Procter's Forest in the same order of magnitude (Table 6.3).

Table 6.3. Phytomass in t.ha^{-1} per compartment in four differently treated forest stands.
Methods: meas.: harvest over 12, 14, 12 and 2.5 plots of 0.01 ha each; r.a.: idem, tree phytomass only calculated over respectively 5, 5, 1 and 1 ha with regression analysis, other compartments by harvest. Tree phytomass: leaves, stems, branches, roots. For more details see text.

Compartment	Forest stand	Phytomass Forest		Procter's Forest		Akintosoela1		Weyerhäuser	
	Method	meas.	r.a.	meas.	r.a.	meas.	r.a.	meas.	r.a.
Leaves									
	trees	9.5	8.5	5.5	7.9	8.4	7.2	5.2	3.7
	palms	8.0	8.0	1.5	1.5	2.6	2.6	1.0	1.0
	others	0.4	0.4	3.2	3.2	3.9	3.9	2.7	2.7
Total leaves		**17.9**	**16.9**	**10.2**	**12.6**	**14.9**	**13.7**	**8.9**	**7.4**
Wood									
	branches	179.1	133.7	93.3	94.8	79.2	51.2	38.0	30.8
	stems	384.7	326.2	213.1	281.4	129.3	99.7	108.8	78.1
	palms	4.5	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Total wood		**568.3**	**464.4**	**306.4**	**376.2**	**208.5**	**150.9**	**146.8**	**108.9**
Lianas									
	all	10.5	10.5	5.3	5.3	1.9	1.9	8.6	8.6
Total lianas		**10.5**	**10.5**	**5.3**	**5.3**	**1.9**	**1.9**	**8.6**	**8.6**
Litter									
	fine	12.2	12.2	9.7	9.7	13.7	13.7	21.8	21.8
	coarse	22.5	22.5	37.7	37.7	108.9	108.9	68.8	68.8
Total litter		**34.7**	**34.7**	**47.4**	**47.4**	**122.6**	**122.6**	**90.6**	**90.6**
Roots									
	roots	65.3	47.1	26.0	50.8	55.5 *	26.3	24.2	32.5
Total roots		**65.3**	**47.1**	**26.0**	**50.8**	**55.5**	**26.3**	**24.2**	**32.5**
**Living phytomass **		**662.0**	**538.9**	**347.9**	**444.9**	**280.8**	**192.8**	**188.5**	**157.4**
**Above ground phytomass **		**631.4**	**526.5**	**369.3**	**441.5**	**347.9**	**289.1**	**254.9**	**215.5**
**TOTAL PHYTOMASS **		**696.7**	**573.6**	**395.3**	**492.3**	**403.4**	**315.4**	**279.1**	**248.0**

* s.d. 143.8 t.ha^{-1}: one plot 511.5 t.ha^{-1}, including below surface buttresses; the other 11 plots 13.9 ± 7.2 t.ha^{-1}.
** Living phytomass: leaves, wood, lianas, and roots; above ground phytomass: leaves, wood, lianas, and litter; total phytomass: leaves, wood, lianas, litter, roots.

Variation in root mass was considerable, and this is particularly striking in Akintosoela1 (see Table 6.3 and footnote there).

Table 6.4.   Root phytomass in a 10.0*10.0*0.9 m plot in Procter's Forest and the value corrected on the basis of basal area values in the plot and the surrounding forest.

Root phytomass	t.ha^{-1}	Basal area	m^2.ha^{-1}
Tree roots measured	160.5	Plot	115.0
Palm roots measured	4.2	Stand	31.6
Total roots measured	164.7		
Corrected according to basal area	45.2	Correction factor, used for tree roots only	0.27

6.2.3 Effects of logging and silvicultural treatments on the amounts of phytomass

In Procter's Forest, in 1966, selective logging of about 20 m^3.ha^{-1} was done, just as in Akintosoela1, but there, 9 years after logging, refinement was carried out. In Weyerhäuser virtually all wood was cut in 1969. Thus, the effects of disturbance, as apparent in Akintosoela1 and Weyerhäuser, can be compared with the lightly disturbed Procter's Forest and the undisturbed Phytomass Forest as controls. Furthermore, we assume that the soil at Procter's Forest is similar to that at Akintosoela1 and Weyerhäuser, due to the close proximity of these forest stands. Assessment of the phytomass took place in 1981-82, which was 6 years after refinement in Akintosoela1 and 13 years after cutting in Weyerhäuser.

It should be remembered that logging means that killed phytomass partially remains in the forest and partially is extracted from the forest. The extraction was estimated by Jonkers & Schmidt (1984) for Phytomass Forest to be 3.1 % of the living phytomass and 2.6 % of its total amount of nutrients. Refinement implies that a certain amount of phytomass is killed but that all phytomass remains in the forest.

In Akintosoela1 total phytomass was 315 t.ha^{-1} and in Weyerhäuser 248 t.ha^{-1} which is 36 % and 50 % less than at Procter's Forest, and 45 % and 57 % less than at Phytomass Forest, respectively. In Akintosoela1, tree leaf mass was 9 % more than in Procter's Forest. In Weyerhäuser, tree leaf mass was even less than 50 % of the value obtained in Procter's forest or in Phytomass Forest (Table 6.3), which means a drastic reduction of this stand's photosynthetic capacity.

Six year after refinement, the amount of living wood (standing stems and branches) in Akintosoela1 was 151 t.ha^{-1}, or 40 % of the wood mass in Procter's Forest. Since treatment six to seven years earlier, basal area grew from about 10 m^2.ha^{-1} to about 18.2 m^2.ha^{-1} (De Graaf 1986), indicating that the reduction in tree phytomass was even more than measured and indicated in Figure 6.1. Thirteen years after harvest, the wood mass in Weyerhäuser had increased from about 40 to more than 109 t.ha^{-1}, which is equivalent to 30 % of the wood mass in Procter's Forest. The wood component represents about 80 % of the total phytomass in Procter's Forest, around 50 % in Akintosoela1 and clearly less than 50 % in Weyerhäuser.

This difference is partially compensated by a higher amount of dead wood in the disturbed stands. The amount of coarse litter grew as a result of logging and refinement: living wood became dead wood. To compare the amount of dead wood lying on the

forest floor in the plots with the amount lying in the whole stands, a line sampling method as developed by De Vries (1973, 1979) was used. As the degree of decomposition of the lying stems showed a wide range, thus not allowing for a simple conversion factor from volume to dry weight, the results of the transect sampling (Table 6.5) cannot be compared directly with the data collected in the phytomass plots (see Table 6.3).

Table 6.5.   Amount of lying dead wood as assessed by total harvest in 0.01 ha plots and by the line intersect method in four differently treated (see Table 5.1) forest stands.

Method			Forest stand			
			Phytomass Forest	Procter's Forest	Akintosoela1	Weyerhäuser
Plots	area	ha	0.12	0.14	0.12	0.025
Dry weight	mean*	t.ha^{-1}	14.9	36.3	99.2	64.8
	s.d.	t.ha^{-1}	16	49.8	69.5	40
Line	length	m		± 1600	± 1600	
Volume	mean	m^3.ha^{-1}	n.a.	87.6	194.9	n.a.
	variance.	m^3.ha^{-1}	n.a.	12.41	45.30	n.a.
	confidence interval 95 %	m^3.ha^{-1}	n.a.	61.4 ≤ V ≤ 113.8	98.4 ≤ W ≤ 291.4	n.a.
Dry weight**	mean	t.ha^{-1}	n.a.	35.0	78.0	n.a.
	variance		n.a.	4.96	18.12	n.a.
	confidence interval 95 %		n.a.	24.6 ≤ V ≤ 45.5	39.4 ≤ W ≤ 116.6	n.a.

* Data for coarse litter in Table 6.3 (respectively 22.5 t.ha^{-1}, 37.7 t.ha^{-1}, 108.9 t.ha^{-1}, 68.8 t.ha^{-1}) include lying and standing dead wood.

** Assuming a mean dry weight of dead wood of 0.4 t.m^{-3} (living standing wood has a dry weight of 0.65 – 0.75 t.m^{-3}).

The mass of fine litter (mainly leaves) present in Akintosoela1 and Weyerhäuser was far more than in Procter's Forest, respectively 40 % and 125 %. Refinement and heavy exploitation caused a reduction of leaf mass in the canopy (see Table 6.3) and possible caused thereafter a slightly higher litterfall in the first year (see below) and a lower litterfall in the following years. However, because more space and more light, water and nutrients became available, the remaining and newly established trees produced probably more leaves (see Akintosoela1, see also Jonkers 1987). A combination of a quicker turnover of the leaves on the tree and a slower decomposition rate may be of importance too. A different equilibrium between leaf production, leaf fall and leaf decomposition may be the result.

As expected, also the amount of coarse litter was larger in Akintosoela1 (109 t.ha^{-1}) and Weyerhäuser (69 t.ha^{-1}) than in Procter's Forest (38 t.ha^{-1}). De Graaf (pers. comm.) estimated that in Akintosoela1 a stem volume of roughly 200 m^3.ha^{-1} had been killed. In Weyerhäuser, from the 234 m^3.ha^{-1} bole volume (inventory 1964; Boerboom 1964), 194 m^3.ha^{-1} was extracted ('s Landsbosbeheer 1971). After both treatments, large amounts of debris (branches and tops) were left on the forest floor. The main part of this coarse litter was lying dead wood, not yet completely decomposed since the refinement six year earlier or the harvest 13 year earlier.

Standing dead wood, as part of the coarse litter, amounted to only 9.7, 4.0 and 1.4 t.ha^{-1} for Procter's Forest, Akintosoela1 and Weyerhäuser, respectively. These figures are probably underestimations, because harvesting standing dead trees is dangerous and plots with large dead trees were rejected for safety reasons.

Lianas formed only a small part of the total phytomass. Liana mass in Akintosoela1 was very low and not even a third of that in Procter's Forest. Cutting of lianas is part of the CSS prescriptions and was apparently successful. Opening up the canopy due to refinement did not lead to a proliferation of lianas, although it is possible that our decision to reject plots with large standing dead trees could have somewhat biased the measurements here. As expected, as a result of its treatment, phytomass of lianas in Weyerhäuser was substantial larger than in Akintosoela1 and Procter's Forest.

Root phytomass was estimated for Akintosoela1 and Weyerhäuser with the regression relation found for Procter's Forest. Thus calculated, root phytomass was 26 t.ha^{-1} in Akintosoela1 and 32 t.ha^{-1} in Weyerhäuser, which is some 40 – 50 % less than in Procter's Forest (see Table 6.3). The larger amount of roots at Weyerhäuser as compared to Akintosoela1 corresponds to the more vigorous growth at Weyerhäuser. However, it should be noted that the estimation of root mass is difficult.

The above findings can best be summarized by discussing them in terms of the effects of the different treatments on total phytomass. Refinement and regrowth in Akintosoela1 resulted seven years after treatment in only about 60 % of the total phytomass in Procter's Forest. Removing virtually all trees and regrowth in Weyerhäuser resulted 13 years after treatment in about 50 % of the assumed pre-felling phytomass (see Table 6.3 and Figures 6.1 and 6.2). These changes were accompanied by shifts in the fractions of phytomass from living to dead phytomass, resulting in increases in coarse and fine litter, the coarse litter probably being mainly remnants of the killed trees or tree parts. In Weyerhäuser, the living phytomass had increased from about 40 t.ha^{-1} (estimation based on basal area; 's Landsbosbeheer 1971) to nearly 160 t.ha^{-1} (living phytomass) amounting to an average net regrowth of 9.2 t.ha^{-1}.y^{-1}.

It is clear, that both harvest and refinement lead to a reduction of the total phytomass in the tropical rain forest. The regrowth of Weyerhäuser, however, may indicate that the restoration capacity of the tropical rain forest is strong.

6.2.4 Nutrient concentrations and nutrient amounts in undisturbed and lightly exploited forest

Average values of nutrient concentrations per compartment and the total amounts per stand are given in Table 6.6 and Figure 6.3. Concentrations of all nutrients were generally higher in Procter's Forest than in Phytomass Forest, except for calcium (wood, lianas, and roots). These exceptions might be due to differences in species composition or in the soil, though the soil factor does not necessarily seem to directly affect the concentrations in the compartments: The Mapane soils are richer in nitrogen, potassium and calcium and poorer in phosphorus and magnesium as compared to the Kabo soils (see Table 6.2). The data also seem to indicate that the forest stands Akintosoela1 and Weyerhäuser

had slightly higher nutrient concentrations than Procter's Forest (Table 6.6). Thus the disturbed forest stand Akintosoela1, and more strongly so the almost totally disturbed Weyerhäuser with its high N concentration in the leaves that is typical of the high number of pioneer species in that stand, seem to have a better ability to uptake nutrients and perhaps profit from nutrients released from the decomposing dead phytomass.

In all forest stands, leaves had the highest nutrient concentrations (see Table 6.6), except for calcium. Usually calcium concentrations in lianas were highest. Fine litter was also comparatively rich, especially in nitrogen, phosphorus and magnesium, but had lower concentrations than leaves. Wood and coarse litter showed low concentrations, as expected. Concentrations in living wood were either somewhat higher or lower than in coarse litter, suggesting that during the decomposition process of wood enrichment can occur due to invasion of decomposing organisms.

Table 6.6. Concentrations and amounts of nutrients in phytomass as calculated with regression analysis in four differently treated (see Table 5.1) forest stands.

	Phytomass Forest		Procter's Forest		Akintosoela1		Weyerhäuser	
	Conc.	Amount	Conc.	Amount	Conc.	Amount	Conc.	Amount
	g/kg	kg.ha^{-1}	g/kg	kg.ha^{-1}	g/kg	kg.ha^{-1}	g/kg	kg.ha^{-1}
Nitrogen								
Leaves	13.1	221.4	16.2	204.1	15.3	209.6	18.4	136.2
Wood	2.9	1346.8	3.8	1429.6	4.2	633.8	4.2	457.4
Lianas	6.4	67.2	7.3	38.7	12.4	23.6	8.6	74.0
Fine litter	12.2	148.8	13.3	129.0	14.2	194.5	14.5	316.1
Coarse litter	3.6	81.0	6.3	237.5	4.5	490.1	2.5	172.0
Roots	7.9	372.1	11.1	563.9	9.3	244.6	4.5	146.3
Total nitrogen		**2237.3**		**2602.8**		**1796.1**		**1301.9**
Phosphorus								
Leaves	0.8	13.5	0.9	11.3	0.9	12.3	0.9	6.7
Wood	0.2	92.9	0.3	91.9	0.5	75.5	0.3	32.7
Lianas	0.4	4.2	1.0	5.3	0.6	1.1	0.5	4.3
Fine litter	0.4	4.9	0.6	5.8	0.6	8.2	0.5	10.9
Coarse litter	0.2	4.5	0.5	18.9	0.3	32.7	0.1	6.9
Roots	0.5	23.6	0.5	25.4	0.4	10.5	0.3	9.8
Total phosphorus		**143.5**		**158.6**		**140.3**		**71.2**
Potassium								
Leaves	9.5	160.6	10.8	136.1	11.6	158.9	11.8	87.3
Wood	2.5	1161.0	2.6	978.1	3.6	543.2	4.1	446.5
Lianas	4.8	50.4	4.8	25.4	6.6	12.5	7.1	61.1
Fine litter	2.5	30.5	2.9	28.1	4.1	56.2	3.0	65.4
Coarse litter	0.6	13.5	1.3	49.0	1.5	163.4	1.1	75.7

Table 6.6. (continued)

	Phytomass Forest		Procter's Forest		Akintosoela1		Weyerhäuser	
	Conc.	Amount	Conc.	Amount	Conc.	Amount	Conc.	Amount
	g/kg	kg.ha^{-1}	g/kg	kg.ha^{-1}	g/kg	kg.ha^{-1}	g/kg	kg.ha^{-1}
Roots	3.5	164.9	4.5	228.6	5.5	144.7	1.4	45.5
Total potassium		**1580.8**		**1445.4**		**1078.9**		**781.5**
Calcium								
Leaves	5.2	87.9	6.3	79.4	8.8	120.6	10.8	79.9
Wood	7.5	3483.0	4.0	1504.8	5.6	845.0	5.0	544.5
Lianas	10.5	110.3	5.3	28.1	13.1	24.9	12.7	109.2
Fine litter	9.1	111.0	6.7	65.0	8.4	115.1	9.9	215.8
Coarse litter	4.4	99.0	4.8	181.0	4.4	479.2	4.4	302.7
Roots	4.1	193.1	1.9	96.5	2.8	73.6	4.4	143.0
Total calcium		**4084.3**		**1954.7**		**1658.4**		**1395.2**
Magnesium								
Leaves	1.6	27.0	2.0	25.2	1.8	24.7	3.5	25.9
Wood	0.5	232.2	0.5	188.1	0.6	90.5	1.0	108.9
Lianas	1.0	10.5	2.1	11.1	1.9	3.6	1.4	12.0
Fine litter	1.4	17.1	1.6	15.5	1.4	19.2	2.0	43.6
Coarse litter	0.5	11.3	0.6	65.3	0.4	43.6	0.5	34.4
Roots	0.7	33.0	1.6	81.3	0.6	15.8	1.2	39.0
Total magnesium		**331.0**		**386.6**		**197.3**		**263.8**

The amounts of nutrients stored in the total plant biomass in Phytomass Forest and in Procter's Forest were of the same order of magnitude. Procter's Forest had about 20 % more N, 10 % more P, 10 % less K and 15 % more Mg. Exception here was again Ca of which, due to a much lower concentration, the total amount stored in Procter's Forest is less than half the amount in Phytomass Forest. The soil in Procter's Forest contained more calcium than the Phytomass Forest soil (Table 6.2). The amounts of nutrients stored in the disturbed forest stands Akintosoela1 and Weyerhäuser were considerably less than those in the non- or little disturbed stands: the amounts of N, P and K all up to 45 - 55 % less, though the decreases in Akintosoela1 were not as drastic as in Weyerhäuser. Amounts of Ca and Mg in the phytomass were also clearly less in Akintosoela1 and Weyerhäuser, but the pattern was not as clear as for N, P and K.

The distribution of various nutrient amounts over the compartments in all four forest stands reflected the differences in phytomass and in nutrient concentrations. These differences were especially clear for Mg and P. The amounts of nutrients stored in leaves were comparable in Phytomass Forest, Procter's Forest and Akintosoela1, but about 30 % lower in Weyerhäuser. In all forests, wood was the most important store for all nutrients, even though it had generally the lowest concentrations. Roots or litter formed the second most important pool. As expected, in the two more strongly disturbed stands

litter was a proportionally much more important pool of stored nutrients than in the other two stands. This is important, because higher percentages of the nutrients stored in the litter layer are likely to enhance leaching.
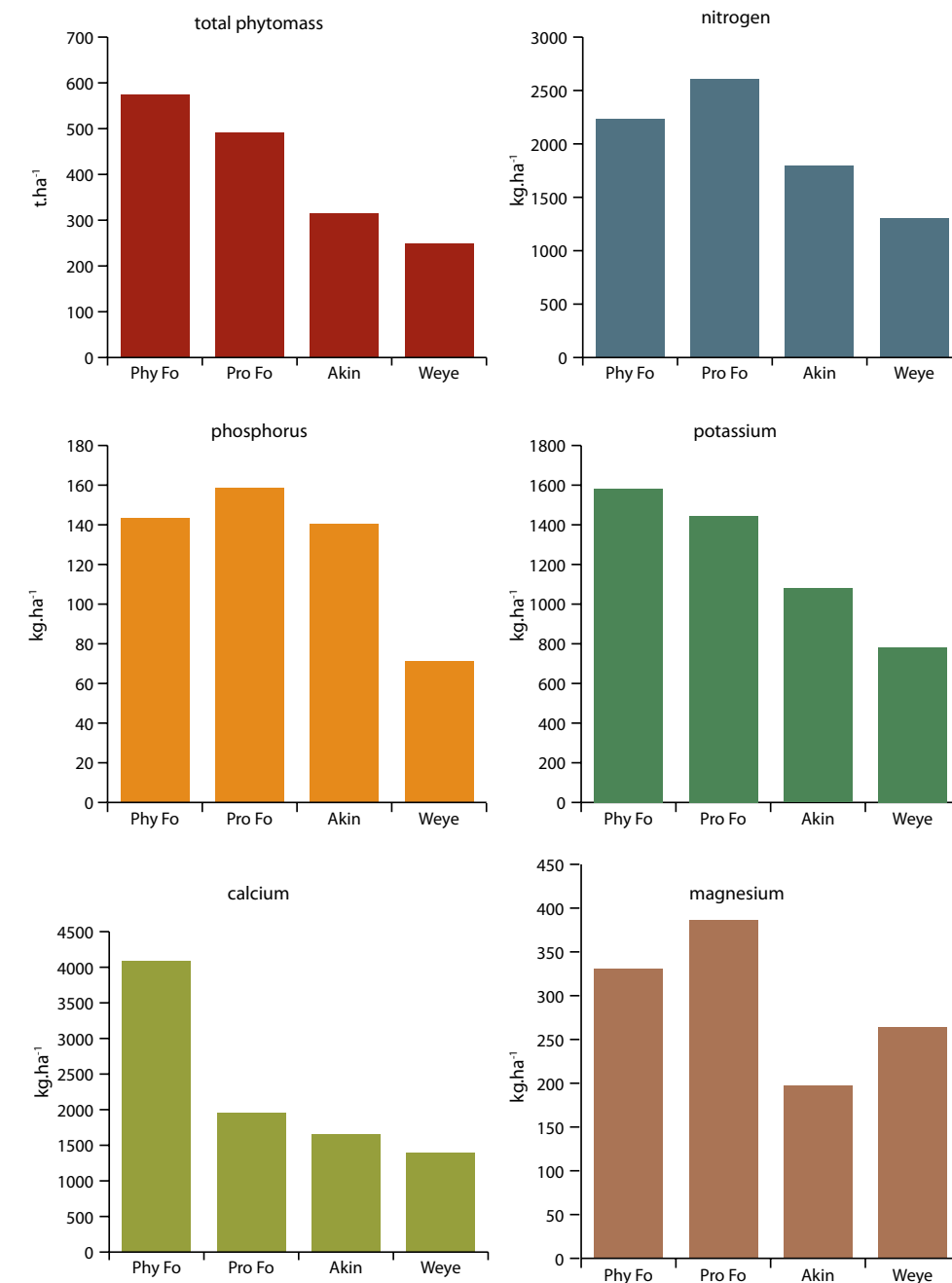

Figure 6.2. Total phytomass and total amounts of N, P, K, Ca and Mg in four differently treated (see Table 5.1) forest stands. Abbreviations see Figure 6.1.
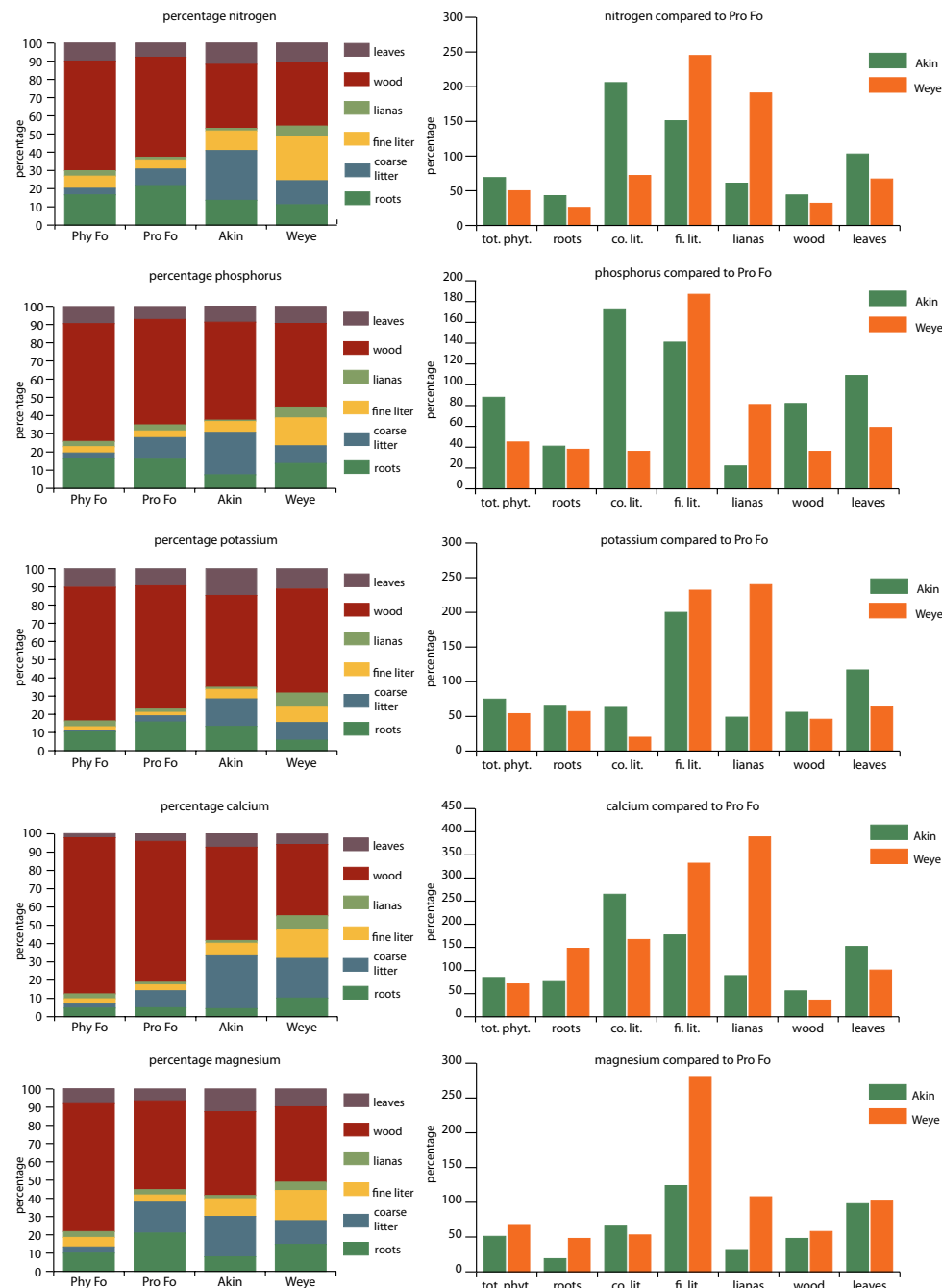
Figure 6.3.   Left: Distribution of nutrient amounts stored in relevant compartments as percentage of total phytomass, calculated with regression analysis, in four differently treated (see Table 5.1) forest stands. Right: Amounts of a nutrient in given compartments in Akintosoela1 (Akin) and Weyerhäuser (Weye) as percentage of the same compartment in Procter's Forest. tot. phyt. = total phytomass; co. lit. = coarse litter; fi. lit. = fine litter.

Coarse litter in Akintosoela1 contained 50 % more Ca, 100 % more N and 50 % more P than in Procter's Forest (see Figure 6.3). Coarse litter in Weyerhäuser contained 150 % more Ca, but the same amount of N and P as in Procter's Forest. This could be the result of a higher load of micro-organisms absorbing N and P.

Lianas play a minor role in nutrient capture and storage in these forest stands though their role at Weyerhäuser might be somewhat more important, due to their abundance in that stand.
In general, roots, representing about 10 % of the total phytomass, often contained more than 10 % of the nutrients in the phytomass.

After disturbance the large amount of dead plant material left to decompose most likely made more nutrients available. This, together with the much increased light availability in the remaining vegetation at Weyerhäuser, allowed the abundance and fast growth of the pioneers there, with their typical high concentration of nitrogen and fast leaf turnover. However, some nutrients, particularly nitrogen and potassium, which are easily leached from the soil, but also magnesium, might become limiting for plant growth. But the concentration data measured by us do not yet clearly indicate such a limiting availability. Unfortunately, however, no soil data of these stands before and after treatment are available.

6.3   Above ground production

6.3.1 Introduction

Primary productivity (the rate of plant biomass production over time) is the main driving force within any ecosystem and forms the basis of estimating the commercial (timber) harvest. This holds also for the humid tropical forests of Suriname as well as for forests managed with the CMS. Nevertheless, this was not fully assessed during the development of the CMS or afterwards. Stem production was mainly assessed as timber production or growth of commercial trees (see Chapter 4). Litterfall, being an indicator of the production of leaves and flower/fruits, and thus a key factor in nutrient cycling, was examined in detail. It is the main flux from the above- to the below-ground nutrient pools. In addition, the production of palms was studied, though in less detail.

Interventions may result in changes in litter production and thus may affect the nutrient cycling in the system.

6.3.2 Stem production

The measurement of dbh over longer periods of time allows calculation of changes in stem diameter which can be translated into changes in standing phytomass, using correlations between dry weights of tree parts and stem diameter. Our measurements allowed an assessment of stem production.

Photo 6.1.   Measuring fresh weight stem wood, Mapane, 1982. (Photo P. Schmidt)

In the MAIN experiment (Kabo), based on inventories of three one ha plots per treatment in 1983 and in 2000, wood, branches and leave phytomass can be estimated, including changes therein over time. The inventories contained over 600 trees with dbh >5 cm. Based on these inventories an average net increase in phytomass of 7.8 t.ha^{-1}.y^{-1} was found for untouched forest (MAIN 41, 42, 43), of which 5.2 t stems, 2.5 t branches and 0.1 t leaves (data Jonkers et al., 2005). For harvested and refined forest (MAIN 18, 21, 33) a net average increase of phytomass of 5.0 t.ha^{-1}.y^{-1} was found, of which 3.2 t stems, 1.5 t branches and 0.3 t leaves.

For Mapane, De Graaf (1986) estimated bole volume increments of commercial species after different treatments. In a lightly exploited, non-refined forest experiment at Mapanebrug (comparable to Procter's Forest) this amounted to an average 1.2 m^3.ha^{-1} annually over the period 1974-1980. For the whole stand of Akintosoela1 (lightly harvested and 'heavily' refined), a bole volume increment over six years (1976-1982) of 11.6 m^3.ha^{-1} or on average 1.9 m^3.ha^{-1}.y^{-1} for commercial species of form class I only was found. Assuming an average specific gravity of 0.72 g.cm^{-3} (calculated on the basis of data from Vink 1977), wood production of commercial species in Akintosoela1 was 7.92 t.ha^{-1} or 1.32 t.ha^{-1}.y^{-1}. For commercial species of form class III, it amounted to 1.1 t.ha^{-1}.y^{-1} (see De Graaf 1986), resulting in a total growth of about 2.4 t.ha^{-1}.y^{-1}. In Weyerhäuser, 13 years after clear cutting, 8.0 t.ha^{-1} leaves, 8.6 t.ha^{-1} lianas and 119 t.ha^{-1} wood were present. This implies a wood growth of 119 – 40 = 79 t.ha^{-1} over 13 years, i.e. an average gross annual regrowth of about 6 t.ha^{-1}.y^{-1}.

6.3.3 Litterfall

Total litterfall in Phytomass Forest and in Procter's Forest amounted to 11.7 and 11.3 t.ha^{-1}.y^{-1}, respectively (see Figure 6.4), or 2.5 and 3.0 % of the total living phytomass. The total litter consisted mainly of leaves, complemented by twigs, flowers and fruits (see Figure 6.5) and contained about 300 and 400 kg.ha^{-1} of nutrients (N, P, K, Ca, Mg).
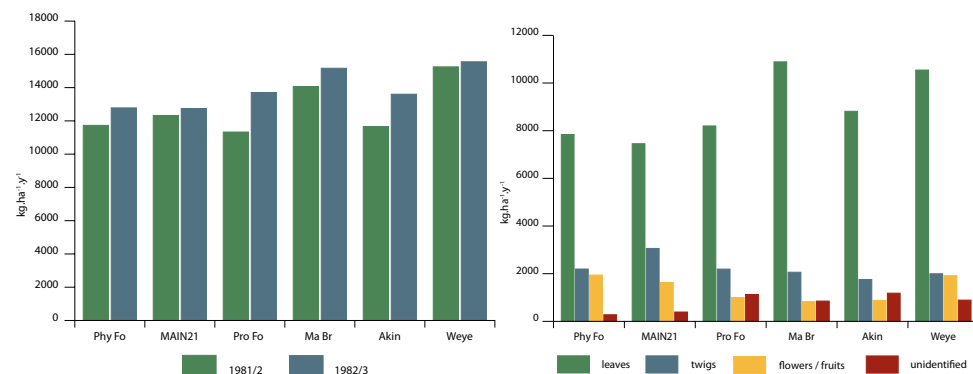
Figure 6.4. Total litterfall in two consecutive years (left) and mean litterfall over two years (right) in six differently treated (see Table 5.1) forest stands. Abbreviations see Figure 6.1.
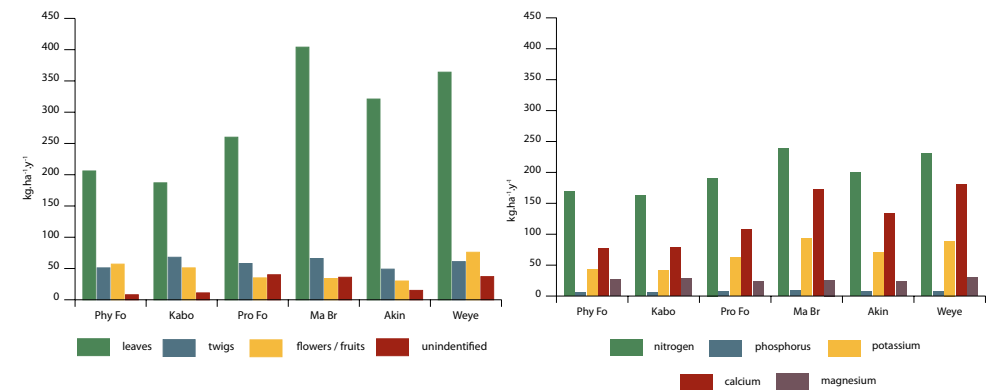

Figure 6.5.   Total mineral (N+P+K+Ca+Mg) fall per tree compartment (left) and per element (right) in six differently treated (see Table 5.1) forest stands. Abbreviations see Figure 6.1.

The amount of fine litter on the forest floor in the various stands varied from 9.7 t.ha^{-1} in Procter's Forest, 12.2 t.ha^{-1} in the Phytomass Forest, 13.7 t.ha^{-1} in Akintosoela1 to 21.8 t.ha^{-1} in Weyerhäuser (see Table 6.3). This resulted in turn-over times (amount of litter falling in a year as compared to the amount lying on the forest floor) of 0.8, 1.0, 1.1 and 1.4 years, respectively. This may be an indication for rapid decomposition, which might lead to increased leaching. However, the large mass of fine roots in the top soil and the good growing conditions guarantee a rapid uptake of released nutrients, thus diminishing the danger of leaching.

Interventions in the Kabo region apparently did not influence total litterfall (compare Kabo exploited in 1978 and refined in March 1982 to Phytomass Forest, see Table 6.6 and 6.7). One has to realize that, depending on the species, poisoning of trees results in dying back of these trees over a period of about two years and that the fall of leaves from dying trees is spread over that period of time. In the long run, interventions also seem slightly to enhance litterfall (compare Mapanebrug and Akintosoela1 to Procter's Forest). In the young forest stand Weyerhäuser, litterfall is considerable, but this stand contains an abundance of pioneers which characteristically have a rapid leaf turn-over. As the standing phytomass is less in the treated forest stands (compare Procter's Forest with Akintosoela1 and Weyerhäuser, see Table 6.3), while litterfall and the amount of litter on the forest floor are larger, a higher percentage of the total phytomass and thus the nutrients is involved in the mobile stage of the nutrient cycle. This might enhance the possibilities for leaching of nutrients. On the other hand, it may be possible that the rate of nutrient uptake in this vigorously growing vegetation of the treated stands is faster and more efficient.

Litterfall was unevenly distributed over the year (see Figure 6.6 and 6.7). In the Kabo area (Figure 6.6), litterfall was highest at the beginning of the dry season (Phytomass Forest 1981, 1982; Kabo 1981). This was confirmed by Jonkers (1987), who reported the shedding of old and the flush of new leaves in this period. In Kabo, between February and April 1982, a refinement was carried out, resulting in a slightly higher litterfall in the rest of that year. In 1983, one year after the refinement, leaf fall was less. This was due to the fact that no new leaves were produced by the poisoned trees. It indicated a less

dense canopy, but leaves were still falling during the whole year. This means that over the whole year a canopy is present. As expected, one year after treatment, the amount of twigs, falling from the dead trees, increased. The fall of flowers and fruits seemed to be enhanced, thus confirming the phenological observations by Jonkers (1987). Flowering apparently increased, possibly due to more sunlight reaching the remaining trees.
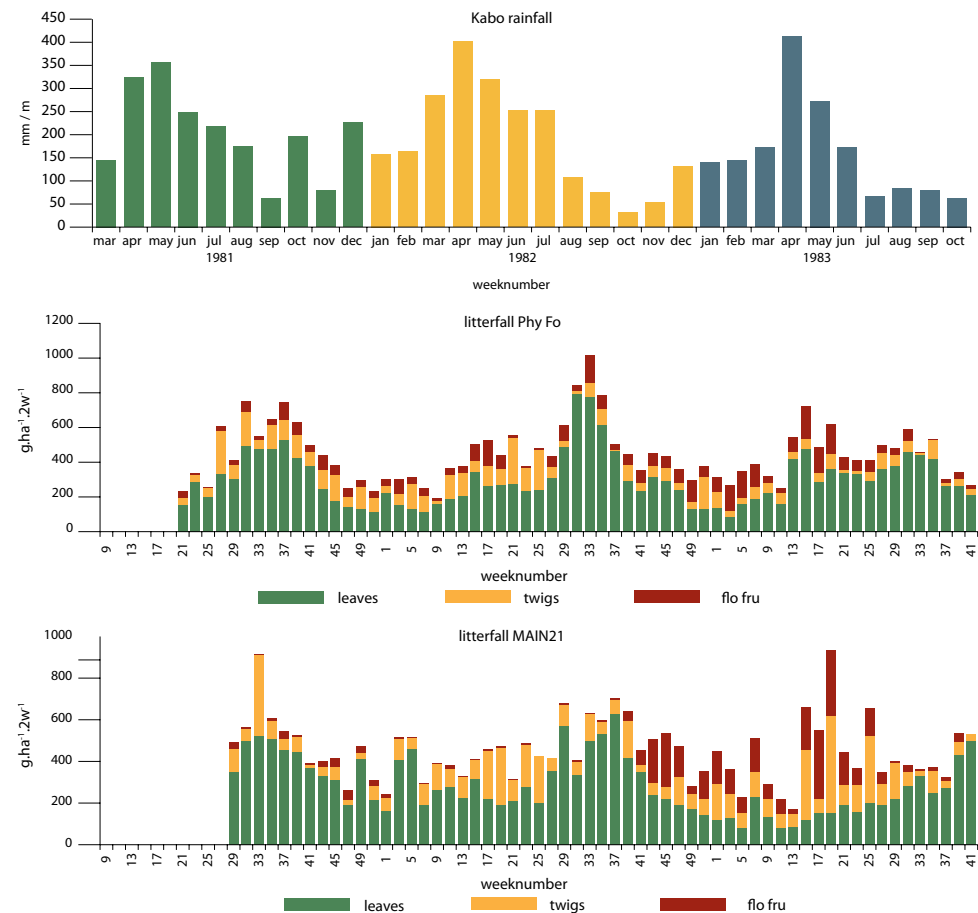

Figure 6.6. Rainfall (in mm per month) and litterfall (leaves, twigs and flowers & fruits) (in gram per hectare per two weeks) in two differently treated (see Table 5.1) forest stands in the Kabo region between March 1981 and October 1983. In MAIN21 a refinement was carried out between February and April 1982. No column in the graph means no data available. Abbreviations see Figure 6.1.

Litterfall in the Mapane region (Figure 6.7) confirmed the observation that litterfall is a bit higher during the dryer periods (Procter's Forest 1981, 1982, 1983; Mapanebrug 1982; Akintosoela1 1982 and Weyerhäuser 1982). The annual rhythm seems to be less smooth in Mapanebrug, Akintosoela1 and Weyerhäuser than in Procter's Forest, which may be due to the higher number of pioneer trees with large leaves, such as *Cecropia* and *Pourouma*. Apart from this observation, no effects of refinements (that had occurred seven years or more before litterfall assessment) and of harvest were observed, indicating a recovery of leaf production to a normal level. Note however the enormous litterfall in

weeks 47 and 49 in 1981 in Mapanebrug, Akintosoela1 and Weyerhäuser, which may have been a result of heavy rain and wind in this period. Unfortunately no complete rainfall and wind data are available for this period. For unknown reasons Procter's Forest did not show this pattern.
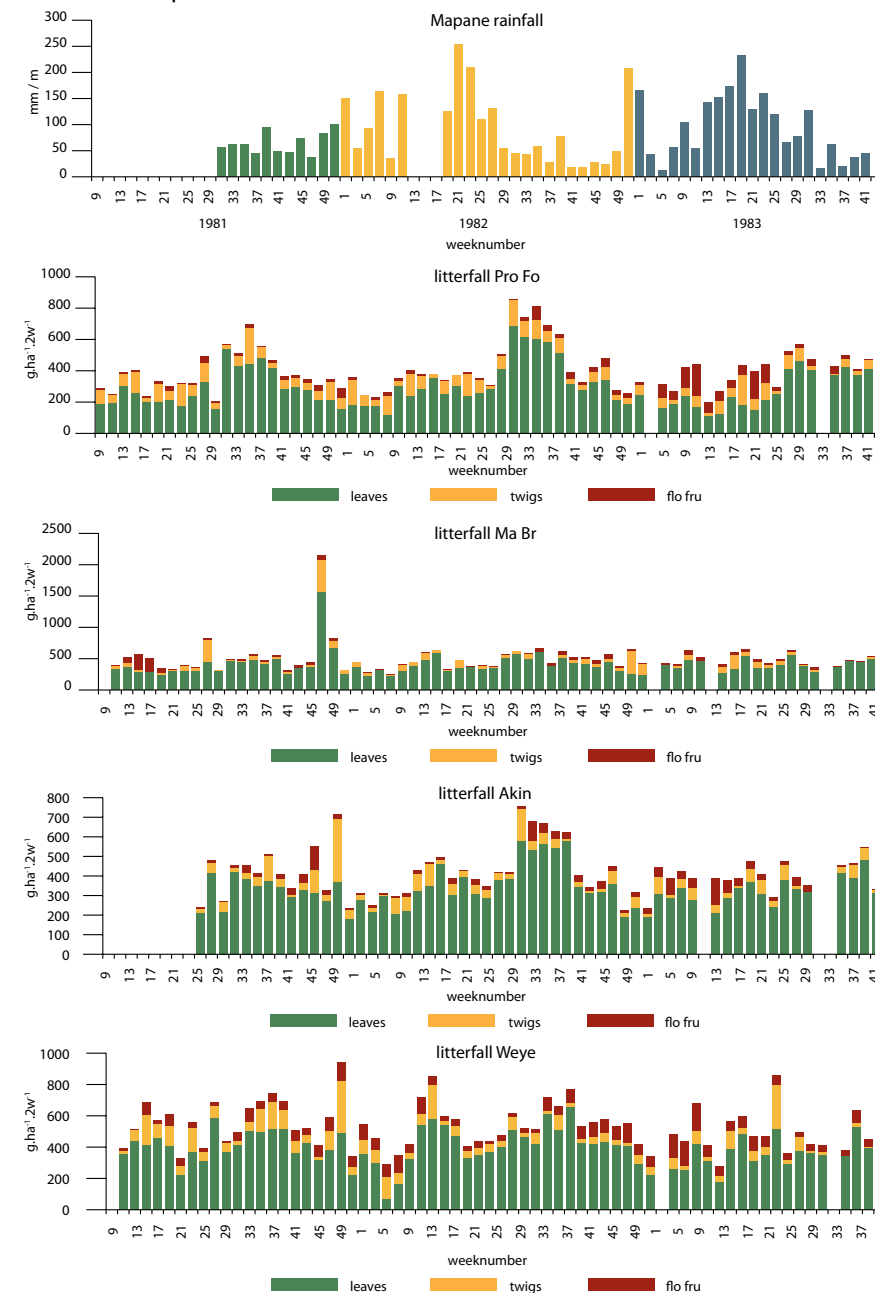
Figure 6.7. Rainfall in mm per two weeks and litterfall (leaves, twigs and flowers & fruits) (in gram per hectare per two weeks) in four differently treated (see Table 5.1) forest stands in the Mapane region between March 1981 and October 1983. No column in the graph means no data available. Abbreviations see Figure 6.1.

If we take the litterfall figures as a proxy of the net production of leaves, highest production took place in Weyerhäuser (15.4 t.ha^{-1}.y^{-1}) and Mapanebrug (14.6 t.ha^{-1}.y^{-1}). The net primary production in Akintosoela1 (12.6 t.ha^{-1}.y^{-1}), Procter's Forest (12.5 t.ha^{-1}.y^{-1}) and Phytomass Forest (12.3 t.ha^{-1}.y^{-1}) was somewhat less. In MAIN, at Kabo, over a 17 years period, there was a net increase in leaf mass of 290 kg.ha^{-1} annually (calculation based on data from Jonkers et al. 2005). This implies that net leaf production was slightly higher than total leaf fall. It can be assumed that this was also the case in Mapanebrug, Akintosoela1 and Weyerhäuser, as there the vegetation was still growing towards a mature state. There is a larger increase in total biomass in Akintosoela1 and Weyerhäuser, because interferences in the stands were far greater than in MAIN and hence the development was more strongly thrown back.

From the above it can be concluded that in the Kabo region each year on average 12.2-12.5 t.ha^{-1} litter contributes to the mineral cycling. In the Mapane region this is 12.5 t.ha^{-1} for Procter's Forest, 14.6 t.ha^{-1} in Mapanebrug, 12.6 t.ha^{-1} in Akintosoela1 and 15.4 t.ha^{-1} in Weyerhäuser. The litter of all the Mapane stands had higher nutrient concentrations than in the Kabo sites. Given the turn-over rates given above, these nutrients become available within 0.8-1.4 years.

Summarizing, it has been shown that harvest and refinement do affect litterfall and its rhythm somewhat, causing a small reduction during the first year after the intervention, but that litterfall is restored to its original level within a couple of years. The same holds for mineral fall.

6.3.4 Palms

Palm growth formed a small part of the total primary production of our forest stands. They contributed substantially to the litterfall and were probably influenced by the treatments. Palm litter was not included in our litterfall studies but was measured separately. Over a period of one year, from January 1982 till January 1983 at Kabo and November 1981 till November 1982 at Mapane, growth, mortality and weight of palm leaves were studied. Figures 6.8 and 6.9 give the growth and mortality values of leaves of some palm species in five forest stands. In Mapane, the total palm leaf mass varied from a minimum of 0.3 t.ha^{-1} in Procter's Forest, 0.8 in Akintosoela1 and 1.0 in Mapanebrug, to a maximum of 1.2 t.ha^{-1} in Weyerhäuser. From Procter's Forest, Schmidt (1981a, b) reported only 1.5 t.ha^{-1} of total palm phytomass, mainly leaves. The production of leaves varied from 0.04 t.ha^{-1}.y^{-1} (Procter's Forest), to 0.14 in Akintosoela1, 0.17 in Mapanebrug, and 0.2 t.ha^{-1}.y^{-1} (Weyerhäuser) (Van der Steege 1983b).

Ohler (1980) estimated that leaf mass for all palms in Phytomass Forest (Kabo region) amounted to 8.0 t.ha^{-1} with a total palm mass of 12.5 t.ha^{-1}. Schmidt (1981a, b), using correlations between height and total weight for a number of palm species (see Table 6.7), calculated that the amount of palm leaves in the 0-10 m layer in Phytomass Forest was 7.8 t.ha^{-1}. However, Van der Steege (1983b) reported a total leaf mass of only 1.8 t.ha^{-1} (based on one small plot of 0.25 ha and extrapolation). These findings indicate the large variability in palm density in Kabo. In Kabo, the density of palms was much higher than in Mapane, where palms were less dominant.

Palm species studied

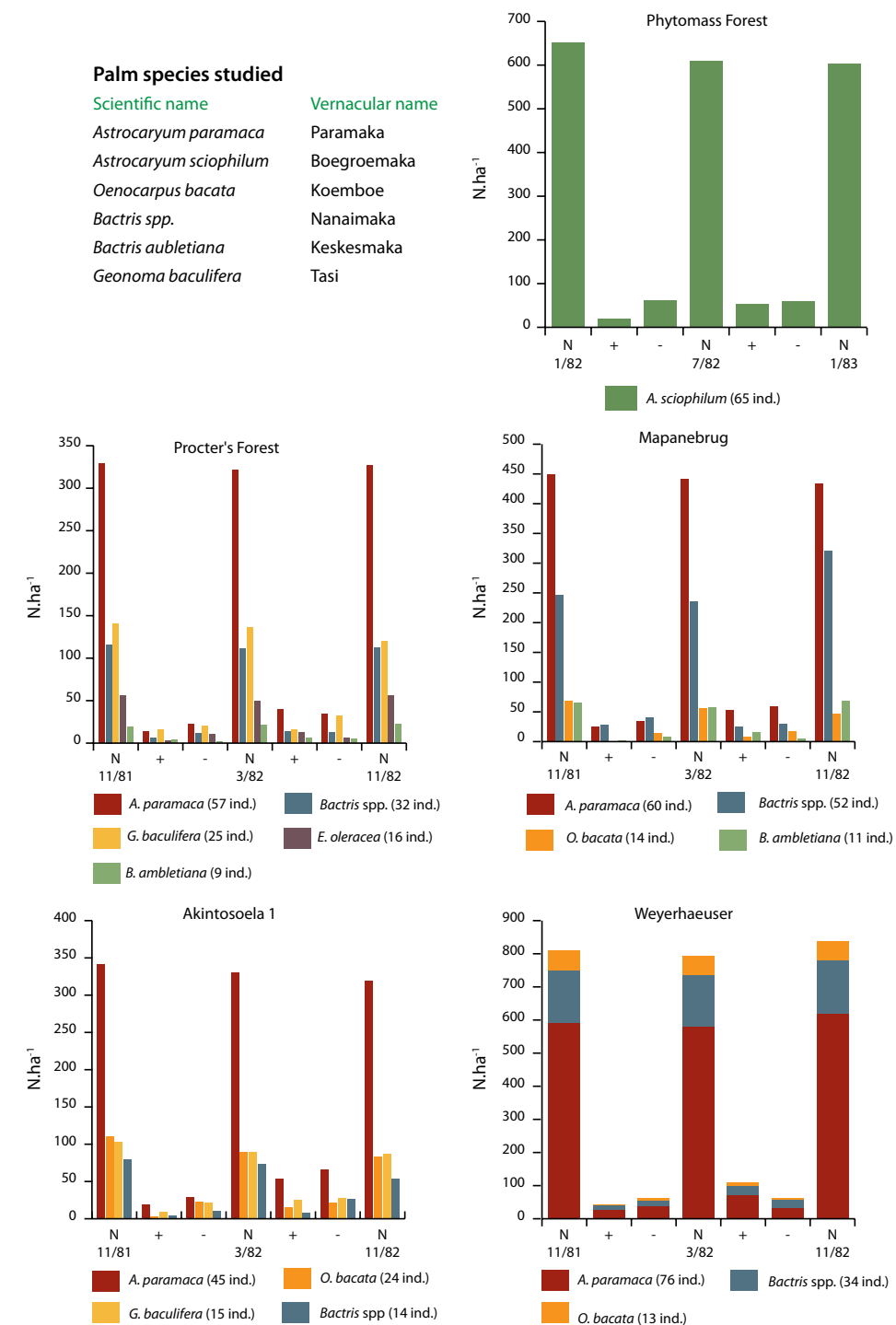| Scientific name	Vernacular name
Astrocaryum paramaca	Paramaka
Astrocaryum sciophilum	Boegroemaka
Oenocarpus bacata	Koemboe
Bactris spp.	Nanaimaka
Bactris aubletiana	Keskesmaka
Geonoma baculifera	Tasi

Figure 6.8.   Number of leaves, leaf growth and leaf fall of palms in two six month periods in five differently treated (see Table 5.1) forest stands. Source: Van der Steege (1983b).

Table 6.7. Coefficients of correlation in linear correlations between height (H, in m) and phytomass (W, in kg dry weight) for palm species. Log W = a + b log H.

Region Kabo

W leaf/H	N	a	B	r^2
Astrocaryum sciophilum	93	0.7595	2.4290	0.9147
Other palm species	12	-1.1645	2.6343	0.8776
All palms	105	-0.7860	2.4152	0.9003
W total/H				
Astrocaryum sciophilum	93	-0.7888	2.6572	0.9172
Other palms	12	-1.2410	2.8164	0.9235
All palms	105	-0.8195	2.6347	0.9021

Region Mapane

W leaf/H	N	a	B	r^2
Astrocaryum paramaca	35	-0.4346	1.5303	0.3957
Other palm species	19	-1.2461	1.7465	0.5993
All palms	54	-1.4754	3.0209	0.7399
W tot/H				
Astrocaryum paramaca	35	-0.4346	1.5303	0.3957
Other palm species	19	-1.1545	2.3059	0.7250
All palms	54	-1.1206	2.5173	0.7517

The leaf production of individual palms was just one leaf per year. This is true for each stand and each species. The average lifespan of a palm leaf ranged from 2.2 year for *Bactis aubletiana* in Procter's Forest to 8.5 year for *Astrocaryum sciophilum* in Kabo. There was variation in lifespan per species over the different forest stands. For example, in Akintosoela1, *Astrocaryum paramaca* leaves had a lifespan of 4.4 years, while in Weyerhäuser this was 6.2 years.
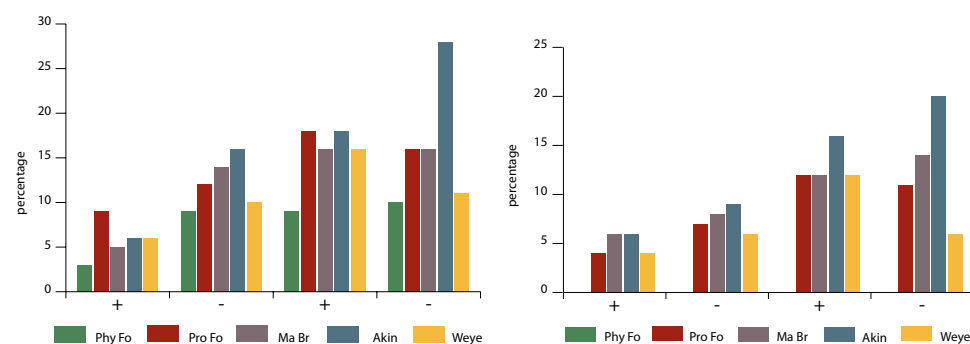
Figure 6.9. Palm leaf growth and fall for all palms and for *Astrocaryum paramaca* palms in two consecutive six months periods as percentage of the numbers of leaves at the beginning of each period in five differently treated (see Table 5.1) forest stands. Abbreviations see Figure 6.1. The Phytomass Forest was assessed from January 1982 to January 1983; the others from November 1981 till November 1982.

These data do not point to clear conclusions about the impact of the CMS treatments on palms. In order to reduce competition between palms and regeneration, it may be advisable to diminish palm density during refinement.

6.3.5 Total primary production

Table 6.8 gives a summary of the measured, calculated and estimated primary production values in six differently treated forest stands. Unfortunately the production values are incomplete and not always comparable. Different methods were used to obtain the values and they are not available for all the stands.

Table 6.8. Summary of measured, calculated or estimated primary production values in phytomass (dry weight in t.ha^{-1}.y^{-1}) or as carbon (between brackets, t.ha^{-1}.y^{-1}) in six differently treated (see Table 5.1) forest stands. N.a. means no data available.

	Phytomass Forest	MAIN 41, 42, 43	MAIN 18, 21, 33	Procter's Forest	Mapane Brug	Akintosoela1	Weyerhäuser
	Untouched	Untouched	Lightly expl. & ref.	Lightly expl.	Lightly expl. & refined	Lightly expl. & heavily ref.	Nearly clear cut
	t.ha^{-1}.y^{-1}	t.ha^{-1}.y^{-1}	t.ha^{-1}.y^{-1}	t.ha^{-1}.y^{-1}	t.ha^{-1}.y^{-1}	t.ha^{-1}.y^{-1}	t.ha^{-1}.y^{-1}
Total litterfall[1]	12.3	12.5	12.5	12.5	14.6	12.6	15.4
Palm leaves[2]	0.2	n.a.	n.a.	0.05	0.17	0.14	0.2
Wood	n.a.	(2.4)[7] 5.2[3]	(1.5)7 3.2[3]	n.a.	n.a.	(1.2) 2.5[4]	(2.9) 6,1[6]
Branches	n.a.	(1.3) 2.5[3]	(0.7) 1.5[3]	n.a.	n.a.	(0.3) 0.7[5]	(1.4) 2.9[5]
Leaves	n.a.	(0.03) 0.1[3]	(0.1) 0.3[3]	n.a.	n.a.	(0.1) 0.3	(0.2) 0.4
Total	**n.a.**	**20.3**	**17.5**	**n.a.**	**n.a.**	**16.2**	**25.0**

1.   Measured in litter traps.
2.   Measured on individual palms.
3.   Based on data from Jonkers et al. (2005).
4.   Calculated from an annual bole volume growth of 1.9 m^3.ha^{-1}.y^{-1} (De Graaf 1986) with an average specific gravity of 0.72 g.cm^{-3} (Vink 1977).
5.   Based on the assumption that the branch production equals 48 % of wood production as in MAIN21
6.   Calculated from standing total stem weight after 13 year minus the same at the start.
7.   Average carbon content factors used: leaves 41.5 %; wood 47 %. Source Ajtay et al. (1979).

The production value in undisturbed Kabo (MAIN 41, 42, 43) of 20.3 t.ha^{-1}.y^{-1} is of the same order of magnitude as found in literature (average 23 t.ha^{-1}.y^{-1}, Ajtay et al. 1979). However, the total amount of phytomass calculated by Jonkers et al. (2005) is, with 550 t.ha^{-1}, higher than found through destructive methods and corrected using correlation factors (see Table 6.3).

Litterfall in all stands is of the same order of magnitude, with highest value for Weyerhäuser (15.4 t.ha^{-1}.y^{-1}) with its many rapidly growing pioneer trees.

Lower values for litterfall were reported from other tropical forests in the same geographical region: 5.47 t.ha^{-1}.y^{-1} in lower montane rainforest in Puerto Rico, 5.87 t.ha^{-1}.y^{-1} in forest on Oxisols in Venezuela, and 11.3 t.ha^{-1}.y^{-1} in moist forest in Panama (Jordan 1989). Such lower values are as expected for the montane forest and the forest on Oxisols, as in those forests trees typically grow leaves with a lower specific leave area and a greater longevity, resulting in a slower turn-over rate.

The total primary production (25 t.ha^{-1}.y^{-1} of which 9 is wood production, see Table 6.8) in Weyerhäuser is relatively high compared to the average value found for all tropical rainforest. This high production can be attributed to the vigorous growth of the vegetation after the severe interference and rapid decomposition of leaves. Values of 4.9 t.ha^{-1}.y^{-1} for wood production were found in Venezuela and Puerto Rico (Jordan 1989).

The data suggest that the undisturbed forest of Kabo is not in a steady state but still increasing in phytomass. The treated forests of Akintosoela1 and Weyerhäuser are also increasing in phytomass. They have not yet reached the amount of phytomass as previous to the treatments.

Jonkers et al. (2005) found that twenty-two years after logging the phytomass of commercial species was often larger than before felling, but the total phytomass had generally not yet recovered fully. His results suggest that refinement had a positive impact on the phytomass growth of species that were considered commercial at the start of the experiment, while the phytomass growth of other species after refinement was similar to the increment in untreated forest. The results were highly variable, however, and large differences between treatments could not always be explained as resulting from the treatments applied. They also found that the phytomass in the three undisturbed plots in Kabo varied.

Net phytomass increase in individual plots varied from a mere 0.4 t.ha^{-1}.y^{-1} to 6.4 t.ha^{-1}.y^{-1}, under different logging and refinement regimes.

The data of Jonkers et al. (2005) also suggested a negative correlation between pre-felling phytomass and phytomass increment. In Chapter 4, it was already shown that natural variation in mortality had a considerable impact on the variation in volume increment. This effect of mortality is also reflected in the changes in phytomass: the high mortality in replication 2 and in plots with the intermediate logging intensity E23 led to considerably less phytomass increment than elsewhere. In other plots, the phytomass in 2000 generally exceeded pre-felling values. Given the fact that by far most nutrients in these forest ecosystems is contained in the living and dead phytomass this increment in phytomass indicates that logging and silvicultural treatment do not result in losses of nutrients.

The impact of logging and refinement on carbon sequestration will be discussed in Section 6.6.

Poels (1987, see also below) in his simulation model also found that the undisturbed forest ecosystem in Kabo, and to a lesser extent the treated forest, is accumulating nutrients. There is no equilibrium at present; the forest is still growing towards its mature stage. This accumulation takes place in the phytomass as well as in the soil.

6.4   Decomposition of leaves and wood

Decomposition is one of the main processes in the cycling of minerals in tropical rainforest ecosystems. Decomposition rates depend on the type of plant material, biological activity in the soil and on environmental factors such as microclimate and soil moisture. Logging and refinement may affect these characteristics.

Decomposition rates of leaves differed from species to species (see Figure 6.10). After 28 weeks (June-December 1982), 68 % of *Tetragastris* leaves had decomposed and 62 % of the leaves of *Inga* (see Van der Steege 1983a). Lowest rates were found in a heavily exploited stand, which was subsequently planted with *Pinus caribaea*, with 44 % loss of weight for *Tetragastris* and 50 % for *Inga*. In the other two stands (refined 14 and 8 years before) decomposition values were higher than in this *Pinus* stand, but lower than in Procter's Forest. Highest rates were found in the most pristine forest stand, Procter's Forest. Fastest loss of weight took place in the first weeks, mainly because of nutrient leaching. In a second observation period (from October 1982 to March 1983), lower decomposition rates were found.
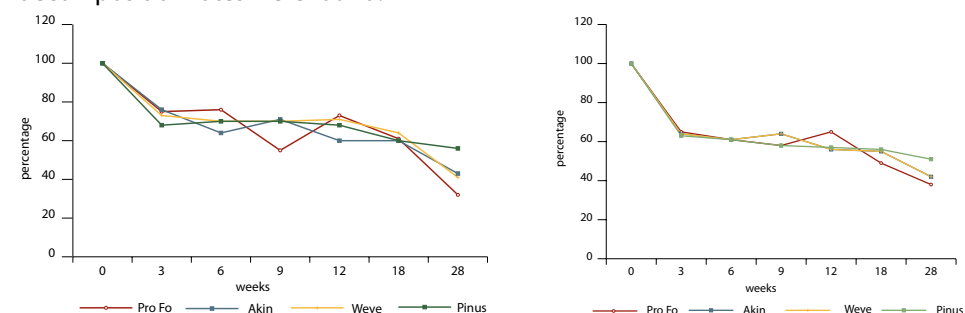

Figure 6.10.   Decomposition rate expressed as percentage remaining dry weight of leaves of *Tetragastris altissima* (left) and *Inga edulis* (right) in four differently treated (see Table 5.1) forest stands. Abbreviations see Figure 6.1; Pinus: *Pinus caribaea* stand, 13 years after clear cut. (Source Van der Steege 1983a).

Mixed natural litter showed lower decomposition rates than freshly cut leaves of single species. After 28 weeks only about 50 % of the mixed litter was decomposed in contrast to the freshly cut and air dried leaves of *Tetragastris* (68 %) and *Inga* (62 %; see above). Freshly cut leaves are richer in nutrients than fallen leaves. Mineral contents are known to decrease with aging of the leaves (Grubb & Edwards 1982; Mason 1976), resulting in lower decomposition rates.

In both observation periods there was a positive correlation between decomposition rate and rainfall. Within one month, small roots and hyphae had penetrated the litter bags. The rate of fungal invasion was positively correlated with the amount of rainfall. Concentrations of minerals in litter seemed to fluctuate during the decomposition

process. At the start they diminished, but later nitrogen and phosphorus increased slightly. This was probably caused by the uptake of these minerals by micro-organisms, which contributed to the decomposition process.

Wood decomposition was much slower than leaf decomposition. After 36 weeks, loss in weight was only 33 % and 21 % for wood of Tetragastris and Inga, respectively.

Only a slight influence of treatments, in the form of slowing down of the decomposition process, could be detected seven years or longer after refinement. This indicates that the danger of leaching is not high.

6.5   Water and nutrient cycles

As part of the CSS research, studies were carried out on the impact of interferences on the total water and nutrient cycles for a whole forest at Kabo. These cycles were studied at the scale of the soil profile and at the scale of entire watersheds. At the level of the soil profile, the following fluxes can be distinguished: aerial input from rain and dust, input from decomposing organic matter and from weathering of minerals. Output takes place in deep drainage, in surface run-off of water and in erosion of soil and litter material.

At the scale of a watershed the same fluxes can be distinguished, although the output is generally combined. The output was measured at the downstream end of the watershed where the creek removes water of both deep drainage and surface drainage from the area, as well as sediment and organic matter resulting from erosion (for details, see Poels 1987).

6.5.1 Water cycle

The hydrology of a small catchment area of 295 ha was studied. In this catchment, two small tributaries of the Ingipipa Creek of similar size, the Eastern Creek and the Western Creek, are present. A dam with a measuring weir was built a short distance from the confluence of both tributaries.

Data were collected on rainfall, evaporation, discharge, topography, soil, substratum and groundwater. The water balance during a period of four years and nine months was simulated using an adapted version of the computer model WOFOST4 (Van Keulen & Wolf 1986) with inputs of measured weather and soil data.

The hydrological year started on November 1 and lasted till October 31 of the next year. Reason for this is that around November 1, the discharge in the creek was lowest and often zero. As a consequence, the discharge in a given twelve-months period (hydrological

Photo 6.2.   Weir to measure water flow, Kabo, 1982.
(Photo K.E. Neering)

year) is the result of the rainfall in the same twelve-months period, facilitating the construction of a water balance.

Computer simulation using the input of these measured data was used to make estimates of other components of the water balance that are difficult to measure. Input to the programme was, next to rainfall and discharge, pan evaporation (Epan), which represents the drying power of the atmosphere for each day. By varying the Pan factor, the ratio between the real water use of the forest and the pan evaporation, it was tried to simulate a discharge corresponding with the measured discharge. The water use of the forest was then divided in transpiration and interception by analysing simulated total water amounts in the system at the beginning and the end of each rainy season, when discharges reached a certain low level (Poels 1987). If the simulated amount of water in the system after a rainy season was lower than before that season, interception was set at a too high level, and vice versa. The calculations were repeated with a new value for interception. After several iterations, a balance was found whereby the extra water use by interception was found. This interception loss is defined as the additional water use on rain days compared with the transpiration that would have occurred under the same climatic conditions but with dry days. The following results were obtained (see Table 6.9):

Table 6.9.   Water balance totals (mm) per hydrological year at the end of each hydrological year.

Hydrological year	1	2	3	4	5	Annual mean
	1979/80	1980/81	1981/82	1982/83	1983/84	
Measured						
Rainfal	1967	2467	2348	1791	1703	2143
evaporation (EPan)	1461	1551	1478	1528	1143	1504
Discharge	296	600	865	294	177	514
Rainfall-discharge	1671	1867	1483	1497	1526	1629
Simulated						
PET**	1659	1732	1673	1713	1292	1694
Interception	218	239	245	232	177	233
effective rainfall	1750	2228	2104	1559	1526	1910
Transpiration	1423	1478	1441	1269	919	1403
Discharge	345	586	855	319	201	526
interception+transpiration	1641	1717	1686	1501	1096	1636
changes in storage	-19	164	-193	-29	406	-19
transpiration/PET	0.86	0.85	0.86	0.74	0.71	0.83
(interception+transpiration)/PET	1.00	0.99	1.01	0.88	0.85	0.97
Measured – simulated						
discharge	-49	14	10	-25	-24	-12.5

Average rainfall and discharge were respectively 2,143 mm and 514 mm per year, resulting in a water use by the vegetation (transpiration and interception) of 1,629 mm per year on average. Length and intensity of the dry season (the period with less than

100 mm rain per month) varied between two and five months per year. The length of the dry period with no or very little discharge varied between zero and eight months per year.

There are large differences between the years, especially in discharge. This is caused by the forest that tries to maintain transpiration at a level corresponding with weather conditions other than precipitation (temperature, radiation, wind speed).

After several simulation runs a good matching between measured and simulated discharges (and measured and simulated groundwater levels) was found. From these simulations, reasonable estimates of transpiration and interception could be derived. Total water use of the forest (transpiration + interception) nearly equals potential evapotranspiration (PET) (factor 0.97).

The extra water use caused by interception, not the total interception, was estimated to be 230 mm.y^{-1} (difference between measured rainfall and effective rainfall) by a total water use of 1,640 mm.y^{-1} (see Table 6.9). As expected, during the dry season moisture stress occurs and transpiration is reduced.

It can be concluded that the water use of the forest at Kabo was very high (76 % of the total rainfall). Similar high values were found in Brazil and Malaysia, but much lower values in forests in Ivory Coast and Venezuela (40-54 % and 38–56 %, respectively, see Bruijnzeel 1991).

6.5.2 Model of organic matter and nutrient flow

An attempt was made to draw up a flow and pools diagram of the phytomass and of two nutrients in major compartments of the undisturbed forest of Kabo, based on the first results of the field experiments, the calculations of the various phytomass values and on some estimated values (Boxman et al. 1985, 1987). This flow diagram was compared to a forest stand two years after treatment. It showed that in spite of the accumulation of decaying dead phytomass and the reduction of living phytomass, logging and silvicultural treatment had resulted at most in a slight increase in the leaching of nutrients. It seemed that the CMS does not lead to serious chemical impoverishment of the ecosystem. Based on this preliminary finding a more detailed study was undertaken by making a simulation model.

The effects of the CMS on the nutrient cycle were studied in detail over a longer period of time, in the catchments of the Eastern Creek, an area of 140 ha of undisturbed forest, and at the Western Creek, an area of 155 ha of forest under the CSS (Poels 1987). Changes in the nutrients in the organic matter cycle were studied by determining the amounts of nutrients in the phytomass and by measuring litter amounts and the composition of litter and soil. Measured data were combined in a model of organic matter and nutrient flows. Changes in nutrients in the hydrological cycle were studied by measuring and analyzing rainfall and creek discharges and also the mineral concentration in rain and creek water.

A computer simulation was made of the amounts, flows and decomposition of organic matter in a plateau soil bearing 540 t.ha^{-1} of living phytomass, in which a stem wood harvest of 15 t.ha^{-1} was followed one year later by a refinement during which 40 % of the phytomass was killed. Figure 6.11 presents the data of the simulation of organic matter pools (t.ha^{-1}) and flows (t.ha^{-1}.y^{-1}) in undisturbed forest and changes during exploitation and refinement. Figure 6.12 gives the nutrients in phytomass and soil organic matter before and after treatment (kg.ha^{-1}). The input data on phytomass are comparable to those presented in Table 6.3 except for the amount of roots, which Poels estimated higher. They were derived from an experiment in the direct vicinity of the MAIN experiment that is not discussed here.

The findings of this simulation study are (Figure 6.11 and 6.12):
- After harvest and before refinement litter amounts and nutrients in litter and soil were slightly higher in the treated western catchment area than in the untreated eastern catchment area.
- Even though 22 months after refinement litter amounts in the treated area increased further, the nutrient amounts in the litter had increased only slightly. Nutrient amounts in the soil had not increased at all, and even decreases were measured. Refinement did not cause significant changes in nutrient amounts in litter or soil. But as the number of living trees was reduced through refinement the amount of nutrients available for the remaining living trees was increases, pointing to a 'fertilizing effect'.
- In the three-year period after the harvest, there was an extra release from the litter of about 150 kg N, 900 kg Ca, 70 kg Mg, 400 kg K and 30 kg P per ha. These nutrients were not retained in the upper 120 cm of the soil.
- In case the vegetation after refinement has a higher mean nutrient concentration than the undisturbed vegetation, which is possible because of the increased production of fresh leaves and twigs combined with a larger nutrient supply than without treatment, the extra release of nutrients would have been less than the amounts quoted above.
- The simulation showed that the weight of the living phytomass reached its lowest level one year after refinement. The amounts of nutrients in living and dead phytomass were at their lowest levels about two years after refinement. The amount of total phytomass, both living and dead, was still decreasing four years after refinement.
- Almost two years after refinement, groundwater samples from auguring to a depth of 7.5 m in the treated catchment did not have higher concentrations of nutrients than groundwater samples from the untreated catchment area. It seems therefore that most of the extra nutrients released by refinement had already passed through the soil and the upper groundwater layers on their way to the creek where some will be extracted by the swamp vegetation.

From a comparison of the amounts of nutrients coming in by rain water and flowing out by the creek, it appeared that there was a net export from the catchment of Si, Na and Mg and a small net accumulation of Ca, K and P in the untreated catchment area of 9, 12 and 0.5 kg.ha^{-1}.y^{-1} respectively. In the treated catchment the accumulation was slightly

less. This means that of the large release of nutrients caused by treatment, only a very small proportion was exported by creek water, at least during the first two years after refinement. If evapotranspiration of the catchment had been reduced by the treatment, the difference in outflow would be somewhat larger.
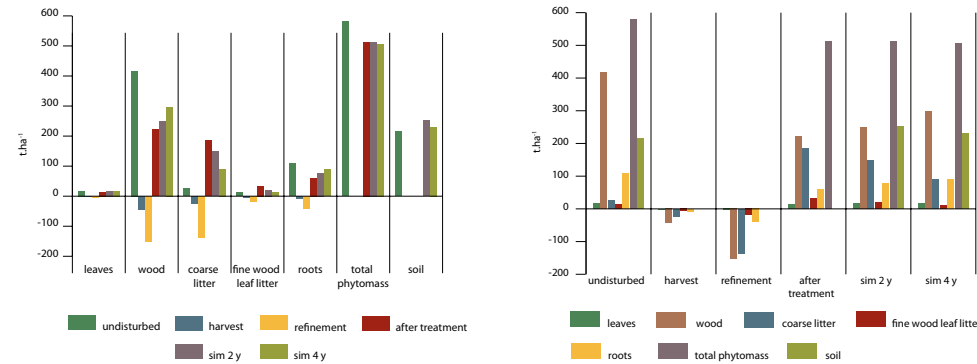

Figure 6.11.   Organic matter pools in undisturbed forest and simulated changes two and four years after exploitation and refinement. Adapted from Poels (1987).

Some considerations based on the above are:
Nutrients leaching to the groundwater can still be picked up by deep roots at several metres depth and probably can even be regained from the groundwater by such roots. A certain loss of nutrients from the plateau and upper slopes is still to be expected as a result of treatment. Nutrient enrichment of foot slopes and valley bottoms will then occur and only small amounts will leave the catchment via the creek water.

The main conclusion from Poels' results of the field experiments and the model output is that: "Forest treatment according to the CELOS Silvicultural System does not result in an unacceptable loss of nutrients from the system. Silviculture based on the natural forest on the brown loamy and sandy soils of the Zanderij formation, is a form of land use of which sustained yields can be expected. As this land use also leads to economic returns (De Graaf 1986), this or similar forest systems could also be of value in other parts of the tropical forest areas, where comparable conditions exist" (Poels 1987). Presently, the forest is not at equilibrium. The area was covered with savanna vegetation during the last glacial period and during that period the soil was intensively leached (see Schulz 1960). Since then, a gradual nutrient accumulation is taking place.

This conclusion is not undisputed, however. In a critical review on nutrient input-output budgets of tropical forest ecosystems analyzing methodological aspects, analytical problems and procedural deficiencies in computation of budgets, Bruijnzeel (1991) doubted that the Suriname forest indeed is accumulating calcium and potassium to such an extent as found by Poels. Bruijnzeel (1989, 1991) based his comment on the difficulties that were met in collecting and analyzing representative precipitation samples as well as the possibilities of unrecorded deep flow through the sandy valley fills.
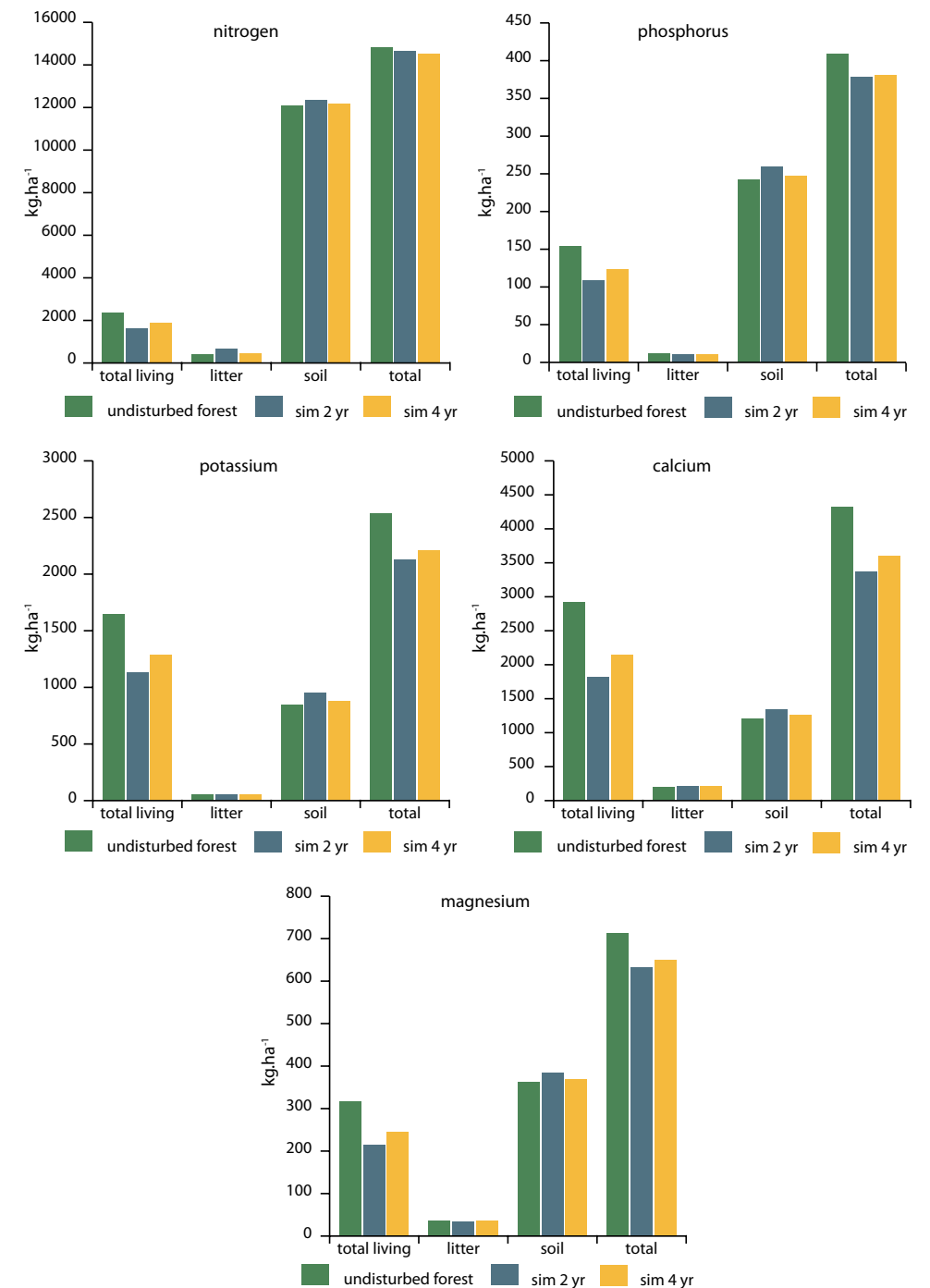

Figure 6.12.   Amounts of nutrients in phytomass and soil organic matter and simulated values two and four years after exploitation and refinement. (Source Poels 1987).

6.6 Carbon sequestration

From the dry-weight production data presented in Table 6.8, an impression of carbon accumulation can be obtained by converting these values into carbon content. In undisturbed forest in Kabo, the net increase in total living phytomass of 7.8 t.ha^{-1}.y^{-1} corresponded to an accumulation of 3.6 t.ha^{-1}.y^{-1} of carbon. In Akintosoela1, the net increase amounted to 1.6 t.ha^{-1}.y^{-1} of carbon accumulating, while in Weyerhäuser the net increase in carbon was 4.5 t.ha^{-1}.y^{-1}.

Table 6.10. Dry weight and carbon[1] stored in total living and dead phytomass in forest under the CMS. Source data see Figure 6.11 and Poels (1987).

	Total living phytomass		Total dead phytomass	
	Dry weight	carbon	Dry weight	carbon
	t.ha^{-1}	t.ha^{-1}	t.ha^{-1}	t.ha^{-1}
Undisturbed forest	542.5	**267.2**	38.1	**19.1**
after treatment (harvest and refinement)	294.7	**140.7**	218.5	**109.2**
Simulation two years after treatment	342.7	**165.7**	170.4	**85.2**
Simulation four years after treatment	403.4	**193.1**	102.6	**51.3**

1. Average carbon content factors used: leaves 41.5%, wood 47%, coarse and fine litter 50%, roots 52%. (Source Ajtay et al. 1979)

The simulated data from Figure 6.11 (MAIN experiment, source Poels 1987), allow the following observations (see Table 6.10): Four years after treatment there was an increase of 52.4 t.ha^{-1} carbon in living phytomass, or an accumulation (uptake out of the atmosphere) of 13.1 t.ha^{-1}y^{-1} of carbon. Dead phytomass (coarse and fine litter) increased due to treatment by 89.1 t.ha^{-1} of carbon. During the four years after treatment, it was diminished by 57.9 t.ha^{-1} as a result of decomposition, leading to an emission of 14.7 t.ha^{-1}.y^{-1} of carbon. Thus, there is not yet a net carbon accumulation in the system.

The situation will gradually change to a position whereby the net increase in phytomass will be greater that the decomposition, resulting in a net carbon sequestration. If we assume a same decomposition rate as in the first four years, which may be high, then it is possible that already after six to eight years after treatment the treated plots form a net sink for carbon. This net sequestering will take place till the forest reaches a steady state.

6.7 Discussion and conclusions

Harvest and refinement will, even if carried out carefully and with respect for the forest according to RIL and FSC instructions and regulations, damage the forest ecosystem. Harvested trees will be exported out of the forest and so will reduce the amount of phytomass and the nutrient capital. Also, harvest and refinement will kill and damage (parts of) trees and other plants. This phytomass will remain in the forest, however, and decompose over a considerable period of time. Leaves of the refined trees will fall within one year, augmenting the litter layer with some 50 %; small branches will become available within one or two years but thick branches will take longer and dead stems

can remain standing for at least ten years and maybe longer.

Directly after these interventions, the ecology of the forest is altered: more light will reach the under-storey of the forest at various places. The amount of water reaching the forest floor will increase due to changes in interception. Temperature conditions inside the forest will change too, as will the impact of strong winds. This will result in changes in species composition, as was discussed in Chapter 5, in timber growth, as was discussed in Chapter 4, and in growth in terms of phytomass and in nutrient cycling, as discussed in this Chapter.

Harvest and refinement reduce the amount of living phytomass. The findings presented above show that, as a result of our experimental treatments, harvesting and refinement lead to a substantial reduction of the living phytomass (compare Figure 6.13). A considerable proportion thereof is transformed, however, into dead phytomass and remains in the forest ecosystem. How large these proportions are depends on the intensity of the treatments, as can be concluded from a comparison of the data in Table 6.3. Due to the interventions the ecological conditions inside the forest change. But these conditions are mainly more favourable for growth than the conditions

Photo 6.3. Measuring fresh weight saw dust, Mapane 1982. (Photo P. Schimdt)

in the undisturbed forest: In the treated forest light, water and nutrient availabilities for the remaining trees are higher. The improved availability is higher soon after the interventions and then gradually decreases as the forest canopy restores itself. As the results from Procter's Forest, Akintosoela1 and Weyerhäuser show, the severity of the intervention has a considerable effect on regrowth. While the forest at Akintosoela1 gradually restored towards a forest somewhat similar to Procter's Forest, it is clear that a heavy refinement will postpone a total recuperation for a considerable period of time. And the intervention at Weyerhäuser was so severe that pioneers could massively establish and they changed the character of the forest substantially, so that recuperation to somewhere similar to the undisturbed forest is a very long-term and complex process. Nevertheless, based on our results we tend to conclude that, due to the interventions, the growing potential of the tropical rain forest ecosystem at Mapane is not damaged by the first harvest and first refinement as prescribed in the CMS system. However, a second refinement and a second harvest have not yet been carried out, and therefore our conclusion remains preliminary.
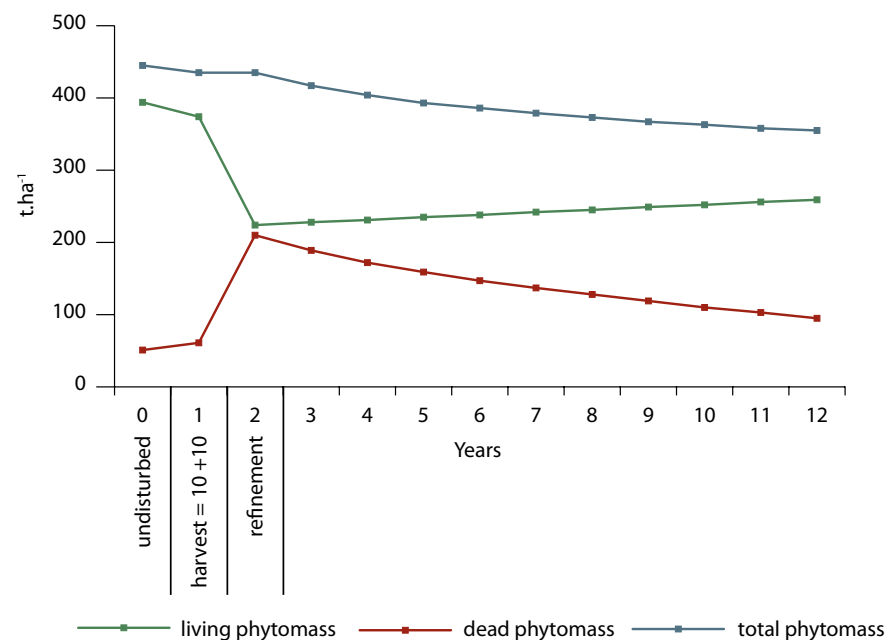
Figure 6.13. Prediction of development of living, dead and total above ground phytomass (dry weight) in the forest stand Akintosoela1 under the CMS.
Assumptions:
Undisturbed forest: Procter's Forest, see Table 6.3.
Harvest: 10 t.ha^{-1} exported from stand, 10 t.ha^{-1} damaged.
Refinement: 40% of living phytomass killed.
Growth: 3.5 t.ha^{-1}.y^{-1} (see Table 6.8: Akintosoela1) over ten years.
Decomposition rate: year 3 10%, year 4 9%, year 5 8%, year 6 and following years 7%.

In this whole process nutrients play a key role. As in many other tropical rain forest ecosystems, in Suriname the soils are poor, notably in phosphorus and magnesium (see Table 6.2) and nutrients liberated from the dead phytomass in the decomposition process can leach, if uptake by the vegetation is slower than the release.

Nitrogen is available in abundance, though it is present in much larger quantities in the soil than in the phytomass (Tables 6.2 and 6.6). Moreover, legumes, of which some species may develop symbioses with nitrogen-fixing bacteria (Pons et al. 2007), form an important part of the forest vegetation (see Table 5.3). Altogether, we expect no problems with regard to the nitrogen availability in these types of forest under CSM application. Phosphorus is available in the systems under study, as elsewhere in the region, in minimal amounts (Table 6.2 and Poels 1987). Poels (1987) found, during the first years after treatment, no extra discharge of phosphorus in creek water in a basin where harvest and refinement were carried out. However, in acid soils extractable (soluble) P, which usually is considered the phosphorus that is readily available for rapid plant uptake, is often a very small percentage of the total P. The ratio of relatively soluble and insoluble forms of P in the soil might be affected by the CMS. Thus, the small amounts indicate that phosphorus is a weak link in the nutrient cycle, and should be monitored whenever the CMS is applied.

Potassium is a highly mobile element, and it was, according to Poels (1987), leached out of the system in 'relatively large amounts'. This occurred mainly during the first year after refinement; in the second year outflow reached more or less normal levels again.

Though a substantial amount of Calcium is present, compared to other elements a large amount (80 %) is bound in wood and coarse litter, the decomposition of which is slow. On the other hand, the presence of high amounts of Calcium in the soil does not guarantee a high availability. Often, only a small percentage of total Calcium is exchangeable, i.e. available for plants and it is prone to leaching. Poels (1987) found an extra outflow of calcium due to refinement up to two years after treatment (see also Jordan 1989).

Magnesium, like phosphorus, is present in relatively small amounts only. Poels (1987) found no clear effect on the outflow of this element due to refinement. Nevertheless, this element should be monitored carefully too.

In the first three years after treatment there is a "fertilizer effect" through increased decomposition of mainly leaves and fine litter falling from the refined trees. These components have the highest nutrient contents, and their release stimulates growth of the vegetation. In this period chances of leaching are high. Nutrient concentrations in wood are much lower than those of leaves, and decomposition of wood and coarse litter is much slower. Therefore, the amount of nutrients, released per unit material per unit of time, is less (see Table 6.6). Only at a later stage of regrowth nutrients released by decomposing wood begin to play a minor role.

An aspect which has not been studied in the CMS experiments is their impact on the presence of mycorrhizae. Root-mycorrhizae symbioses are adaptations to low nutrient conditions, and play an important role in the prevention of leaching. Refinement, that results in killing their host plants, may kill mycorrhizae, resulting both in nutrient losses and in diminished uptake capacity. A rapid and strong development of fine roots and associated mycorrhizae at the soil surface soon after harvest and refinement will minimise losses of nutrients.

At the long term it appears that, as from three years after refinement, the total aboveground phytomass remains more or less constant (Figure 6.13). This does not hold automatically for the nutrient content too. Moreover, the CMS cycle may include a second refinement ten year after the first one and should lead to a second harvest after 25 years. This was not executed in the present CSM study. Thus, even if the results of the first interventions as prescribed in the CMS look promising, it remains to be seen that the growing potential of the forest as indicated by phytomass and nutrient content will stay at the same level. Proper ecological monitoring of any practical application of the CMS is therefore recommended.

References

Ajtay, G.L., Ketner, P. & Duvigneaud, P. 1979. Terrestrial primary production and phytomass. In: Bolin, B., Degens, E.T., Kempe, S. & Ketner, P., (eds.). The global carbon cycle. Scope 13. John Wiley, Chichester UK, pp. 129-181.

Boerboom, J.H.A. 1964. De natuurlijke regeneratie van het Surinaamse mesofytische bos na uitkap. Landbouwhogeschool, Wageningen, The Netherlands.

Boerboom, J.H.A. 1970. Ecologie. CELOS kwartaalverslagen 16, 64-70.

Boxman, O., De Graaf, N.R., Hendrison, J., Jonkers, W.B.J., Poels, R.L.H., Schmidt, P. & Tjon Lim Sang, R. 1985. Towards sustained timber production from tropical rain forests in Suriname. Netherlands Journal of Agricultural Sciences 33, 125-132.

Boxman, O., De Graaf, N.R., Hendrison, J., Jonkers, W.B.J., Poels, R.L.H., Schmidt, P. & Tjon Lim Sang, R. 1987. Forest land use in Suriname. In: Van Beusekom, C.F., Van Goor, C.P. & Schmidt, P. Wise utilization of tropical rain forest lands. Tropenbos Scientific Series 1. Tropenbos, Ede, The Netherlands, pp. 119-129.

Bruijnzeel, L.A. 1989. Moist tropical forest nutrient cycling, the hydrological framework. In: Proctor, J. (ed.). Mineral nutrients in tropical forest and savanna ecosystems. Blackwell Scientific Publications, Oxford, pp.383-416.

Bruijnzeel, L.A. 1991. Nutrient Input-Output Budgets of Tropical Forest Ecosystems, A Review. Journal of Tropical Ecology 7, 1-24.

De Graaf, N.R. 1986. A silvicultural system for natural of tropical rain forest in Suriname. Ecology and management of tropical rain forest in Suriname, I. PhD Thesis, Agricultural University Wageningen, The Netherlands 250 pp.

De Vries, P.G. 1973. A general theory on line intersect sampling with application to logging residue inventory. Mededelingen Landbouwhogeschool Wageningen 73 (11), 1-23.

De Vries, P.G. 1979. Line intersect sampling, statistical theory, application and suggestions for extended use in ecological inventory. In: Cormack, R.M, Patil, G.P. & Robson, D.S. (Eds.). Sampling biological populations. Statistical ecology series, pp. 1-70.

Golley, F.B., McGinnis, J.T., Clements, R.G., Child, G.I. & Duever, M.J. 1975. Mineral cycling in a tropical moist forest ecosystem. University of Georgia Press, Athens, USA. 248 pp.

Grubb, P.J. & Edwards, P.J. 1982. Studies of mineral cycling in a montane rainforest in New Guinea: III The distribution of mineral elements in the above-ground material. Journal of Ecology 70, 623-648.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in a tropical rain forest in Suriname. Ecology and management of tropical rain forest in Suriname, III. PhD Thesis, Agricultural University, Wageningen. The Netherlands, 172 pp.

Jonkers, W.B.J. & Schmidt, P. 1984. Ecology and timber production in tropical rainforest in Suriname. Interciencia 9, 290-297.

Jonkers, W.B.J, Tjon, K. & Wirjosentono, J. 2005. Long-term changes in selectively logged and silviculturally treated tropical rain forest in Suriname, analysis of the 1978-2000 data of Experiment 78/5. Internal report. CELOS, Paramaribo, Suriname and Wageningen University, Wageningen, The Netherlands.

Jordan, C.F. (ed.), 1989. An Amazonian rainforest. The structure and function of a nutrient stressed ecosystem and the impact of slash-and-burn agriculture. Man and biosphere Series volume 2, Unesco and the Parthenon Publishing Group, Paris, France and Carnforth, UK. 176 pp.

's Landsbosbeheer, 1971. Jaarverslag 1969. Paramaribo, Suriname.

Mason, C.F. 1976. Decomposition. Studies in biology, 74. Edward Arnold, London, United Kingdom. 38 pp.

Ohler, F.J.M. 1980. Phytomass and mineral content in untouched forest. CELOS Rapporten 132, CELOS, Paramaribo, Suriname.

Poels, R.L.H. 1987. Soils, water and nutrients in a forest ecosystem in Suriname. Ecology and management of tropical rain forest in Suriname, II. PhD Thesis, Agricultural University Wageningen, The Netherlands, 253 pp.

Pons, T.L., Perreijn, K., van Kessel, C. & Werger, M.J.A. 2007. Symbiotic nitrogen fixation in a tropical rainforest: 15N natural abundance measurements supported by experimental isotopic enrichment. New Phytologist 173, 154-167.

Schmidt, P. 1981a. Productie ecologie. CELOS kwartaalverslag 59 (1981-III), pp. 11-16.

Schmidt, P. 1981b. Productie ecologie. CELOS Kwartaalverslag 60 (1981-IV), pp. 12-19.

Van der Steege, J.G. 1983a. Strooiselafbraak in vier verschillende bosopstanden. Exp. 82/9 Research report, typoscript. 31 p. + Annexes.

Van der Steege, J.G. 1983b. Bladproductie en bladfytomassa van een aantal palmsoorten van het tropisch regenbos van Suriname. CELOS reports no. 138, 33 pp. + Annexes.

Vink, A.T. 1977. Surinam timbers. State Forest Industries, Paramaribo, Suriname, 253 pp.

7   Impacts on the terrestrial fauna

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7.1   Introduction

Ideally the CELOS Management System (CMS) should offer the best of both worlds: the sustainable harvest of native timber tree species in a tropical rainforest environment, and the maintenance of the ecological integrity of this environment. Sustainable timber harvest remains the primary goal of the CMS, however. This is an economic goal with associated social goals, e.g. employment and other benefits for people living in remote areas. An important question that needs to be addressed is to what extent a CMS that achieves its economic goal, also achieves its ecological goal. Conservation organisations such as the WWF correctly point out that the fate of biodiversity in general, and threatened species in particular, will largely depend on what happens to them and their habitats outside of protected areas, e.g. in extensive forestry concessions. It is therefore relevant to assess whether or not the CMS results in a type of forest that satisfies the habitat requirements of the native fauna, and whether threatened animal species will find some form of refuge there. In this chapter information is provided on what is known of the impact of the CMS and similar types of disturbance due to logging on the terrestrial fauna.

7.2   Background

The socio-economic challenge to the foresters who developed the CMS from the 1960s to 1980s was to come up with a system that would allow regular timber harvests, but would only require a modest labor force and limited capital investment. As explained in earlier chapters, the silvicultural challenge to the foresters was to somehow enhance the natural regeneration of commercially interesting trees in the existing, 'natural' forests. The concept they came up with was to redirect the flow of energy and nutrients to a pre-selected subset of tree species with commercial value as timber, to the detriment of trees without such commercial value (non-timber trees). The basic concept of the CMS was and still is selective logging with low collateral damage, and the application of silvicultural treatments. The most critical treatment is the 'refinement' of tree stands, i.e. the systematic killing of mature non-timber trees.

For the CMS to work, natural forest regeneration processes must be kept up and running, such as pollination, seed dispersal, seedling germination and growth, etc., at least as regards timber trees. In the initial version of the CMS, the mere maintenance of forest cover was considered adequate to maintain these processes at the required level. In later versions, additional provisions were made to maintain or enhance the regeneration of timber trees, such as leaving enough mature timber trees to function as parent trees (reproductive function). Another provision added was to restrict hunting, which was originally proposed as a general measure to maintain ecosystem integrity and conserve globally threatened animals (see below).

Photo 7.1. *Alouatta macconnelli* - Guianan Red Howler Monkey. (Photo P. Ouboter)

The importance of this provision has become increasingly clear in recent decades, as a result of research that demonstrated the effectiveness of rainforest animals, including game species, as dispersers of many timber tree species. A few cases in point, relevant to Suriname, are: i) in French Guiana, seeds of *Carapa* spp. (Jansen & Forget 2001) and *Voucapoua americana* (Forget 1994) are dispersed by agoutis, and are largely dependent on these to germinate successfully; ii) *Virola* spp. seeds are dispersed primarily by the Guianan Spider Monkey *Ateles paniscus* and toucan species in French Guiana (Ratiarison 2003, unpublished thesis: chapter II), with e.g. agoutis functioning as secondary dispersers (Forget et al. 2000), and iii) *Tetragastris altissima* is dispersed by a variety of birds and primates in French Guiana (Ratiarison & Forget 2005), and by the Yellow-footed Tortoise *Chelonoides* (= *Geochelone*) *denticulata* in the Brazilian Amazon (Jerozolimski et al. 2009).

In Suriname, fauna studies were implemented in two areas where the CMS had been experimentally applied between the early 1970s and 1980s (see Chapter 5, e.g. Table 5.1):

- at Akintosoela, an area with mixed high dryland forest on undulating land with loamy soil (see De Graaf 1986); fauna studies took place in the Akintosoela1 forest stand, which had been both logged (in 1966 and 1974) and refined (1975), and the Procter's Forest stand, which had been selectively logged only (1966 and 1974); and

- at Kabo, an area with mixed high dryland forest on a low sandy-loamy plateau (see Jonkers 1987); fauna studies took place in a forest stand called the MAIN Experiment, which includes plots that had been left undisturbed, had been selectively logged only (in 1978), and had been both logged (1978) and refined (in the course of 1982-83); the studies also took place in the dryland part of a nearby undisturbed forest stand called the Van Leeuwen Transect.

Below, the results of the CMS-related fauna studies will be reviewed, and discussed in the light of comparable studies that have taken place in Amazonia. Based on this discussion, an attempt will be made to assess the impact of the CMS on the fauna.

7.3 Studies in Suriname on the impact of the CMS on the fauna

7.3.1 Impact on birds

In 1980-81, ornithological research was undertaken in the Akintosoela area. At two forest stands, Procter's Forest and Akintosoela1, birds were captured with mist nets, identified, tagged and subsequently released (De Jong 1982). Both stands had been logged (in 1966 and 1974), and the Akintosoela1 stand had in addition been refined in 1975 (see also Fig. 5.4). The aim of the research was to investigate the impact of refinement on the avifauna of logged forest. The total number of bird captures at both stands was virtually identical, as was the total number of bird species captured (Table 7.1). De Jong (1982) claims that there is a striking difference between the two forest stands when the data is analysed at the functional group level. He groups the bird species into four functional categories based on what he calls habitat preference, in fact preference for forest that has been subject to different levels of disturbance: i) bird species preferring primary forest (undisturbed), ii) secondary forest (disturbed), iii) bird species without such preference, and iv) with unknown preference. Compared to Procter's Forest, Akintosoela1 had about twice the number of captures and species

Photo 7.2. *Pipra erythrocephala* caught with mist net. (Photo B. O'Shea)

of birds that prefer secondary forest, but only about half the number of captures and species of birds that prefer primary forest. De Jong (1982) also analyzed his data by categorizing the bird species in groups based on food preference, but this did not reveal any striking differences between the two forest stands.

Table 7.1. Summary of the results of ornithological research by De Jong (1982) at Akintosoela, Suriname.

Forest stand	total	preferring primary forest	no preference	preferring secondary forest	preference unknown
number of bird captures					
Proctor's Forest	185	28	108	26	1
Akintosoela1	180	9	95	54	1
number of bird species captured					
Proctor's Forest	49	13	27	8	1
Akintosoela1	55	7	27	20	1

De Jong's (1982) results are in line with the expectation that increased forest disturbance due to refinement results in a bird fauna with fewer species that are typical of undisturbed forest and more species that are typical of disturbed forest. More importantly, the results suggest that this increased disturbance effect persists for at least five years. It should be noted that the refinement at Akintosoela1 had been quite intense compared to some of the refinements that were applied later in the Kabo area.

7.3.2 Impact on invertebrates / arthropods

In 2000-2001 a series of parallel studies on the ecological impact of the CMS were undertaken in the Kabo area (NZCS and BBS 2001), including studies on arthropods (De Dijn 2001a). Sampling and data recording took place at 1 ha plots that were part of the MAIN Experiment forest stand, and at a 1 ha plot that was part of the Van Leeuwen Transect stand (De Dijn 2001c). The Van Leeuwen Transect stand and part of the MAIN Experiment stand had remained undisturbed till the research took place; other parts of the MAIN Experiment stand had been both logged (in 1978) and refined (in 1982-83), or had been logged only. The aim of the arthropod studies was to investigate the impact of forest disturbance by logging and refinement on the abundance and species richness of a variety of arthropod groups. Sampling took place in the following 1 ha plots[1]:

- three plots in the MAIN Experiment stand that had been both logged (ca. 30 $m^3.ha^{-1}$) and refined (non-timber trees with dbh > 30 cm poison-girdled), with the original treatment code E23-SR18 (Jonkers 1987; original plot numbers 15, 17 and 36);
- three plots in the MAIN Experiment stand that had been logged only (ca. 30 $m^3.ha^{-1}$), with the original treatment code E23-S0 (plot numbers 14, 26 and 38); and
- two undisturbed control plots, one in the MAIN Experiment stand (original "virgin forest plot" number 41), and one in the Van Leeuwen Transect stand (plot established in 2000, and assigned number 51).

The main study targeted terrestrial arthropods that walk and fly near the soil surface, and can be captured in a standardized manner by means of pitfalls and yellow pots placed at ground level (De Dijn 2001a). Arthropods were sampled in August 2000 by means of these traps (nine traps of each type per plot). Trap contents were conserved, and in the lab the arthropods were sorted out and identified at group level (a total of 31 966 arthropod individuals were collected by means of pitfalls and 10371 by means of yellow pots). The main groups were: Scolytidae (bark beetles), other Coleoptera (beetles), Phoridae (phorid flies), other Diptera (flies, mosquitos, etc.), Formicidae (ants), other Hymenoptera (wasps, bees, etc.), Collembola (springtails), Orthoptera (grasshoppers, roaches, etc.), and Araneae (spiders). The bulk of the individuals collected belonged to these groups, and only these data were used for further analysis. Per individual trap and

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1   these same plots were used for the parallel studies on forest habitat structure (De Dijn 2001b) , tree diversity (Raghoenandan 2001), and amphibians and reptiles (see below).

group, the number of (adult) individuals and species trapped (in fact morphospecies[2]) was counted. These counts served as the basic abundance (A) and species richness (R) data for analysis by means of ANOVA[3]. Two types of ANOVAs were run to deal with an imbalance in the design of Jonkers' (1987) experiment[4]:

- "Full ANOVAs" using data on all treatments, with treatment as fixed factor (three levels: S = silviculturally treated (refined) and logged, L = logged only, and C = control (undisturbed)), and replicate block as random factor (2 blocks only: n°. 1 & 3); and
- "Partial ANOVAs" using only the data on S and L treatments, with treatment as fixed factor (2 levels: S and L), and replicate block as random factor (3 blocks: n°. 1, 2 & 3).

A meta-analysis of the significance of the many ANOVA results is done here: the actual number of significant results per series of ANOVAs is compared with the number of significant results expected based on chance[5].

An overview of the results of these ANOVAs and of the meta-test results is provided in Table 7.2. The results regarding the fixed factor of the Full ANOVAs (see Table 7.2.a and c) show that there is no evidence of significant, consistent differences in the abundance and species richness of arthropod groups between forest that had been both silviculturally treated (refined) and logged, forest that had been logged only, and undisturbed forest. The results regarding the interaction between fixed and random factors do suggest that there was one significant, but inconsistent difference (as to Orthoptera abundance; cf. Table 7.2.c). However, the meta-test results suggest that this ANOVA test result is likely due to chance.

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2   supposed species, differentiated on the basis of differences in shape, size, colour and texture of external body parts; morphospecies (a,k.a. operation taxonomic units; OTU) is a species concept typically used in ecological studies when species-rich groups are studied whose taxonomy is imperfectly known, or when limited expertise is available to identify the species.

3   in principle, the independent ANOVAs based on abundance (A) data in relation to the different groups was one series of tests, and the same based on species richness (R) data was another series; in practice, there were four series of ANOVAs because two types of traps were used, each resulting in A and R data for the different arthropod groups; an individual ANOVA was only performed if the dataset to be entered in the ANOVA passed a Kolmogorov-Smirnov (KS) test of normality.

4   Jonkers' MAIN Experiment incorporated a threefold replication (three replicate blocks), and included three (undisturbed) control plots (numbers 41, 42, 43); however, the location of all these control plots next to one of the blocks, and next to one another, made them pseudo-replicates; one additional control plot was added a posteriori in the form of plot 51, but a third one could not be established due to the widespread disturbance of the Kabo area.

5   based on binomial probabilities [p = 0.05; q = 0.95] for series of ANOVA test results obtained at significance level p = 0.05, and binomial probabilities [p = 0.01; q = 0.99] for results obtained at p = 0.01; cf. Sokal & Rohlf (1995: p. 686-7).

Table 7.2. Overview of the results of series of ANOVAs to determine if logging and refinement in the Kabo area (Suriname) had a significant impact on the abundance (A) and species richness (R) of a range of arthropod groups, based on samples taken by means of pitfall and yellow pot traps (De Dijn 2001a); including meta-test results (based on binomial probabilities) to assess if the number of significant test results per series of ANOVAs is significant.

A and R data was tested for normality using Kolmogorov-Smirnov tests. ANOVAs were only performed for those groups whose data passed this test (i.e. groups listed in the "arthropod groups" row). In case of significant differences in A or R (between treatment levels or replicate blocks), level of significance (p) is indicated with * (p = 0.05) or ** (p = 0.01); the nature of significant differences is indicated with < or > signs; the ~ sign is used to indicate differences that are not significant.

a. Full ANOVAs based on pitfall trap data, with treatment as fixed factor (S = silviculturally treated (refined) and logged, L = logged only, and C = control (undisturbed)), and replicate block as random factor (blocks no. 1 & 3).

	abundance (A)		species richness (R)	
arthropod groups	10: Scolytidae, other Coleoptera, Phoridae, other Diptera, Hemiptera, Formicidae, other Hymenoptera, Orthoptera, Collembola, Araneae		7: Scolytidae, other Coleoptera, Phoridae, other Diptera, Hemiptera, Formicidae, other Hymenoptera	
	groups for which differences in A or R were significant, based on ANOVA test results			
fixed factor	(none significant)		(none significant)	
random factor	(none significant)		(none significant)	
interaction	Orthoptera* C~S>L at 1; C~S<L at 3		(none significant)	
	probability that the observed number of significant ANOVA test results is due to chance			
	ANOVA p = 0.05 (*)	**ANOVA p = 0.01 (**)**	**ANOVA p = 0.05 (*)**	**ANOVA p = 0.01 (**)**
fixed factor	0.60	0.90	0.60	0.90
random factor	0.60	0.90	0.60	0.90
interaction	0.40	0.90	0.40	0.90

b. Partial ANOVAs based on pitfall trap data, with treatment as fixed factor (S and L), and replicate block as random factor (blocks no. 1, 2 & 3).

	abundance (A)		species richness (R)	
arthropod groups	10: same as in a. (see above)		7: same as in a. (see above)	
	groups for which differences in A or R were significant, based on ANOVA test results			
fixed factor	(none significant)		(none significant)	
random factor	Scolytidae* 1>2~3		other Hymenoptera* 1~2>3	
interaction	Phoridae* L~S at 1 and 2; L>S at 3 Collembola* L~S at 2 and 3; L>S at 2		(none significant)	
	probability that the observed number of significant ANOVA test results is due to chance			
	ANOVA p = 0.05 (*)	**ANOVA p = 0.01 (**)**	**ANOVA p = 0.05 (*)**	**ANOVA p = 0.01 (**)**
fixed factor	0.60	0.90	0.60	0.90
random factor	0.40	0.90	0.40	0.90
interaction	0.09	0.90	0.60	0.90

c. Full ANOVAs based on yellow pot trap data, with treatment as fixed factor (S, L and C), and replicate block as random factor (blocks no. 1 & 3).

	abundance (A)	species richness (R)
arthropod groups	6: Scolytidae, other Coleoptera, Phoridae, other Diptera, other Hymenoptera, Collembola	5: Scolytidae, other Coleoptera, Phoridae, other Diptera, other Hymenoptera
	groups for which differences in A or R were significant, based on ANOVA test results	
fixed factor	(none significant)	(none significant)
random factor	Scolytidae* 1>3 other Diptera** 1>3	Phoridae* 1>3 other Diptera* 1>3 other Hymenoptera* 1>3
interaction	Orthoptera* C~S>L at 1; C~S<L at 3	(none significant)
	probability that the observed number of significant ANOVA test results is due to chance	
	ANOVA p = 0.05 (*)	ANOVA p = 0.01 (**)	ANOVA p = 0.05 (*)	ANOVA p = 0.01 (**)
fixed factor	0.73	0.94	0.77	0.95
random factor	0.03	0.06	0.01	0.95
interaction	0.26	0.94	0.94	0.95

d. Partial ANOVAs based on yellow pot trap data, with treatment as fixed factor (S and L), and replicate block as random factor (blocks no. 1, 2 & 3).

	abundance (A)	species richness (R)
arthropod groups	6: same as in c. (see above)	7: same as in c. (see above)
	groups for which differences in A or R were significant, based on ANOVA test results	
fixed factor	(none significant)	Phoridae** L<S
random factor	other Diptera** 1~2>3	Phoridae** 1~2>3
interaction	Scolytidae* L~S at 1; L<S at 2; and L>S at 3 Collembola* L~S at 1 and 2; L>S at 3	(none significant)
	probability that the observed number of significant ANOVA test results is due to chance	
	ANOVA p = 0.05 (*)	ANOVA p = 0.01 (**)	ANOVA p = 0.05 (*)	ANOVA p = 0.01 (**)
fixed factor	0.73	0.94	0.77	0.05
random factor	0.26	0.06	0.77	0.05
interaction	0.03	0.94	0.94	0.95

The results of the Partial ANOVAs (Table 7.2.b and d) do point at a significant, consistent difference in Phoridae species richness (based on sampling by means of yellow pot traps) between forest that had been both refined and logged, and forest that had been logged only. This ANOVA result is not likely due to mere chance (see meta-test result in Table 7.2.d), and it would thus seem that there were indeed more Phoridae species in forest that was both refined and logged than in forest that was logged only. There was also evidence of significant, but inconsistent differences (e.g. not significant in all replicate blocks), such as in the abundance of Scolytidae and Collembola that were sampled with yellow pot traps.

The results regarding the random factor in the ANOVAs (especially those based on samples obtained with yellow pot traps; Table 7.2.c and d) are evidence that there were significant, consistent differences in the abundance and species richness of a number of arthropod groups between the replicate blocks.

Summarizing, the ANOVAs and meta-tests provided no evidence of consistent differences in arthropod abundance or species richness between the undisturbed control plots and the disturbed plots, and little evidence of such differences between forest disturbed due to both refining and logging, and forest disturbed due to logging only. The differences that were observed were mostly inconsistent, co-dependent on a 'random' factor. We assume that this random factor is linked to abiotic and biotic (e.g. vegetation) characteristics that vary independently of disturbance due to logging and refinement. A straightforward explanation for the limited detection of effects of logging and refinement on the arthropod fauna at Kabo may be the modest intensity of the experimental disturbance, and the 20 years of time between this disturbance and the fauna studies, time that in all likelihood has allowed the forest and its arthropod fauna to recover.

As part of the arthropod studies, butterflies were also studied at Kabo, using a sampling protocol that involved the sighting and capturing of butterflies that were active in the forest understorey. Butterflies were captured along trails in the plots with sweep nets; this took place around noon when butterfly activity peaked. A first round of observations and sampling took place in September 2000, and a second (replicate) round in October 2000. Butterflies were assigned to morphospecies, and to the extent possible were identified with their scientific species names. Virtually all belonged to the families Nymphalidae, Pieridae, Hesperiidae, and Lycaniidae; only the data on species belonging to these families was used for further analysis (66 specimens belonging to 29 species collected in September, 120 specimens belonging to 57 species in October 2000).

Using the Jaccard and Sørensen similarity indices (see Krebs 1989), butterfly fauna comparisons were made between the differently treated plots (both refined and logged, logged only, and undisturbed) within each replicate block. The results of these comparisons (Table 7.3) do not provide overwhelming evidence of consistent differences in butterfly fauna between patches of forest that had been treated differently. Nevertheless, based on the more qualitative Jaccard index, one could cautiously conclude that the butterfly fauna of forest at Kabo that had been both logged and refined, differed more from that of undisturbed forest than it differed from that of forest that had been logged only. Caution with the interpretation of these results is warranted, since the size of the butterfly samples was modest.

Table 7.3. Comparison of butterfly fauna samples obtained in the Kabo area (Suriname) in forest plots that differed in terms of treatment (S = silviculturally treated (refined) and logged, L = logged only, and C = control (undisturbed)), using the Jaccard (S_j) and Sørensen (S_s) similarity indices (De Dijn 2001a).

	pairs of plots compared	September 2000 sampling		October 2000 sampling	
		Sj	Ss	Sj	Ss
replicate block 1	C and L	0.15	0.18	0.06	0.07
	C and S	0.11	0.13	0.08	0.08
	L and S	0.13	0.40	0.25	0.40
replicate block 3	C and L	0.00	0.00	0.15	0.23
	C and S	0.00	0.00	0.04	0.13
	L and S	0.38	0.50	0.06	0.06
replicate block 2	L and S	0.25	0.38	0.14	0.18

7.3.3 Impact on amphibians and reptiles

Parallel to the arthropod studies, a study of amphibians (Amphibia) and reptiles (Reptilia) was also undertaken at Kabo (Ouboter & Sahdew 2001). The amphibians and reptiles targeted were those that could be sighted and sampled in the understorey. Observations and the collecting of voucher specimens took place during both day and night, in both the wet season (August 2009) and the dry season (Ocotober 2009). Amphibians and reptiles encountered were identified in the field with their scientific names; identities were checked in the lab based on voucher specimens. A total of 63 Amphibia and Reptilia individuals, belonging to 26 species, were observed during the rainy season, and 75 individuals, belonging to 19 species, during more extensive sampling in the dry season (Table 7.4). Observations took place in most of the plots mentioned earlier (see 7.3.2), as well as outside these plots, along roads and trails leading to them. Both wet and dry season observations were realized only at plots 41 (control; undisturbed), 14 (logged only), and 15 (both logged and refined).

Table 7.4. Results of observations of amphibians (A) and reptiles (R) in the Kabo area (Suriname) in forest plots that differed in terms of treatment (S = silviculturally treated (refined) and logged, L = logged only, and C = control (undisturbed)), and outside these plots (0).

	wet season (August 2009)				dry season (October 2009)						
	0	C	L	S	0	C	L	S	C	L	S
		plot 41	plot 14	plot 15		plot 41	plot 14	plot 15	plot 51	plot 38	plot 36
number of individuals observed											
Amphibia (A)	18	5	2	1	10	2	8	3	4	1	7
Reptilia (R)	18	8	5	6	10	9	3	7	6	3	3
A & R combined	36	13	7	7	20	11	11	10	10	4	10
number of species observed											
Amphibia (A)	9	4	2	1	6	2	5	3	2	1	4
Reptilia (R)	9	8	4	2	8	5	2	4	4	1	2
A & R combined	18	12	6	3	14	7	7	7	6	2	6

The main aim of the analysis of the Amphibia and Reptilia data was to assess if there were significant differences in species richness between differently treated patches of forest. The analysis was problematic, however, due to the low numbers of individuals observed in the field. Nevertheless, using a G test of independence (Sokal & Rohlf 1995), a significant difference (p = 0.05 level) in combined Amphibia + Reptilia species richness was observed, based on data obtained in the wet seasons at plots 41, 14 and 15: the undisturbed plot had more species than the plot that had been logged only, and this one had more species than the one that had been both logged and refined. A note of caution is again warranted because of the small sample size, and because data from the dry season and from other plots does not confirm this.

Based on their observations, Ouboter & Shadew (2001) also pointed out that:
- six of the species (1 amphibian, 6 reptiles) that were recorded in undisturbed plots (C), were not recorded in any of the disturbed plots (L and S); this includes the Collared Tree Lizard *Plica plica* and the Amazon *Gecko Coleodactylus* amazonicus, which they considered species that prefer undisturbed forest; and
- the plots that were both logged and refined were particularly poor in species, and not a single species was unique to these plots.

Ouboter & Sahdew (2001) concluded that there likely has been a local decrease in species richness of amphibians and reptiles at Kabo (particularly of species typical of undisturbed forest) as a result of logging and refining. They observe that in general the Amphibia and Reptilia fauna at Kabo is poor in species, and consists mostly of species that are adaptable opportunists. Given these characteristics of this fauna, they considered it likely that it can withstand the kind of disturbance caused by logging and refinement.

A very recent study by Landburg et al. (in prep.) investigated the possible recovery of the amphibian community in the Kabo area, 30 years after the CMS experiment had taken place there. Heavily logged plots (46 m³.ha⁻¹) and control plots (virgin forest) that were part of Jonkers' (1987) MAIN experiment were studied in 2010, both in terms of forest habitat and amphibian community. It is impossible to assess the actual recovery of the amphibian community of the logged plots due to a lack of data on that community from before the CMS experiment took place in the 1980s. Nevertheless, based on general habitat characteristics, and the data from the control plots, a baseline can be developed of the composition of the amphibian community that must have occurred there. The preliminary conclusions of this study are that 30 years after logging: i) the habitat structure between the two types of plots differed, but ii) amphibian diversity did not differ significantly.

Photo 7.3. *Ameerega trivittata* - Three-striped poison frog. (Photo P. Ouboter)

7.4. Impact of the CMS on the fauna in the light of results of studies elsewhere in the region

7.4.1 Impact on birds

In a recent review on the impact of forestry on tropical birds De Iongh & Van Weerd (2006) concluded that overall bird abundance and species richness may decrease, increase or stay the same as a result of logging. Whether or not an overall effect is observed seems to depend very much on the context, such as 'time since logging' (the time between logging and the study of the fauna). Specific functional groups of bird, such as certain feeding guilds, seem to respond consistently to disturbance due to logging. One guild, the insectivores, always seems to be negatively affected by logging, at least in terms of abundance and species richness. The explanation thereof may lie in a logging-induced decrease in the habitat that is most preferred by many insectivorous birds for foraging, namely continuous forest with an open understorey and closed canopy. Nectarivores and frugivores, on the other hand, were often found to increase in abundance after logging, presumably because forest disturbance favours lianas and herbs, many of which produce abundant food for birds, mainly nectar and berries. These conclusions by De Iongh & Van Weerd (2006) are in agreement with, and in part based on, results of studies in French Guiana[6] (Thiollay 1992, 1999).

Near Manaus (Central Amazonia), Guilherme & Cintra (2001) found that edge and gap-specialist insectivores and nectarivores benefited from selective logging, but only at locations where logging had taken place recently (significant effects recorded in plots logged four years before the bird study, but not in plots logged ten years before). At these locations, the intensity of logging (13 to 25 m^3 timber .ha^{-1} felled) did not appear to modify the impact on birds, nor did silvicultural treatments (frill-girdling). At the lower Rio Tapajos, in Eastern Amazonia, forest plots subject to Reduced Impact Logging (RIL; 18.7 m^3 timber .ha^{-1} felled) were studied about 1.5 years after logging (Wunderle et al. 2006). Here, in the logged forest plots, higher numbers of insectivorous, nectarivorous, and frugivorous birds were recorded than in the unlogged control plots. At three locations near Belém do Para (Eastern Amazonia), selective logging (RIL; 19 m^3.ha^{-1} felled) was observed to lead to a distinct increase in bird species richness some 0.5 years after the logging took place (Azevedo-Ramos et al. 2006).

Photo 7.4. *Trogon viridis* - Amazonian White-tailed Trogon. (Photo P. Ouboter)

The following general conclusions may be drawn based on the results of these studies:

- there typically is a positive impact of selective logging and silvicultural treatments on certain bird guilds, especially nectarivores and frugivores, at least during the first years after logging; and
- there typically are longer-term negative impacts on the insectivorous bird guild.

The results of the CMS-related bird study in the Mapane area (see section 7.3.1) are in line with the Central Amazonian study of Guilherme & Cintra (2001), in the sense that the bird faunas of selectively logged plots and plots that had both been logged and silviculturally treated were quite similar. Since no undisturbed forest was studied in the Mapane area, it is not possible to say if the general conclusions formulated above are also valid in relation to the CMS.

7.4.2 Impact on invertebrates / arthropods

Azevedo-Ramos et al. (2004) present few general conclusions in relation to invertebrates (mostly arthropods), which is hardly surprising, given that the invertebrates are not a single, coherent group of animals, but a multitude of very different taxonomic groups (taxa) with equally different responses to disturbance, as e.g. demonstrated by Lawton et al. (1998). Even within a seemingly homogenous group such as ants, responses are not uniform (see review in Azevedo-Ramos et al. 2004). In the Kabo area (see section 7.3.2.), a heterogeneous set of invertebrate taxa was investigated, which should have increased the chances to detect changes. However, the low taxonomic resolution of the Kabo study (mostly Order level) may have obscured changes, assuming that many of those changes occurred at lower taxonomic levels, and are hard to detect at higher levels because they are likely to cancel one another out.

A number of studies from the Neotropics compared the butterfly fauna of disturbed and undisturbed forest areas. In Belize, Lewis (2001) hardly detected any differences between butterfly faunas of logged and undisturbed locations, while Lawton et al. (1998) found, in Trinidad, that disturbed forest had much more butterflies (both higher total abundance and more species). The result would, however, seem dependent on the methods applied, as evident from the latter study, where sampling based on passive trapping (using fruit baits) did not lead to the detection of differences, while sampling based on active spotting and sampling of butterflies did. In Lewis' study only a passive trapping method was used[7]. This is more than a methodological issue, though, as the fruit-trapping method targets the fruit-feeding butterfly guild only, while the active spotting methods detects a wider range of species belonging to a variety of functional groups or guilds (Wood & Gillman 1998). The impact of disturbance would thus seem to differ between guilds, and analyses would need to be done at the guild level, or better still at the species level.

Similar to the Trinidad butterfly study (Wood & Gillman 1998), recording of butterflies along trails at Kabo proved to be useful, and the results led to the same general conclusion: that the most disturbed plots (at Kabo: logged and refined) have the most divergent fauna.

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6   Observation took place in plots where ca. 10 m^3 timber .ha^{-1} was felled 1 or 10 years before the fauna study.

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7   Lewis (2001) argued that baseline levels of disturbance are high in Belize (where tropical hurricanes are common) and may explain the result of his study (no faunal differences between locations with different levels of anthropogenic forest disturbance).

7.4.3 Impact on amphibians and reptiles

Reviewing the literature on forest amphibians and reptiles, Azevedo-Ramos et al. (2004) concluded that on the one hand forest-interior species tend to be adversely impacted by logging disturbance, while on the other hand generalist frogs and lizards preferring sunny habitats benefit from such disturbance.

Recent detailed studies on the impact of selective logging on forest amphibians were undertaken in Guyana by Ernst, Rodel and collaborators (Ernst et al. 2006, 2007; Ernst & Rodel 2008). Their studies took place in undisturbed and heavily logged forest stands (57 m^3 timber .ha^{-1} felled) in the Mabura Hill area, an area that is comparable to the areas in Suriname where the CMS has been applied. Some key results of these studies are:

- selectively logged forest stands had an amphibian fauna similar to that of undisturbed forest stands, but with fewer species (impoverished);
- while the impact of logging on overall Amphibian species diversity was not clear, the negative impact of logging on functional diversity (number of functional groups or guilds) was very clear;
- the negative impact on Amphibian diversity was more obvious in more recently logged forest (10 vs. 15 years after logging); and
- within the same narrow guild of terrestrial *Leptodactylus* frogs that make foam nests, the impact of logging differed between species that differ in the selection of their breeding habitat.

These results of these studies fit into what may be a general (pantropical) pattern, namely that forest disturbance leads to a change in the composition of the soil surface and litter inhabiting amphibian communities, in the sense that these communities impoverish (lose species) and lose functional diversity (guilds).

The relatively low amphibian and reptile species richness that was observed some 20 years after logging and refinement in the Kabo area (Ouboter & Shadew 2001) is in agreement with this. Preliminary results of a more recent study at Kabo suggest that the amphibian fauna has largely recovered 30 years after logging (Landburg et al. in prep.).

7.5   Final remarks and conclusions

An issue with the above mentioned CMS-related studies in Suriname is the absence of baseline data, i.e. data on the fauna that was present before treatments were implemented. This would not have been a major issue if enough zero-treatment control plots were available for study, but this was not the case either. Lessons should be learnt from this when follow-up research is planned, and when monitoring protocols are developed for 'green' certification.

It also should be noted that even the best data collected so far on the CMS and its impact, is based on the application of one or two timber harvests, followed by a single experimental refinement. The results of the CMS-related fauna studies in Suriname suggest that the impact of the CMS is mild. However, what will happen to the fauna after more than one round of logging and refinement? This question is relevant since

each round of logging and refinement adds changes to the structure and composition of the forest (cf. de Graaf 1986).

An important lesson learnt from logging impact studies in the region is that the impact on the fauna has to be studied at the 'correct' taxonomic and functional or guild level. As regards birds and butterflies, based on the results of several studies mentioned earlier, it is appropriate to study effects at the level of feeding guilds. The studies on amphibians in Guyana (Ernst et al. 2006, 2007; Ernst & Rodel 2008) confirmed the importance of guilds for logging impact studies, although in the case of amphibians, they may need to be defined as breeding guilds.

Although a final conclusion on the impact of the CMS on the fauna cannot be drawn yet, the studies on the impact of the CMS in Suriname and of similar forestry activities in the region do suggest the following:

- negative impact on insectivorous birds, and positive on nectarivores and frugivores;
- reduction of the number of species and guilds of soil surface and litter dwelling amphibians, likely also of amphibians and reptiles in general;

Photo 7.5.   Heliconius butterfly. (Photo B. De Dijn)

- significant changes in the butterfly fauna, but methodological issues obscure the results of studies implemented to date; this is also true for other arthropod studies, which are faced with the magnitude, heterogeneity and limited knowledge of the ecology of the taxa;
- the difference in impact on the fauna between logging only (traditional forestry; RIL), and logging and refinement (which is what defines the CMS) is not very obvious, although there are indications that the refinements do have a greater impact;
- the impact on the fauna persists up to 10-20 years after the initial disturbance (logging, refinement), but impact is often greatest in the first years after disturbance; and
- the impact is not necessarily consistent, but may depend strongly on the context, i.e. the local conditions at particular forest stands which do not fundamentally change as a result of logging or refinement, such as topography, soil, hydrology, etc.

A final remark on hunting and the collecting of animals is also appropriate here, although not directly related to CMS-related studies that have been implemented to date. In areas where the CMS is carried out, the forest will likely become more accessible for hunters and animal collectors. Birds and mammals with a body weight of more than one kilogram typically suffer most from any type of forest disturbance that is associated with open access for hunters and collectors (see Thiollay 1999; Meijaard et al. 2005). As these animals are important as seed dispersers, hunting and animal collecting is a potential threat to sustainable forestry.

Furthermore, a number of threatened and rare animal species are being used as bushmeat, also in Suriname[8]; other species are collected, kept alive and traded as pets[9] (Van Andel et al. 2003). To avoid the extinction of threatened species, and to sustain the fauna that disperses timber tree seeds, it would make sense to enforce an animal hunting and collecting prohibition in forestry concessions, or at least to tightly regulate and supervise such activities in the concessions.

Acknowledgements

References

Azevedo-Ramos, C., De Carvalho, O. & Nash, R. 2004. Animal Indicators: a Tool to Assess Biotic Integrity after Logging tropical Forests? Instituto de Pesquisa Ambiental da Amazonia, Belem do Para, Brazil, 35 pp.

Azevedo-Ramos, C., De Carvalho O. & Do Amaral, B.D. 2006. Short-term effects of reduced-impact logging on eastern Amazon fauna. Forest Ecology and Management 232, 26-35.

De Dijn, B.P.E. 2001a. Assessment of the diversity of insects at Tonka. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 60-75.

De Dijn, B.P.E. 2001b. Habitat diversity assessment at Tonka. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 12-32.

De Dijn, B.P.E. 2001c. Sampling and data analysis. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 10-12.

De Graaf, N.R. 1986 A silvicultural system for natural of tropical rain forest in Suriname. Ecology and management of tropical rain forest in Suriname, I. Thesis Landbouwhogeschool Wageningen, The Netherlands, 250 pp.

De Iongh, H.I. & Van Weerd, M. 2006. The use of avian guilds for the monitoring of tropical forest disturbance by logging. Tropenbos International, Wageningen, The Netherlands, 34 pp.

De Jong, B. 1982. Human Interference in the Tropical Rainforest Ecosystem, Annual Report January – December 1981. Report MAB – Project 949, Center for Agricultural Research (CELOS), University of Suriname, Paramaribo, Suriname.

Ernst, R., Linsenmair, K.E. & Rodel, M.-O. 2006. Diversity erosion beyond species level: Dramatic loss of functional diversity after selective logging in two tropical amphibian communities. Biological Conservation 133, 142-155.

Ernst, R. & Rodel, M.-O. 2008. Patterns of community composition in two tropical tree frog assemblages: separating spatial structure and environmental effects in disturbed and undisturbed forest. Journal of Tropical Ecology 24, 111-120.

Ernst, R., Tillmann, K., Linsenmair, K.E. & Rodel, M.-O. 2007. The impacts of selective logging on three sympatric species of Leptodactylus in a Central Guyana forest. Amphibia-Reptilia 28, 51-64.

Forget, P.M. 1994. Recruitment Pattern of Vouacapoua americana (Caesalpiniaceae), a Rodent-dispersed Tree Species in French Guiana. Biotropica 26, 406 - 419.

Forget, P.M., Milleron, T., Feer, F., Henry, O. & Dubost, G. 2000. Effects of Dispersal Pattern and Mammalian Herbivores on Seedling recruitment for Virola michelii (Mysristicaeae) in French Guiana. Biotropica 32, 452 - 462.

Guilherme, E. & Cintra, R. 2001. Effects of intensity and age of selective logging and tree girdling on an understorey bird community composition in Central Amazonia, Brazil. Ecotropica 7, 77-92.

Jansen, P. A. & Forget, P.-M. 2001. Scatterhoarding by rodents and tree regeneration in French Guiana. In: Bongers, F., Charles-Dominique, P., Forget, P.-M. & Th´ery, M. (eds). Nouragues: dynamics and plant-animal interactions in a neotropical rainforest. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 275 - 288.

Jerozolimski, A., Ribeiro, M.B.N. & Martins, M. 2009. Are tortoises important seed dispersers in Amazonian forests? Oecologia 161, 517-528.

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8   these include the Lowland Tapir, *Tapirus terrestris*, the Guiana Spider Monkey, *Ateles paniscus,* and the Giant Armadillo, *Priodontes maximus*, which are listed on CITES Appendix 1, and are listed as vulnerable (VU) by IUCN.

9   such as all species of Macaw (genus *Ara*), and several species of monkey, such as the Brown Capuchin, *Cebus apella;* these are all listed on CITES Appendix 2.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in a tropical rain forest in Suriname. Thesis Landbouw hogeschool, Wageningen, The Netherlands. 172 pp.

Krebs, C.J. 1989. Ecological Methodology. Harper & Row, New York, 654 pp.

Lawton, J.H., Bignell, D.E., Bolton, B., Bloemers, G.F., Eggleton, P., Hammond, P.M., Hodda, M., Holt, R.D., Larsen, T.B., Mawdsley, N.A., Stork, N.E., Srivastava, O.S. & Watt, A.D. 1998. Biodiversity inventories, indicators taxa and effects of habitat modification in tropical forest. Nature 391/1, 72-76.

Lewis, O.T. 2001. Effect of Experimental Selective Logging on Tropical Butterflies. Conservation Biology 15, 389-400.

Mason, D. 1996. Responses of Venezuelan Understorey Birds to Selective Logging, Enrichment Strips, and Vine Cutting. Biotropica 28, 296-309.

Meijaard, E., Sheil, D., Nasi, R., Augeri, D., Rozenbaum, B., Iskandar, D., Setyawati, T., Lammertink, M., Rachmatika, I., Wong, A., Soehartono, T., Stanley, S. & O'Brien, T. 2005. Life after logging. Reconciling wildlife conservation and production forestry in Indonesian Borneo. CIFOR, Jakarta, Indonesia, 345 pp.

NZCS & BBS. 2001. The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, 80 pp.

Ouboter, P.E. & Sahdew, S.A. 2001. Assessment of Amphibia and Reptilia diversity at Tonka. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, pp. 51-60.

Rahgoenandan, U.P. 2001. Plant diversity assessment at Tonka. In: The Impact of Logging and CELOS Silvicultural Treatments on Biodiversity: Observations of Rainforest Biodiversity in Suriname, Preliminary Findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS), University of Suriname, Paramaribo, Suriname, 32-50 pp.

Ratiarison, S. 2003. Frugivory in the canopy of the Guianan forest: consequences for seed rain. PhD thesis, Universite Paris 6, Paris, France, 192 pp.

Sokal, R.R. & Rohlf, F.J. 1995. Biometry (3rd edition). New York, W.H. Freeman & Co., xix + 887 pp.

Thiollay, J.M. 1992. Influence of Selective Logging on Bird Species Diversity in a Guianan Rain Forest. Conservation Biology 6, 47-63.

Thiollay, J.M. 1999. Responses of an avian community to rain forest degradation. Biodiversity and Conservation 8, 513-534.

Van Andel, T., MacKiven, A. & Banki, O. 2003. Commercial Non-Timber Forest Products of the Guiana Shield. Netherlands Committee for IUCN and Guiana Shield Initiative, Amsterdam, The Netherlands, 98 pp.

Wunderle, J.M., Henriques, L.M.P. & Willig, M.R. 2006. Short-Term Responses of Birds to Forest Gaps and Understorey: An Assessment of Reduced-Impact Logging in a Lowland Amazon Forest. Biotropica 38, 235-255.

Wunderle, J.M., Willig, M.R. & Henriques, L.M.P. 2005. Avian distribution in treefall gaps and understorey of terra firme forest in the lowland Amazon. Ibis 147, 109-129.

Wood, B. & Gillman, M.P. 1998. The effects of disturbance on forest butterflies using two methods of sampling in Trinidad. Biodiversity and Conservation 7, 597-616.

8 The CELOS Management System in relation to Sustainable Forest Management and Certification

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In the previous chapters the CELOS Management System (CMS) is discussed without a clear reference towards the present day's perception of sustainable forest management (SFM). Although the CMS aims at good forest stewardship, it might be questioned whether it reaches the sustainability as proposed by most environmental certification standards. This chapter aims to clarify the extent to which the CMS covers the different components of SFM, and its relevance for forest certification. First, an explanation of sustainability and certification is given (section 8.1). Certification standards make use of principles, criteria and indicators to verify sustainability, while a stepwise approach, such as developed by ProForest (Nussbaum et al. 2003) and explained in section 8.2, seems to be more suitable for the implementation of sustainable forest management. Here, this tool is used to analyze the level to which the CMS covers all present day components of SFM. Therefore a distinction is made between the CMS as a forest management system (section 8.3) and the additional conditions that concern the forest company management system as a whole (section 8.4). Final conclusions are given in section 8.5.

8.1 Sustainable forest management and certification

Early definitions of sustainable forestry concentrated on the timber resource, where forest management aimed at 'sustained yield' of a limited number of commercial tree species. This was in fact the reason to develop the CMS. In the meantime, researchers concluded that sustainable timber production should consider more than timber-trees only, and consequently, the approach changed to sustainable resource management, focusing on the forest as the producer of timber. Many researchers stressed the importance of the forest as an ecosystem in which tree growth profits from several functions delivered by the forest as a whole. It was recognized that the production of timber could only be sustained at an acceptable level (economically and ecologically) if all the forest functions are well respected and preserved, at least to a certain level. The CMS project tried to determine the levels of sustainable harvest and the application of

adequate forest operations, both liberations and harvesting, to sustain these. Recently the importance of other products and services provided by forests has been recognized, particularly those of broader economic and social concern, such as the forest's role in local community livelihoods, rural development, and poverty alleviation. Concepts of sustainable forest management now encompass the continued flow of these products and services, such as protection of fresh water supply, soils and cultural sites, and sustained yield of non-timber forest products, as well as timber. Sustainable forest management has been described as forestry's contribution to sustainable development (Higman et al. 2005). Such development is environmentally sound, economically feasible and socially legitimate. The concept of sustainable development recognizes the fact that utilization of forests will change natural ecosystems, but that conservation is equally important. It also recognizes that utilization of forests is important for achieving national social goals, such as employment and poverty alleviation. A compromise between these goals should be reached (Higman et al. 2005). There are various definitions of sustainable forest management, but they all say essentially the same:

Sustainable forest management is the process of managing forests to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services, without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment (ITTO 1998).

Certification is the process of independent (third party) verification of forest management to meet the norms of a pre-defined sustainable forest management standard. Certification assesses the compliance of a particular forest management system with this standard (Higman et al. 2005). The standard is based on a series of principles for sustainability, and is developed by an organization that administers the certification standard. This organization accredits third parties (certifying bodies, also known as certifiers) to assess the forest management. The organization that administers the certification standard also controls the trademark that tells consumers that products sold from these forests, including timber, are produced in accordance with the standard. Certification is in fact a *credible proof* of sustainable forest management. Certification standards urge forest managers

Photo 8.1. Certified timber in Suriname. (Photo Astra Singh)

to prove sustainable management practices by showing documents, figures, maps, etc. (the so-called verifiers) that provide information concerning their sustainable forest operations and management.

To prove sustainable forest management by means of certification, a system is developed that describes sustainability in generally accepted terms and characteristics, which than can serve as a minimum norm for sustainability. Certification standards therefore describe SFM in terms of principles, criteria, indicators, and norms. During the

process of certification, the auditor assesses the forest management by these criteria and indicators, checking the verifiers that should indicate whether the norms are met. If forest management meets these norms, a certificate is awarded. Only through third party certification and the accompanying trademark, forest management can be recognized internationally as sustainable.

The main question is whether the CMS reaches the level of sustainability as proposed by forest certification standards. Does it provide the norm as required by certification standards, and may it thus serve as a reference for sustainable forest management certification?

8.2   Implementing sustainable forest management

To answer that question, the CMS might be assessed in terms of principles, criteria and indicators for sustainability. Such an assessment clarifies the CMS' level of sustainability, and consequently identifies those aspects (gaps) that still need to be addressed to meet the norms of sustainable forest management. However, it might be questioned whether or not the approach of principles, criteria and indicators is suitable to identify the discrepancy between the CMS and SFM, particularly as regards its practical application.

Although the use of criteria and indicators may be effective in *verifying* sustainable forest management, it turned out to be less useful to *implement* it. Especially the extended list of criteria and indicators discourages forest managers to seek certification. Moreover, they are confronted with a list that is ordered primarily for auditors to assess the forest management. Therefore the arrangement and order of subjects appears less suitable for forest managers to implement sustainable forest management or to transform conventional forest management towards the sustainability standard. The same challenge is encountered when assessing the CMS' level of sustainability. As we focus on the level of compliance when the CMS is *implemented*, it might be better to search for an alternative to compare the management system with current perceptions on SFM.

A good alternative is given by ProForest (Nussbaum et al. 2003). In response to the forest managers' problem, ProForest developed a Modular Implementation and Verification (MIV) toolkit for a phased introduction and application of sustainable forest management standards in order to reach a level of SFM ready for certification. It is a model that helps forest managers to implement SFM by means of a step-wise approach. All elements of sustainable management are subdivided into smaller entities, which are concise, transparent, and can be addressed in an order that suits the forest manager best. It covers the norms of several certification standards and organizations that defined SFM principles and guidelines (e.g. FSC, ITTO, WWF). As such, the MIV is not a certification standard by itself, but provides a toolkit to reach a level of sustainable forest management to be certified. Focusing on the practical application of SFM, it distinguishes the following elements: legal component, technical component, environmental component, social component, and the chain of custody. Each of these components exists of several modules (see Figure 8.1).
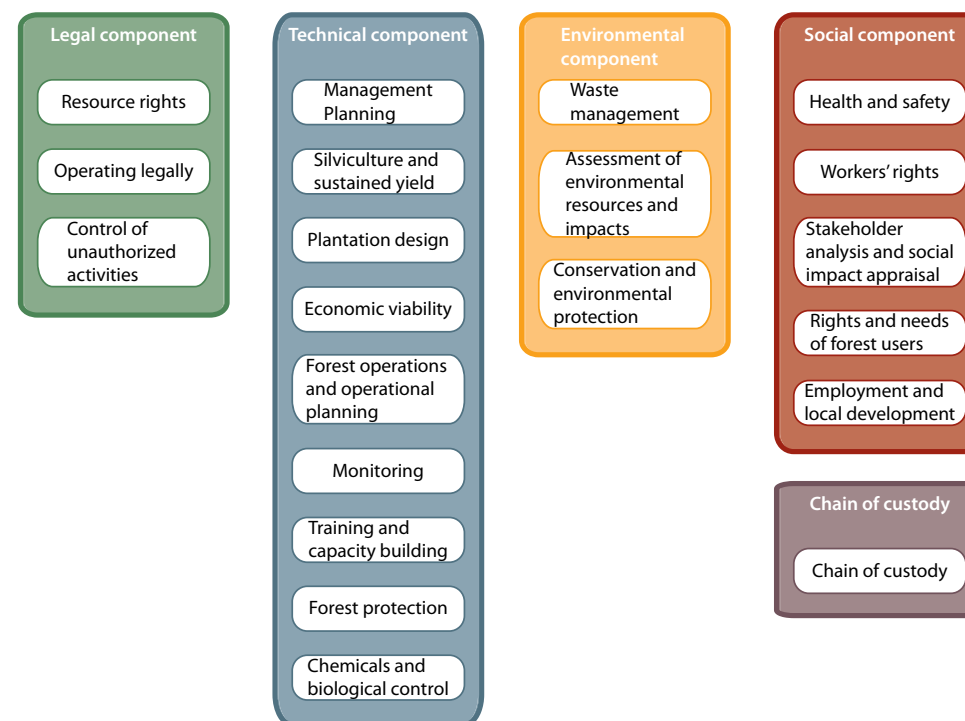

Figure 8.1.   The modules of the Modular Implementation and Verification (MIV) approach, shown schematically (after Nussbaum et al. 2003).

Through this approach, it is relatively easy to analyze one's level of compliance with the standard and to see what still has to be done to meet all requirements. Similarly, the CMS can be compared with the MIV to see to which extent it covers current perceptions on sustainable forestry. This gives a clear picture of the CMS in relation to sustainable forest management and certification standards. Furthermore, those aspects that still need to be addressed are identified as well.

8.3   The CMS as a forest management system

When comparing the CMS with current components of SFM, first the question needs to be answered what beholds the CMS. Many authors have written about the CMS, but what comprises the CMS and what is additional (i.e. relevant for the CMS, but not part of it)? As already explained in section 8.1, over the past decades the focus in sustainable forestry has moved away from trees to the whole forest ecosystem and additional environmental and social aspects. In the meantime such aspects were to varying extent incorporated in the CMS, but in principle the management system is still a purely silvicultural and harvesting system, describing methods to implement silvicultural treatments and harvesting operations in a sustainable way, in which especially ecological and economic sustainability is concerned. Therefore, the CMS is a forest management system and not a forestry industry system. Principally, the CMS excludes all typical company related issues. However, since it was first proposed, many additional comments, recommendations,

instructions and conditions were added in the scope of total forest industry. These practical applications are therefore not part of the forest management system itself and have hardly or not at all been investigated, but do form a valuable addition and are helpful in the implementation of the forest management system.

The CMS research especially focused on the technical aspects of management and its impact on the forest (both biotic and non-biotic) and has lead to the development and elaboration of an extensive silvicultural and harvesting system. Consequently, the CMS impossibly can cover all certification criteria and indicators. Certification concerns the whole forest industry (the company), while the silvicultural and harvesting system are just part of this. From this point of view, the CMS covers only (parts of) several modules in the technical and environmental components. Although the CMS can only be implemented successfully if at least several legal issues are in place (e.g. tenure and concession rights and length of lease), these conditions are not inherent to the system. Neither are the social component and the chain of custody.

All environmental impact research regarding the CMS is meant to provide insight into the effects of forest operations. Consequently, the CMS covers parts of the environmental component, providing relevant information for the assessment of environmental resources and impacts and for conservation and environmental protection. On the other hand, the CMS does not give a clearly outlined operational concept to assess and implement these environmental aspects. Therefore, the CMS does cover the environmental component concerning scientific support though it gives hardly any direction towards implementation.

Regarding the technical component, however, much more is covered. Most obvious are the modules *silviculture and sustained yield*, and *forest operations and operational planning*, which are almost entirely covered by the CMS. The CELOS Silvicultural System (CSS) does provide a clear forest resource assessment to collect information on the volumes of forest products available, including growth and yield data. Moreover, it provides an appropriate silvicultural system that maintains recovery and growth of forest products and prescribes a system to set and control harvesting levels. The CELOS Harvesting System (CHS) does provide good practices for forest operations, disturbing the forest as little as possible. Concerning the other modules in this component, hardly anything is covered by the forest management system. Only a few elements of *management planning*, and *chemicals and biological control* are included.

8.4 The CMS as part of a forest company management system

Although the CMS is principally a forest management system, many researchers made additional comments and recommendations that are related to the company management system. These are most clearly found in the provisional manual to the CMS, edited by Van Bodegom & De Graaf (1991). Based on the provisional manual, these additional comments and recommendations are compared with the components of SFM. The results are presented in Table 8.1, which gives an overview to what extent the CMS covers the MIV modules. Two remarks should be made. Firstly, this table is just an

indication, not based on in-depth study, as that would have exceeded the purpose of this chapter. Secondly, the highest given value (+++) indicates that the CMS covers the concerned module *almost* entirely. None of the modules are completely covered by the CMS and/or added comments. In many cases the CMS covers most of the MIV module (or even more than is required by the standard), but does also miss several issues, especially those that are needed to deliver verifiers for auditors.

Table 8.1. Extent to which the CMS covers the modules of MIV.

Component	Module	Value
Legal	Resource rights	0
	Operating legally	-
	Control of unauthorized activities	-
Technical	Management planning	++
	Silviculture and sustained yield	+++
	Plantation design	Not relevant *1
	Economic viability	+ *2
	Forest operations and operational planning	+++
	Monitoring	++
	Training and capacity building	++
	Forest protection	+
	Chemicals and biological control	++
Environmental	Waste management	-
	Assessment of environmental resources and impacts	++
	Conservation and environmental protection	++
Social	Health and safety	+
	Workers' rights	-
	Stakeholder analysis and social impact appraisal	- *3
	Rights and needs of forest users	- *3
	Employment and local development	- *3
Chain of custody	Chain of custody	+++

*1 The CMS was designed for natural forests, promoting the increment of a naturally developed forest. For plantations other silvicultural systems are more appropriate.
*2 See also De Graaf et al. (2003)
*3 The CMS was developed in a situation of low population pressure on the forest. Almost no pressure to convert forest into agricultural land or to use the forest for extensive cattle-breeding was present. Therefore no special measures for the conservation of local forest values were necessary.

Explanation of used values:
-            nothing mentioned concerning this module
0   only mentioned as a precondition, or information
+   covers little
++   covers several parts
+++   covers the module almost entirely

Legal issues mentioned in the provisional manual are only prerequisites to implement the CMS, and as such do say something about *resource rights*, but nothing about *operating legally* and control of *unauthorized activities*. Moreover, legal issues hardly receive any attention and therefore the legal component is hardly covered. The provisional manual gives much more comments and recommendations concerning the technical component. All modules (except *plantation design*) are addressed to a certain extent. This is quite evident as the technical modules contain aspects that are closely linked to the silvicultural and harvesting systems. The silvicultural and harvesting systems, for instance, also take into account the risk of wind, which is part of the *forest protection* module. Concerning the environmental component some additional comments are made, especially regarding forest-for-zero-management, which is not just a point of reference for future assessments, but is also necessary for the conservation of biodiversity of the forest ecosystem. Because the CMS was developed in an area with a low population density, hardly any attention was given to social issues. For the internal organization, however, several recommendations are made concerning the use of safety clothing,

Photo 8.2. Exploitation road. (Photo K.E. Neering)

importance of safety rules and job rotation. A rather broad elaboration is given concerning record-keeping and log tracking and tracing, which all has to do with the chain of custody. The fact that this component is almost entirely covered in the provisional manual is probably caused by the scientific background of the CMS, stressing the importance of reliable data sets for monitoring. This results in clear recording formats, stressing the importance of good record-keeping.

Although each module is different, as well as the extent to which the CMS covers it, there are several issues that are repeatedly missing, whatever module is concerned:

- In almost every module the MIV mentions that first an assessment needs to be carried out to identify all relevant issues that should be addressed by the concerned module. For example, the *health and safety* module starts with the need to "identify all operations and activities which involve a safety risk or where safety hazards already exist" (Nussbaum et al. 2003: 66). Though the CMS does provide safety prescriptions, in practice other risky operations and activities can easily be overlooked.

- Next, such identification should be followed by the development of plans and/or procedures to anticipate on or decrease risks, dangers, damage, loss, etc. The need to develop such plans or procedures is rarely mentioned in the provisional manual, and if mentioned it says more about operational plans. Moreover, such plans are not preceded by problem identification (to be implemented by the company), but are just mentioned as a requisite to implement the CMS.

- In line with the above mentioned issues, the CMS does say something about monitoring and/or recording, but with a different scope: monitoring and/or recording is principally focused on the harvesting or silvicultural activities to be carried out, while the MIV describes monitoring and/or recording with a focus on checking compliance of implementation, utilization and application of developed plans, procedures, etc.

These issues show that the CMS is based on a different philosophy and starts from a different point of view. Whereas the CMS aims at optimizing harvestable volumes and treating the forest in a sustainable way, SFM standards are focused on sustainable development of the whole industry (at company level), which is elaborated on the basis of a philosophy of good corporate practice as expressed by the Deming cycle (Deming 1982). The Deming cycle expresses a continuous quality improvement model consisting of a logical sequence of repetitive steps for ongoing improvement and learning: identify, plan, do, study (or check), and act. The MIV approach clearly shows the way to implement SFM using the Deming cycle: forest management needs to start with an identification of the problem, followed by the development of a plan to address the problem. Next the plan has to be carried out, after which the application as well as the problem have to be monitored and, if needed, the plan has to be adjusted.

8.5 Experiences with sustainable forest management in the tropics

The previous section might give the impression of the CMS being of limited value regarding sustainable forest management. However, it might be questioned if this does justice to the system, the more if we look at the situation and experiences in the tropics in general.

Initially forest and timber certification was introduced to stop deforestation and forest degradation and to stimulate the conservation of the forest's biodiversity. This in particular regards the tropics and developing countries, where most of the (large-scale) deforestation and forest degradation is taking place. Despite considerable improvements in forest management in many tropical timber producer countries, most forests in these countries still do not meet certification standards because forest management practices are well below the norms as set by international standards (Higman et al. 2005; Nussbaum & Simula 2005; Eba'a et al. 2002). Besides, deforestation and forest degradation is still going on in many countries. A study from 2007 shows that less than 10 % of the world's certified forest area is found in tropical countries (ITTO 2008). It becomes clear that the initial intentions to save particularly tropical forest biodiversity have largely failed.

There are many reasons for the limited progress of forest certification in the tropics. Often the enabling conditions are absent or inadequate, making the process a long and difficult, but challenging one. Countless barriers relate to governance, regulations and the institutional arena, which are difficult for individual forest managers or concessionaires to address. However, there are also constraints at the level of the forest management unit (Nussbaum & Simula 2005):

- In many countries, the implementation of forest management systems is still in development or just recently introduced and their key elements are not yet in place or are inadequate;
- Considerable resources are required to implement the requirements of a certification standard; but developing countries face many institutional, social, human resource and financial constraints, which means that such resources are often scarce;
- The process of implementing the standard can be very lengthy, often taking several years; many factors slow down the development, and it easily stalls for external reasons;
- Another serious constraint is the uncertainty about the benefits of certification; the long and costly process of standard implementation until a certificate is obtained may seem difficult to justify;
- Forest managers are often overwhelmed by a large number of activities to be undertaken in order to meet the standard's requirements. It is difficult for forest managers or external parties to assess clearly the progress made during this period of implementation since so many different activities are being undertaken.

Many of these obstacles also apply to the CMS, which practice is far beyond most current forest management practices. In contrast to most practices in the tropics, the CMS is a forest management system that keeps the production capacity of the forest intact, meaning that forest damage is well below the regenerating capacities of the forest. In this system a long term beneficial forest is promoted, reducing logging damage and nutrient export by means of restricting timber extraction, and stimulating the growth of future crop trees by means of silvicultural treatments. Correct application of this system would give a sustainability level of forest exploitation that currently hardly any tropical company is able to achieve. Companies applying the CMS correctly therefore do reach a very high level of sustainability concerning exploitation and regeneration of the forest. For this reason the introduction of the CMS would be a large step towards sustainable forest management.

8.6   Conclusions

Certification standards require the implementation of appropriate silvicultural systems and harvesting practices that sustain the ecological, economic and social functions for both forests and people. In this sense the CMS is sustainable for the purpose it is meant for (silvicultural and harvesting system). Application of the CMS is however not a guarantee that all norms of SFM are met: almost all legal and social aspects are missing and, concerning the environmental and technical aspects, much more needs to be added or changed before forest management meets the criteria of SFM and could be certified.

The most important conclusion that might be drawn from the comparison is the difference in historical perspective. The CMS was developed in the 1980s when sustainable forestry focused on sound resource-use with no more damage and losses than strictly necessary (reduced impact logging) and economic feasibility by means of silvicultural treatments securing and optimizing future harvests. In the past decades sustainable forestry moved its attention towards additional aspects of the forest industry, in particular to social and conservation concerns. In the meantime the purpose of several processes or activities changed. Log-tracking, for instance, was developed for tree-specific and efficient logging of selected harvestable trees and an appropriate administration of harvested volumes. In certification standards, however, log-tracking is in the first place meant to trace all logs from its origin in the forest to the point of selling through a chain of custody. Focus changed and therefore the norms and concerns changed. Consequently, it is not surprising that the CMS does cover parts of current perspectives of SFM, but that other aspects of the forest industry operations are not (yet) in place or differ from former perspectives. Despite of these changes in perspectives and differences between SFM and the CMS, this silvicultural and harvesting system must still be considered as an appropriate sustainable system.

It might be questioned if all missing issues need to be addressed in the CMS, as principally it is meant as a sustainable silvicultural and harvesting system. The CMS must be seen as an appropriate and valuable system that serves SFM and as such gives a solid base for future forest certification.

References

De Graaf, N.R., Filius, A.M. & Huesca Santos, A.R. 2003. Financial analysis of sustained forest management for timber perspectives for application of the CELOS management system in Brazilian Amazonia. Forest Ecology and Management 177, 287-299.

Deming, W.E. 1982. Out of the Crisis. MIT press, 522 pages, ISBN-13: 9-78026254-115-2.

Eba'a Atyi, R., Nussbaum, R. & Simula, M. 2002. Potential role of phased approaches to certification in tropical timber producer countries as a tool to promote sustainable forest management. Interim Report Prepared pursuant to ITTO Decision 11(XXXII), ITTO, Yokohama, Japan, 30 pp.

Higman, S., Mayers, J., Bass, S., Judd, N. & Nussbaum, R. 2005. The Sustainable Forestry Handbook. 2nd edition, Earthscan Publications Ltd., London, United Kingdom, 332 pp, ISBN: 1-84407-118-9.

International Tropical Timber Organization (ITTO). 1998. Criteria and Indicators for Sustainable Management of Natural Tropical Forests. ITTO Policy Development Series No.7, Yokohama, Japan, 23 pp.

International Tropical Timber Organization (ITTO). 2008. Developing Forest Certification. Towards increasing the comparability and acceptance of forest certification systems worldwide. ITTO Technical Series #29, Yokohama, Japan, 127 pp.

Nussbaum, R., Gray, I. & Higman, S. 2003. Modular Implementation and Verification (MIV): a toolkit for the phased application of forest management standards and certification. ProForest, Oxford, United Kingdom, 95 pp.

Nussbaum, R. & Simula, M. 2005. The Forest Certification Handbook. 2nd edition, Earthscan Publications Ltd., London, United Kingdom, 330 pp, ISBN: 1-84407-123-5.

Van Bodegom, A.J. & De Graaf, N.R. 1991. The CELOS Management System: a Provisional Manual. Informatie en Kenniscentrum (IKC), Vakgroep Bosbouw, Landbouwuniversiteit Wageningen (LUW) en Stichting voor Nederlandse Bosbouw Ontwikkelings Samenwerking, Wageningen, Netherlands, 43 pp.

Part II

Management for sustainable forestry in other tropical countries

9 Guyana

P. van der Hout

9.1 Introduction

Guyana has vast forest resources that cover more than three-quarters of its land area and contain over 1,000 different tree species. Currently, between 12 and 15 of these species are being logged on a commercial scale through a system of concessions. The most sought after species include Greenheart (*Chlorocardium rodiei*), Mora (*Mora excelsa* and *Mora gonggrijpii*), Baromalli (*Catostemma commune*), Purpleheart (*Peltogyne* spp.), Crabwood (*Carapa guianensis*), and Kabukalli (*Goupia glabra*). In 2005, Guyana exported over US$ 52 million in forest products, ranging from roundwood logs and sawn timber, to plywood, moulding and furniture products.

Approximately 52 percent of State Forests have been allocated to timber harvesting concessions. Three types of concessions are being awarded, based on area size and duration:

- Timber Sales Agreement – granted up to twenty-five years for areas in excess of 24,000 hectares
- Wood-cutting Lease – granted for up to ten years for 8,000 - 24,000 hectares
- State Forest Permission – granted for a two-year period on no more than 8,000 hectares

Although Guyana neighbours Suriname directly to the West and although the two countries share a substantial number of commercial timber species, their forests differ considerably. An important difference is the occurrence of stands that are dominated by one or few species, notably Greenheart (*Chlorocardium rodiei*), Morabukea (*Mora gonggrijpii*) and Wallaba (*Eperua* spp.). Despite the occurrence of these so-called reefs, the average volume harvested per hectare is remarkably low. This is due to the high incidence of decay in the aforementioned species – extremely high among Morabukea - and reefs being interspersed by less valuable stands.

9.2   History of forest management in Guyana

The oldest record of timber trade from Guyana dates from 1624. Just as in Suriname, one of the most important activities in the early days of Dutch settlement was the bartering of trade goods with the Amerindians, one of these goods being *Brosimum guianense* (syn. *Piratinera guianensis* – Letterwood or Captain's Letterwood). The trade in Letterwood (see Chapter 2) must have flourished because in 1669 a single ship is reported to have transported 10,000 kg of the timber (Swabey 1950). Letterwood dominated the timber trade until the later part of the 18th century, when *Chlorocardium rodiei* (Greenheart) was first produced in commercial quantities. Most timber came from the old 'Dutch' estates. As they were private property, this situation resulted in a lack of control of woodcutting and, moreover, no direct return to the colonial power, which was by then British (McTurk et al. 1882). This led to the first attempt to regulate woodcutting under the Crown Lands Ordinance of 1871. That provided that rent was payable on woodcutting tracts.

At that time, logging was restricted to the lower rivers. Strenuous manual overland extraction was undertaken within a narrow strip of land about 1 km deep inland along the banks of the rivers. Yet, in 1882 uneasiness concerning the destructive methods of the woodcutters was voiced by McTurk et al. Further observations by the Crown Surveyor in 1889 (ex Swabey 1950) that reefs of Greenheart close to navigable watercourses were becoming increasingly depleted and hence accessible timber stocks scarce, lead to the prospect that timber stocks would be exhausted in the foreseeable future and pressure built to establish some system of forest conservation. This culminated in the passing of the Crown Lands Ordinance of 1886 and new forest regulations in 1890 which featured the following measures: the institution of minimum cutting limits, the obligation to retain economic species spaced throughout the forest, the payment of royalty, the institution of grant registers and removal permits, and the marking out of working blocks.

During the 1880s, a rush from the coastal population to the interior began due to a boost in gold mining and a growing trade in Balata - the coagulated latex obtained from tapping *Manilkara bidentata* (Bulletwood). During the later part of the 19th century and the earlier part of the 20th century, firewood and charcoal production, mainly for domestic use and export to the Caribbean, and Balata bleeding outstripped timber production.

An important step in the recognition of forest management problems was the establishment of a forestry branch at the Department of Lands and Mines in 1908 and the appointment, in 1910, of five forest rangers and a forest officer. During the next 15 years the first forest surveys were undertaken by C.W. Anderson, the first forest officer, and his successor, L.S. Hohenkerk. Between 1908 and 1916 a total of 34 expeditions were made covering all of the easily accessible forest areas (Welch et al. 1975).

In 1925 a Forest Department, independent of the Lands and Mines Department, was established, with B.R. Wood as the first Conservator of Forests. During the next 25 years the Forest Department undertook forest inventories of the most important forest areas by strip enumeration surveys, identified and took samples of hundreds of tree species, prepared and distributed samples of timbers for testing, started investigations on the regeneration of Greenheart forests and established seasoning techniques for local

timbers. By 1935, the distribution of the main commercial species, and in particular Greenheart, was well understood. In the 1920s, Greenheart had a prominent position with a log output of 20,000 m³ per year, accounting for 77 % of the total roundwood output, and rising to 80 % in 1939.

The Second World War affected the supply of mechanical equipment on which the industry depended by that time. Timbers other than Greenheart - especially *Mora excelsa* (Mora) and *Carapa guianensis* (Crabwood) - were available adjacent to rivers and could be extracted with little or no mechanical equipment and an increase in the production of these species was seen. Sawmills to deal with this production sprang up everywhere, and by 1949 their number had increased to 79 (Swabey 1950).

Just after the war, a Developmental Committee was set up to consider the allocation of development aid provided by the British government. A forestry subcommittee was appointed with the task to 1) frame a forest policy, 2) estimate future forest production targets, and 3) draw up specific development projects. C. Swabey, who succeeded B.R. Wood as Conservator, strongly urged that the forest policy should have two basic aims, namely increasing production in order to fill local as well as export demands, and managing the forests on the basis of a sustained yield concept.

In 1948, draft amendments to the Forest Ordinance were published with the aim to work the forests in such a way that they would be permanently productive and not 'mined' as for a mineral (Welch et al. 1975, p.50):

- exploiters were required to submit logging programmes to work their leases in a sequence of contiguous blocks;
- all merchantable timber should be worked out from one block before exploitation extended into the next;
- seed bearers were to be retained for silvicultural purposes;
- worked-out blocks were to be surrendered to the department for regeneration or improvement work to be undertaken.

It took five years for these amendments to be passed and in 1954 the new Forest Ordinance came into effect. This committed the government to create another legal land category, the Crown Forests. Thus the year 1954 marked the legal beginning of control of the Forest Department over 7.5 million ha of Crown Lands, now declared to be Crown Forests. The year 1954 also marked the beginning of a new Ten Year Development Plan for forestry through grants from the Colonial Development and Welfare Scheme of the British government. Four schemes got off the ground, i.e. training of staff, the establishment of a Central Timber Manufacturing Plant, introduction of aerial photo interpretation for forest inventory, and a silvicultural programme.

Also in 1954, new lease agreements under the new Forest Ordinance were concluded for three major firms operating in the Bartica Triangle (West of the Essequibo River and South of the Mazaruni River): British Guiana Timbers Ltd., Willems Timber and Trading Co. Ltd. and Charlestown Sawmills Ltd. These lessees were subjected to the new Regulations compelling them to extract all merchantable timber to the satisfaction of the Forest Department, and to work a sequence of contiguous blocks which were to be handed

back to the government (Fanshawe ex Clarke 1956). The intention was then to assist natural regeneration of Greenheart or, at least, to increase the stocking of Greenheart substantially by poison girdling undesired trees and climber cutting, using funds from the Development Programme (Clarke 1956). Meanwhile, the above mentioned three firms were laying the foundations of the Golden Age of Greenheart. This was largely related to the higher level of mechanisation and the creation of road access to previously inaccessible areas. By 1957, there were 104 woodcutting leases, covering nearly 860,000 ha, and 92 sawmills. The output of timber was 210,000 m³ per year of which 63 % was Greenheart. About 50 % of all timber was exported, some 90 % of which was Greenheart. These levels of timber output and export were maintained up to 1974.

Early exploitation had taken the form of highly selective felling of choice stems of Greenheart, mainly geared towards the export of roundwood pilings and medium sized squared timber. Since the new Forest Regulations were introduced and the mechanisation of the timber industry had increased - especially regarding the production of dressed lumber - logging had become less selective. However, this happened in the sense that almost all the Greenheart was now removed from the felling area rather than the utilisation of other species being increased as intended with the new legislation (Gordon 1961). Clarke in 1956 and Gordon in 1961 stated that supplies of old growth Greenheart were limited and would not last for much more than 30 years at the rate of exploitation at that time, and that, as the more accessible areas would have been worked out, the cost of obtaining Greenheart was to start rising very soon.

Just as at the end of the 19th century, the 1920s and 1940s, it appeared, however, that Greenheart stocks were not exhausted because virgin forests were opened up. This was made possible by the development of new methods of extraction: from manual ('grail stick') haulage to cattle haulage by the end of the 19th century, to steam (and later gasoline) sleigh winches in the 1920s. In the 1930s, the introduction of trucks and semi-trailers had thrown open large areas of forests for logging. In the 1950s, access was further expanded through the introduction of heavy road construction machinery, crawler tractors for stumping and semi-trailer trucks (articulated lorries) for road transportation, and since 1967 through the introduction of the chainsaw and articulated, wheeled skidders. Every time the pressure to regulate timber harvests was thus released by opening up new areas.

In 1966, a Forest Industries Development Programme was launched with the assistance of FAO/UNDP with the aim to carry out a full scale appraisal of the forest resource potential of the country, including forest inventories using aerial photography, and utilisation and marketing surveys. Significant achievements were recorded in the field of sawmilling and saw doctoring, forest inventory, modernising logging equipment and wood preservation by the time the programme was concluded in 1970 (Welch et al. 1975).

In 1979, the Guyana Forestry Commission was established to replace the Forest Department with the intention to finance the Commission using the revenues derived from the harvest of timber, fuelwood and other forest products. However, circumstances, due in large part to the general decline in the national economy, resulted in revenues lower than the cost of its staff and its activities (GNRA 1989). Consequently, these activities were limited to the issue of woodcutting licenses, the occasional adjudication of boundary disputes, and the assessment and collection of revenues.

Despite these constraints, the Forest Regulations were amended with the aid of Canadian International Development Agency (CIDA), creating a new type of harvesting rights, the Timber Sales Agreement, aiming at improved forest management through security of land tenure for 25 years. These Timber Sales Agreements were made available in 1985 and were issued to larger operators. The terms of these agreements, besides the stipulations of the 1953 Forest Act, required the holder to conduct forest inventories and to submit an operating plan for three years' logging and road construction to the Commissioner for approval.

From 1990 on, in light of the projected decline of timber stocks in Asia and Africa, the global market started to look to South America to fill the gap (Colchester 1994, 1997; Sizer & Rice 1995; Sizer 1996). This led to a number of originally Asian timber companies establishing themselves in Guyana and elsewhere in South America. Probably the most radical change for the timber industry in Guyana was the establishment of a large plywood mill in 1992. From 1994, the documented annual timber production soared from 130,000 m³.y⁻¹ to 420,000 m³.y⁻¹ in 1996, accompanied by a shift from sawn timber to plywood species: the share of plywood species in the total production rose from 3 % in 1990 to 53 % in 1996. The arrival of foreign

Photo 9.1.   A Locust (*Hymenaea courbaril*) log of 20 m³ proved to be too heavy to extract in one piece. (Photo P. van der Hout)

owned companies also led to a recovery of the production of Greenheart. Since its Golden Age during 1954 to 1975, when annual roundwood output reached highs of 130,000 m³.y⁻¹, its production had receded to about 50,000 m³.y⁻¹ by the end of the 1980s, but, since 1993, the annual production has been on the rise again with an average of 68,000 m³.y⁻¹ over the years 1993 to 1996 (Guyana Forestry Commission records). The shift in attention towards plywood species raised the number of readily merchantable species from a handful to about 25. The most important plywood species is *Catostemma commune* (Baromalli).

In 1989, the Government of Guyana excised 360,000 hectares of rain forest and donated it to the Commonwealth for research into the conservation and the sustainable and equitable use of tropical rain forests, resulting in the official establishment of the Iwokrama International Centre for Rainforest Conservation and Development in 1996. In addition, in 1989, an intergovernmental agreement was signed with the Netherlands, marking the start of the Tropenbos-Guyana Programme.

The post-1996 period witnessed an Institutional Strengthening Programme on the part of the Guyana Forestry Commission. This was in an attempt to transform the GFC from a traditional public service bureaucracy to a more customer- and performance-focused organisation. This policy was given impetus through the Guyana Forestry Commission Support Project which ran from 1995 to 2002.

As part of the support programme, steps were taken at institutional strengthening in areas of planning capability and management procedures, transparency and accountability of operations, improved staff performance and training, improvement in working environment and facilities and an enhanced public image:

- A National Forest Policy calling for "improved sustainable forest resource yields while ensuring the conservation of ecosystems, biodiversity and the environment" was published in 1997;
- A new forest revenue system was introduced in 1997;
- Improved facilities and staffing at field levels and an independent monitoring unit increased GFC controls;
- A Code of Practice for Timber Harvesting was prepared in 1998 and revised in 2002 providing a set of guidelines and requirements covering all aspects of logging;
- Forest inventory procedures, both strategic and operational, were produced;
- Guidelines for forest management planning were produced;
- Growth and yield models were developed based on tree data collected by Tropenbos and Barama Co.Ltd;
- A management tool called "silvicultural (post-harvest) survey" to determine differential minimum diameter cutting limits was introduced;
- A log tracking system was introduced to control forest operations;
- Revised curricula and syllabuses for the University and School of Agriculture were introduced;
- In-service management training for GFC staff was delivered;
- An in-service training programme incorporating social development and participatory skills for GFC and others was delivered.

The log tracking system in Guyana, introduced in 2000, provides detectable evidence on the legitimacy, location and magnitude of forest operations. The log tracking system currently applies to all operations, including those in State Forests, Amerindian Reservations and Private Properties, and is linked to the State Forest Permit (SFP) Quota System - an initiative to control the volume of produce harvested. The log tracking system is regulated by the use of log tags which are assigned to legal operators at the commencement of an operator's annual renewal of his SFP licence and are available to the operator free of charge. An operator's quota (forest produce volume) is calculated by an estimate of the sustained yield which considers the size of the forest area and captures the minimum log harvesting variables of felling cycle, felling distance and minimum diameter. The quota is equated to the number of standing trees which will yield this volume; and it is the number of trees computed that indicates the number of tags to be issued.

Guyana started working on a national forest certification initiative in 2000 with technical support from the UNDP-Programme for Forests (PROFOR). An NGO, the Guyana National Initiative on Forest Certification (GNIFC), comprising a balanced representation of stakeholders, has developed national standards based on the FSC Principles and Criteria. Guyana's forest certification standards were finalised through a multi-stakeholder process and endorsed by FSC in 2005 after three years of countrywide consultations.

9.3   Research

Guyana has a long history of botanical and ecological study, vegetation analysis, and inventory and tree volume work. Fanshawe (1952) wrote a study of the vegetation types and forest structure some 60 years ago. FAO in the late 1960s undertook countrywide reconnaissance surveys, produced stand tables, vegetation types and volume tables, whilst CIDA in the early 1990s conducted additional inventory, mapping and volume sampling work.

History of silvicultural trials

The first silvicultural trials were established at Aruka in the North West district, where exotic *Khaya ivorensis* and *Tectona grandis* were planted in 1926, but these trials were soon abandoned. In 1931 planting experiments continued at the new headquarters of the Forestry Department at the Penal Settlement on the Mazaruni River. Seeds of exotic species, such as *Swietenia macrophylla*, *S. mahagoni*, *Cedrela mexicana* and *Tectona grandis*, as well as indigenous species, such as *Hymenaea courbaril* (Locust), *Virola michelli* (Hill Dalli), *Peltogyne venosa* (Purpleheart), *Diplotropis purpurea* (Tatabu) and *Dipteryx odorata* (Tonka Bean), were sown.

Simultaneously, experiments concentrating on the natural regeneration of *Chlorocardium rodiei* (Greenheart) were started. The first operations consisted of underbrushing - removing all undergrowth competing with Greenheart seedlings and saplings - in lightly creamed forest near the Mazaruni Station, and were inspired by the Malayan Regeneration Improvement Felling System (e.g. Wyatt Smith et al. 1963).

In 1935, T.A.W. Davis embarked on a series of experiments in order to gain insight into the conditions favourable to the regeneration and growth of Greenheart. Several treatments were compared, including different combinations and levels of thinning of undergrowth, 'understorey' and canopy in unexploited Greenheart forest (Clarke 1956). In 1936, casual examination of the first improvement operations indicated that the technique used was successful to a remarkable degree in stimulating regeneration of Greenheart (Welch et al. 1975). It was therefore decided to concentrate silvicultural work on natural regeneration techniques and the plantation trials were stopped around 1939.

Routine forest improvement operations were launched. About 240 ha of logged forest near the Mazaruni Station were treated in 1937. Further improvement operations were carried out over selected areas of partially exploited forest on both banks of the Essequibo River. Between 1937 and 1943, a total of 8,750 ha of forest were treated in the Labakabra-Tiger Creek and the Moraballi-Seba Creek areas (Fanshawe 1944a, 1944b). The treatment consisted of climber cutting and manipulating the canopy over groups of seedlings, saplings or poles by poison girdling large, undesirable trees. During 1945-46, some 1,290 ha were treated a second time. The improvement work was suspended after 1946 in anticipation of the introduction of the new forest act in which a systematic block method of logging was envisaged.

After the new Forest Regulations were passed in 1954, silvicultural work aiming at the natural regeneration of exploited Greenheart stands was resumed at Barabara at the right bank of the Mazaruni river (Clarke 1956). The silvicultural prescriptions differed from the earlier work. Treatments of increasing intensity were staged over several years (Prince 1971a, 1973) with removal of undergrowth surrounding Greenheart regeneration over a period of six years and finally poison girdling of all canopy trees other than Greenheart in the tenth year. These prescriptions aimed at a gradual conversion to pure stands of Greenheart and were inspired by the Tropical Shelterwood System (e.g. Lowe 1978; Kio et al. 1986).

In 1957, improvement operations continued in the Moraballi-Seba Creek area, although with a modification of the original aims of 1937. Preference of treatment was still given to Greenheart where it occurred, but instead of promoting regeneration of Greenheart solely, regeneration of all valuable species over as much of the forest as possible was promoted. Between 1957 and 1959, 888 ha were given a first treatment, of which 583 ha were given a second treatment to remove all remaining undesirable species from the upper canopy. Two permanent sample plots measuring 80 x 80 m were laid down. One half of each plot - 40 x 80 m - was treated in the way described above and the other half was left untreated. In 1963, K.F.S. King laid down two increment plots, the first in exploited forest near the Mazaruni Station, the second in exploited forest at Barabara which was treated as described above. All Greenheart trees of 5 cm dbh and over were measured annually until 1969.

Based on these two sets of records, Prince (1971a, 1971b, 1973) estimated a rotation for Greenheart up to 50 cm of 150 to 218 years in untreated forest and of 74 to 136 years in treated forest. Given a felling limit of 34 cm (legal limit), he suggested a felling cycle of 100 years in untreated forest and of 60 years in treated forest. The treatments were considered successful in stimulating growth and survival rates of Greenheart. However, these treatments demanded huge investments in time and funds and Prince (1973) concluded that the marginal return on investment was stretched over such a long period and therefore so low that it was not worthwhile to continue improvement operations along these lines.

Other silvicultural investigations during this period focused on *Pinus caribaea* trials on white sands (Vieira 1967; Paul 1977) and on increasing growth of *Virola surinamensis* (Dalli) in the coastal swamp forest (John 1961). Interest in the latter species was instilled by a great demand for plywood production in Suriname at the time.

9.3.1 The Tropenbos-Guyana programme

The Tropenbos programme in Guyana started in 1989 and focused on various biological and physical characteristics and processes, both in unlogged and logged forests. The aim of the programme was to design sustainable forest management systems based on a better understanding of various biological and physical processes. The first phase (1989-1993) of the programme comprised four groups of projects (Ter Steege et al. 1996):
- Inventory and projects of general value;
- Hydrological balance and nutrient cycling;

- Population structure, dynamics and reproduction of important tree species; and
- Growth and productivity in relation to environmental constraints.

Most of the initial Tropenbos research took place close to Mabura Hill at the timber concession of Demerara Timbers Ltd in Central Guyana. Several experiments were conducted in logged and unlogged Greenheart-bearing forests on soils belonging to the Berbice (dekzand) formation, characterised by white sand plateaus with dry evergreen forest (savannah forest) and brown sands and sandy clay loams on slopes and footslopes with mixed evergreen rain forest (mesophytic forest). The first projects focused rather on a better understanding of the processes involved than in measuring impacts of different forest management strategies, such as logging intensity, cutting cycles, harvesting methods, or silvicultural treatments.

Main results from this first phase were (Ter Steege et al. 1995, 1996):
- Nutrient levels, cation exchange capacity, and fertilizer efficiency are very low in sandy soils. Low intensity logging seems to be the best land use option;
- Low intensity logging (< 25 $m^3.ha^{-1}$) appears to have fairly little impact on the hydrological and nutrient cycle at catchment level;
- To avoid erosion and siltation, logging should not occur in a buffer strip along creeks and on steep slopes;
- Shortage of individuals in the lower size classes of Greenheart does not allow a second harvest within 20-25 years;
- Uncontrolled skidding is a main cause for damage to the ecosystem because of destruction of seedlings and saplings, soil compaction on skid trails, leaching losses on skid trails and landings, and unfavourable growth conditions due to high aluminium concentrations and high acidity on trails and landings;
- Gap size should be kept small to minimize changes in microclimate, to favour the establishment of commercial climax species, and to buffer losses in nutrients and water through root absorption and litter input;
- Gaps should be spaced as evenly as possible over the exploited area;
- Single tree fall gaps are preferred above multiple tree fall gaps;
- Exploitation of Greenheart in a polycyclic natural regeneration system seems possible (Zagt 1997); but
- Substantial silvicultural intervention is indicated for sustained yield of Greenheart which should also target seedlings and small saplings (Zagt 1997).

During the second phase the Tropenbos-Guyana programme carried out research with the objective of developing guidelines for sustainable forest management and conservation. Its activities focused on:
- Knowledge of natural resources: physical environment, biodiversity, timber characteristics;
- Parameters for sustainable forest management;
- The significance of non-timber forest products for indigenous communities;
- Training and capacity building.

The research projects were carried out at two sites (Mabura Hill and the North-West district), in or around logging concessions.

Building on results of the CELOS experiments in Suriname an experiment was set up to evaluate the effect of logging intensity on growth and yield in Pibiri (50 km south of Mabura Hill) in 1992. Fifteen plots measuring 2 ha were established in Greenheart-bearing forest. This logging experiment is further described in detail in the following section. The experimental plots were also used for a study on plant diversity (including lianas and herbaceous plants) which was also assessed in plots where logging had taken place earlier in nearby areas. The experimental plots were also used to assess seedling performance, whereby growth and mortality of all seedlings was monitored in 250 quadrats (Rose 2000). At a later stage, 1999-2002, the Pibiri experimental plots were used in two studies; one focusing on the modeling of seed dispersal and regeneration of tropical trees (Van Ulft 2004) and one on long-term responses of tree populations and forest composition (Arets 2005).

Since the first phase of the programme had indicated that gap size was of overriding importance on long-term forest composition and productivity, a large gap experiment was set up at the Pibiri site. The gap experiment was an integrated study of soil, climate, nutrients, plant demography and ecophysiology in artificial gaps varying in size from 50 to 3,200 m^2.

Over the period that Tropenbos was active in Guyana (1989-2001), 48 projects were carried out, 19 during phase I, of which 6 were carried over to phase II, and 29 new projects during phase II.
Some conclusions from these projects in relation to forest management are (conclusions from the logging experiment are discussed separately):

- The 'allowable' gap size – in which the species composition is not significantly different from unexploited forest – is 300 m^2 (Ek 1997);

- Total skid trail area has a significant influence on the number of species after logging: skid trail area should be kept to a minimum (Ek 1997);

- Combined gap and skid trail area has the strongest influence on the number of newly established species after logging: skidding within gaps should be kept to a minimum (Ek 1997);

- Only some liana species are able to connect more host-trees and develop such a diameter that they can have a high impact on logging damage: pre-harvest liana cutting only needs to be applied to those liana species able to connect more host-trees (Ek 1997);

- Most species show their maximum growth rates in gaps of 200 to 800 m^2. A slow growing species adapted to shaded environments can only maintain itself after gap creation by having a size advantage over fast growing pioneers. Consequently damage to seedlings and saplings of desirable species should be kept at a minimum during logging activities (Rose 2000);

- If the gaps created are larger than 800 m^2, this initial size advantage may quickly disappear in the presence of high pioneer species abundances (Rose 2000);

- Indiscriminate skidder activity in conventional logging (as opposed to controlled activity in reduced impact logging) may destroy de seedling bank which consists mainly of shade tolerant (commercial) species while dormant seeds of pioneer species may benefit strongly from soil disturbance (Rose 2000);

- 95 % of natural tree fall gaps were smaller than 300 m^2 and 55 % of the gaps were less than 100 m^2 in size. If it is the objective to preserve current species composition and biodiversity, the impact of logging should stay within these limits;

- Leaching, acidification and mobilisation of aluminium strongly increased in gaps larger than 400 m^2. Considering these hydrochemical aspects, logging gaps should not exceed 400 m^2 (Van Dam 2001);

- Seedlings of pioneer species were found more in logging gaps and especially on skid trails in logging gaps (Van Ulft 2004);

- Since seeds are dispersed over short distances only, it is important that a number of healthy, large trees are left in the forest and that these remaining seed trees are distributed evenly over the forest to ensure that seeds will be available and evenly distributed throughout the logged area (Van Ulft 2004);

- It is possible to manage the forest in a way that results in relatively small changes in functional group composition and still achieves more or less sustained yields (Arets 2005);

- The time after logging to return to commercial volumes and abundances of functional groups that would be similar to unlogged forest may take as much as 100 to 120 years (Arets 2005);

- During logging large, reproductive trees are harvested, which may have implications for the regeneration of the forest after logging; omission of the relation between numbers of adults and numbers of recruits over time will lead to underestimation of the effect of logging on abundances and commercial volumes (Arets 2005).

9.3.2 The Tropenbos logging experiment

The main objective of the logging experiment was to formulate a silvicultural system for sustained timber yield from Greenheart forest in Guyana and similar forests elsewhere (Van der Hout 1999). An experiment was set up whereby conventional and reduced impact logging (RIL) were compared at three different logging intensities; *i.e.* 4, 8 and 16 trees per hectare. To this effect, 18 experimental plots of 2 hectares each were established in Greenheart forest in 1993. Trees of all species with a diameter above 20 cm dbh were identified and measured over the entire plot area, while smaller tree sizes were sampled in subplots of varying size. Logging took place in 1994 and its impacts on the residual tree population, gap sizes and ground disturbance were assessed in 1995. The plots were subsequently measured in 1996, 1997 and again in 2000 (Arets 2005). Silvicultural treatment took place in 1996. Besides the effect of the logging method, the effect of logging intensity was studied to determine at which level of extraction the gains of using RIL would be outdone by increasing logging intensity. The study also examined the costs and benefits associated with a transition from conventional timber harvesting practice to RIL and whether or not post-harvest silviculture would be an option to increase productivity of logged forest (Van der Hout 1999).

The study revealed that total canopy loss due to felling did not differ between conventional and RIL operations at a logging intensity of 8 trees per hectare, but raising the logging

intensity to 16 trees per hectare resulted in a greater canopy loss in case of RIL. This interaction was explained by the difference in felling pattern. In case of conventional logging, trees were felled in clusters, which led to overlapping felling gaps. In case of RIL, felled trees were more uniformly spaced and a herring-bone felling pattern was strictly applied. Multiple treefall gaps occurred much more often in the conventionally logged plots. An increase of logging intensity meant an increase of the number of trees in a cluster in case of conventional logging; *i.e.* an increased overlap in felling gaps. In case of RIL, this meant only a marginal increase in overlap of felling gaps. The average size of felling gaps according to a modified Brokaw definition (*sensu* Van der Meer & Bongers 1996) amounted to 209 m^2 in case of RIL with an intensity of 8 trees per hectare. In case of conventional logging, it amounted to 264 m^2 at this intensity. At 16 trees per hectare, the average gap size amounted to 439 m^2 for RIL and 333 m^2 for conventional logging (Van der Hout 1999).

Photo 9.2. Measuring the diameter of a Wadara (*Couratari guianensis)* above the buttress in one of the experimental plots at Pibiri. (Photo P. van der Hout)

Proper planning and marking of skid trails, a herring-bone felling pattern and the application of winching reduced the ground area affected by skidding considerably: at a logging intensity of 8 trees per hectare the ground area affected by skidding was reduced from 13 % to 8 % of the total area and at a logging intensity of 16 trees per hectare from 21 % to 9 %. In case of RIL, ground disturbance as a result of skidding occurred in 5 % to 8 % of the total felling gap area at logging intensities of 8 to 16 trees per hectare respectively, since ground disturbance was restricted to gaps along skid trails. In the conventionally logged plots this amounted to as much as 30 % to 36 % of the total felling gap area. This difference is of great importance for the future tree species composition in these gaps, since in gaps successful regeneration of shade-tolerant species, a group to which most commercial species belong, is depending on pre-existing seedlings (Brown & Whitmore 1992; Zagt & Werger 1998). Greenheart is locally very common as a seedling but its growth rate is lower than that of accompanying seedlings belonging to other species. Zagt (1997) suggested, therefore, that Greenheart would only be successful in filling a canopy opening if it has an advantage in size compared to close neighbours. Skidding in felling gaps crushes the few commercial seedlings that have this advantage and should therefore be avoided.

In all, RIL damaged fewer trees of dbh ≥ 10 cm per extracted tree than conventional logging (CL) at both logging intensities; 13.1 versus 16.4 trees were damaged at a logging intensity of 8 trees/ha (a reduction by 20 %) and 9.1 versus 10.2 trees at 16 trees/ha (a reduction by 11 %). Felling damaged less trees in RIL at a logging intensity of 8 trees/ha (7.8 versus 8.9 trees damaged per tree extracted), whereas more trees were damaged in RIL at a logging intensity of 16 trees/ha (6.5 versus 5.8 trees). Less trees were injured or

killed during skidding in RIL than in CL at both logging intensities. The reasons for these differences lie partly with the difference in felling method and partly with the fact that group-wise felling was practiced with conventional logging. In case of such clustered felling, the number of neighbouring large trees that can potentially be damaged is smaller.

Several studies have shown that additional cost associated with planning and directional felling can be offset by an increased efficiency of the skidding operation (Hendrison 1990; Barreto et al. 1998; Holmes et al. 2002). In the logging experiment, the implementation of the RIL system led to a threefold increase in pre-harvest planning cost and a twofold increase in felling cost. Those increases were only partly offset by a reduction of skidding cost, which amounted to 5 % only. The aggregate direct cost at the landing was increased by 15 %. On the other hand, the output per day and per hectare was higher under the RIL regime. Without the higher timber recovery the cost-benefit balance of RIL turned out more costly than conventional logging practice.

Logging costs and performance are affected by many different factors. The quantity and quality of available labour, the type and size of the trees to be harvested, topography, carrying capacity of soils, accessibility of the area to be logged and the skidding distances all influence the cost and performance of a particular logging system (Sundberg & Silversides 1988). The impact of these factors was assumed to be substantial due to the size and lay out of the experimental plots. The operational data were therefore standardised by setting a fixed logging intensity of 10 trees per hectare and a skidding distance of 383 m. By costing each activity on a per m^3 - basis, the influence of differences in site quality on the cost benefit analysis was reduced. Modelling skidding costs for a certain fixed distance and load size eliminated the effect of differences in extraction distance and load size.

Photo 9.3. Directional felling techniques applied while felling a Greenheart (*Chlorocardium rodiei*) in RIL. (Photo P. van der Hout)

Standardisation let to similar costs of conventional and RIL; i.e., US$ 28.29 in case of conventional logging and US$ 28.23 for RIL (price level 1998). Cost and performance of pre-harvest planning, tree marking and skid trail demarcation, and loading and trucking were estimated using general guidelines, these figures were less accurate than the cost and performance of felling and skidding. Focusing on the felling and skidding work cycles only showed that the cost of a cubic metre of timber landed at the roadside landing was estimated at US$ 5.60 in conventional logging and US$ 6.32 in RIL.

9.3.3 Effect of logging intensity and silvicultural intervention on growth and yield

Logging in 1994 removed mean basal areas of 1.2, 2.0 and 3.7 $m^2.ha^{-1}$ at logging intensities of 4, 8 and 16 trees per ha, respectively, which translated into removals of 10 %, 13 % and 30 % of the basal area of commercial and potentially commercial trees[1]. Mortality associated with logging considering all trees ≥ 20 cm DBH amounted to 0.4 $m^2.ha^{-1}$ (1.7 %), 0.6 $m^2.ha^{-1}$ (2.8 %) and 1.0 $m^2.ha^{-1}$ (5.0 %) of the initial basal area. Considering commercial and potentially commercial trees only, this amounted to respectively: 0.1 $m^2.ha^{-1}$ (1.8 %), 0.2 $m^2.ha^{-1}$ (2.4 %) and 0.3 $m^2.ha^{-1}$ (2.7 %). Greenheart made up about half of the harvest with an average basal area of 0.5 $m^2.ha^{-1}$, 1.1 $m^2.ha^{-1}$ and 1.6 $m^2.ha^{-1}$ having been removed (23 %, 28 % and 48 % of the initial basal area of Greenheart trees with good and acceptable stem quality, respectively) with associated mortality of 0.6 %, 0.9 % and 1.8%, respectively.

During the two years after logging (1995-1997), net basal area increment rates were positive for the group of commercial and potentially commercial trees but negative for trees of these species with poor stem quality (hollow or crooked) and trees of non-commercial species. This led to an overall decrease in basal area over this period for all treatments (Figure 1). For the period 1997-2000, net basal area of all trees slightly increased in most treatments.

Converting the annual basal area increment to annual volume increment by multiplying the basal area with a conservative form-height factor 10 presented a strong annual volume growth of 1.1 $m^3.ha^{-1}.y^{-1}$ for commercial and potentially commercial trees over the period 1995-1997 in the control plots, reasonable annual volume growth of 0.7 $m^3.ha^{-1}.y^{-1}$ at logging intensities of 4 trees/ha and 8 trees/ha, and 0.4 $m^3.ha^{-1}.y^{-1}$ at a logging intensity of 16 trees/ha. In the following period, 1997-2000, net volume increase became less in the control plots and at a logging intensity of 4 trees/ha but increased strongly at the two higher logging intensities (Table 9.1).

Table 9.1. Net annual volume increment per hectare for the periods 1993-1995, 1995-1997 and 1997-2000 with five treatments: control (no logging), logging intensity 4, 8 and 16 trees/ha and logging intensity 8 trees/ha followed by silvicultural treatment; and three species/quality groups

Treatment	Commercial trees - good or acceptable stem quality			Greenheart - good or acceptable stem quality			Non-commercial species and commercial trees – poor stem quality		
	'93-'95	'95-'97	'97-'00	'93-'95	'95-'97	'97-'00	'93-'95	'95-'97	'97-'00
0	0,2	1,1	0,6	0,4	0,4	0,0	0,4	-2,5	-0,6
4	-8,5	0,7	0,4	-3,7	0,2	0,1	-0,5	-1,7	-0,9
8	-13,1	0,7	1,0	-7,9	0,4	0,4	-2,2	-2,8	0,1
16	-25,3	0,4	1,2	-11,5	0,4	0,4	-4,8	-3,5	0,2
8 +	-15,7	-0,1	2,0	-6,9	0,0	0,5	-1,2	-35,0	1,5

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1   Commercial and potentially commercial trees are trees of commercial and potentially commercial species with good and acceptable stem quality – thus excluding hollow and crooked trees of these species.

If the latter net annual volume growth would be sustained the initial basal area would be restored within 31 years with a logging intensity of 4 trees/ha, 19 years with a logging intensity of 8 trees/ha and 32 years with a logging intensity of 16 trees/ha. To estimate the required cutting cycle the net annual volume growth of only the trees with a diameter ≥ 40 cm DBH was considered. This indicated a cutting cycle of 4, 18 years with a logging intensity of 4 trees.ha^{-1} (12 $m^3.ha^{-1}$), of 31 years with a logging intensity of 8 trees/ha (20 $m^3.ha^{-1}$) and 62 years with a logging intensity of 16 trees/ha (37 $m^3.ha^{-1}$). The sustainable annual allowable cut would thus be around 0.65 $m^3.ha^{-1}.y^{-1}$. This figure is twice the allowable cut that is currently prescribed by the Guyana Forestry Commission. It is, however, uncertain whether the growth rates for 1997-2000 were indeed sustained (the net annual volume increment for this period for this species group in the control plots amounted to 0.40 $m^3.ha^{-1}.y^{-1}$). It would be of great value if the plots of the logging experiment were measured again within the foreseeable future to allow verification of these results.

As far as Greenheart is concerned an annual allowable cut of 0.07 $m^3.ha^{-1}.y^{-1}$ is indicated with a logging intensity of 4 trees/ha, 0.14 $m^3.ha^{-1}.y^{-1}$ with 16 trees/ha and 0.28 $m^3.ha^{-1}.y^{-1}$ with a logging intensity of 8 trees/ha (around 10 $m^3.ha^{-1}$ with a cutting cycle of around 40 years). This implies that the sustainable allowable cut should only include around 40% Greenheart. If a cutting cycle of 25 years is applied, as with the CELOS Management System, this would suggest a logging intensity of 16 $m^3.ha^{-1}$ (around 7 trees/ha) whereby the Greenheart harvest would be restricted to 7 $m^3.ha^{-1}$ (around 3 trees/ha).

The silvicultural treatment consisted of a selective release of potential crop trees by localised elimination of undesirable trees within a radius of 10 m around favoured trees. This treatment reduced the basal area by on average 7.0 $m^2.ha^{-1}$ leaving a mean basal area of 12 m^2ha^{-1}. This implies that the basal area was reduced to approximately 55 % of the pre-harvest value and that the treatment was milder than the treatments that were applied in the CELOS experiments in Suriname and also milder than the treatment advocated by Jonkers (1987, see Chapter 3).

Net annual basal area increment rates were increased strongly by the silvicultural treatment (Table 9.1, Figure 9.1). If this increment rate would be sustained the initial basal area would be restored in only 10 years and a cutting cycle of only 14 years would be suggested with a logging intensity of 8 trees/ha (20 $m^3.ha^{-1}$) followed by silvicultural treatment. The sustainable annual allowable cut would then be around 1.45 $m^3.ha^{-1}.y^{-1}$, which is more than double than without silvicultural treatment. It is not likely that this increased volume increment rate will be sustained, but it is clear that the cutting cycle can be reduced substantially.

Greenheart did not show the kind of reaction that the other commercial species did and the net annual volume increment for Greenheart hardly differed from the same logging treatment without silvicultural intervention. It is perceivable that Greenheart reacts slower to the treatment in the light of its general lower growth rate.
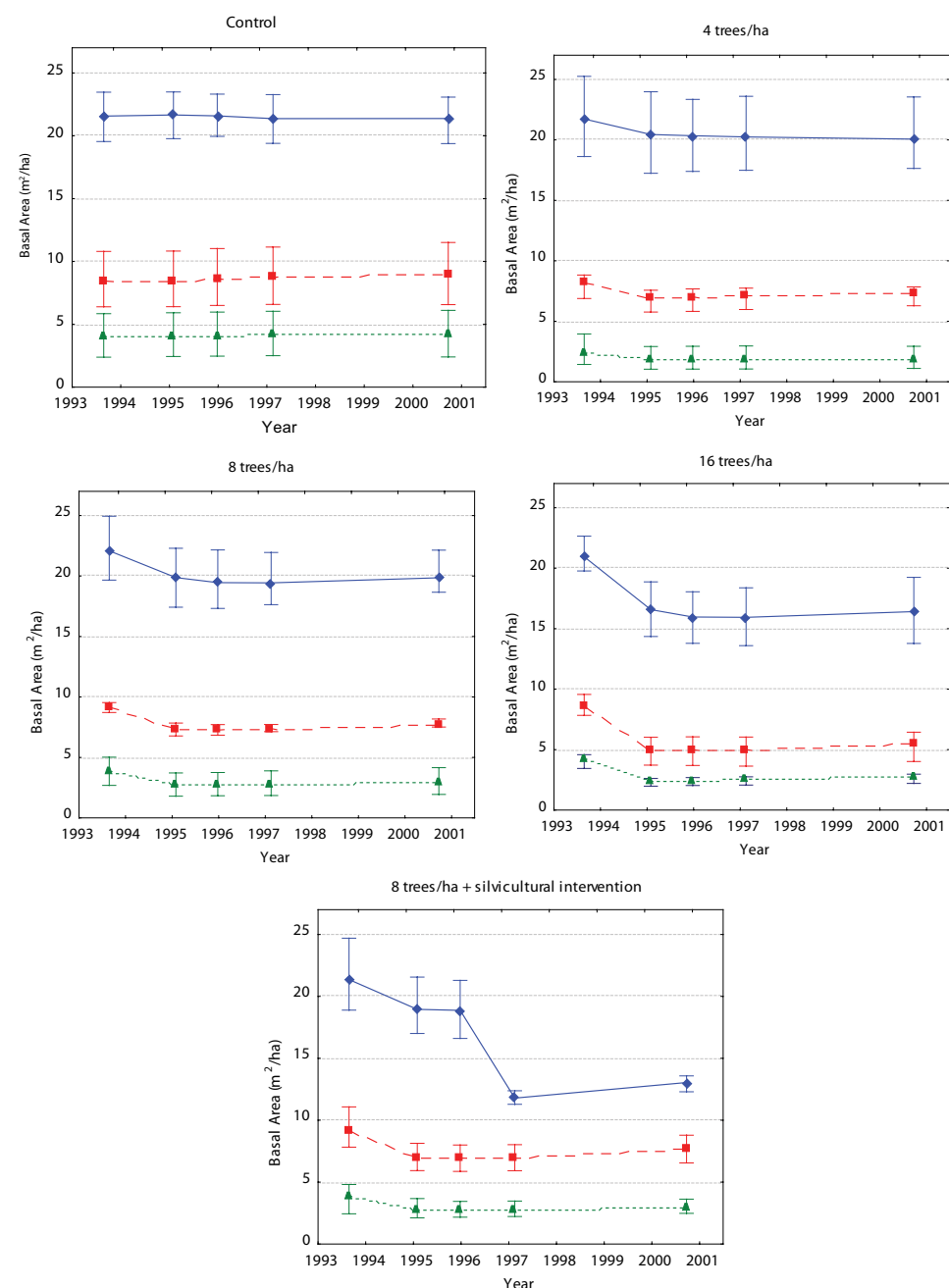
Figure 9.1.   Development of net basal area of trees with a diameter ≥ 20 cm DBH for five different treatments: all trees of all species blue diamonds and blue solid line, commercial and potentially commercial trees with good or acceptable stem quality red squares and red broken line and Greenheart (*Chlorocardium rodiei*) with good or acceptable stem quality green triangles and green dotted line. Basal areas are means of three plots; whiskers denote the spread in the plot values.

Based on this study a number of conclusions were drawn:

- Felling damage, in terms of the number and size of logging gaps or the number of injured or killed residual trees, is foremost determined by the logging intensity, and subsequently by the felling pattern, the spacing between felled trees and the felling method;

- Logging intensity should be limited to 8 trees/ha to avoid excessive logging gap sizes;

- Implementation of RIL reduced the disturbed ground area by two-thirds compared to conventional logging;

- Implementation of RIL was cost-neutral compared to conventional logging;

- Systematic elimination of undesirable trees down to 20 cm dbh is not more effective in improving the illumination of future crop trees than a treatment within a fixed radius of 10 m around future crop trees;

- Silvicultural treatments that are based on a systematic elimination of undesirable trees above a certain diameter limit are wasteful because more trees are eliminated than necessary;

- Preliminary results from the monitoring of the experimental plots suggests an optimum logging intensity of 7 trees per hectare with a logging cycle of 25 years and a maximum logging intensity of 3 Greenheart trees per hectare;

- Preliminary results suggest that the currently prescribed annual allowable cut of 0.33 $m^3.ha^{-1}.y^{-1}$ could be increased;

- Silvicultural treatment showed a strong positive reaction in the first four years after treatment, increasing the net annual volume increment of commercial species (sound trees only) from 0.65 to 1.45 $m^3.ha^{-1}.y^{-1}$;

- In the light of these preliminary results it is strongly recommended to remeasure the experimental plots to verify these preliminary results.

References

Arets, E.J.M.M. 2005. Long-term responses of populations and communities of trees to selective logging in tropical rain forests in Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 13. The Tropenbos Foundation, Wageningen, the Netherlands.

Barreto, P., P. Amaral, E. Vidal & C. Uhl. 1998. Costs and benefits of forest management for timber production in eastern Amazonia. Forest Ecology and Management 108, 9 26.

Brown, N.D. & T.C. Whitmore. 1992. Do dipterocarp seedlings really partition tropical rain forest gaps? in: Marshall, A.G. & M.D. Swaine (eds.). Tropical rain forest: disturbance and recovery (Philosophical transactions of the Royal Society of London, Series B 335): 369 378. The Royal Society, London, UK.

Clarke, E.C. 1956. The regeneration of worked-out Greenheart (*Ocotea rodiaei*) forest in British Guiana. Empire Forestry Review 35, 173 183.

Colchester, M. 1994. The new sultans; Asian loggers move in on Guyana's Forests. The Ecologist 24(2), 45 52.

Colchester, M. 1997. Guyana - fragile frontier; loggers, miners and forest peoples. Latin American Bureau / World Rainforest Movement, London, UK.

Ek, R.C. 1997. Botanical diversity in the tropical rain forest of Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 4, Georgetown, Guyana.

Fanshawe, D.B. 1944a. Improvement operations, Labakabra-Tiger creek area, 1937 1941. Internal report. Forestry Department, Georgetown, Guyana.

Fanshawe, D.B. 1944b. Improvement operations, Moraballi-Seba, 1938 1943. Internal report. Forestry Department, Georgetown, Guyana.

Fanshawe, D.B. 1952. The vegetation of British Guiana; a preliminary review. Institute Paper 29. Imperial Forestry Institute, University of Oxford, Oxford, UK.

GNRA. 1989. National forestry action plan 1990 2000. Guyana Natural Resources Agency / Guyana Forestry Commission / Canadian International Development Agency, Georgetown, Guyana.

Gordon, W.A. 1961. Forest management in the Caribbean. Caribbean Forester 22, 21 25.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 4. Agricultural University, Wageningen, the Netherlands.

Holmes, T. P., G. M. Blate, J. C. Zweede, R. Pereira, P. Barreto, F. Boltz & R. Bauch (2002) Financial and ecological indicators of reduced impact logging performance in the eastern Amazon. Forest Ecology and Management 163, 93-110.

John, C.A. 1961. The rate of growth of Virola surinamensis Warb. Unpublished Departmental Report. Forestry Department, Georgetown, Guyana.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 3. Wageningen Agricultural University, Wageningen, The Netherlands.

Kio, P.R.O., S.A. Ola Adams, B.A. Lapido & F.O.C. Nwonwu. 1986. Natural regeneration technology in use in African High Forests. in: Proc. of the XVIII IUFRO World Congress, Ljubljana, Yugoslavia, Division 1, Vol. 2, 424-437. International Union of Forestry Research Organisations, Vienna, Austria.

Lowe, R.G. 1978. Experience with the Tropical Shelterwood System of regeneration in natural forest in Nigeria. Forest Ecology and Management 1, 193 212.

McTurk, M., W. Russell & G.M. Peake. 1882. Notes on the forests of British Guiana. Timehri (Guyana) 1, 173-215.

Paul, D.K. 1977. The potential for the establishment of long fibre pulp plantations in Guyana. UNDP/FAO, Georgetown, Guyana.

Prince, A.J. 1971a. The rate of growth of Greenheart (Ocotea rodiei Schomb.). Unpublished Departmental Report. Forestry Department, Georgetown, Guyana. 60 p.

Prince, A.J. 1971b. Moraballi Forest Reserve; report on sample plots in improved natural forest. Unpublished Departmental Report. Forest Department, Georgetown, Guyana. 14 p.

Prince, A.J. 1973. The rate of growth of Greenheart (Ocotea rodiei Schomb). Commonwealth Forestry Review 52, 143 - 146.

Rose, S.A. 2000. Seeds, seedlings and gaps - size matters. A study in the tropical rain forest of Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 9. The Tropenbos Foundation, Wageningen, the Netherlands.

Sizer, N. 1996. Profit without plunder: reaping revenue from Guyana's tropical forests without destroying them. World Resources Institute, Washington D.C., USA.

Sizer, N. & R. Rice. 1995. Backs to the wall in Suriname: forest policy in a country in crisis. World Resources Institute, Washington D.C., USA.

Sundberg, U. & C.R. Silversides (eds.). 1988. Operational efficiency in forestry. Volume 1: Analysis. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Swabey, C. 1950. Note on the development of forest policy in British Guiana. Timehri (Guyana) 29, 27 35.

Ter Steege, H., R.G.A. Boot, L.C. Brouwer, D.S. Hammond, P. van der Hout, V.G. Jetten, Z. Khan, A.M. Polak, D. Raaimakers & R.J. Zagt. 1995. Basic and applied research for sound rain forest management in Guyana. Ecological Applications 5, 904 - 910.

Ter Steege, H., R.G.A. Boot, L.C. Brouwer, J.C. Caesar, R.C. Ek, D.S. Hammond, P. Haripersaud, P. van der Hout, V.G. Jetten, A. van Kekem, M. Kellman, Z. Khan, A.M. Polak, T.L. Pons, J. Pulles, D. Raaimakers, S.A. Rose, J.J. van der Sanden & R.J. Zagt. 1996. Ecology and logging in a tropical rain forest in Guyana; with recommendations for forest management. Tropenbos Series 14. The Tropenbos Foundation, Wageningen, the Netherlands.

Van Dam, O. 2001. Forest filled with gaps: effects of gap size on water and nutrient cycling in tropical rain forest. A study in Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 10. The Tropenbos Foundation, Wageningen, the Netherlands

Van der Hout, P. 1999. Reduced impact logging in the tropical rain forest of Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 6. The Tropenbos Foundation, Wageningen, the Netherlands.

Van der Meer, P.J. & F. Bongers. 1996. Pattern of tree fall and branch fall in a tropical rain forest in French Guiana. Journal of Ecology 84, 19 - 29.

Van Ulft, L.H. 2004. Regeneration in Natural and Logged Tropical Rain Forest. Modelling seed dispersal and regeneration of tropical trees in Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 12. The Tropenbos Foundation, Wageningen, the Netherlands.

Vieira, V.S. 1967. Pinus caribaea on white sand soils in Guyana. Commonwealth Forestry Review 46, 317 - 322.

Welch, I.A., L. Harry & W.T. Lord. 1975. A short history of the Guyana Forest Department 1925 1975. Forestry Department, Georgetown, Guyana.

Wyatt-Smith, J., W.P. Panton & B.A. Mitchell. 1963. Manual of Malayan silviculture for inland forest. Malayan Forest Records 23. Forest Research Institute, Kuala Lumpur, Malaysia. 2 vols.

Zagt, R.J. 1997. Tree demography in the tropical rain forest of Guyana. PhD thesis, Utrecht University, Tropenbos Guyana Series 3, Georgetown, Guyana. 251 pp.

Zagt, R.J. & M.J.A. Werger. 1998. Community structure and demography of primary species in tropical rain forest. in: Newberry, D.M., H.T.T. Prins & N.D. Brown (eds.). Dynamics of tropical communities (Symposium of The British Ecological Society 37), 193 - 219. Blackwell Science, London, UK.

10 Precious Woods, Brazil

N.R. de Graaf & T. van Eldik

10.1 General aspects of forest management in the Brazilian Amazon

Timber harvesting in the Brazilian Amazon is regarded by many as predatory (Silva et al. 2006) even after many governmental and private attempts to improve the situation with research, publications and demonstration projects.

The focus of nature conservationists all over the world is on deforestation rather than on the less damaging selective (and often only light) logging. Until recently it was difficult indeed to detect selective logging from satellite observations.

Logging usually opens the area up for further incursions ultimately leading to final clearing for rangeland or agricultural cultivation, so it is an important precursor of deforestation. With a new technique of remote-sensing analysis, an estimate was made of the area selectively logged in the top five timber-producing states of the Brazilian Amazon (Asner et al. 2005). Areas logged per year, in the period between 1999 and 2002, ranged from 1.2 million to about 2 million ha, equivalent to 60 to 123 % of the previously reported annual deforestation area. Also in conservation areas annually areas up to 120 000 ha were selectively logged, a demonstration of the difficulties to guard and preserve these conservation areas. Forest conservation areas need a master but this is difficult to finance, unlike the forest under active production management discussed in this book.

Historically, logging companies in the Brazilian Amazon region only exploited forest areas that afterwards were left and usually became agricultural land leading to agricultural expansion into the forest area. In the beginning of the 1990s, when the Brazilian government determined that forest products may only be obtained and transported if they originated from deforestation authorizations or forest management projects, the Brazilian logging companies started to create forest management projects in order to obtain the necessary credits for transporting their round wood production. Most of these forest management projects were based on manipulated forest inventories and were not even implemented. They were only elaborated on paper as a tool to obtain the necessary credits for the transportation of still conventionally and illegally exploited round woods.

In the late nineties, IBAMA revised and re-analyzed all existing forest management plans in the Brazilian Amazon region. The results were very clear. From a total of 2 800 forest management plans that were registered at IBAMA 1 128 were suspended and 633 were cancelled. During 2001, IBAMA analyzed again 822 forest management plans, of which only 49 % were considered in accordance with the existing law, rules and regulations (Lentini et al. 2003).

Logging in the Brazilian Amazon largely is done by small enterprises, with little mechanization, and if so, often with worn-out heavy skidding machines, some trucks and few, formally untrained but usually experienced personnel. A story apart is the logging of varzea-forest, where the annual inundation facilitates log transport by hand and motor launch. Chainsaws are used widely. They constitute a relatively small investment, though maintenance of these little machines is quite expensive. Until recently logs were sold to mills at low prices, and the deal with the landowner (or colonist without official land titles) often was that roads would be made as payment for the right to take the logs out. This whole procedure breathes a spirit of salvage logging, as the obvious future use of the land continues to be agriculture or rangeland.

Such logging is difficult to control by government, especially taken into consideration the dimensions of the Brazilian Amazon region and the scale of activities that are conducted inside the region. The Brazilian Amazon region comprises a total surface of more than 5 million square kilometres. About 2 500 wood companies are operational inside this region, exploring a total amount of about 28 million m^3 of round wood. The transportation of this volume involves 5 000 to 7 000 vehicles of various types (trucks or barges) dispersed over the roads and rivers inside the region (Lentini et al. 2003).

Government control would be much easier when logging were done by larger and better organized timber companies. Unfortunately, large timber companies only exist in small numbers, but they gained some more terrain in the first few years of this century, helped by governmental studies and regulations, as well as by the stimulus of markets asking for certified timber.

Silviculture in the Amazon so far was largely tree planting, e.g. the extensive Eucalypt plantations of Jari Cellulose SA. Since forest management is a relatively new concept in the Amazon, the main focus is still on regulation and reduced impact logging, two basic requirements for implementing sustained forest management including eventual silvicultural interferences. Experiences with natural forest management are largely experimental, done by EMBRAPA-CPATU, the IFT (Instituto Floresta Tropical), IMAZON and some FSC-certified timber companies.

Most information on the conducted silvicultural experiments is unpublished but in general the early experiences on tree liberation showed that applied interferences, moderately reducing the basal area of the remaining forest stand, were not effective, as competition of the remaining trees forcefully surged up again. The far heavier interferences in experiments in Suriname were regarded as being too strong to be acceptable for the often ecologically-schooled, conservation-minded foresters operating in the Brazilian Amazon region. On the other hand regular thinning in plantation forestry, often removes half of the standing volume in well-growing and young plantations. This is a well accepted procedure in Brazil.

10.2   Precious Woods Amazon

During the early 1990s, a Swiss company investing in tree planting in Costa Rica under the name Precious Woods took the bold step to start a forest management project in the Amazon basin, in Brazil. The country was chosen because at that time it still was possible to purchase forest lands (something that nowadays is much more restricted by law), and what is more important, the forest obtained was largely untouched or only creamed long ago, and available in sufficiently large areas of several hundreds of thousands hectares. The forest was relatively cheap at that time, because one did not see much value in it, even when exploitable. Cost of developing such areas was indeed large, and permits for clearing, the usual way of adding value, already were difficult to obtain. The first studies by Precious Woods of this project in Amazonia indicated good prospects.

In the region of Manaus, it is generally known that the ubiquitous yellow loamy soils (Latosolo amarelo) with very high clay percentages (above 90 % sometimes) but very low absorption capacity are not suitable for permanent agricultural use (after clearing). Alumina saturation also is very high in these soils and structural degradation, such as compaction, is a high risk with and after clearing. Because of the tourist industry the idea of logging is not popular in Manaus, and so far the interest of traditional loggers has not been strong in the region, quite different from the situation e.g. in deforestation zones in the state of Pará. There is also no population pressure on the land, so the risk of illegal settlers along the forest roads is low. There is some traditional settling, with subsistence farming and fishing/ hunting along major rivers, a practice already existing before the Conquista. It appeared that these conditions were fit to introduce the CMS as a form of sustained exploitation (De Graaf et al. 2003). Starting the CMS in actual colonization frontiers as found in e.g. Paragominas (state of Pará) would not have been a valid option, as the social conflicts are too large in that situation to work on land use of such an extensive type.

Selected was an area of some 80 000 ha located at 40 km from the small riverside town of Itacoatiara, which lies some 200 km downstream of Manaus, the capital of the state of Amazonas. The already existing but deficient wood processing installations were located inside the forest area, shortening the round wood transport distances. A public (dirt) road ran through the area, making infrastructure investments for the first years lower. No settlers were found along the road and they also did not arrive later. The forest had no abundance of already popular wood species, but the idea was to introduce lesser used species in due time and to aim for export production.

The general forest inventory estimated a total standing tree volume of 290 m³.ha⁻¹ above 5 cm DBH and a commercial standing tree volume of 80 m³.ha⁻¹ above 50 cm DBH, considering 65 different tree species. Initial programmed harvest volume was set between 30 and 35 m³.ha⁻¹.

A few deforested areas were located close to or in the area occupied by local communities and Precious Woods recognized their traditional land use rights from the very start of the project. Two areas were converted into agricultural land and into rangeland by the former owner. The community areas and converted areas covered 5845 hectares and were left outside the scope of the forest management project. Precious Woods set aside an Absolute Nature Conservation Area of 5 478 hectares. Several thousands of hectares had been heavily logged in the decennium before the purchase, but were included in the forest management area that totalled 69 400 hectares. Inside this forest management area some 8 % were covered with "*Campinarana*" forest, a non-productive forest vegetation type. Furthermore, some 20 % were allocated as stream buffer zones around the many existing water courses inside the forest management area.

The total forest production area resulted in 50 000 hectares that was divided according to the previewed harvest cycle into 25 yearly compartments of around 2 000 hectares each. The capacity of the saw mill was dimensioned according to the annual allowable cut estimated at around 60 000 m³ of round wood delivery. The production of sawn timber was mainly directed to the export market (Europe) for public water works, bridges and construction purposes such as houses and buildings.

10.3   Development of the project

The Forest Management Plan was approved in 1994. The plan was based on the CELOS Management System (CMS) and adapted to the local conditions based on researches done by EMBRAPA-CPATU and INPA (the National Research Institute of the Amazon). A preliminary manual for applying the CMS was translated in Portuguese to aid the knowledge transfer (Van Bodegom & De Graaf 1994). The first years were not easy, and sometimes big mistakes were made. Especially the sawmill, of a quite common and traditional type, gave a lot of trouble. The large capital losses before it really worked were nearly disastrous. It should not have been so, with all experiences, in Brazil as well as in other developing countries, with such low-tech installations. The forest management, however, soon worked well, also because Brazilian field workers are quite good in understanding and adapting to new procedures.

FSC-certification was obtained in 1997. This was at that time the only project for sustained timber production in natural forest in Brazil, but luckily more have followed in later years. The strong link of forest and processing industry under the CMS was logical and necessary to obtain certification, but it made supplementing the processing part with raw material from other, non-certified forest sources impossible. That proved a handicap for milling many species with low standing volumes. The export market (to Europe for example) became increasingly more receptive for lumber from certified sources, which presented a real advantage. Still, the sheer existence of large supplies of

tropical hardwood of competitive qualities, but from uncertified or even illegal sources, exerted a real downward pressure on the price level.

A memorable event was the presentation of the 1998 Corporate Award to Precious Woods, by the Ecological Society of America (ESA) in August 1998. ESA believes Precious Woods Ltd. provides an excellent example of how ecological principles can be used to sustainably manage forest resources. The CELOS Management System was mentioned and special conservation measures (in the Management Plan) for the mostly tree-dependent fauna were appreciated.

During the first years of operation, Precious Woods faced several facts that required adjustments in their forest management plan. It turned out that the forest area yielded less than half of the expected harvest volume. This was mainly due to the occurrence of many hollow and otherwise defect trees in the forest and the fact that the forest area contained relatively low quantities of the commercial species and Lesser Known Species that were wanted by the export market at that time. The sawmill yield also turned out to be below expectations due to inferior log qualities and smaller log dimensions, mix of a large number of different species including many Lesser Known Species, and a lack of production options due to the encountered marketing limitations.

Soon the original forest area of 80 000 hectares was found too small in order to reach sustainability. The sawmill capacity needed to be doubled in order to come to reasonable supply volumes for a successful introduction of the many Lesser Known Species. In total 312 000 hectares of additional forest lands were purchased by the company to expand their forest management base. Luckily these forest lands were still available adjacent to the original forest management area. These areas are being gradually integrated in the existing forest management plan.

It was possible to use the abundant sawmill rejects for generating electricity since a power plant was installed near the mill (Photo10.1). The power plant now supplies as a stable source also much of the electric energy used in the nearby small town of Itacoatiara, which was formerly dependant on costly imported diesel fuel.

Sustained forest management is thought by the authors to be an alternative to just preservation. It needs proof by demonstration, also as an economic option, and this is what the Precious Woods example did (De Graaf et al. 2003) and will continue to show, with constant evaluation, in a situation of learning by doing.

Of course there was a lot of criticism and even contempt, especially with the traditional loggers, that saw the CMS methodology as downright impractical and too costly. Nature

Photo 10.1.   A wood-fuelled power station was built at the sawmill site in Itacoatiara. (Photo N.R. De Graaf)

conservation adepts saw it as another form of organized degradation of native forest. Questions remain until ecological studies have shown the change in the forest functioning to be really acceptable in the long run. It is relatively easier, and at least needs less time, to pass the exam of financial viability than to prove ecological sustainability. But without financial success there will be no follow-up; the enterprise simply breaks down.

10.4   Forest production regulation in the Brazilian Amazon

According to article 15 of the Brazilian Forest Code, law 4.771 of 1965, forest exploitation is only allowed within the context of sustainable forest management projects. The process to apply for a deforestation authorization is still relatively easy as the law allows the conversion of up to a maximum of 20 % of the total property area of rural properties that are located in forested areas. However, the process to apply for a forest management plan approval is known to be very bureaucratic.

Forest management plans are required to be elaborated by accredited professionals and, since April 2003, these professionals are also formally held responsible for the correct implementation and execution of the elaborated sustainable forest management plans. An approved forest management plan has to submit a yearly harvest plan to IBAMA for obtaining the necessary harvest permit.

According to the latest regulations, the minimum harvest diameter of all species is set at 50 cm DBH. Maximum allowed harvest intensity is 30 $m^3.ha^{-1}$ and the harvest cycle is calculated based on a mean annual increment of the commercial stock of 0.86 $m^3.ha^{-1}.year^{-1}$. In practice however, harvest intensities of 30 $m^3.ha^{-1}$ are rarely realized by logging companies and the average is believed to lay somewhere between 18 and 22 $m^3.ha^{-1}$.

Based on the pioneer experiences of Precious Woods in the early 1990s, and other FSC-certified companies later on, the Brazilian forestry authorities adopted various management practices in their regulations. Prospection, or better known in Brazil as the 100 % forest inventory of the commercial tree species, for each annual harvest area prior to harvesting has been obligatory by law since 1998, including micro-zoning of the existing water courses, stream buffer zones and the existence of steep slopes over 45°. Since then harvest permits were based on the presentation of a selected tree population out of the 100 % forest inventory instead of being based on merely simple extrapolations based on 0.1 % forest sampling inventories that had proven to be very vulnerable to data manipulation.

Since the latest regulations, established in December 2006, several advanced criteria for guaranteeing the maintenance of the rare tree species and preserving reasonable populations of seed trees, as applied by the FSC-certified companies, were incorporated. This further restricted the selected tree population for which harvest permits could be applied. The obligation to have controls in place for the traceability of the felled logs and the presentation of a formal harvest report were regulated as well. Another interesting improvement was the elaboration of a formal manual for field inspections, turning them less vulnerable to the so far commonly practised corrupt transactions between logging companies and government agency representatives.

Regarding to forest monitoring and silvicultural interferences, the existing forest regulations are still very general in kind. The need for forest monitoring is mentioned in the regulations. However, there are no criteria defined on how this monitoring should be conducted. A logging company could implement the traditional method of permanent sample plots for their forest monitoring purposes, or simply present a new 100 % forest inventory of an annual compartment at the time it has completed the first harvest cycle.

In Brazil, the most commonly accepted silvicultural interferences are vine cutting and enrichment planting in large felling gaps. Liberation of Potential Crop Trees (PCTs) is not yet being considered as a feasible measure to stimulate growth of the commercial stocks during the harvest cycle. Since regulated forest management in the Brazilian Amazon is only recent and existing forest management plans are still operating in their first harvest cycle, it is expected that it will take several more years before important forest management aspects, like monitoring and silviculture, become more structured and better regulated by the Brazilian forest authorities.

10.5   Current practice

Precious Woods has been implementing the CMS on a commercial scale for over 15 years and during this period various interesting adjustments to the forest management system have been developed by the company.

Forest Inventory with GPS technology
100 % forest inventory of the commercial stock is the key for planning reduced impact logging. At Precious Woods Amazon, a 100 % forest inventory is executed at least one year prior to the harvest operation. During this operation, the yearly compartment is subdivided into small working units of 400×250 meters also referred to as being the 10-hectare plots. Within each 10-hectare plot all individuals above 40 cm DBH of more than 70 different tree species are numbered, identified, measured and located on a map. All existing water courses and slope conditions are also located and indicated on the inventory map.

With the introduction of the new generation of GPS equipment based on the *Sirf III* chipset, it became possible to obtain acceptable GPS coordinates under tropical tree canopy cover within an estimated error between 5 and 10 meters. In 2008, Precious Woods adapted the use of GPS technology in their 100 % forest inventories, following the example of the Digital Model of Forest Exploitation developed by EMBRAPA Acre in partnership with the Environment Institute of Acre (IMAC).

GPS was successfully implemented in the opening of the baselines (400×250 meters) and the 50 meter lines inside the 10-hectare plots. The implemented GPS technology improved the accuracy of the field surveys preventing accumulated distance errors, which occurred frequently in hilly terrain conditions. By using the barometric altimeter of the GPS equipment, it is possible to assess altitude at each 50 meter point inside the compartment. This additional information enabled the elaboration of very accurate and detailed Digital Elevation Models (DEM) and Slope Maps.

At present, the forest inventory crews, consisting of 24 operational forest workers and 7 staff and supporting crew members, are able to inventory 1 600 hectares per month.

Harvest Planning and Control
Originally, the CMS used simple spreadsheets and hand drawn maps for the harvest planning. Considering the scale of operation and helped by the introduction of computer science, it soon became interesting to automate the harvest planning and control. In 1996, Precious Woods started investing in the development of a Database application and a Geographic Information System (GIS). Later on, the further development of this software package was taken over by a forest consultancy firm and 50 %-sister company of Precious Woods named Ecoflorestal.

A specific Database application allows processing and manipulation of large amounts of data. Precious Woods Amazon operates in annual harvest areas of around 10 000 hectares including the stream buffer zones around the existing water courses. This produces an annual harvest volume of around 140 000 m³ of round wood. The 100 % forest inventory collects information on more than 200 000 individual trees. Especially the manipulation of this quantity of data in order to select the trees to be felled and the trees to be preserved for guaranteeing the maintenance of the species and for seed trees, would be very labour intensive if done by a normal spreadsheet application.

The current version of the Database application together with the Arcview GIS application covers the data processing of the 100 % forest inventory data, the selection of the trees to fell and to preserve, automated production of harvest maps and field forms for each 10-hectare plot, harvest production registration per crew and activity, log measurement of the produced round wood, transportation of the round wood to the industry, and the chain-of-custody controls (traceability of logs) required for FSC-certification. Recently, the obtained output of the applied GPS technology in the 100 % forest inventory permitted considerable improvements in the planning of roads and the layout of the skid trails and log landings. The harvest planning, when done well in advance, does also provide interesting information for the Sales Department to plan future deals for particular timber species.

Photo 10.2. Most logs are winched out, over often considerable distances, only lightly disturbing the vegetation, instead of being skidded out behind a tractor from the stump. Here the log has reached the tracked skidder that remains on the skid road. From there a wheeled skidder will take over the load and skid it to the log landing. (Photo N.R. De Graaf)

Harvest Methods

Precious Woods implements reduced impact logging techniques, such as directional felling, careful planning of the access roads, the layout of skid trails and log landings. However, the main difference in the harvest method practised by Precious Woods in Brazil with forest exploitations elsewhere in Latin America is the application of cable winching prior to skidding (Photos 10.2 & 10.3).

Photo 10.3. The tracked skidder shown here is a D4, so it is relatively light and damages the soil under the skid road but little. It is however strong enough as a mobile winching station, which is its main use. (Photo N.R. De Graaf)

For the winching operation tracked skidders are used, equipped with special high-lead winches, and quality steel cables light enough to be drawn from the drum up to 70 meters into the forest by hand. Special techniques to reposition the logs during the winching around obstacles were adopted. The application of cable winching proved to function 100 % on relatively flat terrain conditions. On more steep terrain still 90 % of the logs could be winched normally without the tracked skidder needing to leave the planned skid trails. The winching operation is quite labour intensive and requires 8 forest workers per winching crew. However, productivity reaches between 90 and 100 logs, or about 300 m^3 per crew per day.

The application of the winching technique permits a systematic planning of the skid trails at equivalent distances of 100 meters rather than planning the skid trails according to the projected trees to be harvested. The systematic planning of the layout of the skid trails and log landings permits repeated use over subsequent harvest cycles. This way the heavy machines only degrade the soil under a permanent layout of the skid trails and log landings. In general, the application of this technique considerably reduces the movement of heavy machinery inside the managed forest area. The experience at Precious Woods Amazon is that on average only 2.7 % of the managed forest area is used for the layout of the skid trails. An additional 1.1 % of the managed forest area is used for access roads and log landings. (see also photo 10.4).

Forest Monitoring

Precious Woods initially adopted the permanent sample methodology developed by EMBRAPA-CPATU. In 2003, this methodology was adapted by Ecoflorestal to a forest monitoring system that focused on generating reliable information on growth and yield of the remaining forest stands in order to support the decision making process of the forest manager as regards silvicultural interferences.

The adapted system reduced the sampling intensity to one permanent sample plot of half a hectare for each 200 hectares of production forest area. Furthermore, improved technologies were applied to increase the reliability on diameter and height measurements for obtaining more accurate growth and yield data. Data collection on natural regeneration, saplings, and trees below 15 cm DBH were excluded because of

difficulties with botanical identification. Observations on the sampled trees focussed on crown form and crown position, crown diameter, status and intensity of vine infections, and the damage on the stems and crowns of trees.

Since there is still a serious lack on autecological information on most Amazon tree species, the new system was designed to gather basic data for an ecological grouping of tree species mainly based on their light requirements and their natural diameter growth range, as well as on their diameter distribution pattern and their potential commercial use. Species grouping based on these variables proved to result in satisfactory species categories for a forest manager taking decisions on how to interfere in order to stimulate tree growth of the Potential Crop Trees (PCTs) in the remaining forest stand.

Silvicultural Methods

In most of the silvicultural systems used in Tropical Moist Forests much attention is given to successful regeneration of the valuable species, and often special treatments are applied to secure such regeneration. In Suriname already Schulz (1960) found that regeneration was nearly always present, or coming in after light disturbance, in sufficient numbers, and this was seen also in the forests of Precious Woods near Manaus. Both regions, Suriname as well as Manaus, appear to have comparable forest types and dynamics, although the species composition is different. The problem in silviculture lies more in the low increment of valuable species after logging. Silviculture in the Precious Woods forests is mainly focussed on growth stimulation of Potential Crop Trees (PCTs) by reducing competition for light. Unwanted neighbouring trees that are competing for light with PTCs are eliminated, mostly by applying girdling techniques. Precious Woods Amazon adopted this view from the very beginning.

Precious Woods started its first silvicultural treatments in 1997. Indeed the local management regarded the CELOS Silvicultural Management refinement option as being too strong to be acceptable. Overall refinement was replaced by intensive liberation of marked Potential Crop Trees (PCTs), which could be found in sufficient numbers. This liberation treatment was a variant of one already studied in Suriname, but had been found slightly less effective and somewhat more expensive than overall refinement (De Graaf 1986).

One serious problem arose in applying the original system. While in Suriname the use of arboricides had been accepted (at least in the experimental period of research and early management by the Forest Service), the Brazilian reality was that such arboricides would transform silviculture into a polluting industry, and thus, according to the law, should be more heavily taxed. A double and deep girdle, some 20 cm separated from each other, in which the bark was completely removed, was used as a substitute for frilling and spraying (Photo 10.5).

Photo 10.4. Overview of a forest stand (Compartment B) after logging. The light opening of the canopy is not easily discerned and shows mainly exposed stems. The log landings already have been emptied and cleaned up. (Photo N.R. De Graaf)

(A frill is a series of overlapping axe cuts around the tree base without removing the bark.) Diesel oil, which was not seen as a serious pollutant in Brazil, could be accepted for additional treatment of difficult-to-kill species, e.g. those with abundant latex,

Photo 10.5. Making a double girdle by power saw is a substitute for chemicals to kill undesirable trees. Such tree killing is done to liberate Potential Crop Trees from competing trees, such as this one, in order to promote their growth. (Photo Van Eldik)

Since silvicultural interferences are in fact long-term investments for the next few harvests, a forest manager needs to carefully evaluate how to invest the best way to achieve his forest management objectives. The data gathered in the 100 % forest inventory were used to differentiate the site conditions of the harvested forest areas in three categories: a) areas that even after harvesting are still sufficiently rich in commercial timber to provide a harvest in the next cycle; b) areas that even with treatment will not be able to produce any reasonable harvest next cycle; c) areas that need a liberation treatment to produce enough volume for a next harvest. The categories were grouped on the management map in areas consisting of several or many half 10-ha plots (the basic units). This way the area to be liberated as a rule amounted to some 70 – 80 % of the harvested areas. This meant a considerable reduction in work load, only made possible by the 100 % forest inventory which, together with the collected information in the Database and Arcview GIS application, also permitted the preparation of the basic field maps for guiding the silvicultural operations.

It soon became clear that in the case of reduced impact logging, one often finds more PCTs than can effectively been liberated in the remaining forest stand. Several PCTs will in fact be competing for light with each other and choices are necessary to be made by the forest manager. Initial experimenting tried to define priorities for liberating species groups according to the occurred harvest intensities per compartment. To make the silvicultural intervention more cost effective it was decided to focus the liberation on PCTs with a straight stem form, with acceptable (circular, half circular or irregular crown forms) and having crown positions receiving only vertical light or crowns that were partly shaded by neighbouring trees. This methodology required investing in an additional inventory on PCTs prior to the liberation treatment. It was not possible to use the available data from the 100 % pre-harvest inventory since data on PCTs between 30 and 40 cm were not recorded, and neither information on crown forms and positions. Also, silvicultural interventions should be based on existing forest stand conditions that are found a few years after the harvest.

This treatment has been applied to over 14 000 hectares of managed forest and the implementation on this large scale permitted a reduction of the costs. As Brazilian foremen and forest workers have the ambition to improve their work, mainly labour costs were considerably reduced, namely to 5 hectares per team day, the team consisting of one crew leader and three assistants (De Graaf et al. 2003). Special training was given to personnel for this type of silviculture, for selecting and evaluating PCTs, their crown form and position in the canopy, and determining the need for liberation (see Photo 10.6). It was necessary to explain the field crews why the forest needed to be opened up for regeneration and growth. Killing trees for production was generally accepted, but killing trees to reduce competition without harvesting the timber first needed to be made understood as an useful practice.

Although the silvicultural experiences were considered successful in terms of operational procedures and production, Precious Woods Amazon temporary suspended the applied silvicultural treatments in 2006, because it felt the need to fine-tune the planned interferences on basis of the expected information that becomes available by the adapted forest monitoring methodology described above. This is anticipated to happen within the next few years.

10.6   Main issues restricting Sustainable Forest Management at present

It appears from the results of Precious Woods that the CMS may really be an alternative for rampant logging-induced deforestation frontiers, as was suggested by De Graaf & Poels (1990). For nature conservation it is important that the CMS-option makes more land available for strict reserves. It was hoped for that nature conservation organizations would pick it up and promote the idea. Indeed in 1999 Greenpeace recognized the CMS, as practised by Precious Woods, as an acceptable form of forest use. Conservation International in 2001 still kept seeing it as undesirable, preferring a creaming of forest followed by closure (or restricted access, see Rice et al. 2001).

Sustainable Forest Management may be considered a form of forest domestication, and as such it is not acceptable to everyone. Also the need for increment stimulation of the Potential Crop Trees by silvicultural interferences is not generally recognized. Views on forest management are often determined by an antipathy of the traditional ways of logging, as these are very destructive. Foresters are first of all conservators, and then accept also the felling of trees for making a living from the forest. The CMS means a change in attitude from loggers towards foresters. But probably the former loggers are not easy to convert into forest managers, as it is difficult to teach an old dog new tricks. It might be easier to recruit such forest managers from the group of conservationists, who seem now inclined to see the various possibilities of moderate forest uses (Anderson 1990).

In Brazil, the development of the forestry sector has stagnated since 2005, mainly due to more stringent rules and regulations addressing the problematic and chaotic land tenure situation of forest lands in the Brazilian Amazon region. Also rules and regulations regarding forest management have been tightened since 2006. In fact, sharpened up regulations do not directly affect illegal loggers for the simple reason that they do not comply with them anyway. More stringent rules and regulations only distance them more from becoming legal. A contrary effect of sharpening up rules and regulations is

that it directly affects legal operations by an increased bureaucracy, resulting in costly delays of obtaining the necessary environmental licences for normal operations.

Even though government control and law enforcement have been intensified over the last years, the lack of governmental infrastructure, corruption and falsification practises unfortunately still allows a significant continuation of illegal logging practises. Therefore, the continued existence of unfair competition inside the forestry sector turns the actual scenario for responsible forms of forest management not very favourable in the Brazilian Amazon region.

In 2006, the Brazilian government has regulated forest concessions on public forest lands in order to provide legal access to forest lands for logging companies. As a result of the defined procedures, it required some years before large scale forest concessions could become a reality in the Brazilian Amazon region. One of the main reasons for this slow process is believed to be due to governance inconsistencies that exist between the involved Ministries responsible for the development of Brazilian Amazon region. However, at this moment about 22.5 million hectares of public forest lands are legally appropriate for forest concessions. In 2010, one million hectares were under the different procedural phases for forest concessions. For 2011 the Brazilian Forestry Service planned to bring out another 5.1 million hectares of forest concessions.

An important difference in opinion exists between the agricultural lobby and the conservation-minded lobby about the need for forest preservation and land use planning. The logging lobby just perseveres in their approach, also because predatory logging appears to be cheap, and in the mean time prepares the way for further forest clearing and final agricultural use. This has been the traditional approach, and is tried to be continued. But is agriculture and rangeland really sustainable and profitable in the long term on these poor soils?

In a region with seemingly boundless forests, as is Amazonia Legal, priority is not easily given to sustained forest use. Attention is given rather to alleviation of food scarcity and poverty by granting land to small farmers for e.g. agroforestry, a potentially good approach (Anderson 1990), or by allowing the age-old land use of shifting cultivation. People are rightly the first concern of government. However, in our opinion a better approach would be to provide jobs in sustainable forestry, to furnish an income to buy the food so abundantly grown in the south of Brazil. The deficiencies of shifting cultivation in supplying real development for the people should be well known by and by.

For such sustainable forestry development as discussed above one of the sticking points is the need for capital. The Precious Woods venture has shown much of the way with its daring first entry.

References

Anderson, A.B. (ed.). 1990. Alternatives to Deforestation: Steps toward Sustainable Use of the Amazon Rain Forest. Columbia University Press, New York, USA. pp. 281.

Asner, G.P., Knapp, D.E., Broadbent, E.N., Oliveira, P.J.C., Keller, M. & Silva, J.N. 2005. Selective logging in the Brazilian Amazon. Science 310.

De Graaf, N.R. 1986. A Silvicultural System for Natural Regeneration of Tropical Rain Forest in Suriname. PhD thesis, Agricultural University Wageningen, The Netherlands. pp. 250. Also in the series: Ecology and management of Tropical Rain Forest in Suriname (1).

De Graaf, N.R. & Poels, R.L.H. 1990. The CELOS Management System: a Polycyclic Method for Sustained Timber Production in South American Rainforest. In: Anderson, A. B. Alternatives to Deforestation: Steps toward Sustainable. Use of the Amazon Rain Forest. Columbia University Press, New York, USA, pp 116 -127.

De Graaf, N.R., Filius, A.M. & Huesca Santos, A.R. 2003. Financial analysis of sustained forest management for timber. Perspectives for application of the CELOS management System in Brazilian Amazonas. Forest Ecology and Management 177, 287-299.

Lentini, M., Verissimo, A. & Sobral, L. 2003. Fatos Florestais da Amazônia. IMAZON, Belém, Brazil.

Rice, R.E., Sugal, C.A., Ratay S.M. & da Fonseca, G.A.B. 2001. Sustainable forest management. A review of conventional wisdom. Centre for Applied Biodiversity Science. Conservation International, Washington, D.C., USA.

Schulz, J.P. 1960. Ecological studies on rain forest in Northern Suriname. Vol. 2 in: The vegetation of Suriname. Van Eedenfonds, Amsterdam & 's Lands Bosbeheer, Paramaribo, Suriname. pp 267.

Silva, J.N.M., Pokorny, B., Sabogal, C., de Carvalho, J.O.P. & Zweede, J. 2006. Partnership for good forest management. Tropical Forest Update, Vol 16 (4), ITTO.

Van Bodegom, A.J. & De Graaf, N.R. 1994. Sistema CELOS de manejo. Manual preliminar. Werkdocument IKC Natuurbeheer. Wageningen, The Netherlands. pp. 58.

11 Bolivia

M. Peña-Claros, R. Guzman & M. Dockry

11.1 Brief description of forest management in Bolivia

Bolivia started to implement the Forestry Law (# 1700) in 1996. Since then the Bolivian forestry sector has changed significantly from an unplanned and exploitative logging regime to an organized system based on reduced impact logging techniques and management plans elaborated by trained forestry technicians and professionals. It has also expanded access to forest harvesting by allowing rural and indigenous communities the right to manage forest resources along with private companies. The law also provided a suite of technical tools to ensure the sustainable use of the forest resource. The 1996 forestry law and its implementation has resulted in a diversification of species being used for timber production, an increase in the amount of finished forest product exports, and improvements towards forest sustainability. This latter aspect is most evident in the approximately two million hectares of tropical forests that have been certified as sustainably managed under the Principles and Criteria defined by the Forest Stewardship Council (FSC) (Certificación Forestal Voluntaria 2008).

Despite Bolivia's status as a sustainable forestry leader, there are political, socioeconomic, and ecological challenges to sustainable forest management. Most of these challenges have their origins outside the forestry sector and are related to the development vision being used in the country. These limitations are of concern to the sustainability of Bolivia's forestry sector and their recognition is important in order to be able to mitigate their effects in the future. The rest of this chapter will expand upon the successes and challenges to sustainable forest management in Bolivia.

11.2 Forest reserves and off-reserve tree resources and their utilization

Bolivia is one of the most biodiverse and forest-rich countries in the world, with more than half of its ecosystems in good or excellent conservation status (Ibisch 1998, 2005). The high biodiversity of Bolivia is due to the fact that its territory varies strongly in geomorphology, topography, climate, and soil. Four major ecological regions can be distinguished in Bolivia: the Andean Region, the Amazon Region, the Brazilian Shield Region, and the Great Chaco Region (Navarro & Maldonado 2002). In these broad ecological regions there are 18 Holdridge Life Zones or 199 different ecosystems. These ecosystems comprise a great diversity of forest ecosystems, which vary largely in forest structure, floristic composition, and number of species. Forest types range from cloud forests to tropical dry forests, to Amazonian rain and wetland forests, to Andean mountain forests.

About half of Bolivia is covered with forest: about 53,000,000 ha (BOLFOR II 2008). The Bolivian government has classified about 41,235,500 ha as Permanent Production Forested Lands (TFPP, *Tierras Forestales de Producción Permanente; Decreto Supremo* 26075). The majority of the TFPP are considered production forests (68 %) that have to be managed following the technical norms and practices defined by Forestry Law # 1700. The rest of the TFPP have restrictions on their use because these areas are either included in the national system of protected areas (26 %) or their final major land use category is still to be defined (6 %).

The production forests are located in 7 of the 9 departments of the country and comprise mostly lowland forests. These forests are divided into six regions based on ecological and timber production potential: Chiquitania, Bajo Paraguá, Guarayos, Choré, Pre-andean Amazon and Amazon (Table 11.1). Of the 68 % (i.e. 28,190,600 ha) classified as production forests, 8.5 million ha are currently managed for sustainable timber production (Table 11.2) (Cámara Forestal de Bolivia 2008a). About 25 % of the area under forest management is certified as sustainable forest managed under the scheme of the FSC (Certificación Forestal Voluntaria 2008).

Table 11.1. Average density, basal area, and volume estimates for the six regions in the Bolivian lowland forests. dbh= diameter at 1.3 m aboveground, BA= Basal Area, MDC= minimum diameter for cutting. Data from Dauber et al. 2000.

Region	Density dbh ≥20cm (#/ha)	BA dbh ≥20cm (m².ha⁻¹)	Volume dbh ≥20cm (m³.ha⁻¹)	Density dbh ≥MDC (N.ha⁻¹)	BA dbh ≥MDC (m².ha⁻¹)	Volume dbh ≥MDC (m³.ha⁻¹)
Chiquitania	110	11.7	43	24	4.5	19
Bajo Paraguá	84	8.6	51	5	2.1	16
Guarayos	78	11.0	47	10	3.9	19
Choré	119	17.5	89	13	5.9	33
Pre-andean Amazon	89	13.2	77	9	4.5	30
Amazon	103	15.2	116	7	3.1	27

Table 11.2. Area under forest management and number of contracts by user type and legal rights. Data is from 2007. (Cámara Forestal de Bolivia 2008a).

Legal Rights and User Type	Area (ha)	%	Number of Contracts
Concessions			
Local Social Associations	906,574	11	39
Private companies	5,399,278	64	85
Universities (for research)	262,368	3	3
Properties			
Management areas in indigenous community-owned land	723,168	8	29
Privately-owned property	1,078,275	13	677
Management under previous law			
Harvest contracts	112,000	1	1
TOTAL	**8,481,663**	**100**	**834**

11.3 Historical development in forest exploitation

Bolivia lacked a coherent forest policy until 1974 when the first Forestry Law was enacted. The objective of this law was "development of the forest sector for socio-economic benefits through the use and protection of the forest resources". This law declared all forest to be owned by the state (in accordance with the previous State Constitution), and gave the state the right to issue permits for using the forest both on public and private land (Benneker 2008). Permits were given to enterprises on an annual, short (for 3 years), medium (for 10 years) or long-term (for 20 years) basis. These permits were called logging contracts, and could only be obtained by registered enterprises. To register, enterprises had to present a forest management plan, a reforestation program, and had to demonstrate that they had the ability to process logs. After obtaining a contract enterprises paid revenues and fees based on the volume extracted, which generated a lot of corruption and little control of logging activities.

These requirements for obtaining a contract effectively excluded local and indigenous communities from receiving logging contracts (Benneker 2008). This exclusion caused social conflicts among stakeholders because not all actors had legal access to exploit the forest commercially (Quevedo 2006). The social conflicts culminated in an indigenous march upon the capital city in 1990 to demand, among other things, the rights of indigenous communities to harvest their forests legally and sustainably. This indigenous movement set the social and political stage for the passing of Bolivia's 1996 forestry law (BOLFOR II 2009).

By 1996 there were 173 enterprises operating over an area of 21 million ha of forest, corresponding to 40 % of all the forest in the country (Contreras-Hermosillo & Vargas Rios 2007). Most of the logging contracts given (around 185 by 1996) were short-term contracts, because long-term contracts were difficult to obtain as they had to be approved by the national congress (Contreras-Hermosillo & Vargas Rios 2007). Logging was virtually unregulated and characterized by high-grading, no planning, poor

harvesting techniques and inefficient milling. Nearly all timber harvested belonged to just three species – mahogany (*Swietenia macrophylla*), Spanish cedar (*Cedrela fissilis*) and Spanish oak (*Amburana cearensis*). Mahogany accounted for 60 % of the total export value between the 1980s and early 1990s, and much of it left the country as unprocessed logs (Fredericksen et al. 2003). The consequences of these logging practices were that harvestable trees of the abovementioned species became scarce in most Bolivian forests, residual stands partially lost value due to damage and timber theft, and wildlife poaching compromised forest diversity (Fredericksen et al. 2003).

Forestry Law # 1700 (*Ley Forestal 1700*), passed in 1996, created the legal and institutional framework for a new forest management regime. The law defined access to forest harvesting and provided a suite of technical tools to ensure the sustainable use of forest resources including, among others, the use of reduced impact logging (RIL) techniques during logging operations. Most of these technical tools required by law are commonly required by certification schemes like the one of FSC. Additionally, the new law democratized the access to forests by allowing both private companies and local people grouped in Local Social Associations (*Agrupación Social del Lugar, ASL*) to obtain forestry concessions through the national and municipal governments, respectively. Furthermore, indigenous communities were allowed to legally manage forests within their Indigenous Community-owned Lands (*Tierras Comunitarias de Origen, TCO*), while private property owners were allowed to manage forests within their individual properties. Of the more than 8.5 million ha of managed Bolivian forests, around 75 % are managed by industry through forestry concessions and 32 % is managed by groups that were not recognized under the previous law (Table 11.2) (Cámara Forestal de Bolivia 2008a).

The Bolivian forestry sector has also changed in other aspects. In the last ten years the list of commercial tree species harvested in Bolivia has grown to include "lesser known species" or alternative species previously under-utilized in the market. In 2006, more than 380 tree species were harvested for a total volume of 980,285 m³. However, ten species accounted for 51 % of this volume with the top five most harvested species being *Hura crepitans* (14.9 %), *Dypterix odorata* (7.4 %), *Tabebuia* sp. (5.7 %), *Ceiba pentandra* (5.7 %) and *Amburana cearensis* (3.7 %) (Superintendencia Forestal 2007). Bolivia's capacity for producing forest products has also increased over the years. In 1995, 64 % of forest products exports were in the form of semi-finished products. By 2003 this figure had changed significantly as 61 % of the forest products exported were finished products, generating a total of 145 million US dollars. Currently, Bolivia exports over 50 different types of finished wood and non-timber forest products and more than 20 semi-finished products.

11.4 Productivity, annual allowable cut, silvicultural systems

Production forests have been divided into six regions based on their hydrologic regimes, location, and timber production potential: Chiquitania (6.3 million ha), Bajo Paraguá (3.8 million ha), Guarayos (4.2 million ha), Choré (1.6 million ha), Pre-andean Amazon (4.1 million ha) and Amazon (8.8 million ha). The regions differ in average tree density, basal area, and volume (Table 11.1, Dauber et al. 2000), as well as in number of species harvested and taxonomic identity of the commercial species. Additionally, diameter growth rates differ, with trees from the Chiquitania growing slowest (mean growth rate

0.18 cm.y^{-1}) and trees from Guarayos growing fastest (0.39 cm.y^{-1}) (Dauber et al. 2003, 2005). Consequently, these regions also differ in the volume to be recovered for the second harvest (using a cutting cycle of 25 years; Dauber et al. 2005).

In Bolivia the annual allowable cut is not based on a fixed volume per ha but on the amount of harvestable trees found in a given annual logging compartment. Harvestable trees are inventoried, measured and marked for harvest in each annual logging compartment, following the rule that 20 % of the harvestable trees of every commercial species is left as seed tree. Forest managers use this inventory to prepare an annual operational plan that indicates the estimated harvestable volume to be harvested in the following year. The inventory is also used for other aspects related to forest management, such as elaboration of (logging) maps. The operational plan is revised and approved by the *Autoridad de Fiscalización y Control Social de Bosques y Tierra* (ABT) that grants, regulates, and controls harvesting rights. In 2009 the ABT replaced the former *Superintendencia Forestal* (SF) institution created by Forestry Law # 1700.

The SF granted permission to cut on average 1,291,070 m^3 round wood per year during the period of 1999-2006. The actual extracted volume corresponded, however, to only 40 % of the allowed cut (MDRAMA 2007). Harvesting intensities in Bolivia are rather low compared to intensities elsewhere in the tropics; they range from 1-6 trees/ha (equivalent to 2-10 m^3.ha^{-1}) depending on forest type.
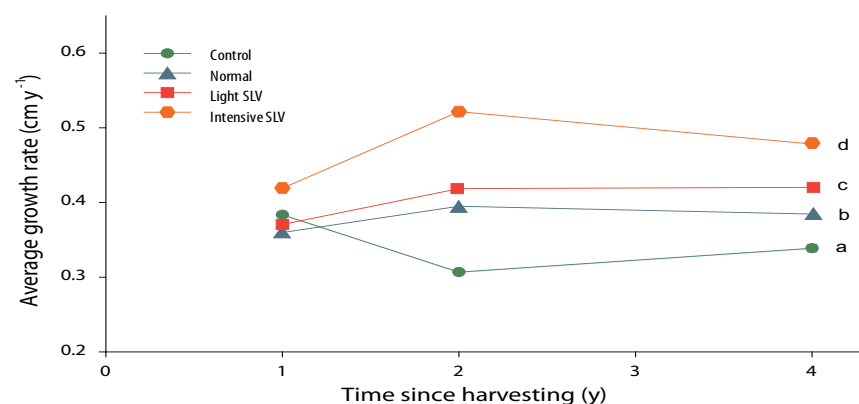

Figure 11.1. The effect of treatment on average tree growth rates through time after different management treatments were applied in a moist forest in the Guarayo region. Data are means ± 1 SE based on all trees sampled in each treatment. Different letters represent significant differences over time. Intensity of logging and application of additional silvicultural treatments increases from control (no logging) to intensive silviculture (SLV). All logged treatments were logged using reduced impact logging techniques. See Table 11.3 for more details on treatments applied.

The main silvicultural treatment currently being applied in Bolivia is timber harvesting itself (Fredericksen et al. 2003). Very few additional silvicultural treatments are used to increase growth rates of future crop trees or to promote the regeneration of commercial species (Snook et al. 2007). This is probably due to the lack of specific information on silvicultural practices within the current legislation (see MDSP 1998; Snook et al. 2007;

Sabogal et al. 2007). Several studies have shown, however, that additional silvicultural treatments are needed to guarantee sustained timber yields (Dauber 2003; Blate 2005; Dauber et al. 2005). Moreover, it has been shown that the application of RIL techniques results in lower growth rates than when RIL is applied together with additional silvicultural treatments (Fig. 11.1; see later for more detail on treatments applied). Thus, application of additional silvicultural treatments together with RIL will produce more timber volume for subsequent harvests (Peña-Claros et al. 2008).

Silvicultural treatments are evaluated in the Long-Term Silvicultural Research Program (LTSRP) that is carried out by the Bolivian Institute of Forest Research (IBIF) in different Bolivian forest types. The LTSRP established a network of large-scale (20-27 ha) replicated plots which received one of four treatments that differed in intensity of logging and the application of additional silvicultural treatments (Table 11.3). The LTSRP is currently underway in the Guarayo, Bajo Paragua, Amazon and Chiquitania regions (see Table 11.1). It monitors over 82,000 trees and covers over 640 ha, using a nested design. The LTSRP plots are established at an operational scale to estimate the logistical feasibility and cost-effectiveness of different silvicultural interventions, as well as the long-term impacts of silvicultural treatments on biodiversity, stand dynamics, and forest ecosystem functions. These plots can also be used to assess the viability and trade-offs of other management options, such as the development of carbon sequestration reserves (e.g., Blate 2005). For more details on methods used and treatments applied see Peña-Claros et al. (2008) and Villegas et al. (2009). The LSTRP plots are part of the National Network of Permanent Plots also managed by IBIF (IBIF 2008).

Table 11.3. General description of treatments applied to LTSRP plots established in different forest types in Bolivia. C=control; N=normal; LS=light silviculture; IS=intensive silviculture. • = management practice applied; • • = management practice applied with double intensity. For more details on methodology see Peña-Claros et al. (2008), Villegas et al. (2009).

Management practices	Treatments			
	C	N	LS	IS
Pre-harvest inventory of merchantable commercial trees, using specific minimum cutting diameters (50 – 70 cm dbh)	•	•	•	•
Lianas cut on merchantable trees 6 months before logging		•	•	•
Skid trial planning		•	•	•
Retention of 20 % merchantable commercial trees as seed trees		•	•	•
Directional felling		•	•	•
Merchantable trees harvested using species-specific minimum cutting diameters (50–70 cm in dbh)		•	•	• •
Pre-harvest marking of future crop trees (FCTs) ≥ 10 cm dbh			•	• •
Lianas cut on FCTs 2 – 5 months before logging			•	• •
Post-harvest liberation of FCTs from overtopping non-commercial trees by girdling			•	• •
Soil scarification in felling gaps during logging				•
Post-harvest girdling of non-commercial trees > 40 cm dbh				•

Photo 11.1. Future crop tree being monitored for its growth rate in LTSRP plots located in the dry forests. The blue line was painted to make the tree more visible during logging operations. (Photo L. Poorter)

Photo 11.2. Lianas have a negative effect on the growth rates of commercial tree species. Research done so far in several forest types in Bolivia showed that liana cutting results in higher growth rates of trees. (Photo M. Peña-Claros)

In the LTSRP plots, additional silvicultural treatments are applied to individual trees or individual logging gaps to reduce application costs and minimize impacts on biodiversity and other ecosystem services. These additional treatments aim to enhance the growth and regeneration of commercial individuals, especially future crop trees (FCT).   FCTs are individuals of commercial species that are too small to be harvested in the first cutting cycle (i.e., for most commercial species individuals with 10-50 cm dbh), but that have an adequate form and growth potential and are expected to be harvested in the future (Photo 11.1). Treatments applied to enhance growth rates of FCTs are cutting of lianas growing on FCTs (Photo 11.2) and girdling of non-commercial trees overtopping FCTs (Peña-Claros et al. 2008; Villegas et al. 2009). Results showed very convincingly that FCTs grow faster when treated than when non-treated, in the Guarayo and Bajo Paragua regions (Peña-Claros et al. 2008; Verwer et al. 2008; Villegas et al. 2008) as well as in the Chiquitania region (Villegas et al. 2009). The results also indicate that trees respond more strongly to liana cutting than to liberation from competing trees (Verwer et al. 2008; Villegas et al. 2009). Given that certain tree species have been shown to respond negatively to liana load in terms of reproduction (e.g., Nabe-Nielsen et al. 2009), we expect that the abovementioned silvicultural treatments will also have a positive effect on regeneration of commercial species by increasing the chances of individual trees to become reproductive and by increasing fruit production.

In Bolivia about 78 % of the commercial species are found to have regeneration problems. This is mainly due to lack of seed trees, the small sizes of logging gaps which create environmental conditions that are not suitable for regeneration, and competing vegetation limiting regeneration (Mostacedo & Fredericksen 1999). Studies assessing regeneration abundance in Bolivian logged forests have found that many commercial species better regenerated in areas disturbed by logging, such as logging gaps, skid trails, and logging roads (Fredericksen et al. 1999; Fredericksen & Mostacedo 2000; Pariona & Fredericksen 2000; Fredericksen & Pariona 2002). Consequently, in the LTSRP plots the treatment

applied to enhance the regeneration of commercial species is soil scarification in logging gaps (i.e. topsoil removal; Table 11.3). This treatment aims to produce adequate microsite conditions for regeneration by removing the existing vegetation, woody debris, and litter and by exposing mineral soil. Soil scarification has been applied when logging gaps met several criteria: located in flat terrain, existence of seed trees in their surrounding, lack of existing advanced regeneration, and possibility of cleaning the area with a skidder blade rapidly (on average 3.5 minutes for 100 m²) to reduce soil compaction. Six years after treatment application treated gaps had 2.5 times higher densities of commercial species than untreated logging gaps but no difference in growth performance was found (Prieto 2008).

11.5   Current practice

The Bolivian Forestry Law and its technical regulations require the application of several management practices (MDSP 1998). These management practices need to be followed in all areas under forest management larger than 200 ha regardless of ownership. The management practices required are:

- A general forest management plan (Plan General de Manejo Forestal, PGMF);
- A forest inventory to develop the PGMF;
- Designation of protected areas within the forest management area;
- Identification and protection of keystone tree species and important areas for wildlife, such as roosting areas, salt licks, and caves;
- Division of the forest management area into logging compartments and annual harvesting areas, requiring the use of a minimum cutting cycle of 20 years;
- Protection of species with low abundances (less than 0.25 trees with a diameter of > 20 cm per ha);
- A census of commercially harvestable species. The census is the basis for preparing the annual operational forestry plan, which is required to obtain permits for transporting timber. The operational plan includes field maps used to locate harvestable trees, seed trees, land characteristics (slopes, water bodies), and roads to be opened;
- The use of minimum diameter for cutting (MDC) commercial species. The MDC is defined in the regulations and is specific for species and ecoregions;
- Retention of 20 % of merchantable trees as seed trees;
- Prohibition of hunting within forest management areas;
- Annual reports of harvesting activities;
- Establishment of permanent plots to monitor and evaluate the impact of timber harvesting in the forest;
- Plans for wood provision, procurement and processing (only applicable when the forest manager owns a sawmill).

Harvesting rights are given to concessionaires for 40 years by the ABT (formerly SF). The harvesting rights are required to be renewed every five years through an auditing process. If companies pass the audit satisfactorily, the harvesting rights are renewed for another 40 years. Unfortunately, so far these audits have never taken place at an operational scale due to budget and technical shortcomings of the former SF.

11.6   Main issues restricting sustainable forest management at present (silvicultural, economical, political)

The Bolivian forestry sector has changed significantly since the enactment of the 1996 forestry law. These changes are best seen by the fact that 25 % of the area under forest management is certified under the FSC scheme. In spite of Bolivia's great advances in terms of planned harvesting (through the use of reduce impact logging techniques), there are still several constraints to sustainable forest management.

Modeling simulations have shown that the volume to be recovered for the second harvest will only be a fraction of what is being currently harvested (Dauber et al. 2005; Keller et al. 2007), but it increases if silvicultural treatments are applied to future crop trees (FCT) (Dauber et al. 2005). Experimental work done at the LTSRP plots indicated also that the application of silvicultural treatments results in higher growth rates of FCTs (Peña-Claros et al. 2008; Villegas et al. 2009). However, to sustain long-term timber yields, it is necessary to consider several (combinations of) options, such as the application of silvicultural treatments to increase growth rates, the use of different rotation cycles for different species, the focusing on fast growing species with good regeneration rates, and the improvement of harvesting and milling efficiency (Fredericksen 2003).

Given that Bolivian forests are so diverse in structure, composition, dynamics, and responses to forest management, it is necessary to define technical norms that incorporate specific practices for each forest type. These norms should also consider and incorporate the ecological and species-specific information that has been generated over the last 10 years. The incorporation of research results into management guidelines has proven to be a slow process in Bolivia and elsewhere. For example, the forest certification movement has heavily promoted the application of RIL techniques to reduce undesirable logging damage. But the need for applying silvicultural treatments to improve the growth of residual trees and to move towards long-term sustained yields in tropical forests has not received the promotion that it merits (Peña-Claros et al. 2008; Putz et al. 2008).

The implementation of the Forestry Law has faced several challenges, most of them originating outside the forestry sector and its regulations. These problems have resulted in an increase in the deforestation rate, an increase in the incidence of wildfires, the expansion of illegal forestry sector activities, an unequal distribution of the economic benefits, and the persistence of imperfect markets dominated by lack of information about wood prices and by single buyers who determine both prices and transaction conditions (Pacheco 2007). Other problems include (Contreras-Hermosillo & Vargas Rios 2007; Pacheco 2007; Benneker 2008):

- Land tenure in Bolivia is insecure, and even forest concessions and areas under forest management in indigenous territories have been occupied by colonist farmers;
- Titling land ownership has been slow and costly. This process has also indirectly promoted deforestation because in many cases only agriculture and livestock production were considered valid economic functions to grant land titles;

- The agricultural frontier is expanding because land is becoming more scarce and also because it is believed that deforestation will help solidify land claims;
- An agrarian vision of development is valued more than forest-based development;
- Illegal logging is persisting;
- The timber production chain is poorly developed;
- There is a lack of a good network of roads, which increases the cost of transport;
- Economic benefits generated by the forestry sector are unequally distributed;
- There are institutional weaknesses for implementing the forestry law;
- There is lack of technical support from the national or local governments to assist small producers, farmers, and indigenous people with their forest management enterprises;
- There is no integrated vision on the forestry sector and other economic sectors such as agriculture;
- Unfavorable taxation conditions for the forestry sector compared to the agricultural sector in terms of fees persist (concessionaires pay between 1-8 US$/ha per annual logging compartment depending on user type, while agricultural land owners only pay 0.03 US$/ha).

In conclusion, Forestry Law # 1700 and its implementation has allowed Bolivia to become one of the world's leaders in sustainable tropical forest management with an increasingly diverse forest products sector, expanded access to forest management for diverse actors, and saw significant areas certified as sustainably managed forest. In the past several years, Bolivia has been undergoing intense political, institutional, and economic changes. One major change was the creation of the *Autoridad de Fiscalización y Control Social de Bosques y Tierra* (ABT) within the *Ministerio de Desarollo Rural y Tierras*. The ABT has replaced the *Superintendencia Forestal* as well as the *Superintendencia Agraria* and has structurally integrated the agriculture- and forestry-related governmental institutions. This change has created some short-term uncertainty in the forestry sector but it could also promote long-term stability in the forestry sector, given that forestry and agricultural policies are so intimately connected. It remains to be seen how these institutional changes, as well as other changes taking place in the country, will affect the forestry sector in the long run and whether Bolivia's standing as a world leader in sustainable forestry will be enhanced or diminished.

References

Benneker, C. 2008. Dealing with the state, the market and NGOs. PhD thesis, Wageningen University and Research Center, Wageningen, the Netherlands.

Blate, G.M. 2005. Assessing trade-offs in multiple-objective tropical forest management. PhD thesis, University of Florida, Gainesville, FL, USA.

BOLFOR II - Bolivia Forestal. 2008. Perfil Forestal de Bolivia. http://www.bolfor.org/contenido/perfil_forestal.asp. Accessed on June 20th, 2008.

BOLFOR II – Bolivia Forestal. 2009. Legados II. http://www.bolfor.org/documentos/ {E72B9040-6109-40FA-A875-2B713C9C5CFA}_Legados%20BOLFORII.pdf. Accessed on October 1, 2009.

Camacho, O., Guzmán, R. & Peña-Claros, M. 2007. Situación del manejo forestal sostenible en la Amazonía boliviana. Recursos Naturales y Ambiente 49-50, 18 – 23.

Cámara Forestal de Bolivia. 2008. Sector Forestal - Cobertura Forestal y Areas Bajo de Manejo. http://www.cfb.org.bo/CFBInicio/ . Accessed on June 20th, 2008.

Certificación Forestal Voluntaria. 2008. Operaciones de Manejo Forestal Certificadas en Bolivia.   http://www.consejoforestal.org.bo/operaciones_manejoforestal.htm. Accessed on June 20th, 2008.

Contreras-Hermosilla, A. & Vargas Ríos, T. 2007. Reformas a la política forestal de Bolivia. Impactos sociales, ambientales y económicos de los primeros cinco años del régimen forestal boliviano. Recursos Naturales y Ambiente 49-50, 18 – 23.

Dauber, E., Terán, J. & Guzmán, R. 2000. Estimaciones de la biomasa y carbono en bosques naturales de Bolivia. Santa Cruz de la Sierra, BO, Superintendencia Forestal.

Dauber, E., Fredericksen, T.S. & Peña-Claros, M. 2005. Sustainability of timber harvesting in Bolivian tropical forest. Forest Ecology and Management 214, 294 - 304.

Dauber, E., Fredericksen, T.S., Peña-Claros, M., Leaño, C., Licona, J.C. & Contreras, F. 2003. Tasas de incremento diamétrico, mortalidad y reclutamiento con base en las parcelas permanentes instaladas en diferentes regiones de Bolivia. Santa Cruz de la Sierra, BO, Proyecto BOLFOR / Proyecto de Manejo Forestal Sostenible.

Fredericksen T.S. & Mostacedo, B. 2000. Regeneration of sawtimber species following selective jogging in a Bolivia tropical forest. Forest Ecology and Management 131, 47-55.

Fredericksen T.S., Rumiz, D., Justiniano, M.J. & Aguapé, R. 1999. Harvesting fre-standing figs for timber in Bolívia potential implications for sustainability. Forest Ecology and Management 116, 151-161.

Fredericksen T.S., Putz, F.E., Pattie, P., Pariona, W. & Peña-Claros, M. 2003. Sustainable forestry in Bolivia: beyond planned logging. Journal of Forestry 101(2),37-40.

Fredericksen, T. S. & Pariona, W. 2002. Effect of skidder disturbance on commercial tree regeneration in jogging gaps in a Bolivian tropical forest. Forest Ecology and Management 171, 223-230.

Ibisch, P.L. 1998. Bolivia is a megadiversity country and a developing country. In: Barthlott, W. & Winiger, M. (eds). Biodiversity - a Challenge for Development Research and Policy. Springer-Verlag, Berlin, Germany, pp. 213-241.

Ibisch, P.L. 2005. Biodiversity conservation in Bolivia -history, trends and challenges. In: Romero A. & West S.E. (eds.). Environmental Issues in Latin America and the Caribbean. Springer-Verlag, Berlin Germany, pp. 55-71.

Instituto Boliviano de investigación Forestal. 2006. Red de Parcelas Permanentes. http:// www.ibifbolivia.org.bo/ESP/red_de_parcelas_permanentes/red_de_parcelas_ permanentes.htm. Accessed on June 20th, 2008.

Keller, M., Asner, G.P., Blate, G., McGlocklin, J., Merry, F., Peña-Claros, M. & Zweede, J. 2007. Timber production in selectively logged tropical forests in South America. Frontiers in Ecology and in the Environment 5, 213 -216.

Ministerio de Desarrollo Rural, Agropecuario y Medio Ambiente. 2007. Base de datos sobre el sector forestal de Bolivia 1997-2007. Proyecto TCP/BOL 3102.

Ministerio de Desarrollo Sostenible y Planificación (MDSP). 1998. Normas técnicas para la elaboración de instrumentos de manejo forestal en propiedades privadas o concesiones con superficies mayores a 200 hectáreas. Resolución Ministerial No. 248/98. La Paz, Bolivia.

Mostacedo, B. & Fredericksen, T.S. 1999. Regeneration status of important tropical forest tree species in Bolivia: assessment and recommendations. Forest Ecology and Management 124, 263-273.

Nabe-Nielsen, J., Kollmann, J. & Peña-Claros, M. 2009. Effects of liana load, tree diameter and distances between conspecifics on seed production in tropical timber trees. Forest Ecology and Management 257, 987-993.

Navarro, G. & Maldonado, M. 2002. Geografía Ecológica de Bolivia, Vegetación y Ambientes Acuáticos. Editorial Centro de Ecología Difusión Simón I. Patiño. Santa Cruz, Bolivia.

Pacheco, P. 2007. El regimen forestal boliviano, una mirada retrospectiva a diez años de su implementacion. Recursos Naturales y Ambientales 49-50, 58-67.

Pariona W. & Fredericksen, T.S. 2000. Regeneracion natual y liberacion de especies comerciales establecidas en claros de corta en dos tipos de bosques bolivianos. Techincal Document #97. Proyecto BOLOFR, Santa Cruz, Bolivia.

Peña-Claros, M., Peters, E.M., Justiniano, J., Bongers, F., Blate, G., Fredericksen, T.S. & Putz, F.E. 2008. Regeneration of commercial tree species following silvicultural treatments in a moist tropical forest. Forest Ecology and Management 255, 1283-1293.

Peña-Claros, M., Fredericksen, T.S., Alarcón, A., Blate, G.M., Choque, U., Leaño, C., Licona, J.C., Mostacedo, B.,Pariona, W., Villegas, Z. & Putz, F.E. 2008. Beyond reduced-impact logging: silvicultural treatments to increase growth rates of tropical trees. Forest Ecology and Management 255, 1295-1306.

Prieto, E. 2009. Effects of soil scarification on the regeneration of commercial tree species in the moist tropical forest of La Chonta, Santa Cruz, Bolivia. Wageningen University, Wageningen, the Netherlands.

Putz, F.E., Sist, P., Fredericksen, T.S. & Dykstra, D. 2008. Reduced-impact logging: challenges and opportunities. Forest Ecology and Management 256, 1427-1433.

Quevedo L. 2006.   Bolivia. In: Cashore B., Gale F., Meidinger E. & Newsom D. (eds). Confronting sustainability: forest certification in developing and transitioning countries. Yales School of Forestry & Environmental Studies. New Haven, US.

Sabogal, C., Snook, L., Boscolo, M., Pokorny, B., Quevedo, L., Lentine, M. & Colám, V. 2007. Adopcion de practices de manejo forestall sostenible por empresas madereras en la Amzaonia de Brasil, Bolivia y Peru. Recursos naturales y Ambientales 49-50, 100-111.

Snook, L., Quevedo, L., Boscolo, M., Sabogal, C. & Medina, R. 2007. Avances y limitaciones en la adopción del manejo forestal sostenible en Bolivia. Recursos Naturales y Ambientales 49-50, 68-80.

Superintendencia Forestal. 2007. Informe Anual 2006. Santa Cruz de la Sierra, BO, Superintendencia Forestal.

Verwer, C., Peña-Claros, M., van der Staak, D., Ohlson-Kiehn, K. & Sterck, F.J. 2008. Silviculture enhances the recovery of overexploited mahogany Swietenia macrophylla. Journal of Applied Ecology 45, 1770-1779.

Villegas, Z., Peña-Claros, M., Mostacedo, B., Alarcón, A., Licona, J.C., Leaño, C., Pariona, W. & Choque, U. 2009. Silviculture treatments enhance growth rates of future crop trees in a tropical dry forest. Forest Ecology and Management 258, 971-977.

Villegas, Z., Mostacedo, B., Toledo, M., Leaño, C., Licona, J.C., Alarcón, A., Vroomans, V. & Peña-Claros, M. 2008. Ecología y manejo de los Bosques Tropicales del Bajo Paraguá, Bolivia. Instituto Boliviano de Investigación Forestal, Santa Cruz, Bolivia.

12   Costa Rica

B. Louman

12.1   Introduction

Costa Rica is a relatively small country in Central America of about 5.1 million hectares in surface area and 4 million inhabitants, but with a great natural diversity distributed over twelve of Holdridge's ecological life zones (Hartshorn 1983). It has been able to convert its deforestation from 46,500 - 49,000 ha.y^{-1} in the 1960s and 70s to a slight net forest cover gain since 1987 (Wendland & Bawa 1996; Camino et al. 2000; FAO 2002). The actual forest area covers 2.4 million hectares (FAO 2007). Although a great part of the changes in forest area – and therefore deforestation rate estimates – may be due to changes in forest definition, differences in methodologies as well as in improved technology (Camino et al. 2000; FAO 2002; Houghton 2003), it also reflects changes in agricultural and forest policies and strategies, as well as the ability of the government and private sector to establish plantations, allow secondary forests to regenerate and implement sustainable forest management (SFM) activities that involve, and go beyond, the sustainable harvest of timber. SFM in natural forests has been relatively successful in Costa Rica, contributing to up to 80 % of the nation's timber supply in 1999 (FAO 2002). Since then – with first commercial tree plantations entering into their final harvests in 1997 – its contribution has rapidly dwindled to about 5 % in the years from 2005 to 2009, with trees outside forests and plantations providing initially an increasing proportion of the national supply (Barrantes & Salazar 2006), but later declining due to a declining demand for timber products (ONF 2010). Some experts presume, however, that within the current structure of the domestic demand, plantation timber will not be able to substitute the high quality timber from natural forests (McKenzie 2003). On the other hand, in recent years the high demand for agricultural crops, such as pineapple and banana, is influencing the demand for timber for pallets, using plantations as their main raw material source (Barrantes & Salazar 2006).

As early as 1997 sawmills saw their traditional raw material supply of large sized logs reduce considerably, forcing them to close or change towards the processing of smaller logs from plantations and secondary forests (Camino et al. 2000). Starting in 2007, Costa Rica has become increasingly dependent on timber imports, first from Nicaragua, but later above all from Chile and Argentina (ONF 2010) to provide its domestic demand for timber products, and stakeholders are discussing whether and how to bring more natural and planted forest area under SFM for timber production.

12.2   Forest reserves and off-reserve tree resources and their utilization

Costa Rica administers its forests through eleven Conservation Areas. In 1999 they administered 1,3 million hectares (approximately 56 % of the total natural forest area) in six management categories, 56 % of which was state owned and 44 % private (FAO 2002). The same source reported that state administered forests reserved for future timber production occupied an area of 286,660 ha. Although legally declared reserves, 74 % of these are still privately owned. Another one million hectares[1] of forest area exists outside these different categories of protection. Most of these forests are secondary forests of different development phases (around 700,000 ha, Camino et al. 2000; FONAFIFO & ONF 2006) and plantations (around 45,000 - 54,000 ha, FONAFIFO & ONF 2006) and may contribute to the future potential for timber production from natural forests in Costa Rica. All of the forest area outside the protected areas is privately owned, usually in properties of less than 300 ha. About 212,000 ha of these had received Payment for Environmental Services (PES) between 1997 and 2008, of which 86 % was assigned to privately protected areas (MINAET 2010, see also Box 1).

Table 12.1.   Types of forest lands with mayor uses in Costa Rica.

Type of forest land	Mayor uses
1. Natural forests	
a. SINAC administered (National Conservation Area System)	Environmental services, some non-timber forest products in forest reserves (such as mosses, berries)
b. Privately protected	Environmental services, in particular tourism, carbon storage, maintenance of biodiversity and protection of water sheds
c. Private multiple use	Timber (construction, furniture), non-timber forest products, environmental services
2. Plantations	Timber (mainly pallets for agro-export, but also construction and furniture), carbon sequestration
3. Trees outside forests	Timber, shade, fruits, carbon sequestration

Planted forests have assumed an important role in the timber supply. Camino et al. (2000) estimated the plantation area at 140,000 ha in 1997 and FAO estimated that it reached 178,000 ha in 2000, all privately owned but of which 154,000 ha were established with some type of state support and the rest through private initiatives by forest companies (FAO 2002). These data may not reflect the extent of plantations of commercial use, which

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1   FONAFIFO 2007 reported 1.3 million ha and assigned 1.1 million ha to the different management categories.

FONAFIFO estimated to be 45,000 ha by the end of 2005 (FONAFIFO & ONF 2006). The newly planted area has decreased from approximately 9,000 ha in the early nineties to less than 3,000 ha annually since the year 2000, raising the expectations of a raw material deficit during the coming years (FONAFIFO & ONF 2006). There are five types of mayor forested areas in Costa Rica (Table 12.1). Of these types, trees outside forests receive increased attention (Van Leeuwen & Hofstede 1995; FAO 2002) and since 2002 the PES system has paid for nearly 2 million trees to be planted in different types of agroforestry systems (FONAFIFO 2008, see also Box 12.1).

Box 12.1.   Payment for environmental services (PES) in Costa Rica.

In its 1996 forest law Costa Rica recognized four types of environmental services: carbon storage and sequestration; maintenance of biodiversity; regulation of a clean water supply; and scenic beauty. A year later, a payment for environmental services scheme was set up that coordinates, on the one hand, the payments received from bi- and multilateral agreements (e.g. Norway, World Bank loan, Global Environmental Facility), from carbon polluters (through a type of carbon tax on the gasoline), water users (hydroelectric power generators and beverage companies) and through sale of certificates. On the other hand, it distributes the funds to the providers of environmental services. This distribution is based on the assumption that existing natural forests provide the said services simultaneously at approximately the same proportion (25 % of total value paid). Plantations are expected to provide more of some of the services (carbon sequestration) and increase the services rendered in relation to the previous land use (mostly degraded pastures). Forest management reduces the total services rendered in comparison to protected forests, but is assumed to maintain the same proportionality between services. This form of Payment for Environmental Services was suspended in 2002 under pressure of environmental groups that argued that forest management already generates an income and that the state should not increase this income through PES. This was replaced by payments for the planting of trees in agricultural systems, since the decision makers considered that this would be more effective, providing services through carbon sequestration and maintenance of biodiversity. The latter above all through providing connectivity between forest fragments. The amounts paid to the providers are determined annually and are based on the opportunity costs of adopting the required good practices, rather than on the quality and quantity of services rendered. In the case of natural forest protection, marginal cattle farming is used as a reference (in 2008 this was about US$ 64 ha^{-1}.y^{-1} paid during renewable five year contract periods). In the case of plantations, the costs of establishing plantations is used as a guideline, actually paying US$ 816 ha^{-1} spread over 5 years, which covers approximately 75 % of total costs. It is assumed that all services are rendered as long as forest, plantation or trees exist and good practices, as indicated in the service contracts, are applied. This simplifies the payments and allows monitoring to concentrate on practices and forest cover, rather than on the costly measuring of services rendered. It does, however, not recognize the different levels of threat that the forests in different areas of the country experience.

12.3   Historical development in forest exploitation

During the 1950s and 1960s, Costa Rica went through a period of colonization of its lowland forest areas, promoting conversion of forests into pasture lands through, among other measures, recognition of land titles on "improved" land (FAO 2002; Hilge et al.

2002). Harvesting of trees in the natural forests was very selective, limited to a few species of high value for the market (e.g. *Cedrela odorata*, *Swietenia macrophylla*), or for local construction and agricultural production purposes (e.g. poles of Minquartia guianensis were cut for the pepper and vanilla cultivation; Camacho & Finegan 1997; FAO 2002; Méndez 2008). Costa Rica had its first forest legislation in 1969, and since 1973 (foundation of the National University, UNA) and 1976 (foundation of the Costa Rican Institute of Technology (ITCR)) national universities offer forestry curricula. It was, however, not until 1984 that the first management plan was elaborated based on an explorative forest inventory. In the new forest legislation of 1986 management plans were incorporated and during the same year it was prohibited by decree to convert forest land use into other types of land use that involved removing the forest cover (MINAE 2002). In 1992 harvest regulations were issued and Certificates for Forest Management (CAFMA) were granted as a form of subsidies for sustainable forest management (Maginnis et al. 1998; FAO 2002). All of these combined induced a rapid evolution of polycyclic management of natural forests, drawing from experiences in other Latin American countries (in particular the CELOS Management System in Suriname) as well as from South-East Asia (e.g. Finegan et al. 1993; Méndez 1993; CATIE 1994; Quirós & Finegan 1994; Wendland & Bawa 1996; Méndez 2008).

In 1996, the Portíco operations in natural Carapa forests in the North of Costa Rica became the first FSC-certified forest operations of the country, a certification which it has maintained ever since. NGOs, such as JUNAFORCA, CODEFORSA and FUNDECOR, assumed a leading role as forest management advisors for large groups of small holders, working with owners of both natural forests and plantations.

From 1994 until 1998 different actors, driven by the private sector and supported by the government, studied the impacts of timber harvesting in the country. They formed a working group to prepare a proposal for a standard for sustainable forest management for Costa Rica using the impact studies as basis for the development of indicators. This standard was incorporated into the 1996 forest legislation, and its criteria and indicators were formally approved as legal norms in 1998 (CNCF 1999). This standard was revised in 2002 and a new revision was done in 2007 resulting in a new, less prescriptive standard, gazetted in 2008 (MINAE 2008).

In the early nineties, interest increased in forest goods and services other than timber and the 1996 forest law recognizes for the first time the value of forests for the provision of four types of services: water regulation, maintenance of biodiversity, carbon sequestration and storage, and scenic beauty. A system was set up to channel money from users to the producers (Payment for Environmental Services or PES, see Box 12.1) and the first payments were made in 1997. Originally, this scheme also included PES for forest management that complied at least with legal norms for harvesting and post-harvesting treatment of the forests. In order to ensure the production of environmental services in the forest, the new legislation put restrictions on timber harvests: increasing the costs of planning, reducing the annual allowable cut, requiring more water and soil protection measures within management units, and requiring the implementation of silvicultural treatments. To compensate for these extra costs, it was decided to also implement payment for the maintenance of environmental services through sustainable

forest management (Campos et al. 2001). In spite of the positive effect of PES on the quality of forest management (Louman et al. 2005), this modality was suspended in 2002 in favour of payment for tree planting within agroforestry systems (FONAFIFO 2008), thought to be a more effective way to produce the desired services (mainly carbon sequestration and maintenance of biodiversity).

Interestingly, between 1992 and 1996 the supply of timber from natural forests and plantations reduced considerably, while after the implementation of the 1996 legislation it went back to 1992 levels and beyond (McKenzie 2003) until the new forest management standard started to be implemented in 1999 and PES for forest management was suspended in 2002. After that, management of natural forests has decreased again (Barrantes & Salazar 2005). The strict regulations, the long administrative processes to obtain harvesting permits (FAO 2002; Méndez 2008), and the lack of compensation for measures that maintain environmental services have probably contributed to this decline. But also the reduction in harvestable forest areas due to overcutting in the eighties and early nineties (McKenzie 2003), the slow adaptation of the processing industry to changing market and supply conditions (FAO 2002), the strong competition from cheaper wood from plantations in and outside the country and substitution of wood by other cheaper or more durable (but not necessarily more sustainable) materials in house construction have played a role.

12.4   Silvicultural systems, productivity, annual allowable cut

In Costa Rican natural forests, according to the 1996 forest law, silvicultural systems have to be polycyclic. Until 2008 the main criteria for these systems was a minimum length of the cutting cycle of 15 years and application of minimum cutting diameter limits (60 cm for all species) as well as a maximum cutting intensity (60 % of harvestable trees of a species; Maginnis et al. 1998). These criteria have been converted into technically justifiable criteria according to each forest type and forest operation (MINAE 2008). Data on forest recovery during the first (official) complete management cycle starts to become available, indicating that if harvesting and management is implemented according to the national standards the forest recover the harvested volumes (Méndez 2008) while no apparent structural or compositional changes occur (Delgado et al. 1997; Alfaro 2006). In practice this means an average harvest of between 10 and 20 $m^3.ha^{-1}$ per harvest or on average 0.67-1 $m^3.ha^{-1}.y^{-1}$ (Camacho & Finegan 1997; SINAC 1999; Alfaro 2006; FONAFIFO & ONF 2006).

FONAFIFO & ONF (2006) estimated the forests available for timber production to be 533,000 ha. They estimate that using the currently

Photo 12.1. Detailed planning of timber harvest is the most important silvicultural activity in Costa Rican natural forests. All commercial trees and terrain characteristics are measured and mapped, as are the trees that for specific silvicultural reasons should not be cut. (Photo FUNDECOR 2001)

common cutting cycle of 15 years, this would allow annually about 35,000 ha to be harvested, in contrast to the 2005 figure of about 3,000 ha annually (derived from the same publication). With an average harvest of 15 m³.ha⁻¹ the harvest of 35,000 ha.y⁻¹ represents 525,000 m³.y⁻¹, ten times the current level of harvesting and approximately 33 % of the expected demand for timber in 2020 (FONAFIFO & ONF 2006). The rest will have to come from plantations or be imported.

12.5   Current practice

Forest management in Costa Rica occurs mainly in smallholder plots with an average size of approximately 70 ha (Maginnis et al. 1998). Management planning is usually done by a registered forest regent, holder of a forestry degree, and legally responsible for the veracity of planning documents and supervisory reports. The forest regent shares this responsibility with the land owner and together they have to supervise the implementation of harvesting, usually done by contractors. Planning and implementation need to follow strict rules, set out in the standard for natural forest management. This standard has recently been modified (MINAE 2008), but up to date only few operators have obtained experience under the new rules.

Due to the small size of the operations, management and harvest planning are usually done simultaneously for the whole forest area. As a first step a team enters to set up a network of inventory lines and take topographic measures that allow drawing a detailed topographic map of the area at a scale of approximately 1:1000 to 1:4000. This is followed by a commercial inventory of all trees more than 60 cm diameter at breast height (dbh) of all commercial species (up to 40 in each forest plot) and an inventory of all trees greater than 30 cm dbh of all species, in sample plots of 30 x 100 m, covering usually about 4.5 % of the productive area[2] (Photos 12.1 & 12.2). Tree location is estimated using GPS or the dense inventory line network as reference. Most organizations, such as FUNDECOR, have developed their own computerized methods to do so, allowing them

Photo 12.2.   Potential seed trees are clearly marked in the field to prevent felling damage. Here: *Carapa guianensis*. (Photo CATIE archives 2010)

to draw accurate maps with contour lines at 2 to 5 m intervals, location of protection zones due to nearness of water courses or steep slopes[3], delineation of productive forest area, location of commercial trees and their natural felling direction, and the location of the road network needed to extract the trees (FAO 2001).

Planning is followed by reduced impact logging operations, applying directional felling and, in about 40 % of the cases (Obando 1997), 30 m cables to extract the timber. Usually small bulldozers are used both for road work and timber extraction. Log landings are placed outside the forest area wherever possible.

Post harvest activities used to be based on silvicultural plans, following diagnostic sampling adapted for mixed-age forests from Asian line sampling (Hutchinson 1993). This sampling was designed to indicate whether liberation treatment would be necessary or not, tallying the number of outstanding future crop trees and evaluating their social position in the forest. Due to the abundance of commercial trees in the forests and the possible need for additional treatments, adaptations were made to the sampling design, eliminating the tallying of trees with a dbh below 10 cm and adding the tallying of all trees within the 10 × 10 m plots to get an idea of basal area competition (Quirós 1998). In the first years of

Photo 12.3.   A forest several years after timber harvest and light liberation treatments. (Photo Marie Landry 2007)

its application this sampling produced very useful results, but organizations that only worked in one type of forests, using more or less a constant harvesting intensity and similar extraction methods, found that the results of the sampling became repetitive and did no longer justify the costs (about US$ 9 ha⁻¹, Quirós & Gómez 1998). The new forest management standard does no longer require diagnostic sampling, unless the impacts of proposed harvesting cannot be predicted from previous studies (Photo 12.3).

Liberation of future crop trees is the main silvicultural treatment that has been applied in the Costa Rican tropical lowland forests. Considering the effects of removal and death of trees through harvesting and silvicultural treatments together, legislation allows for a maximum reduction of 40 % in the basal area of trees above 30 cm dbh. While in research plots initial results have been very promising, achieving growth rate increments of up to 50 % (e.g. Camacho & Finegan 1997), later research indicated that more studies need to be done on the response of individual species in different size classes. This should allow for the liberation of those crop trees that have a good response potential (e.g. Galván et al. 2006) and may avoid increased mortality (e.g. Alfaro 2006). Since 2002, after suspension of PES for forest management, few operations apply silvicultural treatments

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[2]   The new forest management standard (MINAE 2008) no longer applies a minimum cutting diameter (MCD) of 60 cm but allows operators to justify MCDs for different species in different forest types. The implementation of the commercial inventory needs to be adjusted accordingly.

[3]   The legal limit was 60 % but FUNDECOR applied 35 % for use of machinery and 75 % for cutting and cable extraction. The new standards (MINAE 2008) no longer prescribe maximum slopes above which harvesting is not allowed, but require impact reduction measures adequate to the local circumstances.

or prepare silviculture plans and the norms only require doing so if necessary for the maintenance of the structure and floristic composition of the forest.

Different organizations have established more than 500 permanent sample plots (PSP) in the Costa Rican forests (Finegan, pers. comm.[4]), some of which have greatly contributed to the current knowledge on the natural forests, their management and its impacts. Until recently, however, this information was scattered and little accessible for researchers and forest managers. Considering the increased importance of monitoring of changes in the forests due to management and climate change, these organizations have formed a research network that should allow the forest sector to adapt to changing circumstances and improve the information needed to adequate decision-making.

12.6   Main issues restricting sustainable forest management at present

Current legal natural forest management practices can be considered good (Louman et al. 2005; Barrantes & Salazar 2006) but only supply 5 % of the local timber demand, the rest coming from plantations, trees outside the forest and imports. Major threats to natural forest management are illegal logging and forest conversion (e.g. Barrantes & Salazar 2006; Campos et al. 2007) and fires (SINAC 2006). With an increasing demand and the inability of plantations to provide the necessary raw materials (McKenzie 2003; Barrantes & Salazar 2006) the pressure on the natural forests will increase as will the threat of illegal logging (FONAFIFO & ONF 2006).

Managed natural forest will remain an important source of timber in the near future (McKenzie 2003; Barrantes & Salazar 2006; FONAFIFO & ONF 2006) but will only be able to do so if a sustainable manner of its management is promoted. This requires the forest sector to address a number of limitations (extracted from McKenzie 2003; FAO 2004; FONAFIFO & ONF 2006; Campos et al. 20007; Méndez 2008):

- Improve control mechanisms; financial and human resources are insufficient to implement detailed control on forest and timber transport operations. Current mechanisms still facilitate corruption while legal offenses are mildly punished. Although improvements in these aspects are very necessary, these may have little effect if these are not accompanied by improvements in any of the other factors mentioned below.
- Increase participation of society in promotion of sustainable forest management; environmentalists lobbying has achieved very strict legislation for forest management, making it easier to convert forests (illegally) into agricultural land than to apply forest management. Society is conservation-oriented and PES for protection has been able to increase the protected forest areas by about 40 %. However, non-protected areas continue to be converted or are heavily degraded by uncontrolled logging and agricultural activities. SFM could have an important role in conserving the forest cover in these areas, as well as in the increasing area

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4   Bryan Finegan, October 2008. Director of the chair of forest ecology of CATIE. He participates in the newly established research network.

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under secondary forests. This will not be possible if society maintains a poor, sometimes erroneous image of SFM.

- Improve administrative procedures for approval of harvesting; waiting for six months or more for harvest plan approval has made many forest owners opt for other forms of land use, including protection but also gradual conversion into agricultural lands.
- Reduce excessive legislation related to forest management; related to the previous point, costs of forest management are elevated by excessive legislation, in particular related to the standards for forest management. These have recently been modified and greater transparency and flexibility has been created. It is still too early to assess the effects of these changes. No effect could be seen during 2009, but this may have been due to the global financial crisis (ONF 2010), rather than to lack of effectiveness of the changes in the standard. Without additional options for financing forest activities, however, the realized changes may not achieve the desired effects.
- Additional financial resources for forest management (such as PES, cheap credits, private investment); only few forest operators have invested in plantations and improved forest management, considering the road between investment and profit making too long and risky. Experiences in the private sector have shown that reducing the fixed costs through economies of scale, increasing the price of timber for the producers through market association, and making money available before harvesting through forward payment schemes, all contribute to the motivation of forest owners to invest. So did the PES system. While the latter was suspended for forest management in 2002, the other options are not widely available but could be promising.

Photo 12.4. After recognition of ecosystem services in the 1996 forest law and partially due to the complicated procedures to obtain forest management permits, many forest owners preferred forest management for protection rather than for timber production, and receive an income from payment for environmental services, rather than from timber sales.
(Photo Colegio de Ingenieros Agrónomos de Costa Rica 2008).

- Several forest owners are venturing into the carbon market, while companies outside the forest sector, in response to calls for greater social responsibility, have started to invest into the maintenance and enhancement of carbon stocks in private (degraded) forests. These funds are creating a demand for management of the carbon stock in the forests, requiring adjustments in the existing SFM guidelines.
- Improve competitiveness of the industry at all shackles of the value chain; particularly primary industry is little developed in Costa Rica. The current characteristics of the raw material supply (smaller diameters, lower quality timber) requires for investments in new machinery and development of new products.

- Improve the information base as well as the monitoring and research capacity; forests are complex and still little is known of the long-term reaction of specific species to forest management and climate change. Although legislation has improved enormously over the past decade, still policy decisions are made without knowing the consequences or those of previous policy decisions. Monitoring frameworks and research could contribute to better decision-making in the future. However, in spite of the 2000 national forest inventory that, with the assistance of FAO, developed a good methodology to collect information on multiple resources in and outside a network of permanent sample plots, no inventory or monitoring framework exists in Costa Rica.

SFM practices were originally derived from the CELOS experiences, in particular regarding the harvesting system. Over time, Costa Rica has gone well beyond the CELOS system in the application of exact planning tools and adjusting silvicultural treatments to national objectives with greater emphasis on the conservation of biodiversity. Lessons learned from these experiences have allowed the forest sector to revise the legal framework and come up with a proposal of forest management standards more appropriate for the current situation. This development, however, led to the development of a highly technified and regulated SFM, even to such an extent that the resulting high planning and administrative costs, combined with the reduced harvesting levels, did not make SFM an attractive land use proposition for many private forest owners, in particular where PES could be received for forest protection without much investment (Photo 12.4). Innovative financing mechanisms and the political will to set up adequate legal, administrative and monitoring systems will be necessary if SFM is to fulfil its potential contribution to Costa Rican's economic development without further degrading the forests' capacity to provide ecosystem services.

References

Alfaro, T. 2006. Estudio de condiciones para segundas cosechas en bosques naturales en la zona Norte de Costa Rica. Tesis Mag. Sc. CATIE, Turrialba, Costa Rica. 134 pp.

Barrantes, A. & Salazar, G. 2006. Uso y aportes de la madera en Costa Rica. Estadísticas 2005. Oficina Nacional Forestal (ONF), San José, Costa Rica. 28 pp.

Camacho, M. & Finegan, B. 1997. Efectos del aprovechamiento forestal y del tratamiento silvicultural en un bosque húmedo del noreste de Costa rica; el crecimiento diamétrico con énfasis en el rodal comercial. CATIE, Turrialba, Costa Rica. Serie técnica, informe técnico no. 295. Colección Manejo Diversificado de Bosques Naturales no. 11. 38 pp.

Camino, R. de, Segura, O., Arias, L.G. & Pérez, I. 2000. Costa Rica. Forest strategy and the evolution of land use. Evaluation country case study series. World Bank, Washington DC, USA. 128 pp.

Campos, J.J., Finegan, B. & Villalobos, R. 2001. Management of goods and services from neotropical forest diversity: diversified forest management in Mesoamerica. In: CBD technical note 3, 5-16.

CATIE (Centro Agronómico Tropical de Investigación y Enseñanza). 1994. Modelo de simplificación de planes de manejo para bosques naturales de la región centroamericana. CATIE, Turrialba, Costa Rica. 29 pp.

CNCF (Comisión Nacional de Certificación Forestal) 1999. Estándares y procedimientos para el manejo forestal sostenible y la certificación forestal en Costa Rica. CNCF, San José, Costa Rica. 51 pp.

Delgado, D., Finegan, B., Zamora, N. & Meir, P. 1997. Efectos del aprovechamiento forestal y el tratamiento silvicultural en un bosque húmedo del noreste de Costa Rica. Cambios en la riqueza y composición de la vegetación. CATIE, Turrialba, Costa Rica. Serie técnica, informe técnico no. 298. Colección Manejo Diversificado de Bosques Naturales no. 12. 43 pp.

FAO (Food and Agricultural Organization) 2001. El uso de computadoras, porgramas e instrumentos electrónicos en la planificación y seguimiento de planes de manejo del bosque húmedo tropical – un caso en Costa Rica. Manejo forestal – documento de trabajo no 1. FAO, Roma, Italy. 75 pp.

FAO. 2002. Estado de la Información Forestal de Costa Rica. Santiago, Chile. Proyecto GCP/133 RLA-FAO Información Forestal y Manejo Sostenible.

FAO. 2004. Estado y Tendencias de la Ordenación Forestal en 17 Países de América Latina por Consultores Forestales Asociados de Honduras (FORESTA). Documentos de Trabajo sobre Ordenación Forestal; Documento de Trabajo FM/26; Servicio de Desarrollo de Recursos Forestales, Dirección de Recursos Forestales, FAO, Roma. Mayo 2004 (Inédito). Online: http://www.fao.org/docrep/008/j2628s/J2628S00.HTM

FAO. 2007. The state of the world's forests 2007. Rome, Italy.

FAO & CATIE. 2000. FRA: Bibliografía comentada, cambios de la cobertura forestal, Costa Rica. Programa de evaluación de recursos forestales. Documento de trabajo 36. Roma, Italia. 55 pp.

Finegan, B., Sabogal, C., Reiche, C. & Hutchinson, I. 1993. Los bosques húmedos tropicales de América central: su manejo sostenible es posible y rentable. Revista Forestal Centroamericana 6, 17-27.

FONAFIFO (Fondo Nacional de Financiamiento Forestal). 2007. Estudio de monitoreo de cobertura forestal de Costa Rica 2005. Resumen ejecutivo. Consultant report Project ECOMERCADOS, FONDOS GEF – ECOMERCADOS CONVENIO DE DONACIÓN TF 023681. 7 p. online: http://documentacion.sirefor.go.cr/archivo/cobertura/cobertura002.pdf. 22 Oct 2008.

FONAFIFO. 2008. Distribución de las Hectáreas Contratadas en Pago de Servicios Ambiéntales, por Año y por Modalidad, Período 1997-2007. Corte al 20 de mayo 2008. Online: http://www.fonafifo.com/text_files/servicios_ambientales/distrib_ha_Contratadas.pdf. Consulted 22 Oct 2008.

FONAFIFO & Oficina Nacional Forestal (ONF) 2006. La Madera en Costa Rica. Situación actual y perspectivas. 23 p. online: http://www.oficinaforestalcr.org /media_files/download/MADERAENCOSTARICA,SITUACIONACTUALYPERSPECTIVAS,2006.pdf. 23 Oct 2008.

Galván, O., Louman, B., Galloway, G. & Obando, G. 2006. Efecto de la iluminación de copa en el crecimiento de Pentaclethra macroloba y Goethalsia meiantha. Implicaciones para la silvicultura de los bosques tropicales húmedos. Naturales y Ambiente 46-47, 117-126.

Hartshorn, G.S. 1983. Chapter 7, Plants. Introduction. In: Janzen, D.H. (ed). 1983. Costa Rican Natural History. Chicago, USA, University of Chicago Press, 118-157.

Hilge, L., Jiménez, W. &, Vargas, E. 2002. Los viejos y los árboles. Editorial de la Universidad de Costa Rica, Inbio, San José, Costa Rica. 423 pp.

Houghton, R.A. 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850- 2000. Tellus B, 55, 378-390

Hutchinson, I. 1993. Puntos de partida y muestreo diagnóstico para la silvicultura de bosques naturales del trópico húmedo. CATIE, Turrialba, Costa Rica. Serie técnica, informe técnico no. 204. Colección Silvicultura y Manejo de Bosques Naturales no. 7. 32 pp.

Louman, B. & De Camino, R. 2004. Capítulo 1. Aspectos generales. In: L. Orozco Vïlchez (ed). Planificación del manejo diversificado de bosques latifoliados húmedos tropicales. CATIE, Turrialba, Costa Rica. Serie técnica, manual técnico no. 56, 1-54.

Louman, B., Garay, M., Yalle, S., Campos, J.J., Locatelli, B., Villalobos, R., López, G. & Carrera, F. 2005. Efectos del pago por servicios ambientales y la certificación forestal en el desempeño ambiental y socioeconómico del manejo de bosques naturales en Costa Rica. Colección Manejo Diversificado de Bosques Naturales. Publicación no. 30. CATIE. Serie Técnica. Informe Técnico NO. 338. 31 pp.

Magginis, S., Méndez, J. & Davies, J. 1998. Manual para el manejo de bloques pequeños de bosque húmedo tropical (con especial referencia a la zona norte de Costa Rica). Lara y segura asoc. San José, Costa Rica. 208 pp.

McKenzie, T.A. 2003. Tendencias y para el Sector Forestal Nacional de Costa Rica Hasta el Año 2020. Consultant report for the Comisión Forestal de América Latina y el Caribe (COFLAC) Proyecto Tendencias y Perspectivas del Sector Forestal de América Latina. 23 p. available online: http://documentacion.sirefor.go.cr/archivo/ tendencias/ tendencias2020_2_.pdf. (22 Oct 2008).

Méndez, J. 1993. Manejo del bosque natural en la Región Huetar Norte de Costa Rica. Revista Forestal Centroamericana 6, 42-49.

Méndez, J. 2008. El manejo silvicultural policíclico en bosques húmedos de bajura en la Región Norte de Costa Rica. Oral presentation VI Latin American Forestry Congress, Venezuela, 2-5 April 2008. 16 p + figures and tables.

MINAE (Ministry of the environment and energy). 2002. El éxito forestal de Costa Rica en cinco casos. San José, Costa Rica, 60 pp.

MINAE (Ministry of the environment and energy). 2008. Estándares de sostenibilidad para manejo de bosques naturales: principios, criterios e indicadores, código de prácticas y manual de procedimientos. La Gaceta 115, 24-27.

MINAET (Ministry of the environment, energy and telecommunication) 2010. Readiness Preparation Plan Costa Rica. San José, Costa Rica.

Obando, G. 1997. Evaluación del desempeño de vías de transporte menor asistido por computadora para el aprovechamiento selectivo de guácimo (Goethalsia meiantha) en un bosque húmedo tropical de tierras bajas ubicado en Sarapiquí, Costa Rica. Tesis, Mag. Sc. CATIE, Turrialba, Costa Rica. 105 pp.

Oficina Nacional Forestal (ONF) 2010. Costa Rica Forestal. Usos y aportes de la madera en Costa Rica, estadísticas 2009. ONF, Belén, Heredia, Costa Rica. 23 pp. disponible en www.onfcr.org. Accessed 23 March 2011.

Quirós, D. 1998. Muestreos para la prescripción de tratamientos silviculturales en bosques naturales latifoliados; guía de campo. CATIE, Turrialba, Costa Rica. Manejo forestal tropical no 4. 8 pp.

Quirós, D. & Gómez, M. 1998. Manejo sustentable de un bosque primario intervenido en la zona Atlántica norte de Costa Rica: Análisis financiero. CATIE, Turrialba, Costa Rica. Serie técnica, informe técnico no. 303. Colección Manejo Diversificado de Bosques Naturales no. 13. 22 pp.

Quirós, D. &, Finegan, B. 1994. Manejo sostenible de un bosque natural tropical en Costa Rica. CATIE, Turrialba, Costa Rica. Serie técnica, informe técnico no. 225. Colección Silvicultura y Manejo de Bosques Naturales no. 9. 25 pp.

Sader, S. & Joyce, A. 1988. Deforestation Rates and Trends in Costa Rica, 1940 to 1983. Biotropica 20, 11-19.

SINAC (Sistema Nacional de Areas de Conservación). 1999. Breve descripción del estado de los recursos forestales en Costa Rica. San José, Costa Rica. 21 pp.

SINAC. 2006. Estrategia nacional de manejo del fuego de Costa Rica 2006-2010. Online: http://documentacion.sirefor.go.cr/ archivo/incendios/emf_2006.pdf. 22 Oct 2008.

Van Leeuwen, A.C.J. & Hofstede, A.M. 1995. Forests, trees and farming in the Atlantic zone of Costa Rica. CATIE, Guápiles, Costa Rica. Serie técnica Informe técnico no 257. 48 pp.

Wendland, A. & Bawa, K.S. 1996. Tropical forestry: The Costa Rican experience in management of forest resources. Journal of sustainable forestry 3, 91-156.

13 Cameroon

B. Foahom & P. Schmidt

13.1 Cameroon in brief

Cameroon is a Central African country, covering 475,000 km^2, situated between latitudes 2° and 13° N; longitudes 8°30′ and 16°10′ E. This position endows the country with diversified ecological and climatic conditions, ranging from semi-desert conditions in the north to tropical rain forest climates in the south, and hence many quite different vegetation types (see Letouzey 1968), and harbours 80,000 ha of plantation forest.
The population totals 19.4 millions (2010), with an annual growth rate of 3 %, and a density of 34.4 persons per km^2. Nearly half of the population lives in rural areas (FAO 2005), indicating the importance of forest for the population.

The total forest cover, with different types of forests ranging from evergreen forest to forest-savannah mosaic, is estimated to be 22.5 million hectares, of which 16.5 million are dense humid forests with high potential for logging (MINFOF 2005; De Wasseige et al. 2009). After some fluctuations at the start of the 21st century timber production has stabilised at about 2.3 million m^3 as from 2006 (De Wasseige et al. 2009). Logging is highly selective as only two species (*Triplochyton scleroxylon* and *Entandrophragma cylindricum*) account for more than 50 % of the production. Of the six types of logging rights, Forest Concession is the most important one in terms of the total volume of timber produced. About 100 Forest Concessions, made up of 110 Forest Management Units, and covering a total area of 6.5 millions hectares, presently have been granted. 45 % of this has been attributed to Cameroonians and 55 % to foreigners (MINFOF 2010). The above figures do not include non-conventional logging, an informal activity that is essentially illegal. Nevertheless, it remains the main source of lumber for local need/use, as the production from logging companies is meant mainly for export (Foahom 2007). Moreover, forest harvesting is not confined to logging but includes gathering of non-timber forest products (NTFPs, see Van Dijk 1999).

Even though the Forest sector's contribution to the national GDP (6 %) is the highest in the Congo Basin and represents the State's third source of hard currency, this contribution is still far from its real potential (De Wasseige et al. 2009).

13.2 Development of forest management till 1994

The first forest regulations of Cameroon date from 1974. Until then, activities in the forestry sector were governed by a colonial ordinance. The 1974 regulations were revised in 1981 and implemented in 1983. Procedures regarding licences, exploitation control and taxes were documented in a guide entitled "*Cahier des procédures pour l'exploitant forestier*" (Guidelines for forest exploitation procedures) (MINAGRI 1988).

Photo 13.1. Tropical rain forest near Kribi, photographed from Mont d'Elephant. (Photo Hans Vellema)

The forest was perceived mainly as a timber producing ecosystem, resulting in the marginalisation of other forest functions and products. So also did forestry research or any other action directed at forest management. Research activities focussed overwhelmingly on biological and technological factors, aiming at generating more knowledge on biological characteristics of forest ecosystems and their potential to produce timber, and developing silvicultural techniques for the most important timber tree species. Even if the quest for sustainability was a matter of concern in those days, it tended to focus on sustainable timber production.

Forest exploitation licences were granted to private companies for a period of five years and were renewable. The concession areas were divided into working coupes of 2,500 ha called "*Assiette de coupe*". After a coupe was closed, re-entry to harvest more timber was not permitted. The licensee nominated the coupes in advance. Maps were produced, showing the positions of harvestable trees, proposed forest roads, and the inventory results of commercial species. Other forms of logging permits are described below.

There were 45 tree species listed as obligatory for inventory purposes. It was not allowed to fell

Photo 13.2. Flushing *Lophira alata*. (Photo Tropenbos International)

trees smaller than a diameter specified in the "*Cahier*". The minimum diameter varied from 50 to 100 cm, depending on the species. Average volume extracted per hectare was estimated at 5 m^3 out of a commercial volume of about 35 m^3 (Evans 1990) as a consequence of the prevailing selective logging.

The writing of a Forest Management Plan was not a prerequisite to forest exploitation. Gazetted permanent production forest was almost non-existent, and timber production came from short-term concessions of one to five years.

13.3   Forest policy and its implementation since 1994

FAO's 1986 Tropical Forest Action Plan and the Rio Summit of 1992 stimulated the development of a new forest policy (NFP), accepted by parliament in 1994. Emphasis was shifted from the tree to the entire forest, including:
- the protection of the country's forest heritage;
- the participation of the local populations in the whole process of forest management;
- the improvement of the forest's contribution to the GDP, while preserving its productivity.

The NFP aimed at integrating the new perception of sustainable forest management, taking into account its multiple functions, and to safeguard the benefits derived by Cameroonians, now and in the future. The NFP consists of a set of institutional and legal regulations (law n° 94-01 of January 1994) and implementing instruments, such as the National zoning plan (Côté 1993), the National forestry action programme (MINEF 1995) and Guidelines for the elaboration of forest Management Plans and for Community forests (MINEF 2001). In the framework of this law, two ministries (the Ministry of Forests and Wildlife, MINFOF; and the Ministry of Environment and Natural Protection, MINEP) and one implementing institution (the National Agency to Support Forest Development, ANAFOR) were set up.

A new strategic plan, entitled "Forest-Environment Sector Programme" (PSFE) (MINEF 2003), is the outcome of an evaluation of ten years of implementation of the NFP, indicating a number of shortfalls:
- institutional shortfalls due to poor involvement of all parties including research institutions;
- specific shortfalls, such as poor integration of environmental concern into logging operations and limited application of Forest Management Plan procedures, due to inadequate knowledge and tools;
- poor coordination leading to poor capitalisation of outcomes generated by actions implementing the NFP.

The PSFE is therefore a coherent framework for improved implementation of the NFP, in order to meet the challenge of sustainable use of forest resources by all stakeholders. The PSFE, implemented since 2005, consists of five components:
- Component 1: Environmental management of forest activities (MINEP);
- Component 2: Production forests management and valorisation of forest products (MINFOF);
- Component 3: Biodiversity conservation and valorisation of wildlife products (MINFOF);
- Component 4: Community management of forest and wildlife resources (MINFOF);
- Component 5: Institutional reinforcement, training and research (MINFOF).

13.4   Forest reserves and off-reserve tree resources and their utilisation

The NFP stipulates that the national forest estate includes, in conformation with ITTO guidelines (1990), two forest categories: Permanent Forest and Non-Permanent Forest (Figure 13.1). Permanent Forests should cover at least 30 % of the national territory and reflect the nation's ecological diversity. So far, 22 % of the national territory has been allocated, including game ranches (FORAF 2008). For the southern-forested area, covering 14 millions ha, a National Zoning Plan (Côté 1993) forms an indicative framework for land use planning which is open to negotiation among stakeholders during implementation. Timber tree resources originate from diverse national forest estate types of Permanent and Non-Permanent Forests (Figure 13.2). Production Forests are meant mainly for timber production and account for more than 80 % of the total timber production (Figure 13.2). However, protected areas (Forest Protection) are not free from logging activities, especially not from non-conventional, i.e. mainly illegal, logging.
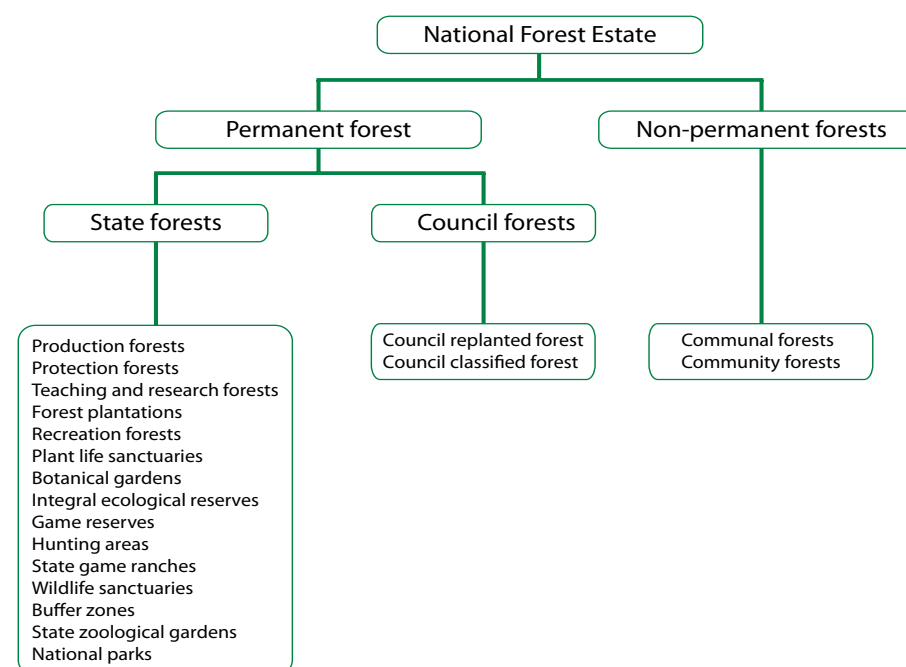
Figure 13.1.   Categories of classified forest in Cameroon (Foahom et al. 2001).

According to the law, logging activities should be conducted, based on different categories of logging rights, as provided by the 1994 forest law:

- *Sales of Standing Volume*: Applied to state forest (permanent forest), logging should be undertaken in accordance with its management plan for a limited period of time. Applied to communal forests, it is an authorization to exploit, in an area not exceeding 2,500 ha, a specific volume of standing timber for sale;

- *Exploitation Permits*: This allows the extraction of not more than 500 m³ timber for commercial ends in one non-permanent forest;

- *Individual Felling Authorisation*: This allows the extraction of not more then 30 m³ of wood for non-commercial use from non-permanent forests. It is granted for a non-renewable period of three months, only to Cameroonian nationals.

- *Exploitation Contract (Concessions):* This aims at a long-term timber supply out of Production Forests for the wood processing industry of the licence-holder. It is agreed upon for a maximum period of 30 (2 times 15) years and is re-assessed every third year. It applies to a concession that may include one or more Forest Management Units (FMU) and does not exceed 200,000 ha.

- *State Exploitation or Sub-contracting Agreement*: It allows exploitation in state forests. This can be done either through the sale of standing volume or through an exploitation contract. However, the forest may be exploited by the administration in case there is need to recuperate the forest products concerned or in case of an experimental project.

- *Wood Recovery Permit*: It allows exploitation, when a forest has to be cleared for industrial or agricultural purposes, such as the establishment of an oil-palm plantation, where all trees would be destroyed anyway. It does not require trees of a minimum diameter to be left, nor a forest inventory.

- *"Vente de Coupe"*: It allows exploitation only in a non-permanent forest which can be converted into other forms of land use. It does not require a management plan and logging can be sub-contracted.

Photo13.3. Timber transport to the harbour of Kribi. (Photo H. Duiker)

As logging and forest exploitation remain an important economic sector in Cameroon, the government is struggling to ensure sustainable management of the forest resources. The different types of logging permits are currently allocated and the trend for a specific type to be more attractive depends on how easy the permit is obtainable. Of these eight types of logging permits, concessions (FMUs) are the ones that require management plans and which are allocated through a competitive bidding process. Next to these different legal logging rights and practices, non-conventional logging is a current practice in Cameroon, which is essentially illegal and informal. There are not many precise data on this activity, but so far it is clear that not only many people are involved, but also that chainsaw logging and lumbering, which is a main activity in non-conventional logging, appears to be the main source of lumber for local markets (Foahom 2006).

According to the 1974 Land Ordinances, all unoccupied land, considered here as Non-Permanent Forests, belongs to the state. In national forest estates (mainly Production Forest), logging companies are granted rights on forest resources to be harvested but not on the land. In Non-Permanent Forests, local people are granted user rights to meet their day-to-day needs (harvesting NTFP and construction materials, farming, hunting,) but they are not considered as land owners, unless they are holders of a state-issued land certificate. The certificate is issued provided that the said land bears visible signs of human presence, such as a building or perennial crops. Exploitation of trees in such areas is based on specific logging rights (see above), which are not restricted to individuals or communities close to that forest. Trees belong to an individual or a group, as far as those are planted by him, her or them; their user rights can be allocated to other people (to a third person). This applies only to timber trees, for trees producing NTFPs (*Baillonella toxisperma*, for example) form part of a heritage when they grow on farms. Local people can claim right on trees belonging to such an area (Non-Permanent Forest) and can use them accordingly, whether it is a fallow or a current farm.
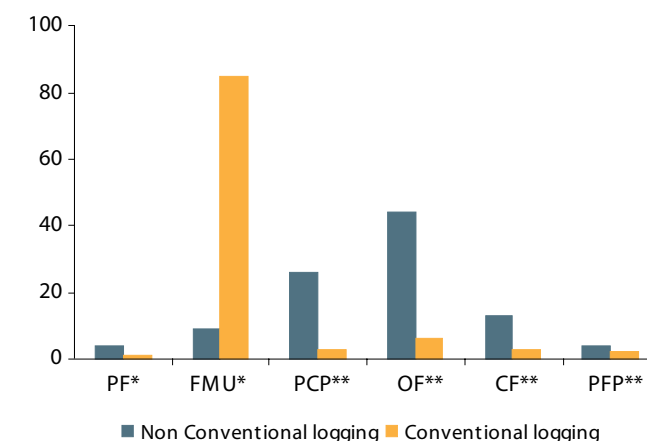

Figure 13.2. Percentage of tree resources according to different logging areas (Foahom 2006):
* Permanent Forests: Protection Forest (PF) and Forest Management Units (FMU).
* Non-Permanent Forest: Perennial Crop Plantations (PCP), Old Fallows (OF), Community Forest (CF) and Private Forest Plantations (PFP).

13.5. Productivity and annual allowable cut

The logging potential of Cameroon is quite substantial (Table 13.1). The figures in Table 13.1 include all actual and potential commercial timber tree species, estimated to be about 600 species. However, under prevailing economic conditions, most tropical countries are not achieving anywhere near the value that should be attained from harvesting, processing and marketing tropical moist forest species (Plumptre 1996), and this applies also to Central African countries (PFBC 2006). In Cameroon for example, average volume extracted, estimated at 7-10 m³.ha⁻¹, and the average logging intensity, less than one tree per hectare, are low, compared to estimated figures of 50-80 m³.ha⁻¹ in South-East Asia and 10-20 m³.ha⁻¹ in Brazil (Karsenty & Maître 1994; Jonkers & Foahom 2003). This considerable difference is probably due to a selective choice of timber species in Cameroon (Figure 13.3).

Table 13.1. Estimated volume of exploitable timber according to land vegetation cover (MINFOF 2005)

Type of vegetation cover	Logging potential		
	Mean	Total	Percentage
	m³.ha⁻¹	10⁶ m³	%
Forest lands*	54.0	1,147.5	92.9
Other woodlands	1.6	23.4	1.9
Other lands	5.7	64.4	5.2
Total	26.0	1,235.3	100.0

* Congo-Guinean floristic region (Letouzey 1968) covering about 45% of the national territory

The forest management plan (FMP) concept was introduced in 1994 as part of the NFP, aiming at ensuring the production capacity of Production Forests including not only economic function, but also ecological and social functions of the forest. One of its main objectives is to ensure a continuous supply of timber. Consequently, timber yields should not exceed the net volume increment of the species to be harvested. The FMP therefore fixes the annual allowable cut (AAC). The AAC is expressed in terms of maximum yearly exploitable surface area (*Possibilité par contenance*) and/or the maximum volume of forest products (*Possibilité par volume*) to be extracted.
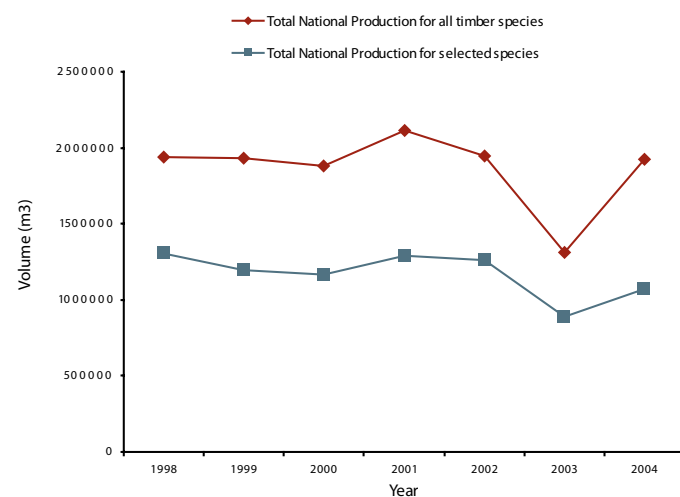

Figure 13.3. Selective logging in Cameroon, with four species representing more than 60% of the total timber production (Foahom 2006). Selected species are *Triplochiton scleroxylon, Lophira alata, Entandrophragma cylindricum, Afzelia bipindensis*).

Within the framework of the Tropenbos-Cameroon Programme, the so-called TROPFOMS (TROPical FOrest Management support System) model was developed (Eba'a 2000) as a tool to help the forest manager to determine sustainable production levels of production forests. For a given forest, the model calculates the growing stock at steady state, estimates the cutting cycle, the amount of timber to be harvested during each cutting cycle and the length of the conversion period. TROPFOMS is considered the best

model available in Cameroon, mainly because it includes the economic and ecological management aspects too. However, TROPFOMS has its limitations. As reliable increment and mortality data from Cameroon are not available, data used for its development were from Liberia. This applies to many other yield calculation programmes utilised in Cameroon, including the one used to estimate the AAC. Like in any model, the reliability of the output depends on the quality of the input data. Data collected in Cameroon and used in due time to update the model will certainly improve its reliability.

13.6. Silvicultural systems in Cameroon

In Cameroon, some silvicultural systems were applied or tested on a larger (practical) or smaller (experimental) scale:

- The **Natural regeneration system** "*Amélioration des Peuplements Naturels* (APN)" (natural stand improvement) was designed for the management of 175,000 ha semi-deciduous production forest in Deng-Deng (east Cameroon) (FAO 1977). Improvement operations were applied when at least 15 trees per hectare were available for future logging (diameter 20 to 40 cm). Twenty-two timber species in four timber quality classes were considered. Silvicultural operations undertaken three to five year after logging consisted of liana cutting and sanitary thinning to reduce competition. Natural regeneration was recorded but not provoked. Tending was planned in case regeneration occurred. If not, enrichment planting had to be applied, using some Sterculiaceae and Meliaceae timber species. This attempt to develop a management system for the Deng-Deng semi-deciduous forest was not successful due to institutional obstacles. More recent experiments testing an adapted form of the CELOS Management System are described in Section 7.

- **The Enrichment techniques** "*Méthode des grands layons*" (new lines method, Photo 13.3) and "*Méthode des Placeaux*" (small quadrat plots) were used to establish about 5,000 ha forest plantation some 70 years ago.

- **The Conversion techniques** "*Méthode de sous-bois*" (understory method), "*Méthode du Recrû*" (regrowth method), mechanised methods and methods associating crops (Taungya, for example) have been applied in Cameroon. Most of these and other methods developed in Central and West Africa and overseas were tested in Cameroonian context. Experimental plots were established in the most important forest zones in the Congo-Guinean region. *Aucoumea klaineana* (Okoumé), one of Africa's prime timber species, is presented here as an illustration (Table 13.2). Various silvicultural methods were tested. Preliminary results showed that the "new lines method" was not appropriate for the species, while the "mechanised strip method", a thinning operation, could be appropriately undertaken after 15 years, taking into consideration the mean diameter and the number of elite trees. The stand under the "regrowth method" was of somewhat less quality, but still acceptable. Thinnings in *Aucoumea* stands are delicate. The remaining elite trees have to be surrounded by dominated, suppressed trees, thus protecting the stand against 'black cancer' attacks.

Table 13.2. Characteristics of *Aucoumea klaineana* stands under three silvicultural treatments (Foahom 2005a)

Parameter	Dimension	Silvicultural treatment (*)		
		New lines methods	Mechanised strips	Regrowth methods
Years after treatment (age of plantation)	y	16	14	18
Density (d)	n.ha⁻¹	176	527	370
Basal area (G)	m².ha⁻¹	12.0	21.6	19.7
Diameter of tree of mean G (Dm)	cm	29,5	22,8	26.0
Mean annual increment (MDI)	cm.y⁻¹	1.8	1.6	1.4
Dominant trees	n.ha⁻¹	86	248	133
Co-dominant trees	n.ha⁻¹	53	190	96
Suppressed trees	n.ha⁻¹	37	89	141
Elite trees (among dominants trees)	n.ha⁻¹	7	114	96

(*) The 3 treatments apply to disturbed forest (after logging), with 3 different methods of land preparation :
- New Lines methods: Open East-West plantation lines 5 m wide, 10 to 20 meters apart. In order to improved the amount of light reaching the plantation lines, all trees (between lines) of more than 20 cm diameter are also poisoned.
- Mechanised strips: Mechanical land preparation where natural forest is completely destroyed, than line planting at 3 to 5 m apart.
- Regrowth methods: Manual land preparation where the forest is completely destroyed manually using cutlass/chainsaw (for trees less than 20 cm diameter, at 40 cm above ground) and poison (for trees more than 20 cm diameter). Forest floor is preserved and line planting is undertaken at 3 to 5 m apart.

Forest plantations in Cameroon cover a total area of about 80,000 ha. All these plantations were established by the State, the most recent ones in the 1990s. Unfortunately, most of them failed as a consequence of lack of adequate tending. Since the 1990s only some small short rotation stands of *Eucalyptus* sp. have been planted by private persons in the Western Savannah zone.

Photo 13.4. An enriched forest stand with *Terminalia ivorensis* at Bilik (Cameroon), using silvicultural enrichment technique (new lines method). (Photo B. Foahom)

Conversion techniques are often looked at as a system that simplifies the ecosystem, especially concerning monospecific stands. It has been shown, however, that the vegetation/species diversity of the natural regrowth under broad-leaved plantation stands is comparable to that of the surrounding, somewhat disturbed, natural forest (Foahom et al. 2005; Ngueguim 2007). Moreover, forest plantations present the advantage of yielding up to five times the volume of (harvestable) timber per ha, compared to natural stands and even more when one takes into consideration the selective character of logging activities in natural forest.

For quite a long time, the question to plant or not to plant has been discussed, thus underlining differences in the perception of its opportunity (Dupuy 1989). The reluctant attitude vis-à-vis forest plantations prevailed as they were considered to be costly. Whether it is better to plant or not to plant depends on the starting point (the forest quality) and the aim to be achieved. Moreover, timber from plantations is gaining a significant share of the market. This development may in the long run reduce the pressure on natural forest. In Cameroon, planting is gaining importance, through the government's strategy to stimulate planting operations by the private sector, communities, individuals, etc. As the state is no longer engaged in production activities, including plantations, the stimulation of plantations is the main task of ANAFOR. The policy framework for it, the "*Programme National de Reboisement*" (MINFOF 2006), was recently launched. Silvicultural techniques for the most important timber and NTFP tree species are being developed too (Foahom 1992; Sunderland et al. 2000).

13.7   Experiences from the Tropenbos-Cameroon Programme

Within the framework of the Tropenbos-Cameroon Programme, a natural regeneration technique, adapted from the CELOS Management System (De Graaf 1986; Jonkers 1987; Hendrison 1990; De Graaf & Van Rompaey 1990) and Côte d'Ivoire experiments (Miélot & Bertault 1980; Maître 1988), was tested between 1995 and 2001. Two types of silvicultural treatment, pre-felling and post-felling treatments, were studied. Prior to this, the phenology of 86 timber species and the forest structure was assessed. The diameter class distribution was found to be similar to the exponential model as described by Rollet (1979), meaning that a steady increase in the number of trees of harvestable sizes after silvicultural treatment can be expected (Bibani & Jonkers 2001).

→ The pre-felling treatment consisted of cutting all lianas with a diameter > 2 cm, aiming at reducing felling damage and stimulating the growth of climber infested trees. Large lianas were expected to contribute to logging damage and to compete with trees for light and nutrients. On the other hand, lianas do play an important role in biodiversity and as sources of non-timber forest products (NTFP).
The result of liana cutting on logging damage appeared to be negligible, however (Parren & Bongers 2001). This unexpected result can be explained by the fact that the trees to be felled were emergent trees with their crowns above the forest canopy. Lianas may contribute to logging damage when they connect the crown of the tree to be felled with crowns of other trees. However, the substantial distances between an emergent tree crown and other crowns make that such connections are rare, in spite of the abundant presence of lianas (Jonkers & Van Leersum 2000).
The impact of liana cutting on tree growth still needs to be proven as a recording period of many years is required to demonstrate such an effect. As a matter of fact, liana cutting costs about 1 US $ per hectare, and is therefore inexpensive. In case this operation proves to be effective in stimulating tree growth, the treatment should be adjusted to preserve NTFP climbers, such as rattans (*Ancistrophyllum secundiflorum* and *Calamus* spp.) and *Strophanthus gratus*, a major NTFP used in the pharmaceutical industry (Van Dijk 1999).

→ The post-felling treatments aimed at stimulating the growth of timber trees. This was done through a liberation treatment in which trees competing with timber trees for light

were killed. Major NTFP producing species were preserved regardless of their position in relation to timber trees, however, and were also expected to benefit from the treatment.

Two different treatments were applied in the same experiment as the pre-felling treatments (Bibani & Jonkers 2001; Jonkers & Foahom 2003). The treatments are based on four lists of valuable species occurring in the plots (Essama Etoundi 2002):

- List 1: 35 currently commercial timber species;
- List 2: 35 species, having the potential to become marketable timber species within 25 years (Zijp et al. 1999);
- List 3: 34 species, which produce important non-timber forest products, which grow to sizes > 20 cm dbh and which are not on lists 1 and 2;
- List 4: all other tree species.

In treatment A, all species of lists 1 and 2 in the size class 20-50 cm dbh were liberated. Larger trees were not liberated because they suffered little from competition; smaller trees were not liberated because competition for light is needed to stimulate their height increment and these small trees themselves give only meagre competition. The treatment consisted of killing trees > 30 cm dbh which competed directly for light with the trees to be liberated and which were on list 4. Trees to be killed were administered a plant hormone (arboricide) to the bark over a height of approximately 10 cm all around the tree. The treated trees gradually shed their leaves and died over a period of a few years. The dead trees generally remained standing and progressively fell apart. The treatment therefore caused hardly any damage to the remaining vegetation, and nutrients stored in the killed trees were gradually released.

Photo13.5. Baka pygmies collecting non-timber forest products in the forest. (Photo J.Schneeman)

Treatment B focused on currently commercial timber species and the liberation treatment was combined with a partial removal of the canopy. Only species of list 1 were liberated and the minimum diameter for trees to be killed in the vicinity of trees to be liberated was 20 instead of 30 cm. Furthermore, all large canopy trees, which belonged to a list 4 species and all commercial timber trees with diameters above the felling limit, were killed.

In addition to boosting timber production and preserving NTFP producing tree species, the treatments should also preserve the biodiversity and the stability of the forest ecosystem. To estimate the immediate effects on tree growth, plant biodiversity and phytomass, a large variety of treatment prescriptions (more or less species eliminated, other diameter limits, etc.) was simulated in a three-dimensional model of a forest transect. Treatments A and B were chosen, because they combine a considerable reduction

in light competition with preservation of all of tree species and a moderate reduction in phytomass.

So far, the preliminary results of the treatments are promising. The input required for both treatments applied were modest as only 1.1 man-day and about 8 litres of a 5 % solution of the arboricide P80 per ha are needed (Essama Etoundi 2002). Furthermore, a post-treatment enumeration showed that there was no reduction in the number of tree species. However, the (positive or negative) effects of the treatments on growth, regeneration and mortality of timber species still need to be proven. Ecological, economic and social (NTFP) aspects will then be important criteria to be considered. This will require a long time span. Unfortunately, for administrative reasons, no assessment has been undertaken until now, but the experimental permanent sample plots are available for study at any moment.

It is beyond the scope of this publication to describe all flanking research carried out to assess the ecological, economical, social, and other consequences of the treatments in this system. All results are summarized in Jonkers & Foahom (2003).

13.8 Main issues restricting sustainable forest management at present

The government of Cameroon has committed itself to manage its forest resources according to international standards conform bilateral and multilateral conventions of which Cameroon is a party. A new forest policy (NFP) was thus formulated in 1994, aiming at implementing sustainable forest management, based on concepts formulated in these conventions. Even though the NFP has been applied in some instances, sustainable Forest Management is still far from being reached.

The state is no longer engaged in forest plantations. Forest management plan prescriptions, in terms of forest regeneration, are not seriously taken care of. Natural regeneration techniques to be applied in forest management units require low impact logging practices, an innovation which is still far from being implemented by the majority of logging companies. Moreover, the silvicultural system designed and tested by the Tropenbos Cameroon Programme in the 1990s is the only one of its kind in Cameroon and still requires proving its effects on growth, regeneration and mortality of timber species. On the other hand, the already tested enrichment and conversion techniques are likely to support the National Regeneration Programme adopted in 2005 and launched in 2006.

Illegal logging remains an important issue, also as a consequence of some existing forms of logging grants such as "vente de coupe". The total forest area exploited as "*vente de coupe*" increased in recent years. As it is mostly granted for Non-Permanent Forests, it does not require a management plan. Moreover, logging can be subcontracted to others (logging companies, concession owners), thus undermining responsibility and accountability for forest exploitation and at the same time opening ways to exploit the forest as much as possible. Apart from the limitations, such as a maximum legal area of 2,500 ha and time restrictions, "vente de coupe", which is of course a legal logging grant,

appears to be less constraining for loggers. In a comparable way, most of the logging rights and wood recovery permits are open to wide abuse, without any concern with regard to the NFP goal.

"The mysteries of the tropical rain forest are still far from being revealed to us. Consequently, research occupies a prominent place in the field of conservation and sustainable use of tropical rain forest" (Pronk 1998). Tropical forest ecosystems are complex systems. Moreover, the prevailing reductionist approaches used now, instead of integrated holistic approaches, do not lead to sustainable management. As a consequence of the former approaches, insufficient scientifically sound tools for forest policy implementation exist, resulting in a weak application of available knowledge. There still is a strong tendency to resort to speculation, rather than to what is known. Some key institutions of the Cameroon forestry sector and their staff are still anchored in traditional forestry, resisting to adopt innovations, and believing strongly that the forest is a gift from God, which can be used in any way (Foahom 2005b).

Logging activities are most of the time still without full commitment to sustainable forest management. As a matter of fact, the concessionaires, after assignment, have three years to prepare a forest management plan. During that period, logging occurs on the basis of a provision in the law (three years temporary

Photo13.6. Abandoned logging road.
(Photo J. Schneeman)

convention). Unfortunately, this period is usually illegally extended. However, some improvement was recorded recently. In 2008, 65 Forest Management Units (4.2 million ha) out of 109 (6 million hectares) had their management plans approved, of which 13 (895,492 ha) were attributed FSC certificates (De Wasseige et al. 2009).

Non-conventional logging is organised in the form of a complex chain linking many people. It is clear that the way it is conducted does not fit with sustainable forest management requirements. Each link in the chain can be a dubious one, by which good governance, transparency, legality, etc. can be endangered.

Logging is still concentrated on very few species. The consequence is that forest exploitation and the forest industry are far from achieving the value that could be attained from harvesting timber, while logging damage remains an important issue. The annual deforestation in Cameroon of about 0.88 % is still above the 0.78 % African average.

The concept of Community Forests was introduced in the NFP to improve the involvement of the local population in forest management. Unfortunately, much needs still to be done

in this respect. The access to community forests is still difficult for local communities due to complex procedures. A mediation process as developed in Cameroon (Lescuyer 2002; Jonkers & Foahom 2003) aims at ensuring that stakeholders share the benefits as well as the burdens resulting from sustainable forest management. Avoiding situations where a stakeholder or a part of the local population enjoys most of the benefits while the other suffers most of the burdens is the goal. However, the process still needs to be improved. Moreover, local populations which quite often profit substantially from the forest (Lescuyer 2002) are not well organised and therefore not able to defend their position with respect to forest exploitation.

References

Bibani Mbarga, R. and Jonkers, W.B.J. 2001. Silvicultural monitoring in permanents sample plots in Ebom forest, Southern Cameroon. In: Jonkers, W.B.J., Foahom, B. and Schmidt, P. (eds) (2001). Seminar proceedings "Sustainable Management of African Rain Forest". Part II: Symposium. The Tropenbos Foundation, Wageningen, The Netherlands, 102-111.

COMIFAC. 2006. Les forêts du bassin du Congo: Etat des forêts 2006. PFBC, 256 pp.

Côté, S. 1993. Plan de zonage du Cameroun méridional. MINEF Poulin Thériault. Inc., Montreal, Canada.

De Graaf, N.R. 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Series Ecology and Management of Tropical rain forest in Suriname 1. Agricultural University, Wageningen, The Netherlands. 265 pp.

De Graaf, N.R. and Van Rompaey, R. 1990. The CELOS experiments on silviculture with regeneration in Suriname. MAB/IUFRO/FAO. 14 pp.

De Wasseige C., Devers, D., Marcken de, P., Eba'a, A.R., Nasi, R. & Mayaux, P. 2009. Les forêts du Bassin du Congo: Etat des forêts 2008. Office des publications de l'Union Européenne. Luxemburg. 425pp.

Dupuy, B. 1989. Plaidoyer pour le reboisement. Bois et Forêts des Tropiques 221, 25-31.

Evans, W.R. 1990. La durabilité de l'exploitation forestière au Cameroun: étude de quelques cas. Consultancy report prepared for WWF. Foundation Renewable Resources, Banbury, UK.

Eba'a Atyi, R. 2000. TROPFOMS, a decision support model for sustainable management of South-Cameroon's rain forests. PhD-Thesis, Wageningen University, The Netherlands.

Essama Etoundi, J. 2002. Le déroulement des activités de terraindu sous-projet sylvicole F2, Programme Tropenbos Cameroon. Tropenbos-Cameroon Reports 02-1. Tropenbos-Cameroon Programme. Kribi, Cameroon. 33 pp.

FAO 1977. Aménagement de la forêt de Deng-Deng (Cameroun). Rapport Technique 2. Rome, Italy. 49 pp.

FAO (2005). The state of the world's Forest. FAO, Rome, Italy. 153 pp.

Foahom, B. 1992. Potentiel sylvicole de quelques espèces forestières de bois d'œuvre en forêt semi-caducifoliée au Cameroun. In: ONADEF/MINEF, Avenir des plantations forestières au Cameroun Rapport Séminaire-atelier, Bamenda, Cameroon, 97-122

Foahom, B. 2005a. Le point sur les essays sylvicoles à la Mangombé et Kienké en forêt dense humide du Sud Cameroun. IRAD/CSFSE (Rapport interne), Yaoundé, Cameroon.

Foahom, B. 2005b. Case study: State of knowledge as applied to sustainable forest management in Cameroon. International Course on Development of National Forest Policies and Strategies, March 8 – 18, 2005, Pretoria, South-Africa. 14 pp.

Foahom, B. 2006. Logging activities in Cameroon, with special reference to chainsaw milling and lumbering. International dissemination workshop on Chainsaw milling and lumber trade in West Africa. Accra 5-6 December 2006.

Foahom, B., Nkongmeneck, B.A., Pouentoumoun J.M., Kouodiekong L. and Caspa R. 2005. Gestion des plantations forestières et possibilités d'intégration de la conservation de la diversité floristique du sous-bois. Revue Scientifique de l'IRAD 2005.

Foahom, B. 2007. Logging activities in Cameroon, with special reference to chainsaw milling and lumbering. In: Proceedings of International dissemination workshop on: the Chainsaw milling and lumber trade in West Africa. Accra, Ghana, 5-6 December 2006 (in press).

FORAF 2008. Fiche de collecte de données sur les indicateurs de suivi de l'état des forêts d'Afrique Centrale, niveau national. Cameroun, RDC, RCA, Gabon, Guinée Equatoriale. Projet FORAF, Kinshasa, RDC.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 4. Agricultural University, Wageningen, the Netherlands.

ITTO 1990. Guidelines for the sustainable management of natural tropical forests. ITTO technical Series 5. Yokohama, Japan.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 3. Wageningen Agricultural University, Wageningen, The Netherlands.

Jonkers, W.B.J. and Van Leersum, G.J.R. 2000. Logging methods in South Cameroon: methods and opportunities for improvement. International Forestry Review 2(1), 11-16.

Jonkers, W.B.J. and Foahom, B. 2003. Sustainable management of rainforest in Cameroon. Tropenbos-Cameroon Series 9. The Tropenbos-Cameroon Programme. Kribi, Cameroon. 93 pp.

Karsenty, A. et Maître, H.F. 1994. L'exploitation et la gestion durable des forêts tropicales: pour de nouveaux outils de gestion. Bois et Forêts des Tropiques 240, 37-52.

Lescuyer, G. 2002. Environmental assessment as a new tool for sustainable management? An application in south-Cameroon rain forest region. Tropenbos-Cameroon Documents 13. The Tropenbos Cameroon Programme, Kribi, Cameroon. 133 pp.

Letouzey, R. 1968. Etude phytogéographique du Cameroun. Encyclopédie Biologique, Lechevalier, Paris, France. 508 pp.

Maître, H.F. 1988. Dynamique et production des peuplements naturels de forêt dense humide en Afrique. Bois et Forêts des Tropiques 213, 3-12.

Miélot, J. and Bertault, J.G. 1980. Etude dynamique de la forêt dense de Côte d'Ivoire. SODEFOR/CTFT. Abidjan, Côte d'Ivoire. 166 pp.

MINEF 1995. National Forestry Action Programme of Cameroon. Forest policy document. MINEF. Yaoundé, Cameroon.

MINEF 2001. Arrêté n° 222/A/MINEF du 25 mai 2001 fixant les procédures d'élaboration, de suivi et de contrôle de la mise en œuvre des plans d'aménagement des forêts de production du domaine permanent. MINEF, Yaoundé, Cameroon. 18 pp.

MINEF 2003. Programme Sectoriel Forêts et Environnement (PSFE). Document de Programme. MINEF, Yaoundé Cameroon. 95 pp.

MINAGRI 1988. Cahier des procédures pour l'exploitant forestier" (guidelines for forest exploitation procedures), Forestry Department of the Ministry of Agriculture, Yaoundé, Cameroon.

MINFOF 2005. Evaluation des ressources forestières nationales du Cameroun: 2003-2004. Unité Technique du projet d'Inventaire forestier national en collaboration avec la FAO. MINFOF, Yaoundé Cameroon. 90 pp.

MINFOF 2006. Programme National de Reboisement. République du Cameroun. Ministère des Forêts et de la Faune. Yaoundé, Cameroon. 104 pp.

MINFOF 2010. Understanding the Voluntary Partnership Agreement of the FLEGT process. Cameroon-EU Cooperation, Yaoundé, Cameroon. 22 pp.

Ngueguim J.R. 2007. Dynamique de croissance et diversité floristique dans les peuplements forestiers plantés de Bidou et Mangombé. Mémoire de DEA. Université de Yaoundé 1, Yaoundé, Cameroon. 50 pp.

Parren, M.P.E. and Bongers, F.J.J.M. 2001. Does climber cutting reduce felling damage in southern Cameroon? Forest Ecology ad Management 141, 175-188.

PFBC 2006. Les forêts du Bassin du Congo. Etat des Forêts 2006. COMIFAC-MAE France-Union Européenne-USAID. 256 pp.

Plumptre, R.A. 1996. Links between utilisation, product marketing and forest management in tropical moist forest. Commonwealth Forestry Review 75, 316-324.

Pronk, J.P. 1998. Opening speech. In: Tropenbos (ed.). Seminar Proceedings « Research in Tropical Rain Forests : Its challenges for the future », 25-26 November 1997. The Tropenbos Foundation, Wageningen, The Netherlands, 17-19.

Rollet, B. 1979. Application de diverses méthodes d'analyse de données à des inventaires forestiers détaillés levés en forêt tropicale. Oecol. Plant 14, 319-344.

Sunderland, T.C.H., Clark, L.E. and Vantomme, P. (eds.) 2000. Les produits forestiers non-ligneux: Recherches actuelles et perspectives pour la conservation et le développement. FAO. Rome, Italy. 304 pp.

Van Dijk, J.F.W. 1999. Non-timber forest products in the Bipindi-Akom II-region, Cameroon: a socio-economic and ecological assessment. Tropenbos-Cameroon Series 1. The Tropenbos-Cameroon Programme. Kribi, Cameroon. 197 pp.

Zijp, M.A., Polman, J.L. and Tongo Bokam T. 1999. MoreLKS: manual for a computer programme on Cameroonians lesser-known timbers and end-use requirements. Tropenbos-Cameroon Documents 2. Tropenbos-Cameroon Programme. Kribi, Cameroon. 75 p. + floppy disc.

14   Ghana

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14.1   General aspects of forestry in Ghana

Ghana's total land area is estimated at 23.9 million hectares of which 15.7 million ha lie within the savanna zone (SZ) in the north while the remaining 8.2 million ha are within the tropical high forest zone (HFZ) in the south. The savanna zone is characterized by an open canopy of trees and shrubs with a distinct ground layer of grasses (Hall & Swaine 1981). Woodland covers about 9.4 million ha of the savanna zone, producing mainly woodfuel and small amounts of building poles for local use. The main economic activities in that zone include production of livestock and annual crops, such as cereals, root crops and cotton.

The high forest zone, dominated by farmlands and fallows with about 20 % being occupied by forest reserves (Nolan & Ghartey 1992; Hawthorne & Abu-Juam 1995), produces timber to meet the country's demand. A transitional zone that consists of a mixture of dry forest and savanna vegetation occurs between the HFZ and the SZ.

The HFZ comprises nine forest types each having distinct plant associations and characteristic rainfall patterns and soil conditions (Hawthorne 1993). These are the Wet Evergreen, Moist Evergreen, Moist Semi-deciduous South East, Moist Semi-deciduous North West, Dry Semi-deciduous Inner Zone, Dry Semi-deciduous Fire Zone, Upland Evergreen, Southern Marginal and Southern Outlier forest types. In general, these forests are wet in the south west, turning increasingly drier towards the north and east (Treue 2001).

Ghana's deforestation rate is presently estimated at approximately 65,000 ha per year. Much forestland outside the forest reserves (in the so-called off-reserve areas) has been degraded and converted to farmland over the past decades. The current off-reserve forest areas consist of a mosaic of agricultural fields, mostly cocoa and food crop farms, fallow lands, secondary forest patches and trees around settlements (Mayers et al. 1996; Kotey et al. 1998). About 350,000 ha of off-reserve areas are currently available for timber production (Affum-Baffoe 2010). Many timber trees exist in the off-reserve areas and an inventory of this area in 1996, showed a standing tree stock of about 268 million m^3 of timber. Before 2000, at least half of the timber harvested came from off-reserve areas, but this has declined in recent years (Hansen & Treue 2008). Today, the country's forest resources are highly degraded. Wildfires, agriculture and indiscriminate logging (mainly through chainsaw milling) have contributed to this situation.

14.2   Historical developments in forest exploitation

Early commercial exploitation of the natural forest resources dates back to the 15th century. Trade in kola nuts (seeds of *Cola nitida*) within the West African sub-region, and later wild rubber (*Funtumia elastica*) and palm oil (*Elaeis guineensis*) to Europe was reported between the 15th and 18th century (cf. Parren & De Graaf 1995). Quantitative data on exports of these products to Europe between 1911 and 1934 appear in the annual reports of the colonial forestry division (Asamoah-Adam et al. 2006). Timber exploitation, mainly of African mahogany (*Khaya* and *Entandrophragma* spp), started in 1891 when about 3000 m^3 of mahogany were exported (Taylor 1960). The trade has since grown steadily and become an important economic activity. In 2009, the forest sector contributed 4 % to Ghana's Gross Domestic Product (GDP).

Photo 14.1.   Forest near Kakum in Ghana.
(Photo Tropenbos International)

Forest regulatory mechanisms applied to forest reserves
The main forest regulations applied in Ghana involved the application of minimum felling diameters, felling cycle lengths, and a selected number of stems for allowable cut (selective logging). Other silvicultural interventions, for example tending, were only used on an experimental basis and thus at a small scale. Species were grouped using commercial or silvicultural considerations and on that basis the allowable cut was determined and silvicultural treatments targeted. In addition, forest policy controls (e.g. log export ban, export levy) were introduced to prevent excessive exploitation of some species. These regulations were implemented at the national level (Asamoah-Adam et al. 2006).

Minimum felling diameter
The application of felling diameter limits in Ghana commenced with the passing of the Timber Protection Ordinance in 1907. Logging was mainly controlled through application of minimum felling diameters to prevent and protect the felling of immature trees (Taylor 1960). These felling limits were revised in 1910, 1958, 1972, 1989 and 1997 (Ghartey 1992; Ofosu-Asiedu et al. 1997). The minimum felling diameters applied before 1950 were lower than the later limits, possibly because felling and skidding operations during the early period were not mechanized or capable of handling heavy logs. Felling

Photo14.2 Forest in the Goaso region, Ghana. (Photo Tropenbos International)

limits between 50 cm and 110 cm dbh are now used in Ghana for the exploitation of over 60 species from 49 genera (Asamoah-Adam et al. 2006).

Since 1989, minimum felling limits are fixed at a point in the species diameter distributions at which the average national stocking shows a sharp decline (Ghartey 1992). The 1997 revision adopted a diameter range similar to that of 1989, but classified some species into lower or higher limit categories based on additional variables, such as average diameter increments of different dbh classes, ten-year average annual exploited volume, stocking km^{-2} of stems above 40 cm dbh, and prevalence of decay in exploited stems of specific species (Ofosu-Asiedu et al. 1997).

Felling cycle lengths
Two different felling cycle lengths were instituted sequentially between 1960 and 1989 for forest reserve management in Ghana. A felling cycle of 25 years was started in the 1960s, when working plans for some forest reserves were first produced and the respective forests were opened for timber exploitation and silvicultural treatment. In 1972, a management operation, termed "salvage felling", was introduced to remove so-called over-mature trees. It was explained that the then on-going enumeration surveys had shown a preponderance of large diameter trees that were dying and or losing their timber value because of defects. It was believed necessary to remove them through commercial logging before they were lost to natural mortality. Although in other places, salvage felling is done with felling limits that are higher than in normal coupes, in Ghana the same felling limits were applied. Annual log production was increased by opening more areas to harvest, not necessarily by allowing re-entries into previously logged forests. Under this operation, all reserved forests with or without management plans were to be logged within 15 years. The records indicate that the salvage felling, which should have ended in 1987, continued until 1990 in the absence of an alternative yield regulation method. After 1987, salvage felling operations offered an unprecedented chance for second cycle felling in some forest reserves earlier than expected (Boakye-Dapaah 1990). In 1990, a forty year felling cycle was introduced based on the average time of passage estimated for most of the high value species to grow from the next lower diameter class to the exploitable class (Boakye-Dapaah 1990; Asamoah-Adam et al. 2006).

14.3 Productivity, annual allowable cut, silvicultural systems

In Ghana, two broad approaches have been used for determining permissible cut. They are the formula and direct diameter methods. Between 1950 and 1971 three formula methods developed by Jack, Kinloch, and Kandambi, all colonial foresters, were introduced (Anon. 1962). They were all derivatives of the Brandis method (Osmaston 1968) used in the Teak forests of the Far East, and part of the classical European methods

(Brasnett 1953). The Jack, Kinloch and Kandambi formulae determined the permissible cut as the total basal area recruitment for stems above 50 cm dbh (Anon. 1962), but the cut was prescribed in number of stems for each economic species per annual coupe. The yield was selected from stems within the felling diameter classes and usually the bigger stems were chosen first. When the total calculated yield was not obtainable from the available stock of exploitable trees, the deficit could not be taken from the lower diameter class (Asamoah-Adam et al. 2006). Between 1972 and 1989, and alongside the salvage felling regime, only the Minimum Felling Diameter (MFD) was used as the means to determine the permissible cut. By this method all stems of a given species recorded to be above the MFD during a 100 % timber inventory in a compartment were selected for felling (Anon. 1972, Anon. 1995).

After the 1989 national forest inventory, another formula method was introduced. This was based on the number of stems above the MFD and the number in the next lower dbh class. It provides for 40 % retention of trees above the MFD in moist and 60 % in dry forest to retain canopy structure, seed production and biodiversity level (Anon. 1995). Currently the formula is given as: $Z = 0.5Y + 0.2X$ (for the moist forest), and $Z = 0.25Y + 0.2X$ (for the dry forest)
where Z = the total permissible number of stems, Y = the number of stems of a given species above the MFD, and X = the number of stems of a given species in the next lower diameter class to the MFD.
The formula is applied at the compartment (128 ha) level and the Y and X estimates are obtained from a 100 % inventory (stock survey) of all timber trees above the X dbh class for each species. Vanclay (1993) indicated that the yield prescribed by this formula, if considered against diameter recruitment and stem mortality over a 40 year felling cycle, can be sustainable only when the ratio of X:Y is 3:1, a situation that is rare in the tropical moist forest. Furthermore, Asamoah-Adam (1999) pointed out that the 40-60 % retention envisaged by the above formula cannot be attained, because the algebraic equation for the retention input is incorrect. For instance, when the value of Y equals X, it means 70 % and 45 % of the mature commercial stems will be cut in a moist or dry forest, and the respective retention will become 30 and 55 % instead of 40 and 60 %, respectively. As the ratio of X to Y increases the retention value diminishes, but that is not what was intended. The continued use of this formula therefore, makes sustained timber production doubtful (Asamoah-Adam et al. 2006).

A timber yield and growth simulation model (GHAFOSIM) was developed by Alder (1990), but has not been used yet to determine the permissible cut at forest reserve level. This is due to the limited number of species for which increment data were available at the time of developing the model. However, it has been used at the planning level to provide estimates of stand mortality and species group time of passage that were used as inputs for the current yield regulation formula (Anon. 1995). The model was also used to determine the national annual allowable cut.

Silvicultural systems
Commercial exploitation of timber in Ghana began in the late 19th century. The rate of extraction even at that time led to the realization of the need to backstop exploitation by a management system that would forestall depletion of commercial stocks. However, this

was not possible without adequate knowledge about the ecology of the natural forest, growth patterns and silvicultural characteristics of the commercial species. Therefore, from about 1946, a series of silvicultural experiments were established to provide the requisite silvicultural insight for promoting natural regeneration and increasing stand productivity.

Photo 14.3. Transport of round wood. (Photo Tropenbos International)

The success of the systems adopted in those days in the silvicultural practice in tropical Asia led to the evolution of several silvicultural systems with many variations in other tropical forests. Noteworthy among the various forms of silviculture in tropical moist forests have been the tropical shelterwood systems and polycyclic systems (Dawkins & Phillip 1998). In Ghana a selection management system, or the modified selection system (MSS), was introduced in 1956. It was fashioned after the Malaysian selective system and included the concept of sustained yield. Although it was not regarded as a silvicultural system, in the absence of adequate information upon which to manage the forest under a silvicultural system, its application was justified as stand improvement (Mooney 1963).

Under the system, all economic trees with dbh > 67 cm were stock mapped along with improvement thinning of smaller trees of economic species (this was referred to as combined operations). Selective felling then followed, with yield regulated by minimum girth limits and a calculated maximum basal area on a 25-year cycle (see Baidoe 1970; Asabre 1987). Between 1958 and 1970, about 259,000 ha of forest have been thus treated. However, unlike the dipterocarp-rich forests of Malaysia and similar to Nigeria, Ghana's forests are characterized by low frequencies of valuable commercial species in the middle size classes. This meant that seed sources of desirable commercial species that were expected to constitute the regenerating crop were limited. Indeed, as noted by Asabre (1987), the modified selection system was a negation of silvicultural principles because exploitation consistently removed the best phenotypes and genotypes. Consequently, the system was abandoned in 1970 and girth increment sample plots were established throughout the high forest zone to provide information on growth and an understanding of the silvicultural measures necessary for satisfactory regeneration of the forest. In the interim, as already mentioned, a salvage felling system was adopted over a 15 year cycle with a view to remove, quickly, all over-mature trees because of the high incidence of decay that stemmed from the yield regulatory measures that had been applied.

Enrichment planting techniques were also tried in the 1940s and 1950s mainly in the wet evergreen forest belt to improve the stocking of poorly stocked forest reserves in Ghana. This system involved the planting of two-year-old striplings at 5 m intervals in cleared lines of 1.8 m wide. The lines were 20 m apart and parallel. Tending operations,

such as cleaning and further canopy openings, were carried out to enhance the growing conditions of the young trees (see Asabre 1987; Prah 1994). But owing to inadequate knowledge above the extent of canopy manipulations that would ensure success, coupled with high operational costs, the system was discontinued in the early 1960s after about 2500 ha had been planted in two forest reserves.

Silvicultural experiments in Ghana

The major silvicultural systems that were experimented in Bobiri Forest Reserve were the Tropical Shelterwood System (TSS) and its variant the Post-Exploitation System (PES). The Girth Limit selection System (GLS), which remains the main management system in Ghana, was also experimented with but with harvesting followed by limited silvicultural operations to promote regeneration of the commercial crop.

The TSS was applied to over 4800 ha of forest (Osafo 1970) and followed a protocol similar in all respects to the classical TSS as practiced in Nigeria. Climber cutting and over-wood removal through poisoning of large non-economic tree species (dbh > 90 cm) were followed by a series of silvicultural thinning and liberation operations over thirty-six 4-ha blocks in the experimental research area. These were carried out prior to commercial harvesting which took place in about the sixth year after initiation of the interventions. Thinning and liberation involved the removal of unwanted species that competed with the regenerating crop. The schedule of operations that was followed is summarized in Table 14.1.

Table 14.1.   Schedule of operations for TSS

Year	Operation
1	demarcation, stock survey, cutting of all large lianas and first canopy opening (medium density)
2	second canopy opening (light density)
3	first cleaning and assessment for regeneration
4	second cleaning
5	third cleaning
6	commercial exploitation
7	climber cutting and tending of coppiced regeneration that followed the exploitation
10	climber cutting
17	thinning and over-wood removal as dictated by the state of regeneration

Thus, canopy opening events were carried out in two stages. There was an initial medium density (2,300 stems ha^{-1}) opening of the canopy by the removal of valueless trees, poles and shrubs with heights up to 6 m and dbh ≤ 10 cm in the first year. This was followed by a light density canopy opening in the second year, cutting all valueless species 9 m in height with low heavy crowns and 28 cm to 48 cm dbh in addition to the poles and shrubs. Subsequent cleanings took place in the third, fourth and fifth years, followed by commercial exploitation in the sixth year. Climber cutting and tending operations on coppiced trees that were damaged by exploitation were carried out in the seventh year and again in the tenth year.

These disturbances resulted in an average basal area reduction from ca. 30 m² per 2 ha to 10 – 12 m² per 2 ha. Consequently, there was very little shade from the shelterwood which consisted of the tall mature trees with crowns 24 - 30 m above ground, poles with small crowns 12 m high and a sparse scattering of saplings and poles of valuable species with small crowns at lower levels. The greater proportion of each 4-ha block was in full light; and where there was direct overhead cover, there was ample sidelight.

As no direct revenue was expected from TSS until about the sixth year when commercial exploitation was carried out, experiments were also initiated to determine whether sufficient regeneration could be obtained by opening the canopy after exploitation. This also meant that revenue was available in the first year of operations and this system became known as the Post-Exploitation System (PES). In contrast to the TSS, climber cutting, canopy opening and cleaning operations under the PES were carried out after the commercial harvesting.

An assessment of results showed at that time, that regeneration under the PES consisted largely of those species that were left after exploitation, notably the so-called class II species that were of lesser economic importance. Regeneration of the valuable economic (class I) species was poor because most of the mother trees had been removed during the harvest. On account of the poor results obtained at that time, and given that the costs of operation were similar between the TSS and PES, the latter was discontinued.

The main objective of the experiments on the GLS was to obtain information on the effect of exploitation preceded by climber cutting and followed by the treatment of felling gaps by cutting up branches of felled trees and pilling the slash in gaps. In addition, improvement cleanings were carried out entailing the cutting of all non-valuable trees and shrubs in the dense lower story. Short, thick-boled species with characteristic large crowns and which attained the lower middle story when mature (e.g. *Carapa procera*, *Trichilia prieuriana*, *Trichilla manadelpa*, *Panda oleosa* and *Myrianthus* spp) were cut. The purpose was to attract new regeneration following commercial exploitation, and to improve the existing crop by encouraging saplings, poles and middle size classes of valuable and non-valuable upper canopy species. Saplings of non-valuable trees that normally attain the upper middle and dominant canopies were not cut, as the intention was to remove them, to the extent possible, in the improvement thinning that would be carried out ten years later. The timing of operation under the GLS can be summarized as shown in Table 14.2.

Table 14.2. Schedule of operations for GLS

Year	Operation
0	stock survey and yield prescription as per Working Plan, principally under the Brandis yield control system with a 10-year felling cycle
1	climber cutting and commercial exploitation
2-5	post-exploitation treatment of felling gaps by climber cutting and cutting up broken crowns and pilling the slash in small piles to create openings for crowns
10	improvement thinning

Essentially, therefore, the various interventions resulted in differences in the structure of forest in the treated stands, with a tendency towards a more or less uniform structure in TSS and PES relative to the GLS forest. On the whole, however, trees in the treated stands had more light relative to unlogged forest, although many trees had poor crowns, probably as a result of previous suppression, including the effect of climbers.

At present, forest management is based on a polycyclic system that involves mainly the harvesting of commercial species using a minimum felling diameter limit, felling cycle lengths, and a selected number of stems as the allowable cut. This diameter limit selection system is being used on a 40-year felling cycle. This is supposed to result in less damage to the residual forest and ensure sufficient regeneration. However, the current practice is such that selection harvesting removes only the most highly valued species and often does not provide appropriate conditions for their regeneration.

14.4   Main issues restricting sustainable forest management

Overexploitation and illegal logging
The excessive harvesting of timber far exceeding the annual allowable cut (AAC) is an important single factor contributing to deforestation and forest degradation in Ghana. In recent times, logging activity has been intensified more in the semi-deciduous zones than in the evergreen forest due to greater densities of desirable timber species. Illegal logging activities are having a serious toll on the timber resource base in Ghana. A major problem associated with the excessive logging is the insufficient attention given to logging practices. In most cases, no proper management procedures are followed during these logging operations.

The current AAC for timber is 2 million m³ but this amount has been exceeded by total actual harvest for over a decade. Until 2004 the AAC was 1 million m³. However, in 1999 the total timber harvest was estimated to be about 3.7 million m³, which was almost four times the AAC set at that time (Birikorang 2001). According to the AAC estimates, approximately 25 % of the 1996 recorded timber extraction represents an over-exploitation, predominantly of valuable timber (the so-called scarlet star) species. The current AAC of 2 million m³ consists of 1.5 million m³ and 0.5 million m³ from the off-reserves and forest reserves, respectively. The off-reserve AAC was set high due to the desire to salvage timber trees before they are lost to the widespread illegal exploitation and conversion of forest to agriculture and other land-uses like mining. Even so, the current total timber harvest, estimated at 3.3 to 3.7 million m³ (Hansen & Treue 2008), exceeds the current AAC. The challenge now is to protect over-exploited species against the demand pressure through control-of-supply measures; to create a sustained production of timber from off-reserves; and to divert demand away from over-exploited and over-utilised species and towards under-utilised species (Treue 2001).

Fortunately, the latter option actually exists in Ghana. The substantial resource within the forest reserves of under-utilized species forms a security of raw material supply and a marketing challenge for the timber industry. The over-exploitation of certain species within forest reserves forms a management challenge to the Forestry Commission,

which should set things straight in the long-term interest of the nation including the timber industry (Treue 2001).

In line with the above, a drastic reduction of logging activities would be needed. This is difficult to realize, since many interests are at stake and so far there is lack of political will to take such drastic steps. Given the fact that the condition of many production forests is poor or confined to slopes with an incline of over 30 %, an AAC of less than 1 million m³ might be nearer to reality. The increase of the AAC from 1 million m³ to 2 million m³ in 2004 under current forest conditions underscores the lack of political and administrative will to take drastic steps to reduce logging activities. In addition, financial returns of the forest sector are not sufficiently redirected to this sector for a financially sound implementation and execution of the forest policy. This shows an unsustainable situation in sustainable forest management in Ghana.

Closely related to the problem of over-exploitation is the widespread illegal harvesting of timber. This hampers any strategies seeking to reduce over-exploitation, forest degradation and deforestation and to ensure sustainable forest management. Illegal logging in Ghana accounts for over 50 % of total timber harvest. Such illegal activities result in huge damage to the environment and to the forest resources and negatively affect the local communities who depend on forests for their livelihood. It also deprives the government of revenues.

According to Birikorang (2001), out of about 3.7 million m³ of timber harvested from the forest in 1999, illegal harvesting and chainsaw lumbering accounted for 1.5 million m³. No proper management procedures are followed and negative environmental consequences often result from the operations of these illegal timber operators, who most often harvest timber from areas reserved for biodiversity and other environmental purposes.

Attempts at using legislative instruments to outlaw chainsaw operations as a regulatory measure failed to control the situation. This is because of the inadequate capacity of the forestry sector to enforce the legislations and corruption within the sector and law enforcement agencies being very high. Another major reason is the inadequate response of policy to satisfy the domestic demand for timber. Since 2005, various strategies are being implemented to mobilize chainsaw operators into alternative productive ventures, such as forest plantation thinning and coppice management, forest boundary demarcation and clearing, assisting timber companies in timber harvesting operations and recovery of timber off-cuts in the forests.

The forestry sector is further pursuing appropriate measures to ensure that adequate quantities of mill-sawn lumber and other wood products are available to meet the needs of the domestic market. Among these measures are policies to compel sawmills to sell to the domestic market and setting up of mobile mills in strategic locations for the production of lumber to feed various localities. These measures have so far not been successful. The sector is also exploring the feasibility of charging chainsaw operators all the statutory fees and charges for the grant of access to the resource to fell and crosscut trees just as the legitimate logging and saw milling companies. Meanwhile, debates and

stakeholder consultations are ongoing to come out with appropriate control measures and policy options (e.g. see Marfo 2010).

Export as the driving force for timber harvest
The general trend during the period 1986-96 has been increasing export revenue and an increasing volume of processed wood exports. Harvest for export has played a significant role in this respect. During the period 1986-96, the export harvest made up 60-94 % of the total recorded timber extraction. Hence harvest for export has in the past been the dominant driving force behind timber exploitation in Ghana. This estimated percentage of the harvest for export out of the total recorded extraction depends entirely on the assumed recovery rates and the reliability of the data. However, the recovery rates used here are

Photo 14.4.   Chainsaw milling is an important activity in Ghanaian forestry. (Photo G. Ametsitsi)

probably on the high side and the official timber extraction data most probably under-estimates the actual harvest by at least 10 %. As a matter of fact, there are no indications of significant discrepancies between the official data on export volumes and actual export volumes during the period 1986-96 (Treue 2001).

Low forest taxes & fees regime
Forest revenue is generated mainly through royalties, rental fees and silvicultural charges. From the economic point of view, often in the timber industry, a substantial residual economic value remains (before tax) after accounting for production costs and imputing sufficient profit to sustain the enterprise over the long term. This residual value or stumpage value in reference to the value of the standing timber is the maximum price a logger would be willing to pay to the government under competitive conditions. Meanwhile, the government practices discretionary allocation of timber resources and is known to have the lowest rent collection record in West Africa (Birikorang & Rhein 2005). Between 2000 and 2003, the government captured less than half of the revenue accrued to it.

The Ghanaian forest authorities have frequently established inappropriate forest revenue systems in which timber royalties do not cover the cost of managing the forest. The forest fees do not cover the full economic cost, neither does it cover full operating cost. Until recently, timber royalties were charged per tree and value was estimated at less than 2 % free on board (fob) price per m³ of round log multiplied by the average tree volume of the species at the minimum felling diameter. Additionally, inefficiencies in the system have resulted in non-payment of stumpage fees by timber operators. It has been estimated that non-payment of stumpage fees covers 600,000-700,000 m³ per year. Such a system is inefficient as a mechanism for recovering stumpage value, thus promoting wastage both in the forests and at the mills.

An analysis of the forest fees in Ghana shows that forest fees have been too low in absolute terms to protect the resource or slow down exploitation. The system resulted

in an inadequate market-incentive differentiation between species, thus leading to over-exploitation of highly desirable timber species and under-exploitation of abundant but less-desirable species.

Weak institutional structures

The failure of the Forest Authorities to adequately control and manage the forest sustainably has resulted in large-scale encroachment on the forest reserves. Weak administrative machinery to monitor and patrol the forest is also the underlying factor for increasing bush fire in the forest areas. The weak administrative machinery may also be the result of inadequate funding for the operations of the forest authorities.

The weak administrative machinery is often a measure of the gap between projected revenues and what is actually collected, or the ability to generate enough revenue to cover the cost of operation. The income generating ability of the Forest Authorities determines the efficiency in managing the forest. Until 1998, the FSD was able to collect less than 60 % of its potential revenue due to be collected. The Service was therefore unable to cover the full cost of forest management. It could not acquire the basic equipment needed for forest management and monitoring. This gave rise to widespread illegal timber operations across the country. The illegal operators became very sophisticated and, in their illegal operations, could outwit the Forest Authorities.

Over-capacity and inefficiencies of the timber industry

Ghana is among the countries in West Africa having a well-developed sawmilling industry and the export of timber has been a key activity in the country. The Ghanaian timber industry is made up of 130 wood-processing units and about 200 other enterprises focus on furniture production. There are over 41,000 small-scale carpenters registered with the Association of Small Scale Carpenters. The small-scale carpenters represent the largest group of end-users. They require about 219,000 m^3 of sawn timber annually. This represents about 72 % of the total domestic timber requirement for the entire country (Agyarko 2000).

The timber industry is characterized by an over-capacity of out-dated and inefficient mills. It was reported that new factories were installed in the late 1990s and early 2000s to bring the processing capacity to about 5.2 million m^3, which is far in excess of the annual allowable cut of 2 million m^3 (Agyeman et al. 2003). The increase in mill capacity is attributed largely to the availability of relatively cheap raw material. Worsening the situation is the fact that the industry is operating at a low recovery rate (20-40 %) due to the inefficiency of the mills.

The timber industry is seriously distressed due to unavailability of trees for felling and growing demand for timber. Consequently, a major problem facing the timber industry is the large unutilized capacity of out-dated machinery and low rates of recovery. The timber industry requires significant restructuring and a reduction in the milling capacity to fully support the achievement of sustainable forest management. Increasing demand for timber has resulted in a decreasing resource base and affected the quality of the forests. The current extraction rates are unsustainable either in the long-term or short-term.

References

Adam, A. R. 1999. Timber yield determination and allocation in selective logging systems. Ghana Journal of Forestry 8, 23-30.

Affum-Baffoe, K. 2010. Global Forest Resources Assessment 2010. Country Report, Ghana. FRA 2010/077. Rome, 2010. 49 pp.

Agyarkko, T. 2000. Country forestry outlook paper – Ghana. FOSA working paper.

Agyeman, V.K., Ayarkwa, J., Owusu, F.W., Boachie-Dapaah, A.S.K., Adade-Mensah, A., Appiah, S.K., Oteng-Amoako, A., Asamoah-Adam, A.R. & Pattie, D. 2003. Technological and Investment Profiles of Some Lesser Used Timber Species in Ghana. ITTO/FORIG/FC. Ghana.

Alder, D. 1990. GHAFOSIM. A prediction system for natural forest growth and yield in Ghana. Final report for Ministry of Lands and Natural Resources, Department of Forestry, (Under assignment from ODA, UK). 114 pp.

Anon. 1962. Forestry Department Annual Report 1962. Accra, Ghana

Anon. 1970. Forestry Department Annual Report 1970. Accra, Ghana.

Anon. 1972. Forestry Department Annual Report 1972. Accra, Ghana.

Anon. 1995. Timber yields from the forest reserves of Ghana. An analysis of the implications of sustainable forest management. Forestry Department (Planning Branch). Kumasi, Ghana. Conducted by the Ghana Forestry Commission, Accra, Ghana. (unpublished).

Asabre, P. K. 1987. Attempts at sustained yield management in the tropical high forests of Ghana. In: Mergen, F. & Vincent, J. R. (eds), Matural management of tropical moist forests. Silviculture and management prospects of sustained utilization. Yale University, New Haven, USA. 48-70.

Asamoah-Adam, K., Pinard, M.A. & Swaine, M.D. 2006. Nine decades of regulating timber harvest from forest reserves and the status of residual forests in Ghana. International Forestry Review 8, 280-296.

Baidoe, J.K. 1970. The selection system as practiced in Ghana. Commonwealth Forestry Review 49, 159–165.

Birikorang, G. 2001. Ghana Wood Industry and Log Export Ban Study Report 2001. Forestry Commission Final Report. 55 pp.

Birikorang, G. & Rhein, M. 2005. Reforming Ghana's forest fiscal regime. Phase 1 report submitted to the Forest Sector Development Project, Forestry Commission, Accra, Ghana.

Boakye-Dapaah, A.S.K. 1990. Overviews of interim yield regulation measures. Paper presented at Forestry Department/ Timber Contractors Workshop. Kumasi, Ghana. 13-14 November 1990.

Brasnett, N.V. 1953. Planned management of forests. Allen and Unwin. London, UK.

Dawkins, H. C. & Philip, M. S. 1998. Tropical moist forest silviculture and management: A history of success and failure. CAB International, Oxford, UK. 359 pp.

Ghartey, K. K. F. 1992. Felling limit and production of under-sized logs. Paper presented at special meeting of Forestry Department working committee on felling diameter limits. Forestry Department, Kumasi, Ghana (unpublished).

Hall, J. B. & Swaine, M. D. 1981. Distribution and ecology of vascular plants in a tropical rain forest. Forest vegetation in Ghana. W. Junk, The Hague, The Netherlands. 383 pp.

Hansen, C.P. & Treue, T. 2008. Assessing illegal logging in Ghana. International Forestry Review 10, 573-590.

Hawthorne, W.D. 1993. FROGGIE; Forest Reserves of Ghana Graphical Information Exhibitor. Part 2 (First Draft). Forest inventory and management project, Forestry Department, Planning Branch, Kumasi, Ghana. Unpublished.

Hawthorne, W.D. & Abu Juam, M. 1995. Forestry Protection in Ghana. Forest Conservation Series No. 14, IUCN, Gland, Switzerland.

Kotey, E.N.A., Francois, J., Owusu, J.G.K., Yeboah, R., Amanor, K.S. & Antwi, L. 1998. Falling into place. Policy that works for forests and people series No. 4, International Institute for Environment and Development, London, UK.

Marfo, E. 2010. Chainsaw Milling in Ghana: Context, drivers and impacts. Tropenbos International, Wageningen, the Netherlands. 64 pp.

Mayers, J., Howard, C., Kotey, E.N.A., Prah, E. & Richards, M. 1996. Incentives for sustainable forest management: a study in Ghana. IIED Forestry and Land Use Series no. 6. International Institute for Environment and Development, London, UK.

Mooney, J.W.C. 1963. Silviculture in Ghana. Commonwealth Forestry Review 42: 159-163.

Nolan, T.M. & Ghartey, K.K.F. 1992. Management of the tropical high forest of Ghana. Planning Branch, Forestry Department, Kumasi, Ghana.

Ofosu-Asiedu, A., Oteng-Amaoko, A., Foli, E.G., Agyeman, V.K. & Adam, A.R. 1997. Felling Diameter Limit Study. Final report on study commissioned by Ministry of Lands and Forestry, and Forestry Department Ghana. FORIG, Kumasi, Ghana.

Osafo, E. D. 1970. The development of silvicultural techniques applied to natural forests in Ghana. FPRI Technical Note 13. Forest Products Research Institute, Kumasi, Ghana. 16 pp.

Osmaston, F.C. 1968. The Management of forests. Allen and Unwin, London, UK. 384 pp.

Parren, M. P. E. & de Graaf, N. R. 1995. The Quest for Natural Forest Management in Ghana, Côte d'Ivoire and Liberia. Tropenbos Series 13, Wageningen, The Netherlands. 199 pp.

Prah, E.A. 1994. Sustainable management of the tropical high forest of Ghana. Commonwealth Secretariat, London, UK.

Taylor, C.J. 1960. Synecology and silviculture in Ghana. Thomas Nelson and Sons, Edinburgh, UK. 418 pp.

Treue, T. 2001. Politics and economics of tropical high forest management. A case study of Ghana. Forestry Science, volume 68. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Vanclay, J.K. 1993. Report on the forest inventory and management project in Ghana. Prepared for ODA (UK).

Part III

Conclusions and recommendations

15   Prospects for the CELOS Management System

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The central question of this publication is: can the CELOS Management System (CMS) contribute to an improved management of tropical rainforests? Obviously, this book would not have been published if the answer to this question had been NO. But the answer is not a simple YES either.

The CMS was formulated in the 1980s, after many years of research in Suriname (see Chapter 2). It included a Reduced Impact Logging (RIL) method and silvicultural interventions (see Chapter 3), which are referred to as the CELOS Harvesting System (CHS) and the CELOS Silvicultural System (CSS). The CMS should result in a yield of approximately 20 m³.ha⁻¹ once every 25 years. The research findings obtained show that the growth of commercial timber species after logging and the best performing CSS treatment is such that this sustained yield should indeed be possible (see Chapter 4). The CSS treatment consists of killing large lianas and all non-commercial trees larger than 20 cm dbh. In most cases, one silvicultural intervention will be sufficient, although three were originally foreseen. In Suriname, forest management without silvicultural treatment will seldom result in such a sustained yield, but this does not necessarily apply to other countries (see e.g. Section 9.3.3).

Considerable efforts were made to investigate the environmental and ecological impact of the CMS. It is obvious that CMS interventions are intended to change the tree species composition, but the studies conducted did not show unacceptable effects on the plant biodiversity, fauna, and biomass and nutrients (see Chapters 4, 5, 6 and 7). This does not imply, however, that undesirable ecological side-effects are negligible and that there is no need for additional corrective measures (see Section 15.1).

Since the 1980s, technical innovations and new concepts of sustainability have emerged, which were not incorporated in the CMS. Furthermore, the risk of overexploitation has increased as the timber market accepts more species and trees of smaller dimensions

than in the 1980s. Hence, the CMS techniques need to be updated and the CMS concept needs an upgrade. This in itself is an example of how forest management continuously needs to adapt to changing conditions to ensure sustainability of use.

Sustainable forest management requires an enabling legal environment. Existing legislation in many tropical countries seldom makes sustainable forest management attractive, as is illustrated clearly in the cases presented (e.g. Ghana and Costa Rica, Chapters 12 and 14). For instance, logging companies often are made responsible for the management of their concessions, while a major part of the return on investments becomes available during the second logging cycle, that is, after their licences have expired. As these companies do not profit from the long-term benefits of sustainable forest management, they will be inclined to minimize all forest management expenditures which are not profitable in the short term. This is an important constraint for the introduction of sustainable forest management in general, and of the CMS in particular, and requires more attention than it has been given so far.

15.1   Suggestions for technical modifications

The CHS has served as a basis for RIL methods developed in countries such as Brazil, Bolivia, Costa Rica, Guyana and Cameroon (see Chapters 9, 10, 11, 12 and 13). The experiences obtained in these countries can be used to further develop the CHS. Simply copying a complete RIL method from elsewhere is not a good strategy, however, as terrain conditions and forest composition determine the optimal method to a large extent. An important innovation is the introduction of Geographical Information System (GIS) as a mapping tool. This makes mapping easier, less costly and more accurate. Furthermore, it is recommended to carry out liana cutting during the pre-felling inventory rather than after logging, thus incorporating it in the CHS. This modification is likely to reduce logging damage and to facilitate directional felling.

In many countries, including Brazil, Belize and Guyana, RIL has been expanded with additional measures for environmental protection and sustained yield, cast into so-called Codes of Practice for Timber Harvesting. These codes evolved out of the 1996 FAO Model Code of Forest Harvesting Practice (Dykstra & Heinrich 1996). Suriname is currently developing such a Code of Practice based on the Guyana Code of Practice and current harvesting regulations, such as the concession conditions and guidelines for exploitation plans.

The draft Code of Practice for Suriname includes measures to protect rare timber species and vulnerable sites, such as steep slopes and riparian fringes, and presents detailed requirements with regard to pre-harvest forest inventory; planning and construction of roads, bridges, culverts, roadside landings and skid trails; directional felling; controlled winching and skidding; administrative/registration requirements; post-harvest requirements; operational hygiene and occupational health and safety.

The CSS uses a list of species to be cut in the second harvest, which is foreseen after 25 years. For Suriname, the present CELOS list of commercial tree species (CELOS 2002; see also Annex 1), which is based solely on timber characteristics, provides a good basis for

updating the list used previously in the CELOS silvicultural experiments. However, timber quality is not the only criterion to be used for such a silvicultural list: the size which a species can attain and its growth rate are other characteristics to be considered (see Annex 1). Furthermore, adding species to the list does not necessarily result in more profitable future yields. More species on the list means that more trees are retained and that there is more competition in silviculturally treated stands. This results in slower growth rates of the established commercial species. In other words, the implication of adding species with an uncertain commercial potential to the list is a decrease in production of more valuable timber species. The optimal list may vary from forest to forest and it is therefore recommendable to work with a flexible list, which includes currently preferred species and a selection of potentially commercial species where appropriate. The decision to expand or reduce such a list should be based on yield prediction (see Section 15.2).

Refinement techniques should be improved as more information on specious behaviour becomes available, for instance through field trials. In Brazil, Precious Woods has employed a modified CSS, where elimination of unwanted trees is restricted to the immediate vicinity of commercial trees. This has advantages: it may lead to a reduction in costs and it better preserves those parts of the forest where commercial timber species are rare or absent. However, trees also endure considerable competition from other trees that are not their immediate neighbours, and this will negatively affect the growth response of the commercial trees (see Chapters 4 and 5). Another modification is the use of an adapted chainsaw to double ring-bark trees to be killed (see Photo 10.5). This technique has less impact on the environment than poison-girdling, but it may be less effective in eliminating unwanted trees. It may also be less cost-efficient. As the effects of these modifications have not yet been analyzed, it is too early to advocate or discourage their application.

Any forest management plan should include an approach to deal with undesirable ecological effects. Ecological monitoring and measures to prevent poaching and illegal felling should be part of this approach. As part of biodiversity conservation targets it may be desirable to leave representative parts of the forest completely and permanently untouched to preserve flora and fauna, as recommended by many authors (e.g. Van Bodegom & De Graaf 1991) and required by certification schemes. One may also consider to adjust the sequence in which forest compartments are logged and treated silviculturally in such a way that each compartment where forestry operations are in progress is adjacent to compartments which have been and will be left untouched for a prolonged period of time. Thus, management compartments may be arranged in a chessboard-like pattern, where the "black compartments" are logged and treated during the first half of the cutting cycle and the "white compartments" in the years thereafter. The "white compartments" will then serve as temporary buffer zones for the "black compartments" and vice versa. Furthermore, it is obvious that vulnerable sites, where logging is not allowed according to the Code of Practice for Harvesting Operations, are left untouched during silvicultural interventions.

15.2   Suggestions for upgrading forest management

After the CMS was formulated in the 1980s, forest management, deforestation and forest degradation gradually became significant topics on the international political agenda as a result of a growing concern about issues such as dwindling timber resources, biodiversity loss, climate change and the livelihoods of forest dwelling people. This led to a range of initiatives aimed at stimulating sustainable forest management. One of the first was the development of criteria and indicators for the certification of forest management. The extent to which the CMS meets these standards is discussed in Chapter 8. It is obvious that many modules of current certification schemes are not covered by the CMS: the CMS is a set of methods to grow and harvest timber on a sustainable basis rather than a complete management system for a forestry enterprise. Nevertheless, the CMS provides methods for harvesting and stand treatment that lie at the heart of sustainable forest management. The system will need to be upgraded when certification standards are to be met (see Chapter 8 for details). The example of Precious Woods, where the CHS and the CSS are incorporated in a certified management system, shows that this is feasible (see Chapter 10).

More recent international initiatives related to forest certification and sustainable forest management are the European Union's FLEGT (Forest Law Enforcement, Governance and Trade) Action Plan, the United Nations' REDD (Reducing Emissions from Deforestation and forest Degradation) Programme and other REDD initiatives, and a number of financing schemes directed mainly at nature conservation or forest management by local communities. The FLEGT Action Plan[1] intends to increase the capacity of developing and emerging market countries to control illegal logging, while reducing trade in illegal timber products between these countries and the European Union. Sustainably managed forest operations have more costs than illegal producers, who pay less fees and taxes and do not invest in forest management. As illegal logging is widespread, this competitive disadvantage is a major constraint for the implementation of sustainable forest management. Therefore, FLEGT promotes sustainable forest management in an indirect way by curbing the activities of illegal logging operators and by impeding their access to the European market.

The REDD Programme[2] is part of the global effort to reduce climate change. Its objective is to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. The upgraded version of REDD, "REDD+", goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (see Global Canopy Foundation 2008). At the time of writing, the programme is still under development. It is predicted that financial flows for reductions in greenhouse gas emission from REDD+ could reach up to US$ 30 billion a year.

Although the estimated REDD financial flow may be somewhat optimistic, as it was calculated before the 2008 financial crisis, and although this sum has to be shared by a vast number of beneficiaries, it may contribute substantially to the future financial benefits of sustainable forest management, in spite of additional costs involved. Guyana, for instance, may receive up to US$ 250 million until 2015 from Norway to finance its national REDD+ programme[3].

Of course, carbon stocks and their fluctuation in time have to be quantified in order to qualify for participation in this scheme. As this is tightly linked to tree biomass, tree growth models are helpful to achieve this. The estimates for living and dead biomass given in Chapter 6 and the growth and mortality data in Chapter 4 provide an input for such assessments in Suriname. In other regions, local data should be used for carbon assessments.

Growth models are not only needed for assessing carbon sequestration, but also for the regulation of timber yields. When the CMS was formulated there was no need for yield regulation other than specifying minimum diameter limits for trees to be felled, as harvest intensities were low. The risk of overexploitation has increased since, not only because more species and smaller logs are accepted by the timber market, but also because more and more concessions are issued for forests which have been logged at least once before and have not fully recovered from previous exploitation. Various yield regulation models have been developed in the last decades, among others in Cameroon (see Chapter 13) and in various South American countries (e.g. Van Gardingen et al. 2006; Gourlet-Fleury et al. 2005; Alder 2002; Alder et al. 2002; Phillips et al. 2002), but recommended maximum harvest levels (expressed as Annual Allowable Cut) are not always enforced. Such yield regulation models should be implemented to define sustainable harvest levels and can at the same time be expanded to estimate carbon storage and carbon sequestration associated with these harvest levels. The Brazilian model, for instance, estimates volume growth of both commercial and non-commercial species. Such estimates can be converted into biomass growth estimates, and subsequently to the amount of carbon sequestration in living trees. Such an adapted model has been used to estimate the impact of RIL on carbon sequestration in Malaysia (see Putz et al. 2008).

15.3   A future for the CELOS Management System

In 1996, Schmidt & Hendrison stated: "The CELOS Management System (CMS) has special features which make it suitable for the sustainable management of tropical rain forests. Being one of the few management systems based on relatively long-term research and tested in semi-practical operations, it deals with ecological, silvicultural and operational aspects. The system is sufficiently developed to control commercial logging operations, to reduce logging damage, and to lead to regeneration of the remaining forest, thus fitting in with current perceptions of natural resource management and sustainable development. It offers promising prospects for Suriname and other tropical countries, where lowland rain forests are subjected to exploitation [...]. Apparently, the first stage of the development of the CELOS forest management system can be considered

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1   http://www.euflegt.efi.int
2   http://www.un-redd.org

3   http://www.regjeringen.no/en/dep/md/Selected-topics/climate/the-government-of-norways-international-/guyana-norwaypartnership

successfully accomplished. The introduction of the CMS on a larger scale should be promoted by establishing a Model Forest Management Unit." It seems appropriate to conclude that this statement is still valid.

So, the question "can the CELOS Management System contribute to an improved management of tropical rain forests?" can be answered with YES, but the system needs to be adjusted and expanded and is not necessarily applicable in all rainforests. Some suggestions for improvements are given above, but it is left to the users of this book to further develop the system and to adapt it to local conditions, new insights and opportunities and the requirements of future generations.

References

Alder, D. 2002. Simple diameter class and cohort modelling methods for practical forest management. In: ITTO, Proceedings of the Malaysia-ITTO International workshop on growth and yield of managed tropical forests, 25-29 June 2002, Kuala Lumpur, Malaysia.

Alder, D., Oavika, F., Sanchez, M., Silva, J. N. M., Van der Hout, P. & Wright, H. L. 2002. A comparison of species growth rates from four moist tropical forest regions using increment-size ordination. International Forestry Review 4, 196-205.

CELOS 2002. CELOS-list of commercial tree species 2000. CELOS, Paramaribo, Suriname.

Dykstra, D.P. & Heinrich, R. 1996. FAO model code of forest harvesting practice. FAO, Rome, Italy.

Global Canopy Foundation 2008. The Little REDD Book: a guide to governmental and non-governmental proposals for reducing emissions from deforestation and degradation. http://www.amazonconservation.org/pdf/redd_the_little_redd_book_dec_08.pdf.

Gourlet-Fleury, S., Cornu, G., Jésel, S., Dessard, H., Jourget, J.-G., Blanc, L. & Picard, N. 2005. Using models to predict recovery and assess tree species vulnerability in logged tropical forests: a case study from French Guiana. Forest Ecology and Management 209, 69–86.

Phillips, P.D., Van der Hout, P., Arets, E.J.M.M., Zagt, R.J. & Van Gardingen, P.R. 2002. Modelling the natural forest processes using data from the Tropenbos plots at Pibiri, Guyana. SYMFOR Technical Note Series No. 9. Edinburgh, The University of Edinburgh, United Kingdom. 25 pp.

Putz, F.E., Zuidema, P.A., Pinard, M.A., Boot, R.G.A., Sayer, J.A. et al. 2008. Improved tropical forest management for carbon retention. PLoS Biol 6, 1368-1369.

Schmidt, P. & Hendrison, J. 1996. Future prospects for the application of the CELOS Management System. Pp. 63-64 in: Schmidt, P. & Schotveld, A., Sustainable management of the Guyana rain forest. Proceedings of the seminar Management systems for natural forests in the tropics. 23rd February 1996, Wageningen, The Netherlands. Hinkeloord report 18, Wageningen University, Wageningen, The Netherlands and Coproduction nr. C-8, National Reference Centre for Nature Management, Wageningen, The Netherlands.

Van Bodegom, A.J. & De Graaf, N.R. 1991. The CELOS Management System: a Provisional Manual. Informatie en Kenniscentrum (IKC), Vakgroep Bosbouw, Landbouwuniversiteit Wageningen en Stichting voor Nederlandse Bosbouw Ontwikkelings Samenwerking, Wageningen, The Netherlands, 43 pp.

Van Gardingen, P., Valle, D. & Thompson, I. 2006. Evaluation of yield regulation options for primary forest in Tapajos National Forest, Brazil. Forest Ecology and Management 231, 184-195.

The work is done, now some rest! (Photo P. Schmidt)

Annex 1. Selection of timber species for current and future harvests

The CELOS Management System uses three lists of species, which are to be logged in ongoing and future harvest operations. A list of all currently marketable species is used in the pre-felling inventory of harvestable trees. The logging company uses this inventory among others for marketing purposes, but often only part of the species inventoried can be exploited profitably. This depends, among others, on the prices on the timber market, the location of the forest (transport costs) and terrain conditions (costs of harvesting). Hence, a timber company will generally use a species list in its felling operation, which is shorter than the inventory list, and this list may vary from forest to forest and from year to year.

A third list is used in silvicultural operations. This list includes the species which are likely to contribute to the second harvest, which is foreseen after 25 years. Historical evidence has shown that it is possible to make a reasonable prediction of the future market potential of tree species, based on studies of timber characteristics: the list, used in the CELOS experiments of the 1970s included almost all species which were marketable in 2000. The few timbers which had entered the market since the 1970s and which were not on this list mostly were either rare species, which had not been adequately investigated, or species, which had been rejected because they seldom grow to timber size (see also Section 4.5).

The present CELOS list of commercial tree species (CELOS 2002) includes all timber species which are either currently on the market or have the potential to enter the market in the foreseeable future. This list, which is based solely on timber characteristics, provides a good basis for lists to be used in silvicultural operations. However, timber quality is not the sole criterion to be used for such a silvicultural list: the size which a species can attain and its growth rate are other factors to be considered. For example, a species such as *Lecythis corrugata* should not appear on such a list, although it has an attractive straight stem and produces timber of acceptable quality. This is because too few trees of this common species grow to timber size and because the species responds poorly to silvicultural treatment (see Section 4.5). Another example of a marketable species that should not be on the list is *Eperua falcata* (wallaba). This tree is mainly found in so-called savanna forest, where it can be quite common, and in marshy areas. The CSS is not meant for savanna and marsh forests however, and in mesophytic rain forest, wallaba trees remain too small and are too rare to anticipate future commercial exploitation.

An example of a species, which did not qualify for inclusion in the CELOS list of commercial species, but which may nevertheless be considered locally for the list used in silvicultural operations, is *Sclerolobium albiflorum*. This species has a limited commercial potential (see Comvalius 2001), but its exceptionally fast growth (Section 5.4) may justify such a decision, especially in forests where the species is common and where more valuable timber species are poorly represented.

Species number	Species code	*Scientific name*	Vernacular name	Category1
1	11560101	*Fagara pentandra*	Pritijari	Commercial A
2	11680204	*Qualea rosea*	Bergi gronfolo	Commercial A
3	11353101	*Peltogyne venosa*	Purperhart	Commercial A
4	11353201	*Platymiscium ulei*	Koenatepi	Commercial A
5	11400102	*Carapa guianensis; C. procera*	Krapa	Commercial A
6	11400201	*Cedrela odorata*	Ceder	Commercial A
7	11420201	*Brosimum paraënse*	Satijnhout	Commercial A
8	11420203	*Brosimum guianense*	Letterhout	Commercial A
9	11351801	*Diplotropis purpurea*	Zwarte kabbes	Commercial A
10	11430203	*Virola surinamensis*	Laagland baboen	Commercial A
11	11351601	*Dicorynia guianensis*	Basralokus	Commercial A
12	11580301	*Manilkara bidentata*	Bolletri	Commercial A
13	11580401	*Micropholis guyanensis var. guyanensis*	Wit riemhout	Commercial A
14	11580402	*Micropholis guyanensis var. commixta*	Zwart riemhout	Commercial A
15	11590401	*Simarouba amara*	Soemaroeba	Commercial A
16	11600101	*Sterculia pruriens*	Okro oedoe	Commercial A
17	11680201	*Ruizterania albiflora*	Hoogland gronfolo	Commercial A
18	11680202	*Qualea coerulea*	Laagland gronfolo	Commercial A
19	11430201	*Virola michelli*	Hoogland baboen	Commercial A
20	11170101	*Goupia glabra*	Kopi	Commercial A
21	11020201	*Loxopterygium sagotii*	Slangenhout	Commercial A
22	11030301	*Xylopia aromatica*	Pegrekoe pisi	Commercial A
23	11080101	*Jacaranda copaia*	Goebaja	Commercial A
24	11080204	*Tabebuia serratifolia*	Groenhart	Commercial A
25	11120206	*Protium decandrum*	Grootbladige tingimoni	Commercial A
26	11120207	*Protium tenuifolium*	Harde bast tingimoni	Commercial A
27	11120301	*Tetragastris altissima*	Rode sali	Commercial A
28	11351901	*Dipterix odorata; D. punctata*	Tonka	Commercial A
29	11120401	*Trattinickia burserifolia; T. rhoifolia*	Ajawatingimoni	Commercial A
30	11330503	*Ocotea glomerata*	Harde zwarte pisi	Commercial A
31	11270401	*Platonia insignis; Rheedia benthamiana*	Geelhart; Pakoeli	Commercial A
32	11290101	*Humiria balsamifera*	Blakaberi; Meri	Commercial A
33	11330302	*Licaria canella; L. cayennensis*	Kaneelhart	Commercial A

1   Categories: Commercial A: species on the Jonkers (1987) list of commercial species; Commercial B: other timber species currently on the market; Commercial P: potentially commercial species; Secondary species: pioneer species without commercial potential; Other: other non-commercial species.

Species number	Species code	Scientific name	Vernacular name	Category1
34	11330502	Ocotea globifera	Harde witte pisi; Wanapisi	Commercial A
35	11330506	Ocotea canaliculata; O. petalanthera	Witte pisi	Commercial A
36	11330509	Ocotea rubra	Wana	Commercial A
37	11350301	Parkia nitida	Agrobigi	Commercial A
38	11351001	Andira inermis; A. surinamensis	Rode kabbes	Commercial A
39	11120302	Tetragastris hostmannii	Tingimonisali	Commercial A
40	11680305	Vochysia tomentosa	Wanakwari	Commercial A
41	13060202	Schefflera morototoni	Kasaba oedoe	Commercial A
42	11680302	Vochysia guianensis	Wiswiskwari	Commercial A
43	11270601	Symphonia globulifera	Mataki	Commercial A
44	11330401	Nectandra grandis	Zachte zwarte pisi	Commercial A
45	03340201	Couratari guianensis	Ingipipa	Commercial B
46	04354101	Vataireopsis speciosa	Djongo kabisi	Commercial B
47	02352101	Eperua falcata	Walaba	Commercial B
48	04354001	Vatairea guianensis	Gele kabbes	Commercial B
49	02340403	Lecythis corrugata	Hoogland oemanbarklak	Commercial B
50	02120208	Protium polybotryum	Rode bast tingimoni	Commercial B
51	00350201	Inga alba	Prokoni	Commercial B
52	05420101	Bagassa guianensis	Kaw oedoe	Commercial P
53	04190303	Terminalia dichotoma	Bosamandel	Commercial P
54	04190301	Terminalia amazonia	Kalebashout	Commercial P
55	04080202	Tabebuia capitata	Makagrin	Commercial P
56	05353402	Pterocarpus rohrii	Hoogland bebe	Commercial P
57	05370101	Antonia ovata	Lika oedoe	Commercial P
58	04020401	Tapirira guianensis	Weti oedoe	Commercial P
59	04020103	Anacardium spruceanum	Boskasjoe	Commercial P
60	03580504	Pouteria guianensis	Jamboka	Commercial P
61	04020402	Tapirira guianensis var. elliptica	Hoogland weti oedoe	Commercial P
62	00540313	Licania obidensis	Kleine kwepi	Commercial P
63	04353001	Ormosia coccinea	Hoogland kokriki	Commercial P
64	04352401	Hymenolobium flavum	Maka kabbes	Commercial P
65	00353505	Sclerolobium paniculatum	Witte djedoe	Commercial P
66	00353502	Sclerolobium guianense	Savanne djedoe	Commercial P
67	00352801	Martiusia parviflorum	Bosmahonie	Commercial P
68	04430103	Iryanthera sagotiana	Broedoe oedoe	Commercial P
69	00160101	Caryocar glabrum	Gladde sopo oedoe	Commercial P

Species number	Species code	Scientific name	Vernacular name	Category1
70	00540304	Licania heteromorpha	Zwampanaura	Commercial P
71	00580103	Chrysophyllum pomiferum	Djoe bolletri	Commercial P
72	04290201	Sacoglottis guianensis	Bofroe oedoe	Commercial P
73	04260301	Laetia procera	Pintokopi	Commercial P
74	04580506	Pouteria ptychandra	Kimboto	Commercial P
75	04580507	Pouteria cuspidata	Pintobolletri	Commercial P
76	03540401	Parinari campestris	Rode foengoe	Commercial P
77	00160102	Caryocar microcarpum	Ruwe sopo oedoe	Commercial P
78	04350302	Parkia pendula	Kwatakama	Commercial P
79	01350602	Pithecellobium corymbosum	Bostamarinde	Commercial P
80	02540101	Couepia caryophylloides	Anaura	Commercial P
81	02120202	Protium arachouchini a.o.	Tingimoni	Commercial P
82	02353501	Sclerolobium albiflorum	Rode djedoe	Commercial P
83	02340405	Eschweilera odora	Hoogland manbarklak	Commercial P
84	03190101	Buchenavia capitata	Gemberhout	Commercial P
85	04640201	Lueheopsis flavescens; L. rugosa	Katoen oedoe	Commercial P
86	01350604	Abarema jupunda	Sopo oedoe, fijnbladig	Commercial P
87	03250701	Drypetes variabilis	Weti foengoe	Commercial P
88	01330504	Ocotea oblonga	Zilverpisi	Commercial P
89	02353504	Sclerolobium micropetalum	Zwarte djedoe	Commercial P
90	03350101	Balizia pedicellaris	Tamaren prokoni	Commercial P
91	03350501	Piptadenia suaveolens	Pikinmisiki	Commercial P
92	03350606	Pithecellobium pedicellaris	Tamaren prokoni	Commercial P
93	03540302	Licania majuscula	Foengoe	Commercial P
94	01040201	Aspidosperma cruentum	Kromanti kopi	Commercial P
95	00450601	Myrcia sylvatica	Savannegujave	Other
96	02353503	Sclerolobium melinonii	Djadidja	Other
97	00550301	Chimarrhis turbinata	Sinja oedoe	Other
98	00550401	Coussarea paniculata	Boskoffie	Other
99	02353603	Swartzia benthamiana	Bergi bebe	Other
100	00540704	Hirtella racemosa	Behaarde kwepi	Other
101	00540601	Excellodendron barbatum	Rode kwepi	Other
102	03040401	Couma guianensis	Pera	Other
103	00450602	Myrcia section armeriela	Kronmoko	Other
104	00580102	Chrysophyllum cainito	Sterappel	Other
105	03250401	Chaetocarpus schomburgkianus	Fomang	Other

Species number	Species code	Scientific name	Vernacular name	Category1
106	00421001	Trynatococcus amazonicus	Olie oedoe	Other
107	03310301	Poraqueiba guianensis	Witte bast jakanta	Other
108	00400403	Trichilia propingue	Melisali	Other
109	03040801	Macoubea guianensis	Sokosoko mapa	Other
110	00670201	Rinorea spp.	Lele tiki	Other
111	01030302	Xylopia longifolia	Hoogland pegrekoe	Other
112	01270503	Rheedia macrophylla	Hoogland pakoeli	Other
113	03540306	Licania incana	Sabana foengoe	Other
114	03540309	Licania micrantha	Zwarte foengoe	Other
115	03540312	Licania stricta	Kleinbladige zwarte foengoe	Other
116	01330101	Aniba hostmanniana	Waikara pisi	Other
117	01330303	Licaria guianensis	Kaneel pisi	Other
118	01330510	Ocotea schomburgkiana	Savanne pisi	Other
119	01350607	Pithecellobium racemosum	Fijnbladige rode kabbes	Other
120	00570502	Talisia pedicullaris	Bosknippa	Other
121	00670202	Rinorea passoura	Manari tiki	Other
122	02340408	Eschweilera subglandulosa	Manbarklak	Other
123	01430202	Virola sebifera	Pintri baboen	Other
124	00670102	Paypayrola guianensis	Taja oedoe	Secondary sp.
125	00670101	Paypayrola confectiflora	Asisi oedoe	Other
126	00581001	Achrouteria pomifera	Laurierkers	Other
127	02120204	Protium heptaphyllum	Kleinbladige tingimoni	Secondary sp.
128	00580201	Ecclinusa cuneifolium	Kwatta bobbi	Other
129	02340404	Eschweilera longipes	Berg manbarklak	Other
130	00570503	Talisia spec.	Jan Krappa	Other
131	03540402	Parinari excelsa	Kleinbladige rode foengoe	Other
132	01420601	Perebea laurifolia	Manletterhout	Other
133	00730101	Piper aduncum	Mananesiwiwiri	Secondary sp.
134	00110102	Cordia nodosa	Knooptafelboom	Secondary sp.
135	4380201	unknown species2	Unknown	Other
136	330601	unknown species2	Unknown	Other
137	05220101	Diospyros guianensis	Blaka oema	Other
138	00040202	Aspidosperma exelsum	Zwart parelhout	Secondary sp.
139	00041001	Bonafousia undulata	Merki tiki	Other
140	04110101	Cordia alliodora	Tafelboom	Other

Species number	Species code	Scientific name	Vernacular name	Category1
141	460601	unknown species2	Unknown	Other
142	02340401	Eschweilera amara	Bergoemanbarklak	Other
143	50610810	Solanum americanum	Ajoenawiwiri	Other
144	00690101	Duratea castaneifolia	Hei oedoe	Other
145	00480301	Heisteria cauliflora	Bosdruif	Other
146	00340409	Eschweilera labriculata	Dwergoemanbarklak	Other
147	00270801	Vismia angusta	Manpinja	Other
148	00250201	Alchorneopsis trimera	Manbebe	Secondary sp.
149	99999999	unknown species	Unknown	Other
150	06040203	Aspidosperma marcgravianum	Wit parelhout	Other
151	02120101	Hemicrepidospermum rhoifolium	Getande tingimoni	Other
152	00220102	Diospyros cauliflora	Awariston	Other
153	70551202	Psychotria cuspidata	Witte bofroekasaba	Other
154	60410101	Abuta grandifolia	Kapoeasiri	Other
155	00030401	Anaxogorea mutica	Jari jari	Other
156	00680301	Vochysia densiflora	Appelkwari	Other
157	00630101	Siparuna guianensis	Jarakopi	Secondary sp.
158	00550801	Isertia coccinea	Kandra oedoe	Other
159	00450702	Calycorectes bergii	Bosgujave	Other
160	4380301	unknown species10	Unknown	Other
161	00450301	Calypthrantes speciosa	Labawala	Other
162	05500101	Coccoloba latifolia	Bradilifi	Other
163	99999998	unknown species	Unknown	Other
164	99999997	unknown species	Unknown	Other
165	99999996	unknown species	Unknown	Other
166	99999995	unknown species	Unknown	Other
167	99999994	unknown species	Unknown	Other
168	70610101	Brunfelsia guianensis	Manbitawiwiri	Other
169	540702	unknown species2	Unknown	Other
170	00450501	Marlierea montana	Kwakoe	Other
171	00270802	Vismia cayennensis	Pinja	Secondary sp.
172	05550201	Capirona surinamensis	Dede oedoe	Other
173	00200101	Tapura guianensis	Pakira tiki	Other
174	00200102	Tapura capitulifera	Bergi pakira tiki	Other
175	00230103	Sloanea trichosticha	Ravenjang	Other
176	00250501	Conceveiba guianensis	Hoogland panta	Other

Species number	Species code	Scientific name	Vernacular name	Category1
177	00251801	Mabea piriri	Koto tiki	Other
178	00110107	Cordia laevifrons	Hoogland tafelboom	Other
179	00270201	Caraipa densiflora	Laksiri	Other
180	01020202	Loxopterygium spec.	Hoogland slangenhout	Other
181	00310101	Dendrobangia boliviana	Rode bast jakanta	Other
182	00330507	Ocotea puberula	Papaja pisi	Other
183	00330508	Ocotea spec.	Kras pisi	Other
184	00351703	Dimorphandra pullei	Pesi oedoe	Other
185	70730199	Piper spec.	Anesiwiwiri	Secondary sp.
186	00353601	Swartzia arborescens	Alanja oedoe	Other
187	00330403	Nectandra pisi	Zwarte pisi	Other
188	00251905	Pogonophera schomburgkiana	Geri oedoe	Other
189	05340502	Gustavia hexapetala	Konkoni oedoe, hoogland	Other
190	00355101	Martiodendron parviflorum	Witte pintolocus	Other
191	05460102	Guapira spec.	Prasara oedoe	Other
192	05460101	Guapira olfersiana	Njamsi oedoe	Other
193	05430101	Iryanthera hostmannii	Sre bebe	Other
194	05400401	Trichilia roraimana	Sorosali	Other
195	05380102	Byrsonima spicata	Lonto kasi	Secondary sp.
196	05353801	Tachigalia paniculata	Djedoe	Other
197	05550101	Amajoua guianensis	Marmeldoos	Other
198	05340501	Gustavia augusta	Konkoni oedoe, laagland	Other
199	00330104	Aniba taubertiana	Pisi	Other
200	05260102	Casearea javitensis	Oema oedoe	Other
201	05260101	Casearea arborea	Redi oedoe	Other
202	05230102	Sloanea grandiflora	Boskoeswe, kleinbladig	Other
203	05230101	Sloanea eichleri	Rafroe njanjan	Other
204	05150201	Jacaratia spinosa	Awara oedoe	Other
205	00090101	Bixa orellana	Boskoeswe	Other
206	05360101	Hebepetalum humeriifolium	Pakira oedoe	Other
207	00550901	Palicourea guianensis	Panga panga	Secondary sp.
208	00390301	Bellucia grossularioides	Gewone mispel	Other
209	00390101	Miconia spec.	Mispel	Secondary sp.
210	04580501	Pouteria cladantha	Zwarte jamboka	Other
211	04390201	Mouriri acutiflora	Spikri oedoe	Secondary sp.
212	04420302	Cecropia sciadophylla	Manbospapaja	Secondary sp.

Species number	Species code	Scientific name	Vernacular name	Category1
213	04420304	Cecropia peltata	Boroma	Secondary sp.
214	04420801	Pourouma spp.	Granbospapaja	Secondary sp.
215	04450401	Eugenia coffeifolia	Boskers	Other
216	04480101	Chaunochiton kappleri	Patakwama	Other
217	04480201	Minquartia guianensis	Alata oedoe	Other
218	04540301	Licania apetala	Kwepi	Other
219	04540310	Licania ovalifolia	Santi oedoe	Other
220	04540501	Prunus myrtifolia	Amandelhout	Other
221	04420202	Brosimum parinarioides	Doekali	Other
222	04580101	Chrysophyllum auratum	Bosappel	Other
223	04400301	Guarea guarea	Doifisiri	Other
224	04580503	Pouteria gonggrijpii	Apra oedoe	Other
225	04580512	Pouteria spec. 1	Witte jamboka	Other
226	04580514	Pouteria spec. 2	Zwarte pintobolletri	Other
227	04620101	Laplacea fructicosa	Swa oedoe	Other
228	04640101	Apeiba echinata	Kankan oedoe	Other
229	04650101	Ampelocera edentula	Kwaskwasi	Other
230	04680203	Qualea dinizii	Gujavekwari	Other
231	04400302	Guarea kunthiana	Zwarte doifisiri	Other
232	04640102	Apeiba tibourbou	Fokofoko oedoe	Other
233	04570501	Talisia megaphylla	Bosknippa	Other
234	04570201	Cupania hirsuta	Gawetri	Secondary sp.
235	04260302	Laetia spec.	Hoogland pinto kopi	Secondary sp.
236	04040101	Ambelania acida	Batbati	Other
237	04040501	Geissospermum sericeum	Bergibita	Other
238	04100102	Bombax crassum	Boskatoen	Other
239	04170201	Maytenus myrsinoides	Zoutmeti oedoe	Other
240	04220103	Diospyros spec.	Pikapika	Other
241	04250601	Croton matourensis	Tabakabron	Other
242	04250801	Hevea guianensis	Hevea	Other
243	04251001	Hyeronima laxiflora	Ajo ajo	Other
244	04251101	Maprounea guianensis	Pikin tiki	Secondary sp.
245	04251201	Pera bicolor	Pepre oedoe	Other
246	04420301	Cecropia obtusa	Bospapaja	Secondary sp.
247	04251602	Sapium klotzschgianum	Merki oedoe	Other
248	04030101	Annona montana	Boszuurzak	Secondary sp.

Species number	Species code	Scientific name	Vernacular name	Category1
249	04270701	Tovomita choisyana	Bosmangro	Other
250	04340402	Eschweilera chartacea	Rode bast tite oedoe	Other
251	04340406	Eschweilera poiteaui	Gele bast tite oedoe	Other
252	04340407	Lecythis simiorum	Witte bast tite oedoe	Other
253	04350202	Inga spp.	Swietbonki	Secondary sp.
254	04350901	Alexa wachenheimii	Neke oedoe	Other
255	04351201	Copaifera guianensis	Hoepelhout	Other
256	04352701	Macrolobium angustifolium	Watrabiri	Other
257	04353004	Ormosia paraensis	Kokikri	Other
258	04353607	Swartzia remigifer	Boegoeboegoe	Other
259	04251601	Sapium aubletianum	Gomhout	Other

References

CELOS 2002. CELOS-list of commercial tree species 2000. CELOS, Paramaribo, Suriname.

Comvalius, L.B. 2001. Surinamese timber species: characteristics and utilization. CELOS, Paramaribo, Suriname.

Annex 2.   Publications and reports resulting from the CELOS Managament System (CMS) programme

Anonymous. 2001. The impact of logging and CELOS silvicultural treatments on biodiversity: Observations of rainforest biodiversity in Suriname, Preliminary findings, September 2001. Report for WWF-GEFCP, National Zoological Collection (NZCS) and National Herbarium (BBS). University of Suriname, Paramaribo, Suriname.

Anonymous. 2006. Preparing the study on practical scale operations of CMS, Final project document. FSS/PHS, Parmaribo, Suriname.

Betlem, J.L. 1983. Overzicht van de permanente proefperken van het project LH/UvS 01. CELOS rapporten 137. CELOS, Paramaribo, Suriname.

Bhadran, C.A.R. 1965. The introduction of regular forest management. Report to the Government of Suriname, FAO, Rome, Italy.

Bodegom, A.J. van,. 1981a. Inversieniveaus en driehoekshypothese. Student report, Wageningen University, Wageningen, The Netherlands.

Bodegom, A.J. van,. 1981b. Natural regeneration and increment. Internal student report, CELOS, Paramaribo, Suriname.

Bodegom, A.J. van,. 1982. Gevolgen van selectieve exploitatie in het mesofytisch regenwoud te Sarwa, Suriname: de eerste 14 jaar. Student report, Wageningen University, Wageningen, The Netherlands.

Bodegom, A.J. van, & De Graaf, N.R. 1991. The CELOS Management System: A provisional manual. IKC-NBLF-LNV, Wageningen University and Foundation BOS. Wageningen, The Netherlands.

Bodegom, A.J. van, & De Graaf, N.R. 1994. Sistema CELOS de manejo: manual preliminar. Workdocument IKC 65. IKC-NBLF, Wageningen, The Netherlands.

Boer, K. 1982a. Beschrijving van 16 diepboringen van hydrologische proef 78/34. Internal report, CELOS, Paramaribo, Suriname.

Boer, K. 1982b. Landmeetkundige opname Z.O. kwadrant hydrologische proef 78/34. Internal report, CELOS, Paramaribo, Suriname.

Boerboom, J.H.A. 1965. De natuurlijke regeneratie van het Surinaamse mesofytische bos na uitkap = The natural regeneration of the mesophytic forest (tropical rain forest) of Surinam after exploitation = La regeneracion natural de la selva mesofytica tropical de Surinam despues de su aprove - chamineto. Wageningen University, Wageningen, The Netherlands.

Boerboom, T., Kruijt, B. & Muller, H.J. 1987. De invloed van veranderingen in bodemomstandigheden, zaadbeschikbaarheid en licht- en microklimaat op de vegetatieontwikkeling. Student report, Wageningen University, Wageningen, The Netherlands.

Boxman, O., De Graaf, N.R., Hendrison, J., Jonkers, W.B.J., Poels, R.L.H., Schmidt, P., Tjon & Lim Sang, R. 1985. Towards sustained timber production from tropical rain forests in Suriname. Neth. J. of Agric. Sc. 33, 125-132.

Boxman, O., De Graaf, N.R., Hendrison, J., Jonkers, W.B.J., Poels, R.L.H., Schmidt, P. & Tjon Lim Sang, R. 1987. Forest land use in Suriname. In: Beusekom, C.F. van, Goor, C.P. van, Schmidt, P. (Eds), Wise utilization of tropical rain forest lands. Tropenbos, Scientific Series 1, Wageningen, The Netherlands, 119-129.

Bruin, L.H.P. & Tjoe-Awie, E.C. 1980. De bodemgesteldheid van het proefcentrum Kabo (verslag van een detailbodemkartering). Report 69, Dienst Bodemkartering, Paramaribo, Suriname.

Busink, R.L. 1981. Stand structure and phytomass in unexploited forest at Kabo, (experiments 78/21 and 78/22), 1978/1979: interim report of the first results. Student report, Wageningen University, Wageningen, The Netherlands.

Carilho, S.T., 1983. Stage-rapport (CELOS). Internal student report, CELOS, Paramaribo, Suriname.

Carvalho, J.O.P. de, Silva, J.N.M., Lopes, J. do C.A., Costa, H. B. da, Valcarcel, V.J. & De Graaf, N.R. 1984. Estudio de la reduccion de densidad en un bosque tropical humedo denso debido a la exploracion mecanizada. Nota Technica, IICA Tropicos Informacion al dya, Alerta, Dasonomos. Nos 22 23, 7 - 12.

Catelan Febrero, R.L. 1984. Report of a study practice in Suriname. Internal student report, Wageningen University, Wageningen, The Netherlands.

CELOS, 1967 – 1983. CELOS kwartaalverslagen 1-67. CELOS, Paramaribo, Suriname.

CELOS, 1972 - 1976. Report for the year 1971, 1972, 1973, 1974 of the Centre for Agricultural Research in Suriname. Wageningen University, Wageningen, The Netherlands.

De Graaf, N.R. 1969. Aantekeningen praktijktijd Suriname, 1967-1968. Internal student report, Wageningen University, Wageningen, The Netherlands.

De Graaf, N.R. 1976. Growth and mortality of valuable timber species in worked out and successively naturally regenerated mesophytic forest in Surinam. Internal report, CELOS, Paramaribo, Suriname.

De Graaf, N.R. 1982. Sustained timber production in the tropical rainforest of Suriname. In: Wienk, J.F., Wit, H.A. de (Eds.), Proceedings of the joint workshop on 'Management of the low fertility acid soils oft the American humid tropics'. San José, Costa Rica, 175-190.

De Graaf, N.R. 1983. Bosbouw in tropish regenwoud in Suriname. Ned. Bosb. Tijds 55, 199-211.

De Graaf, N.R. 1986. A silvicultural system for natural regeneration of tropical rain forest in Suriname. Management of Tropical Rain Forest in Suriname 1. PhD Thesis Wageningen Wageningen University, Wageningen, The Netherlands.

De Graaf, N.R. 1987a. Natural regeneration of tropical rain forest in Suriname as a land use option. Neth. J. of Agric. Sc. 35, 71 - 74.

De Graaf, N.R. 1987b. Tropical lowland rain forest management for sustained timber production in Suriname, moulded in the CELOS management system. In: Cardozo, R., Solano, J.F. (Eds.), Memorias Reunion Nacional de Silvicultura, Bogotá, Colombia. CONIF, Serie de Documentacion 9, 67-80.

De Graaf, N.R. 1991. Managing natural regeneration for sustained timber production in Suriname: The CELOS Silvicultural and Harvesting System. In: Gomez Pompa, A., Whitmore, T.C., Hadley, M. (Eds.), Rain forest regeneration and management. Man and the Biosphere Series, Vol. 6. UNESCO, Paris, France. 393 - 405.

De Graaf, N.R. 1992. Secondary forest - Should it be an option in forest management in Suriname? Proceedings of the Humid Tropical Lowlands Conference: Development strategies and natural resource management. June 1991, Panama City. DESFIL, Bethesda, Maryland, USA.

De Graaf, N.R. 1996a. Amazon high forest management for sustainable timber production: problems and options for the silviculturist in charge. In: Anonymous (Ed.), Recherche sur les ecosystèmes forestiers de Guyane. Actes du Séminaire Interne de Silvolab, Avril 1994, 146.

De Graaf, N. R. 1996b. Natural forest management for sustained timber production in the humed tropics,, with special reference to Latin America. In Schmidt, P., Schotveld, A. (Eds.) Sustainable management of the Guyana rain forest. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands. 17-28.

De Graaf, N.R. 2000. Reduced impact logging as part of the domestication of neotropical rain forest. Internat. For. Rev. 2/10, 40-44.

De Graaf, N.R. Filius, A.M. & Huesca Santos, A.R. 2003. Financial analysis of sustained forest management for timber. Perspectives for application of the CELOS management system in Brazilian Amazonia. For. Ecol. Man. 177, 287-299.

De Graaf, N.R. & Geerts, J.M.P. 1976. Techniek natuurlijke verjonging drooglandbos. CELOS rapporten 114. CELOS, Paramaribo, Suriname.

De Graaf, N.R. & Hendrison, J. 1993. The quest for sustainability: silvicultural research in Suriname since 1900. In Wood, P.J., Vanclay, J.K., Wan Razali Wan Mohd (Eds.), Proceedings of The Tropical Silviculture Workshop IUFRO Centennial Conference. Berlin 1 3 September 1992, 101-111.

De Graaf, N.R., Koning, D. & Spierings, M. 1996. Some conditions and possibilities for successful application of the CELOS Management System. BOS NiEuWSLETTER Vol 15(2), No 34, 74-83.

De Graaf, N.R. & Poels, R.L.H. 1990. The CELOS Management System: a polycyclic method for sustained timber production in South American rainforest. In: Anderson, A.B. (Ed.), Alternatives to deforestation: Steps toward sustainable use of the Amazon rain forest. Columbia University Press, New York, USA, 116 -127.

De Graaf, N.R., Poels, R.L.H. & Rompaey, R.S.A.R. van,. 1999. Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. For. Ecol. Man.124, 123-135.

De Graaf, N.R. & Rompaey, R.S.A.R. van,. 1992. The CELOS experiments on silviculture with natural regeneration in Suriname. Case study for the Workshop on the management and conservation of the tropical moist forest ecosystem, Cayenne, Guyane, March 1990, 17.

De Graaf, N.R. & Vletter, J. de, 1979. Een voorlopige schatting van de aanwas aan waardevolle houtsoorten in het Mapanegebied, bij een kapcyclus van twintig jaar in hoog drooglandbos. Internal paper, CELOS, Paramaribo, Suriname.

Dekker, M. 2001. The influence of the CELOS Silvicultural System on the occurrence of a number of pioneer and climax tree species in the tropical rain forest of Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

Dekker, M., & De Graaf, N.R. 2003. Pioneer and climax tree regeneration following selective logging with silviculture in Suriname. For. Ecol. Man. 172, 183-190.

Dijn, B. de, 2003. Vertical stratification of flying insects in a Suriname lowland rainforest. In: Basset, Y., Novotny, V., Miller, S.E., Kitching, R.I. (eds.) Antropods in tropical forests. Cambridge university perss, Cambridge, UK, 110-122.

FAO, 1993. Case study No. 1: Suriname – the CELOS Management System. In: FAO, Management and conservation of closed forest in tropical America. FAO Forestry paper 101, Rome, Italy.

Fraser, A.I., Busby, R.J.N. & Paul, D.K. 1977. Forest Regeneration Suriname. International Forest Consultancy, Edinburg and Suriname Forest Service, Paramaribo, Suriname.

Fretes, J.A. de,. 1984. Micromorfologie van een Oxisol en een Ultisol uit Suriname. Internal student report, Wageningen University, Wageningen, The Netherlands.

Gelens, M.F. 1982. Een vergelijking van twee bosprofiel-tekenmethodes (Experiment 82/14): een beschouwing van bosstructuren binnen Expt. 67/9A. CELOS rapporten 135, CELOS, Paramaribo, Suriname.

Gieteling, C.J. 1970. Groei en mortaliteit der waardehoutsoorten in geexploiteerd en natuurlijk verjongd drooglandbos. CELOS rapporten 38, CELOS, Paramaribo, Suriname.

Gómez Soubrier, A. 2000. The influence of CELOS silvicultural system on wood characteristics of Tetragastris altissima. Student report, Wageningen University, Wageningen, The Netherlands.

Groot, D. de,. 1996. Policy as a condition for good forest management. In Schmidt, P., Schotveld, A. Sustainable management of the Guyana rain forest. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 53-57.

Hagg, H. & Pel, M. 1985. Successie na ontbossing in het tropisch regenwoud van Suriname Student report. 2 dl. + 1 bijlage Student report, Wageningen University, Wageningen, The Netherlands.

Hagman, F.A. & Schenk, K. 1981. Non-destructieve bepaling van de staande fytomassa in licht geëxploiteerd bos in het Mapane gebied. Internal student report, CELOS, Paramaribo, Suriname.

Hagman, F.A., Schenk, K. 1982. Boomdiameterbepalingen. CELOS rapporten 134, CELOS, Paramaribo, Suriname.

Hendrison, J. 1990. Damage-controlled logging in managed tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 4, PhD Thesis Wageningen University, Wageningen, Suriname.

Hendrison, J. 1996. The management of a forest venture under CELOS Management System. In Schmidt, P., Schotveld, A. (Eds.) Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 45-52.

Hendrison, J. & De Graaf, N.R. 1987. Algunas notas sobre el manejo del bosque tropical humedo en Surinam. Revised edition of the paper in Actas del primer seminario internacional sobre manejo de bosque tropical humedo de la region de Centro America (SEMBOTH), Esnacifor, Siguatepeque, Honduras, Noviembre 1986. Internal report, CATIE, Turrialba, Costa Rica.

Hout, P. van der,. 1983a. Aanzet tot de toepassing van directional felling bij de houtoogst in het Surinaams drooglandbos. Student report, CELOS, Paramaribo, Suriname.

Hout, P. van der,. 1983b. Techniek natuurlijke verjonging. Voorlopige evaluatie expt 67-9B. Student report, CELOS, Paramaribo, Suriname.

Hout, P. van der,. 1984. Praktijkverslag van zesmaands praktijk bij het Centrum voor Landbouwkundig Onderzoek in Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

IJssel, W.F. van,. 1982. Praktijkverslag. Internal student report, CELOS, Paramaribo, Suriname.

IJssel, W.F. van,. 1983. Is het mogelijk om het arboricideverbruik bij de zuivering te verminderen? Internal student report, CELOS, Paramaribo, Suriname.

Jansen, J.J., Bongers, F., De Graaf, N.R., Jonkers, W.B.J., Sterck, F.J., Stuiver, B.M. & Wirjosentono, J. (2005). Secondary data analysis Mapane plots 1981-1997. Internal report, CELOS, Paramaribo and Wageningen University, Wageningen, The Netherlands.

Jonkers, W.B.J. 1974. Groei en mortaliteit der waardehoutsoorten in geexploiteerd en natuurlijk verjongd drooglandbos: opname en verwerking 1973. CELOS rapporten 99-1, CELOS, Paramaribo, Suriname.

Jonkers, W.B.J. 1983. Forestry research in the tropical rainforest of Suriname. BOSNiEuWSLETTER, 2(3), 10-14.

Jonkers, W.B.J. 1984. Exploitation, natural regeneration and increment. Experimental plan and progress report on experiment 78-5. CELOS rapporten 141, CELOS, Paramaribo, Suriname.

Jonkers, W.B.J. 1987. Vegetation structure, logging damage and silviculture in a tropical rain forest in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 3. PhD Thesis, Wageningen University, Wageningen, Suriname.

Jonkers, W.B.J. 1999. Planning for research and implementation of the CELOS forest management system. Working document project GCP/SUR/001/ NET. FAO and Ministry of Natural Resources, Paramaribo, Suriname.

Jonkers, W.B.J. 2002. Reduced impact logging in Sarawak, Guyana and Cameroon: the reasons behind differences in approach. In Enters, T., Durst, P.B., Applegate, G.B., Kho, P.C.S, Man, G. (Eds.), Applying reduced impact logging to advance sustainable forest management. RAP Publication 2002/14. FAO, Bangkok, Thailand.

Jonkers, W.B.J. & Hendrison, J. 1987. Prospects for sustained yield management of tropical rain forest in Suriname. In: Figueroa Colon, J.C., Wadsworth, F.H., Branham, S., (Eds.), Management of the forests of tropical America: prospects and technologies. Institute of Tropical Forestry, USDA Forest Service, Rio Piedras.

Jonkers, W.B.J. & Schmidt, P. 1984. Ecology and timber production in tropical rainforest in Suriname. Interciencia 9, 290-297.

Jonkers, W.B.J., Tjon, K. & Wirjosentono, J. 2003. Long-term effects of logging in a Neotropical rain forest in Suriname. In: International expert meeting on the development and implementation of national codes of practice for forest harvesting: issues and options. International Forestry Cooperation Office, Forestry agency, Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan,157-166.

Jonkers, W.B.J., Tjon, K. & Wirjosentono, J. 2005. Long-term changes in selectively logged and silviculturally treated tropical rain forest in Suriname: analysis of the 1978-2000 data of Experiment 78/5. Internal report, CELOS, Paramaribo and Wageningen University, Wageningen, The Netherlands.

Jongkind, C.C.H. 1984. Onderzoek aan het eerste jaar van de successie na kappen en branden op lokatie 'Tonka' in het tropisch regenwoud van Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

Jongkind, C.C.H. 1984. Een sleutel voor de klimmende soorten van de familie der Bignoniaceae voor Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

Kiepe, P. 1984. De stroom van water en nutrienten in het tropisch regenwoud. Internal student report, Wageningen University, Wageningen, The Netherlands.

Leeflang, C. 1983. Is het mogelijk om het arboricide verbruik bij de zuivering te verminderen? Internal student report, CELOS, Paramaribo, Suriname.

Leersum, G.J.R. van, 1984a. Simulation of various silvicultural treatments. Student report, Wageningen University, Wageningen, The Netherlands.

Leersum, G.J.R. van, 1984b. Winchsystems and shortwoodlogging (Expt 82/18). Student report, Wageningen University, Wageningen, The Netherlands.

Leersum, G.J.R. van, 1984c. Uitsleepschade (Expt. 83/12). CELOS rapporten 143, CELOS, Paramaribo, Suriname.

Leeuwen, M.H.W. van, 1983. Relation between soil and vegetation in tropical rain forest in Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

Lenne, J.E. 1972. Verslag praktijktijd Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

Lenne, J.E. & Wiersum, K.F. 1970. Vrijstellingstechniek natuurlijk verjongd drooglandbos: onderzoekproject no. 67/9; behandeling en opname 1970. CELOS rapporten 43, CELOS, Paramaribo, Suriname.

LH/UvS 01. 1979. Human interference in the tropical rain forest ecosystem. Annual Report for 1978, CELOS, Paramaribo, Suriname.

LH/UvS 01. 1981. Human interference in the tropical rain forest ecosystem. Annual Report for 1979, CELOS, Paramaribo, Suriname.

LH/UvS 01. 1982a. Human interference in the tropical rain forest ecosystem. Annual Report for 1980, CELOS, Paramaribo, Suriname.

LH/UvS 01. 1982b. Human interference in the tropical rain forest ecosystem. Annual Report for 1981, CELOS, Paramaribo, Suriname.

LH/UvS 01. 1983. Human interference in the tropical rain forest ecosystem. Annual Report for 1982, CELOS, Paramaribo, Suriname.

LH/UvS 01. 1984. Human interference in the tropical rain forest ecosystem. Annual Report for 1983, CELOS, Paramaribo, Suriname.

Mellink, W.H.H. 1981. Velschade in Surinaams drooglandbos. Student report, Wageningen University, Wageningen, The Netherlands.

Meyenfeldt, C.F.W.M. van, 1975. Arbeidskundig onderzoek van houtteeltkundige werkzaamheden t.b.v. natuurlijke verjonging van het drooglandbos. CELOS rapporten 106, CELOS, Paramaribo, Suriname.

Mohren, G.M.J. 1981. Kort verslag van een studiereis naar het Centrum voor Landbouwkundig Onderzoek (CELOS) te Paramaribo, Republiek Suriname, 28 januari tot 1 maart 1981. Student report, Wageningen University, Wageningen, The Netherlands.

Mueller, U. 1998. Effects of refinements on the development of a neotropical rainforest after controlled logging in Suriname. Student report, Wageningen University, Wageningen, The Netherlands.

Nieuwenhuis, J. 1977. Techniek natuurlijke verjonging drooglandbos: vrijstelling en grondvlaktemetingen in het proefperk "Mapanebrug". Techniek natuurlijke verjonging: opname, hoogte - en grondvlakmetingen in het proefwerk "Akintosoela". CELOS rapporten 123, CELOS, Paramaribo, Suriname.

Oesterholt, J.M. 1983. Grondvlakverloop, inwas, diametergroei en mortaliteit in het proefperk Goliath. Internal student report, CELOS, Paramaribo, Suriname.

Oesterholt J.M., 1985. Winch systems and short wood logging: expt. 82-18. Student report, Wageningen University, Wageningen, The Netherlands.

Ohler, F.M.J. 1980. Phytomass and mineral content in untouched forest: onderzoekproject 78/22; N, P, K, Ca en Mg gehalten in het ecosysteem ongestoord altijd groen seizoens-regenbos te Kabo. CELOS rapporten 132, CELOS, Paramaribo, Suriname.

Ohler, F.M.J. 1981. Verslag drie maanden praktijktijd bij project LH/UvS 01. Internal student report, Wageningen University, Wageningen, The Netherlands.

Oliemans, M.C. 1982. Verslag tropen-stage in Suriname, periode oktober 1980 – september 1981. Internal student report, CELOS, Paramaribo, Suriname.

Poels, R.L.H. 1987. Soils, water and nutrients in a forest ecosystem in Suriname. Ecology and Management of Tropical Rain Forest in Suriname 2. PhD Thesis Wageningen Wageningen University, Wageningen, The Netherlands.

Poels, R.L.H., De Graaf, N.R. & Wirjosentono, J. 1998. Growth and mortality of trees after various experimental silvicultural treatments for natural regeneration in Suriname. Hinkeloord report 25. Wageningen University, Wageningen, The Netherlands.

Procter, J. 1979. Ecological research and land use planning in the Suriname rainforest: a cooperative project between Suriname and the Netherlands. In Furtado. J.I. (Ed.). Abstracts Vth International symposium of tropical ecology, Kuala Lumpur, Malaysia, 16-21 April 1979. pp 153-154

Ramdhan, P. & Jogi, R. 1982. Schademeting bij de houtoogst in het Mapanebos. Internal student report, CELOS, Paramaribo, Suriname.

Renes, G.J.B. 1972. Aantekeningen praktijktijd Suriname 1970 - 1971. Student report, Wageningen University, Wageningen, The Netherlands.

Rompaey, R.S.A.R. van, 1987. Bosbouw in het tropischregenwoud: evaluatie van een vrijstellingsexperiment in Suriname. Internal report. Rijksuniversiteit Gent, Ghent.

Scheltens, E.B. & Hetzler, J.R. 1975. Groei en mortaliteit der waardehoutsoorten in geexploiteerd en natuurlijk verjongd drooglandbos. Techniek natuurlijke verjonging. CELOS rapporten 103, CELOS, Paramaribo, Suriname.

Schmidt, P. 1983. Voortgangsrapport 1978 - 1982 van het project LH/UvS 01 (MAB-project 949) "Antropogene ingrepen in het ecosysteem tropisch regenwoud". CELOS rapporten 136, CELOS, Paramaribo, Suriname.

Schmidt, P. 1995. Duurzaam bosgebruik in Suriname. In: Anonymous (Ed.), Duurzame ontwikkeling in Suriname; Het milieu: prioriteit of bijzaak. Proceedings Studiname Symposium 1995. Rotterdam, The Netherlands, 40-47.

Schmidt, P. & Hendrison, J. 1996a. A model forest management unit as an implementing tool for the CELOS Management System. BOSNiEuWSLETTER 15(2), 84-88.

Schmidt, P. & Hendrison, J. 1996b. Future prospects for the application of CELOS Management System. In Schmidt, P., Schotveld, A. (Eds.) Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 63-64.

Schmidt, P. & Schotveld, A. (Eds.) 1996. Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands.

Schotveld, A. 1996. Introduction. In: Schmidt, P., Schotveld, A. Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 11-12.

Schotveld, A. & Schmidt, P. 1996a. Executive summary. In: Schmidt, P., Schotveld, A. Sustainable management of the Guyana rain forest. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 7-10.

Schotveld, A. & Schmidt, P. 1996b. Management systems for natural tropical forests: the practical value of the CELOS Management System. BOSNiEuWSLETTER 15(2), 89-92.

Schulz, J.P. 1960. Ecological studies on rain forest in northern Suriname. The vegetation of Suriname, vol. II. Van Eedenfonds, Amsterdam, The Netherlands.

Schulz, J.P. 1967. La regeneracion natural de la selva mesofitica tropical de Surinam despues de su aprovechamiento = The natural regeneration of the mesophtyc forest of Surinam after exploitation. CELOS bulletins 3, CELOS, Paramaribo, Suriname.

Snieders, W. 1983. Strooiselafbraak in vier verschillend behandelde opstanden. Internal student report, CELOS, Paramaribo, Suriname.

Staudt, F.J. 1977. Arbeidskundig onderzoek van werkzaamheden ten behoeve van natuurlijke verjonging van het drooglandbos, zuiveringsarbeid. Internal report, Wageningen University, Wageningen, The Netherlands.

Steege, H. ter, Bongers, F. & Werger, M. 1996. Ecological constraints for forest management in the Guianas. In: Schmidt, P., Schotveld, A. (Eds.) Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 29-44.

Steege, H. ter, Laumans, B., Laumans-Bus, D., Zondervan, G. & Bongers, F. 2003. Long-term effects of timber harvesting in Mapane – north Suriname. In: Steege, H. ter (Ed.), Long-term changes in tropical tree diversity. Tropenbos Series 22. Tropenbos International, Wageningen, The Netherlands, 79- 94.

Steege, J.G. van der, 1983a. Bladproductie en bladfytomassa van een aantal palmsoorten van het tropisch regenbos van Suriname. CELOS rapporten 138, CELOS, Paramaribo, Suriname.

Steege, J.G. van der, 1983b. Strooiselafbraak in vier verschillende bosopstanden. Exp. 82/9. Student report, CELOS, Paramaribo, Suriname.

Sterringa, J.T. 1971. Een onderzoek naar de vegetatiestruktuur van recent geexploiteerd drooglandbos in het Mapane gebied, Suriname, 1968/69. Student report Wageningen University, Wageningen, The Netherlands.

Taus, M.I. 1979. Verslag semi-detail kartering van een areaal aan de Pampoenkreek (stroomgebied Tibiti). Internal report 186, Dienst Bodemkartering, Paramaribo, Suriname.

Tjon Lim Sang, R.J.M. 1983. Overzicht van de permanente successieproefperken van het project LH/UvS 01. Landbouwuniversiteit, Wageningen, The Netherlands.

Vester, H. 1986. Kiemecologie en zaadverspreiding in het 'CELOS Silvicultural System'. Student report, Wageningen University, Wageningen, The Netherlands.

Vet, de, F. J. 1984. Dataverwerking in het project LH/UvS 01. CELOS rapporten 142, CELOS, Paramaribo, Suriname.

Vierhout, J. 1983. Physical degradation of yellow kaolinitic oxisols of the Zanderij formation in Surinam: a field study. CELOS rapporten 139, CELOS, Paramaribo, Suriname.

Vletter, J. de,. 1972. Suksessie in geëxploiteerd drooglandbos: de vierde opname. CELOS rapporten 74, CELOS, Paramaribo, Suriname.

Voordouw, J.J. 1982. Productie en minerale samenstelling van strooisel. Internal student report, CELOS, Paramaribo, Suriname.

Voordouw, J.J. 1985. Vertical distribution of light intensity in tropical rainforest in Suriname with relation to silvicultural treatment. Student report, Wageningen University, Wageningen, The Netherlands.

Waagmeester, N. 1996. The CELOS Management System (CMS) has to come out in the open. In Schmidt, P., Schotveld, A. (Eds.) Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 59-61.

Walsum, P.E.V. van, 1980. Praktijktijdverslag. Internal student report, CELOS, Paramaribo., Suriname.

Werkhoven, M., De Graaf, N.R., Jonkers, W.B.J, 1996. Surinam. In: Harcourt, C.S., Sayer, J.A. (Eds.), The conservation atlas of tropical forests: the Americas. Simon and Schuster, New York, USA. 301-310.

Wouters, A.J.M. 1978. Techniek natuurlijke verjonging drooglandbos: tussentijdsverslag van de resultaten in de proefperk "Akintosoela". CELOS rapporten 129, CELOS, Paramaribo, Suriname.

Zadelhoff, F.J. van, & Jonkers, W.B.J. 1974. Groei en mortaliteit der waardehoutsoorten in geexploiteerd en natuurlijk verjongd drooglandbos: opname en verwerking 1973. CELOS rapporten 99, CELOS, Paramaribo, Suriname.

Ziel, H. van,. 1982. Praktijkverslag. Internal student report, CELOS, Paramaribo, Suriname.

Zondervan, G.J. 1972. Groei en mortaliteit der waardehoutsoorten in geëxploiteerd en natuurlijk verjongd drooglandbos: opname en verwerking 1971; rapportering over het verloop der werkzaamheden. CELOS rapporten 61, CELOS, Paramaribo, Suriname.

Zondervan, G.J. 1996. Forest practice in Suriname? How it looks like and what it could be. In Schmidt, P., Schotveld, A. (Eds.) Sustainable management of the Guyana rain forests. Hinkeloord report 18, Wageningen University and National Reference Centre for Nature Management, Wageningen, The Netherlands, 13-16.

Zwetsloot, R. 1982. Skidtrails, een inleidend onderzoek. Internal student report, CELOS, Paramaribo, Suriname.

This book, with contributions from 25 authors, tells in brief the history of forestry in Suriname and some other tropical countries. It reveals how the work on forestry in Suriname led to the development of a potentially sustainable forest management system, integrating a harvesting and a silvicultural system. And it documents the long-term effects of applying this system as apparent from a great deal of research in experimental forest stands of CELOS in Suriname. This information holds the evidence to determine the potential of the CELOS Management System to serve as a model for other systems of sustainable management of tropical forests in Suriname and beyond, particularly in other Latin American countries in the region with similar forests.

By making knowledge work for forests and people, Tropenbos International contributes to well-informed decision making for improved management and governance of tropical forests. Our longstanding local presence and ability to bring together local, national and international partners make us a trusted partner in sustainable development.