

5 Impacts on forest structure and plant species diversity

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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.

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	Akintosola1	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 m ² .ha ⁻¹	n.a.	Light	Light	Light	All trees > 27 cm dbh removed, ± 200 m ² .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.

5.2 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.

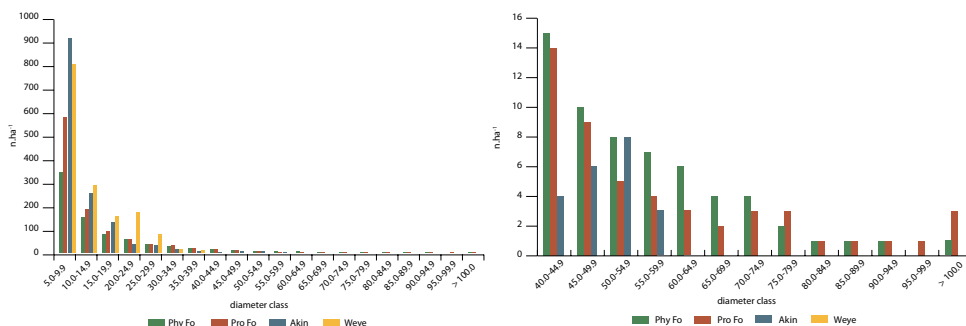


Figure 5.1. Diameter distribution (cm) in trees (standardized per ha) in four differently treated (see Table 5.1) forest stands. Surface of inventory Phytomass Forest 5 ha; Procter's Forest 5 ha, Akintosoela1 1 ha; Weyerhäuser 0.25 ha.

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.

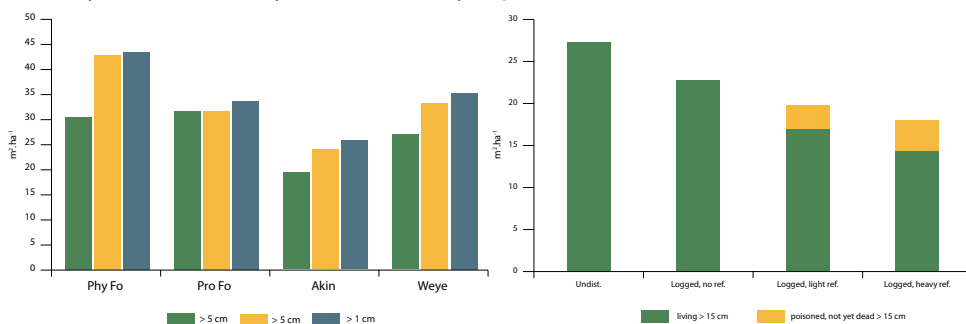


Figure 5.2. Left: Basal area of all tree species in four differently treated (see Table 5.1) forest stands as assessed in a forest inventory (green, 5 ha in Phytomass Forest and Procter's Forest and 1 ha in Akintosoela1 and Weyerhäuser) and in phytomass plots (yellow and blue, 0.12 ha in Phytomass Forest, 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 $m^2 \cdot ha^{-1}$ 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 $m^2 \cdot ha^{-1}$. In refinements with a 20 cm diameter

limit basal area was reduced to about $9.8 \text{ m}^2 \cdot \text{ha}^{-1}$ (De Graaf 1986). Seven years later the basal area reached $19.2 \text{ m}^2 \cdot \text{ha}^{-1}$. The secondary forest of Weyerhäuser had grown, in 13 years, to a basal area of $27 \text{ m}^2 \cdot \text{ha}^{-1}$. 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 $> 23 \text{ cm dbh}$ in 1969.

No assessment of the standing volume of all trees in treated forest stands was carried out. However, assuming an average specific gravity¹ of $0.72 \text{ g} \cdot \text{cm}^{-3}$, 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 $426 \text{ m}^3 \cdot \text{ha}^{-1}$ ($\text{dbh} > 24.5 \text{ cm}$) mentioned by Schulz (1960). Striking, however, is the very low standing volume of trees $> 5 \text{ cm dbh}$ 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.).

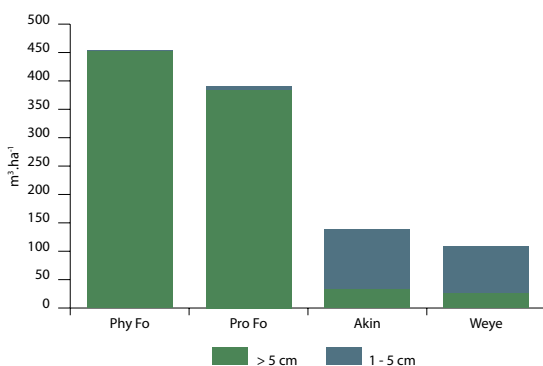


Figure 5.3. Standing volume of all trees in four differently treated (see Table 5.1) forest stands, estimated on the basis of phytomass data

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

¹ Calculated from Vink (1977). Probably an overestimation due to the fact that no secondary species are included.

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.

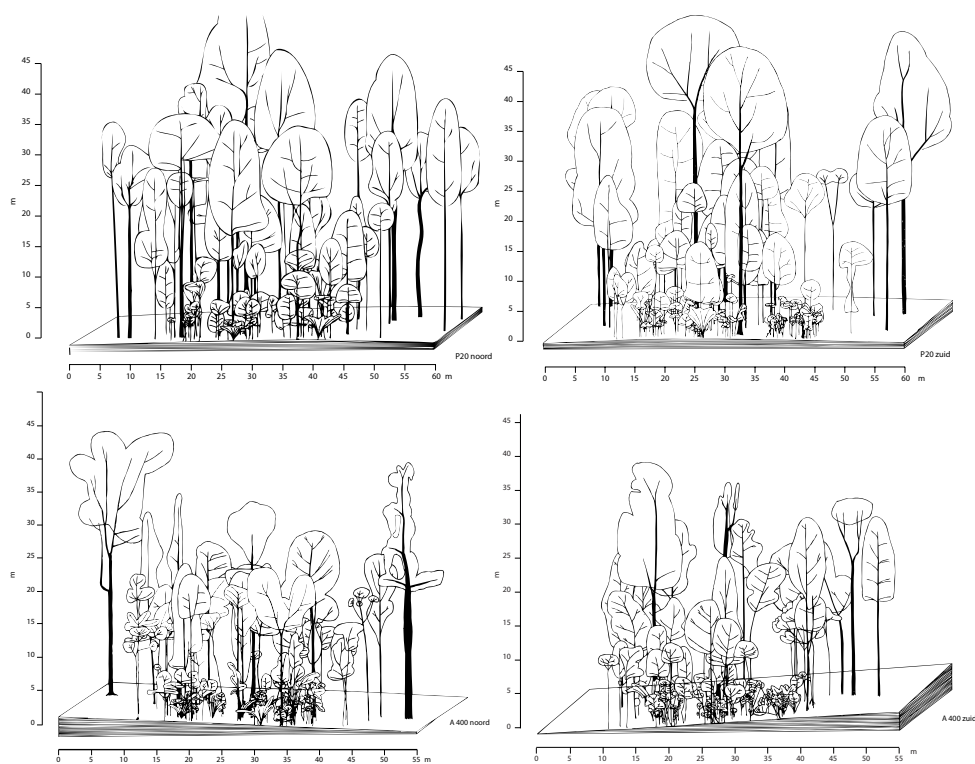


Figure 5.4. Profile diagrams in Procter's Forest (P20) and Akintosoela1 (A400). Profiles were drawn in 1983 along an East-West running straight central line. In the profiles only those smaller trees (> 2 m height) were drawn that grew close to the central line. (Source Voordouw 1985). On this central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

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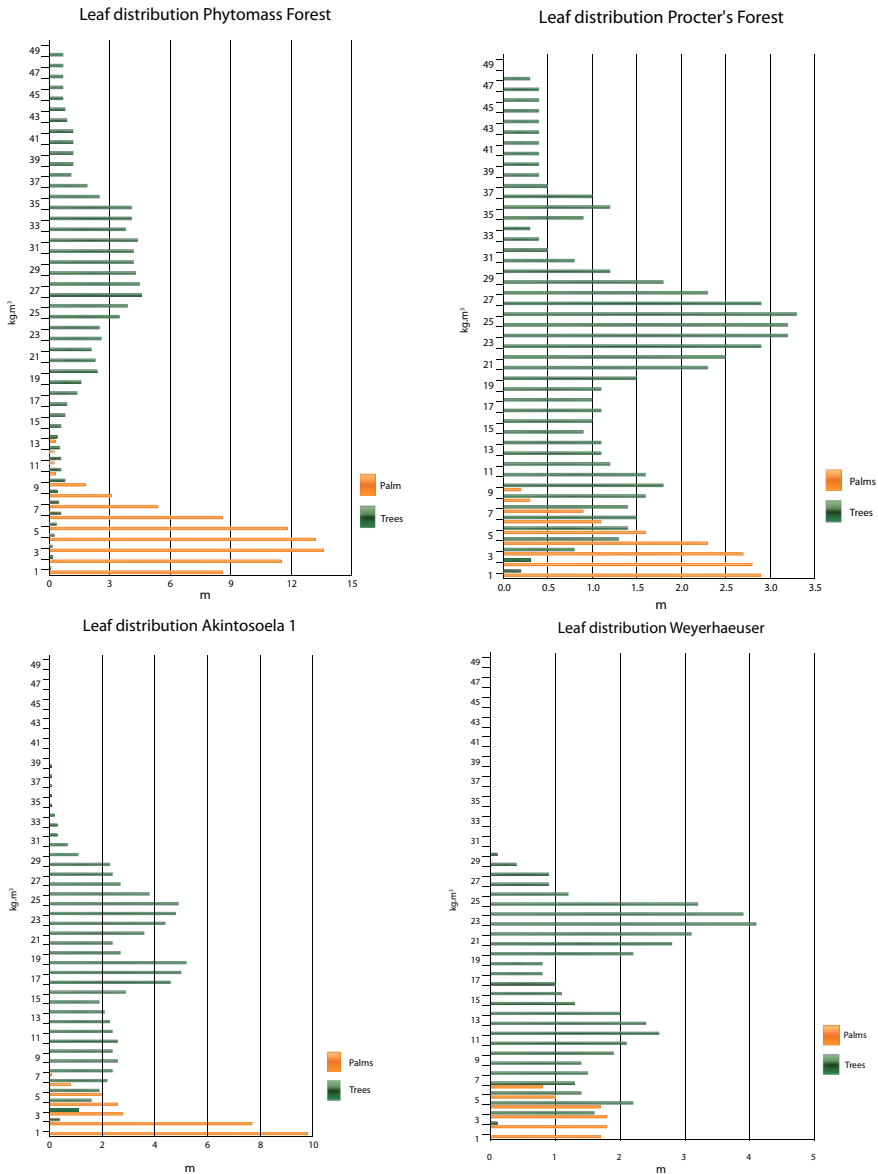


Figure 5.5. Distribution of tree and palm leaves (kg.m^3 , X-axis) along tree height (m, Y-axis) in Phytomass Forest (not treated, above left), Procter's Forest (lightly exploited, above right), Akintosoela1 (exploited and refined, below, left) and Weyerhäuser (clear cut, below, right). For more details 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.



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

The effects of treatments on leaf mass distribution were studied in the Phytomass Forest (12 plots), Procter's Forest (14 plots), Akintosola1 (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).

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 *Sclerobium 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 *Sclerobium micropetalum* (Ducke) (Photo P. Schmidt)



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



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

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



Photo 5.9. Root system of *Sclerobium 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)

Henderson (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).

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- ∞ Basal area and standing volume initially are considerably decreased, but (in Akintosoela) 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, Lecythydaceae, 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*

5. Impacts on forest structure and plant species diversity

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							
	Phy Fo		MAIN21 ¹		Pro Fo		Ma Br ²		Akin ²		Weye	
Forest stand												
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							
	Phy Fo		MAIN21 ¹		Pro Fo		Ma Br ²		Akin ²		Weye	
Forest stand	1979		1981		1980		1981		1981		1981	
Year of inventory	4*0.25 ha		1*0.25 ha		4*0.25 ha		1*0.25 ha		4*0.25 ha		1*0.25 ha	
area	n/ha		n/0.25ha		n/ha		n/0.25ha		n/ha		n/0.25ha	
Data	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)									
<i>Qualea rosea</i>	19.6	18.7	23.1	20.4	19.3	31.8	20.7	20.2	35.3
<i>Dicorynia guianensis</i>	21.7	20.9	19.6	25.6	24.1	22.2	20.8	20.1	18.7
<i>Virola michelli</i>	6.3	6.0	7.4	7.3	6.9	7.9	8.0	7.0	9.4
<i>Jacaranda copaia</i>	3.9	3.4	4.9	4.1	3.6	8.1	4.4	4.1	8.4
<i>Tetragastris altissima</i>	6.2	6.0	7.2	8.0	7.7	9.2	7.1	7.1	8.4
<i>Manilkara bidentata</i>	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									
<i>Lecythis corrugata</i>	12.1	12.1	12.7	10.9	10.2	14.4	12.9	8.4	13.9
<i>Protium polybotryum</i>	2.3	2.3	2.4	1.7	1.7	1.6	4.3	3.7	4.7
<i>Couepia caryophylloides</i>	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									
<i>Inga spp.</i>	7.4	7.0	12.8	8.1	7.1	28.4	8.1	4.6	39.3
<i>Pourouma spp.</i>	9.5	8.3	13.8	2.8	2.3	9.0	7.5	3.5	22.0
<i>Palicourea guianensis</i>	1.0	1.0	14.0	2.0	2.0	23.0	1.7	1.7	15.3
<i>Cecropia sciadophylla</i>	1.7	1.7	2.7	3.5	1.5	2.5	1.0	1.0	11.0
<i>Cecropia peltata</i>	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									
<i>Dendrobangia boliviana</i>	20.9	20.8	17.3	22.0	18.7	16.4	18.3	11.4	9.3
<i>Sclerolobium melinonii</i>	6.0	6.0	6.8	7.7	3.0	3.5	6.6	3.0	7.1
<i>Mabea piriri</i>	1.5	1.5	2.5	3.0	3.0	5.0	2.0	2.0	7.0
<i>Bixa orellana</i>	4.1	3.6	3.9	2.7	2.3	4.8	4.4	3.4	6.0
<i>Chaetocarpus schomburgkianus</i>	7.7	7.6	5.7	8.9	6.9	5.6	8.0	5.3	5.0
<i>Swartzia benthamiana</i>	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 species 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.

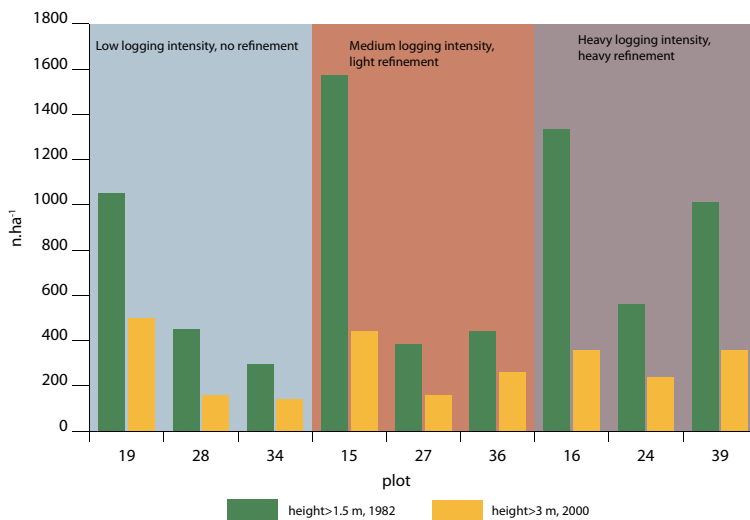


Figure 5.6. Palm densities in nine plots of the MAIN experiment. Treatments applied: plots 19, 28 and 34: low logging intensity, no refinement; plots 15, 27 and 36: medium logging intensity, light refinement; plots 16, 24 and 39: high logging intensity, heavy refinement. Adapted from Jonkers (1987) and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

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