a silvicultural system for natural regeneration of tropical rain forest in Suriname

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N.R. de Graaf

A SILVICULTURAL SYSTEM FOR NATURAL REGENERATION OF TROPICAL RAIN FOREST IN SURINAME

Proefschrift

ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
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Abstract

A polycyclic system is proposed and discussed for the economically accessible mesophytic (evergreen seasonal) forests in Suriname. In this system, known as Celos Silvicultural System, a restricted amount of about 20 m^3 quality timber is taken once about every 20 years in a well controlled selection felling operation. This seemed to be the best compromise between economic demands and ecologic constraints in the highly mixed forest growing on chemically very poor soils. It was found that selection felling had to be followed by refinement using arboricides, three times during the cycle, to release commercial species, and provide economically sufficient increment. The system was tested experimentally over more than a decade. Main principles were maintenance of a high level of biomass to prevent leaching of nutrients from the ecosystem, and minimum interference, assuming the original forest is best adapted to ecological conditions.

The results of four big field experiments are given in many tables, graphs and stereophotographs.

CIP-GEGEVENS KONINKLIJKE BIBLIOTHEEK, DEN HAAG

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Agricultural University, Wageningen, 1986

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STELLINGEN

1

Een zinvol gebruik van een ecosysteem als produktiemiddel is beter voor het behoud – zij het gedeeltelijk – daarvan dan een verbod tot aantasting dat niet kan worden doorgevoerd wegens bestuurlijke onmacht.

Dit proefschrift

2

Zonder maatschappelijk waardeerbare productie, bijvoorbeeld van verhandelbaar hout, wordt het beheren en beschermen van uitgestrekte tropische regenbossen onbetaalbaar.

Dit proefschrift

3

Bij beperkte manipulatie door houtoogst en zuiveringen blijft tropisch regenbos in Suriname nog steeds tropisch regenbos, in tegenstelling tot wat Jacobs stelde, namelijk dat door uitkap van hout en bosbouwkundige manipulaties een regenbos zozeer ontwricht wordt dat het zijn andere dan houtleverende functies verliest.

M. JACOBS, 1983. Het tropisch regenwoud: de visie van een bioloog. Panda Nieuws jaargang 19, no. 1.

4

Ingrepen ter vermindering van onderlinge concurrentie in de boompopulatie van regenbos in Suriname zijn, mits weloverwogen toegepast, duidelijk opbrengstverhogend in economische zin.

Dit proefschrift

5

Het idee van Ashton dat bomen in tropisch regenwoud boven een bepaalde afmeting niet of nauwelijks meer met versnelde groei reageren op een verminderde concurrentie, is waarschijnlijk ontstaan door een verkeerde omschrijving van dominantie, en geldt zeer duidelijk niet voor veel soorten in het surinaamse drooglandbos.

P.S. ASHTON, 1981. In Age and growth of tropical trees: new directions for research. Yale Univ. Bulletin no 94.

6

Om een bepaalde ecologisch ongewenste produktiewijze te verhinderen is in het verleden door veel samenlevingen het taboe gehanteerd als doeltreffend middel.

MARVIN HARRIS, 1977. Cannibals and Kings

7

Het taboe op aantasting van tropisch regenwoud zoals dat door sommige natuurbeschermers in ontwikkelde landen wordt voorgesteld, zal alleen met bijbetaling aan de man kunnen worden gebracht.

8

De geringe hoeveelheid jaagbaar wild in de regenbossen van tropisch Zuid-Amerika, is een van de ernstigste beperkingen voor de welvaart in de enkele nog bestaande traditionele indiaanse gemeenschappen.

9

Om de bevolkingsaanwas te verminderen is de doeltreffendste strategie die van het verminderen van het voordeel dat kinderen opleveren, omdat het gebruik van geboortebeperkende middelen vooral gedreven wordt door eigenbelang.

MARVIN HARRIS, 1977. Cannibals and Kings.

10

Voor kinderen is weinig passende arbeid te vinden in bosbouw welke gebruik maakt van natuurlijke verjonging, zodat dit bedrijf minder dan kleinschalige landbouw zal leiden tot kinderrijke gezinnen, al werpt het sprookje van Klein Duimpje een enigszins relativerend licht op deze stelling.

11

Doordat mijnbouw een van de pijlers van de economie van onze westerse samenleving is geworden heeft zij ook de mentaliteit van de overige bedrijfstakken in die zin omgebogen dat duurzaamheid van produktie wel met de mond geroemd maar niet metterdaad vergoed wordt: duurzaamheid lijkt te duur.

12

Bij Homo sapiens is het afbakenen van het territorium met uitwerpselen, zoals veel zoogdieren dat doen, een voorbijgaande fase in de ontwikkeling van jeugdige individuen, welke ontwikkelingsgang bij intellectueel sterk begaafde oudere individuen tenslotte uitmondt in het produceren van geschriften welke als geurvlaggen in het te bestrijken maatschappelijk gebied staan geplaatst.

R.A. WILSON, 1985. Hoe u uw vrienden van de apen kunt onderscheiden. Bres 110.

Stellingen behorende bij het proefschrift van N.R. DE GRAAF,
Wageningen, 23 april 1986.

Aan mijn vrouw Hannie

Curriculum vitae

Nicolaüs Reitze de Graaf werd geboren op 27 september 1941, in Modjowarno, op Java, en maakte op dat eiland de Tweede Wereldoorlog mee. Na terugkeer in Nederland doorliep hij de lagere school te Oosterbeek, een jaar MULO, en daarna het Gymnasium B aan het Christelijk Lyceum te Arnhem waarna hij in 1960 aanving met de studie in de Bosbouw aan de Landbouwhogeschool te Wageningen. In 1967 behaalde hij het kandidaatsexamen, en in 1970 het ingenieursexamen, waarbij de houtteelt (tropische specialisatie), de bosexploitatie, de fytopathologie (algemene plantenziektenkunde) en de tropische bodemkunde de ingenieursvakken waren.

Na een periode van enkele maanden werken op het Laboratorium voor Fytopathologie van de Landbouwhogeschool, werd hij begin 1971 als wetenschappelijk medewerker van de Landbouwhogeschool uitgezonden naar het Centrum voor Landbouwkundig Onderzoek in Suriname om daar bosbouwkundig onderzoek te verrichten voor de LH-afdeling Bosbedrijfsregeling en Houtteelt in de Tropen, onder andere aan het onderwerp dat in dit proefschrift ter sprake komt. Na een kort verblijf aan de LH in Wageningen in 1976 vertrok hij in 1977 weer naar Suriname, om eerst als onderzoeker, later als projectleider, mede te werken aan het onderzoeksproject 'Antropogene ingrepen in het ecosysteem tropisch regenwoud'. In 1982 keerde hij terug naar Wageningen, en sindsdien werkt hij als wetenschappelijk medewerker bij de huidige Vakgroep Bosteelt van de Landbouwhogeschool.

This thesis will also be published in the series Ecology and management of tropical rain forests in Suriname.

Preface

Often human interference in tropical rain forest is considered to be a negative influence on one of the world's most complex ecosystems. Although this may be true from an ecological point of view, not all human interference is destructive. The task of foresters, especially silviculturists, is to interfere with forest to make it more serviceable to man but at the same time to ensure that it is perpetuated.

Theories about the silvicultural treatment of tropical rain forest have to be tested in practice. In Suriname, theories formulated 20 years ago have been put into practice, and the results of more than 15 years experiments on natural regeneration and forest handling are discussed in this book. While there are still more questions than answers, a very promising ecological and economic approach has been found.

Part I presents firstly, general information about Suriname, a short description of the Forestry Belt, the categories of silvicultural systems used and a discussion of the need for management of tropical lowland forests. In Part II, the silvicultural system adopted by the Centre for Agricultural Research in Suriname (CELOS) is described with reference to the experimental results presented in Part III to support the point of view presented on the direction of future silvicultural practice. In Part III, firstly silvicultural research carried out before 1965 is reviewed and then the methodology and results of four major experiments on silviculture carried out after 1965 are described in detail. A short summary of each experiment has been included.

A silvicultural system is defined regionally because flora, fauna, soils, climate and human population all have effect on the course and results of manipulation of the forest vegetation. Thus ideas about silviculture developed locally should be extended to other regions with caution, even if the forests appear to be similar. Generalization creates confusion in many cases, and wholesale copying is bad policy. The best way to transfer silvicultural ideas may be to stimulate the establishment of silvicultural experiments in those countries wishing to benefit from the experience of others. This approach takes time, but leads ultimately to better adaptation and understanding, and is a source of inspiration for adequate management of the forest. It is often a race against time to understand the forest sufficiently and to develop an appropriate management system, before it is irreparably degraded. It is hoped that the ideas presented in this book about silviculture in Suriname will have a positive effect on the further development of silviculture in that country, and also on forestry in other countries.

The type of work presented in this book cannot be done by one individual alone. Often foresters are individualists, who enjoy working in isolation in the forest. However, forestry is not simply people working in a forest, but a symbiosis formed by forests and people. It has been a pleasure for me to work in the forests of Suriname, and I have learned much from my assistants. For his help in my first years in Suriname, I would like to mention especially Hans Jubitana from Cassipora. I learned a great deal from him, and I hope that I can now teach something about silviculture to others who need to make their living from the tropical rain forest.

I wish to thank the Professor and my colleagues in the Department of Silviculture in the Agricultural University, Wageningen, for allowing me to work in Suriname for so many years. My absence from Wageningen has increased their own tasks. I would like to mention especially Professor I.A. de Hulster, who sent me to Suriname in 1971; Dr. J.H.A. Boerboom, who guided me during these many years; and Professor R.A.A. Oldeman, for his support in the last years. Further, I wish to thank the Samenwerkings Overeenkomst Commissie of the LH-UvS Projects after 1976, especially the Suriname Section, which provided the support to allow the work to continue during periods of unexpected setbacks.

Working in the forest areas supervised by the Dienst 's Lands Bosbeheer (Suriname Forest Service), my colleagues and I were given all the co-operation that could be given by this Service. I would like to thank especially the former Chief Conservator, Ir. F.C. Bubberman, for his support of our research work, and Ir. A.T. Vink, Dr. J.P. Schulz, Ir. F. Vreden, Ir. J. de Vletter, and many others in the Forest Service who assisted us in so many and varied ways.

I would like to thank my colleagues in the LH-UvS projects for their assistance and comradeship. When I was Project Leader, they gave me moral support and physical assistance for which I am grateful.

I am grateful to the successive Directors of CELOS, especially Drs. H. O. Prade, and to the staff of the institute for their technical and administrative assistance with our work.

The many forestry students who did their field-work in Suriname deserve my praise for the way they set about their tasks. They have contributed a great deal to this work.

Others whom I would like to mention especially are: Mr Dawson, computer programmer and operator, who on many occasions worked enthusiastically late into the night to process field data; Mr Wolff, foreman of the recording team in later years, and Mr Humphrey Sabajo and Mr Marius Narsingh. Although the group of people working on the LH-UvS Project became so large that it is not possible to mention them all by name, I very much appreciate their co-operation and assistance throughout the years.

The Treub Foundation (Society for Tropical Scientific Research) in the Netherlands gave timely financial assistance for the drawing of some of the forest profile diagrams shown in this book. Last but not least, I thank Mrs H. J. West for her assistance with the English text.

CONTENTS

Summary

Suriname is a relatively small country of about 16 million ha, and less than half a million inhabitants, on the north coast of South America. While about 80 % of the country is covered with tropical forests, forestry development in Suriname has been concentrated in the Forestry Belt, of 1½ million ha of economically accessible natural forest land between the poorly drained low coastal area and the inland hills. Types of silvicultural systems used include uniform plantations of exotic or indigenous species; strip planting systems of exotic or indigenous species; and natural regeneration, that is manipulation of the original vegetation.

The need for management of the rain forest stems from the abuse of accessible natural resources which are not actively controlled. Revenue from the forest is required to provide a permanent income to finance effective management of large forest areas, especially in poor countries. For this, a silvicultural system to guarantee sustained yield in the long term is desirable, but such a system takes time to develop and test.

The Celos Silvicultural System worked out in this book offers a technically feasible balance of economic and ecological aspects of timber production in the mesophytic (evergreen seasonal) forests of the Forestry Belt. Ecological constraints, which are more constant in time, are given priority over short-term economic conditions. The nutrient poor soils of the region are susceptible to degradation following deforestation, and the nutrient store of the ecosystem, which is largely locked in the vegetation, should be preserved as much as possible. This indicates that the original forest should not be clear felled, and that other means of harvesting products have to be developed.

For timber production planning this leads to adoption of a form of selection felling, followed by silvicultural treatment. Socio-economic considerations favour extensive management with a low input per hectare, but with high return on capital and labour, taking advantage of the abundancy of forest. The system is a type of extensive land use, which is acceptable only in thinly populated regions. Technically the system is easy to implement with much unskilled labour, and only a few trained labourers and professional staff.

Timber harvesting, being the first action in forest management, needs to be planned and carried out carefully to reduce wastage of valuable timber and damage to the residual stand. The low volume per ha taken in present day harvesting systems should not be increased to economize on harvesting cost, and timber

should be harvested with due consideration to silvicultural aspects. The amount should be restricted to what can be taken without undue harvesting damage, depending on the system used, and the standing volume and dimensions of commercial species.

Silvicultural treatments after harvest are necessary to promote production of commercial timber in the residual stand. Mortality in lightly exploited forest is only slightly higher than in unexploited stands, but the recovery of commercial volume is very slow, because of the reduced population of commercial species. On the basis of the present species list a second economic harvest is not possible within a period of 50 years. Modifying the species list constantly to obtain enough volume for succeeding harvests will easily deteriorate the market position for the timber industry. This is because the product will be lower in quality or higher in price because of a need for expensive processing methods.

From field experiments done since 1965 and even earlier, information has been obtained about the influence of silvicultural measures on growth and mortality of valuable timber species in the highly mixed mesophytic forest. The most important of these measures, reduction of the competition in the stand, required the restricted use of powerful arboricides, and considerable input of unskilled labour. No machinery was used in silvicultural treatments, except to transport people and materials.

The selective treatments which are referred to as refinements, to compensate for the harvesting pressure on populations of preferred timber species, are discussed in the framework of the natural dynamics of the forest. In undisturbed forest gap forming by trees falling alive or dying standing provides space for development of other trees. These processes are accelerated and intensified by the silvicultural treatments, but not to the extent that the forest structure is destroyed and the ecosystem disorganized. Increment of commercial timber is increased five to tenfold by the optimal treatment, which reduces the cycle of felling considerably.

Data on increment and harvesting indicate the adoption of a polycyclic system with a restricted net timber harvest of about 20 m^2 per ha, once about every 20 years. Timber taken should be of high quality from an accepted list of about 50 species. The low cost of the input, and the quality of the product has to compensate for the low volume output per hectare. Three refinements have to be carried out during the cycle, at a total cost of about ten man-days and 40 litres of arboricide mixture per ha for all silvicultural work, including line cutting.

Refinement reduced phytomass considerably, but regrowth was vigorous. Little leaching of nutrients from the killed phytomass into the creeks that drain the forest occurred. Effects of the reduction of numbers of non-commercial species on ecological stability have not as yet been detected; long-term studies over quite large areas of treated forest are still needed.

Apart from the increased timber production, further advantages of the silvicultural system are that only small changes are induced in the ecosystem, which is a safeguard against ecological disaster, and also retains the possibility to adopt another option in future. Hydrology is changed little, the risk of forest fire differs

Samenvatting

Een bosteeltsysteem voor natuurlijke verjonging van tropisch regenbos in Suriname.

Suriname is een relatief klein land van ongeveer 16 miljoen hectare met minder dan een half miljoen inwoners, en is gelegen aan de noordkust van Zuidamerika. Het is voor meer dan 80% van zijn oppervlakte bedekt met tropische bosformaties. De ontwikkeling van de bosbouw in Suriname heeft zich geconcentreerd in de zogenaamde Bosbouwgordel, een gebied van ongeveer 1,5 miljoen ha, bedekt met natuurlijke bosformaties, en gelegen tussen de slecht afwaterende, laaggelegen kustvlakte en het heuvelgebied van het binnenland. De grenzen van deze Bosbouwgordel worden vooral bepaald door de mogelijkheid om op economisch verantwoorde wijze ontsluitingswegen aan te leggen. Er kunnen drie categorieën van bosteeltsystemen onderscheiden worden: aangeplante monoculturen met exoten of inheemse soorten, lijnbeplantingen met exoten of inheemse soorten, en natuurlijke verjonging, waarbij het oorspronkelijke bos gemanipuleerd wordt.

Beheer blijkt noodzakelijk, vanwege het misbruik dat wordt gemaakt van toegankelijk maar niet actief beheerd bos en andere natuurlijke hulpbronnen. Inkomsten uit bos zijn nodig om effectief beheer van grote bosarealen te financieren, vooral in arme landen. Een bosteeltsysteem dat duurzame opbrengsten garandeert is hierbij ten zeerste gewenst, maar het kost tijd om dit te ontwikkelen en te testen.

Het hier uitgewerkte bosteeltsysteem, het Celos Silvicultural System, is een compromis waarin economische en ecologische aspecten van werkhoutproduktie in het mesofytisch bos (evergreen seasonal forest) van de Bosbouwgordel tegen elkaar afgewogen zijn, terwijl het technisch uitvoerbaar blijft. De ecologische beperkingen hebben hierbij voorrang gekregen boven de economische aspecten. De chemisch arme bodems van de regio zijn gevoelig voor degradatie na ontbossing, en het voedingsstoffenkapitaal van het ecosysteem, grotendeels in de vegetatie opgesloten, dient zoveel mogelijk bewaard te blijven. Dit betekent dat bij gebruik van het bos het hout niet met kaalkap geoogst mag worden. Indien produktie van werkhout het doel is, dan leidt deze gedachtengang tot het kiezen van selectieve kap als beheersvorm. Sociaal-economische overwegingen leiden tot een voorkeur voor extensief beheer met een lage input per ha, maar met een hoog rendement op kapitaal en arbeid. Dit is mogelijk door de overvloed aan bos. Dit beheer gebruikt veel grond, en is alleen acceptabel in dun bevolkte streken. Het bosteeltsysteem is technisch eenvoudig uit te voeren, met veel handarbeid, en is geschikt voor omstandigheden dat er weinig geschoold lager- en stafpersoneel beschikbaar is.

De houtoogst, die de eerste bezigheid te velde bij invoering van geregeld beheer is, dient zorgvuldig gepland en uitgevoerd te worden, om verspilling van kostbaar hout en schade aan de blijvende opstand te beperken. Een besparing op oogstkosten mag niet de voornaamste reden zijn om de huidige lage volumina hout die geoogst worden op te voeren, en de oogst dient met duidelijke aandacht voor bosteeltkundige aspecten uitgevoerd te worden. De te oogsten hoeveelheid dient beperkt te worden tot wat zonder al te grote schade genomen kan worden, wat afhangt van het gebruikte oogstsysteem, het staande volume en de afmetingen van de handelshoutsoorten.

Bosteeltkundige behandelingen na de oogst zijn noodzakelijk ter bevordering van de bijgroei van de handelshoutsoorten in de blijvende opstand. De mortaliteit is in licht geëxploiteerd bos slechts weinig hoger dan in ongerept bos, maar het herstel van het oorspronkelijk volume aan handelshoutsoorten gaat zeer langzaam, vanwege de sterke reductie van de populatie van bomen van deze soorten. Het is niet mogelijk een tweede houtoogst uit te voeren op economisch verantwoorde wijze binnen een periode van vijftig jaar, bij een gelijk gebleven lijst van handelssoorten. Een voortdurend bijstellen van deze lijst ter verkrijging van voldoende oogstvolume per ha, zal gemakkelijk leiden tot een verslechterde marktpositie van het hout. De reden is dat de kwaliteit achteruit gaat, of dat de prijs zal stijgen omdat de verwerkingstechnieken duurder zijn geworden.

Uit sinds 1965 gevolgde houtteeltkundige veldproeven werden gegevens verkregen omtrent de mogelijkheden om de groei en mortaliteit van waardevolle houtsoorten in het sterk gemengde natuurlijke bos te beïnvloeden door teeltmaatregelen. De belangrijkste van deze teeltmaatregelen is het verminderen van de concurrentie in de opstand. Dit hield het beperkt gebruiken van krachtige arboriciden in, met aanwending van veel ongeschoolde arbeid. Er werden geen machines gebruikt bij de teelt, behalve voor vervoer van personen en middelen.

De toegepaste teeltmaatregelen, aan te duiden als zuiveringen, bieden compensatie aan de handelssoorten voor de selectieve druk van de oogst. Ze worden besproken in het kader van de natuurlijke dynamiek van het bos. De gaten welke ontstaan door neerstortende levende bomen of staand afstervende bomen verschaffen in ongerept bos ruimte aan andere bomen om zich te ontwikkelen. Deze processen worden versneld en geïntensiveerd door de houtteeltkundige behandelingen, maar niet zozeer dat de bosstructuur grotendeels teloorgaat en het ecosysteem ontredderd wordt. De bijgroei aan verkoopbaar hout neemt vijf- tot tienvoudig toe door de beste behandeling, en dit verkort de kapcyclus aanzienlijk.

Gegevens omtrent bijgroei en aspecten van de oogst geven aanleiding een polycyclisch systeem voor te stellen, met een beperkte houtoogst van netto ongeveer 20 m^3 per ha, eens in de circa 20 jaar. Het te oogsten hout dient van hoge kwaliteit te zijn. Hierbij wordt een lijst van ongeveer vijftig geaccepteerde handelssoorten gehanteerd. De lage teeltkosten en de kwaliteit van het produkt moeten compensatie bieden voor het lage oogstvolume per ha. De zuivering wordt drie maal uitgevoerd gedurende de kapcyclus van twintig jaar, en de totale kosten bedragen ongeveer tien mandagen en veertig liter arboricidemengsel per hectare voor alle teeltkundige werk, inclusief lijnenkap.

De zuiveringen reduceerden de fytomassa aanzienlijk, maar er trad een krachtige hergroei op. De uitspoeling van nutriënten uit de gedode fytomassa met het door de boskreken afgevoerde water bleek gering. Invloed van de vermindering van de aantallen bomen van niet-handelssoorten op de ecologische stabiliteit kon tot nu toe nog niet worden vastgesteld. Langdurige onderzoeken over vrij grote arealen behandeld bos zijn daarvoor nog nodig.

Behalve de toegenomen aanwas van handelshoutsoorten, zijn verdere voordelen van het teeltsysteem dat slechts geringe wijzigingen in het ecosysteem aangebracht worden. Dit biedt beveiliging tegen ecologische rampen, en laat ook de mogelijkheid tot ander grondgebruik voor de toekomst open. De hydrologie wordt nauwelijks beïnvloed, het gevaar voor bosbrand is niet groter dan voor het oorspronkelijke bos, en de opbrengst aan bosbijprodukten kan grotendeels behouden blijven, voor zover de beheerder dit aantrekkelijk acht. Verwaarlozing van eenmaal behandelde opstanden is niet zo nadelig als bij bosaanplant en resulteert voornamelijk in verminderde produktie aan handelshoutsoorten. Het teeltsysteem wordt in het kort vergeleken met aanverwante systemen in andere delen van de wereld.

Aangaande de praktische uitvoering van het systeem worden de veldwerkzaamheden besproken, het gebruik van arboriciden om ongewenste bomen te doden, de lijst van preferente soorten, en de kosten van de werkzaamheden. De laatste worden ook vergeleken met die in andere streken.

Het derde deel van het boek behandelt de vier grote houtteeltkundige proeven welke de gegevens leverden waarop het concept stoelt. De proefnemingen waren beperkt tot mesofytisch bos in de Bosbouwgordel, aangezien dat de vegetatie met de beste mogelijkheden voor houtproduktie was. De onderzoeksmethoden lagen meer in de lijn van het benaderen van het bos als een ondoorzichtig systeem (black box), waarbij proefpercelen teeltkundig behandeld en vervolgens bestudeerd en gemeten worden gedurende lange perioden, dan dat gewerkt werd aan het opstellen van theoretische modellen van boomgroei of bosontwikkeling. De behandelde proefopstanden werden gedurende zeven tot 15 jaar gevolgd, meestal met jaarlijkse metingen. De opzet van de proeven was niet altijd optimaal, maar het scala van behandelingen bleek een goede greep te zijn geweest. De metingen beperkten zich merendeels tot de gebruikelijke opname van omtrek op borsthoogte, inheemse naam, vorm en conditie van de te meten boom, en opname van het totale grondvlak van een opstand. Daarnaast werd informatie verzameld over behandelingskosten en organisatie van de behandelingen, waaraan in later jaren de resultaten van ecologisch onderzoek aan parameters van belang voor de bosteelt werden toegevoegd. De gegevens werden met de computer verwerkt, waarbij de uitdraai zeer eenvoudig werd gehouden, om recombinatie van voorlopige resultaten van berekeningen mogelijk te houden.

De resultaten van de proeven worden gebracht in tabellen en figuren, waaronder ook bosprofieldiagrammen en stereofoto's van de vegetatie in de proefperken.

De opzet van het eerste experiment dateerde uit de periode dat de aandacht gevestigd was op monocyclische beheerssystemen. Daardoor was deze proef meer gericht op de vorming van een homogene opstand met zaailingen en staken van de handelshoutsoorten dan op het verbeteren van de opbrengst van verkoopbaar hout op korte termijn. De proefresultaten over een periode van 14 jaar wezen op goede mogelijkheden om de aantallen staken en middelgrote bomen op te voeren, door doden van bomen van niet-handelshoutsoorten. De resulterende opstand kan echter volgens huidige maatstaven niet als optimaal worden beschouwd, noch qua bosstructuur, noch in economisch opzicht, daar de monocyclische benadering tot hoge kosten leidt en tevens tot ongewenst homogene bossen.

In het tweede experiment werd de dynamiek in licht uitgekapt bos zonder verdere houtteeltkundige ingrepen bestudeerd, over een periode van negen jaar. Groei en mortaliteit bleken tot een lage produktiviteit aan handelshoutsoorten te leiden, te laag om een beheersysteem op te baseren.

Het derde experiment omvatte de toepassing van een aantal behandelingsschema's en behandelingsmethodieken in licht uitgekapt bos welke gevolgd zijn over een periode van 12 jaar. Enkele van de onderzochte behandelingsschema's hielden de mogelijkheid in van toepassing van een polycyclisch systeem, en hierop vooral is de aandacht gericht geweest bij de bespreking van de proefresultaten. De interpretatie van de resultaten werd bemoeilijkt door de relatief geringe aantallen bomen die per behandelingsschema bestudeerd konden worden. De gemiddelde omtrekgroei per diameterklasse bleek de beste aanwijzing te geven of een behandelingsschema geslaagd was.

Het vierde experiment was een proef op semi-praktijkschaal, om het in het vorige experiment optimaal bevonden behandelingsschema te testen. De tijdspanne was te kort om definitieve gevolgtrekkingen toe te staan, maar de populatie van bomen van handelshoutsoorten was in het meetplot van 16 ha groot genoeg om een eerste schatting van het oogstbaar volume aan het einde van de eerste kapcyclus mogelijk te maken. De structuur van de opstand bleek langzamerhand weer acceptabel te worden, nadat hij eerst was verslechterd door de houtteeltkundige behandeling. De houtoogst wordt zeer vergemakkelijkt door een open ondergroei aan het eind van de cyclus.

Het Celos Silvicultural System werd ontworpen voor grote aaneengesloten arealen licht verstoord mesofytisch bos in de Bosbouwgordel, om een duurzame bron van hout voor de industrie te vormen en om veel arbeidsplaatsen te verschaffen op een ecologisch aanvaardbare wijze. Het systeem kan zich verder ontwikkelen en een hogere doeltreffendheid bereiken, maar dat zal alleen gelukken bij uitvoering door toegewijde bosbouwers.

Part I

Silviculture in Suriname

1 Silviculture in Suriname

1.1 General information about Suriname

In the seventeenth century, the Dutch established the colony of Suriname on the northern coast of South America. During the succeeding centuries much of the low-lying coastal area along the natural waterways was developed for agriculture, and agricultural products were the mainstay of the economy. During the twentieth century the bauxite mining industry developed, and finally dominated the economy. The timber industry has been only of minor importance, contributing 2-3% to the gross domestic product and is located mainly in and around the capital city, Paramaribo.

Suriname has a small population of less than half a million which occupies approximately 16 million ha. During the colonial period, the population became quite heterogeneous as a result of the import of slaves from Africa and later, contract labour from India and Indonesia. The original Amerindian population may very well have numbered more than half a million, but numbers dwindled early in colonial history as a result of imported diseases, and in some cases, raids. At present as a separate group, they form only 2% of the total population, but they have mixed with the other groups. The population of Suriname is concentrated in the coastal area, especially in Paramaribo and in the productive rural areas. Only 10% live in the interior, which is now largely uninhabited. However, before the seventeenth century quite a large population must have lived there, as shown by abundant potsherd finds during road construction (Boerboom and Wiersum, 1983).

Suriname can be divided roughly into four landscape types: the young coastal plain; the old coastal plain; the Zanderij or cover landscape; and the basement complex or interior uplands. Young and old coastal plain are almost flat or only elevated a few metres, and generally have heavily textured and badly drained marine clay soils interspersed with sandy areas. The Zanderij landscape (see Fig. 1.1) with predominantly sandy and sandy loam soils, tapers from about 70 km wide in the west to about 10 km wide in the east. The landscape is slightly undulating, and generally well drained by many creeks in a dendritic pattern. The basement complex covers the remaining 80% of Suriname, and has soils formed on metamorphic igneous and sedimentary rocks of the Guyana Shield. The landscape is undulating, with *in situ* developed deeply weathered soils, which generally have a high clay

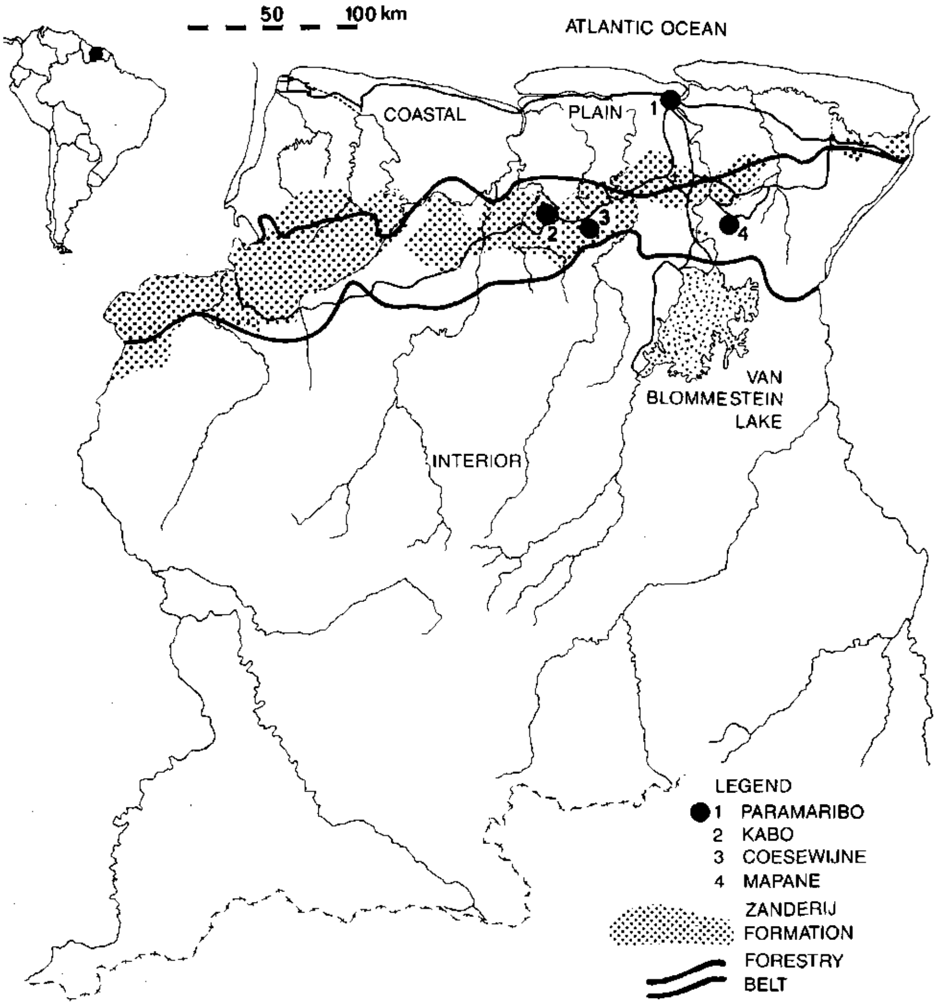


Fig. 1.1 Map of Suriname, showing location of the Forestry Belt, and forest research areas.

content, but are mostly well drained internally.

Dominant vegetation in these landscapes is forest, which covers more than 80% of the total surface area of the country, with open areas dominated by herbs and grasses mainly in the coastal plain and Zanderij landscape and in the extreme south. Most of the potentially accessible mesophytic high forest, which is the main source of timber, is in the last two landscapes mentioned above. According to the classification of Beard (1946, in Boerboom, 1964), these mesophytic forests are included in evergreen seasonal forests. Other types of exploitable forest, but probably of less importance for permanent forest management, are swamp forest in the coastal plain, marsh forest along the water courses and high savanna forest on excessively drained soils. These have been described in detail by Lindeman and Moolenaar (1959), and more concisely by Vink (1970). Recently, a detailed colour vegetation map of the coastal area has been completed by Teunissen (1978).

Soil maps have been prepared by the local Soil Survey (Dienst Bodemkartering) on various scales. Parts of the map of scale 1 : 100 000 are reproduced in Figs 6.1 and 6.2.

The climate of Suriname is warm and humid. Mean daily air temperature on the coastal plain is about 27 °C, with an annual range of about 2 °C and a daily range of 8 °C. Fluctuations increase southwards. Mean annual rainfall on the coastal plain is about 2 200 mm, with a long dry season from August to the beginning of December, and a short dry period in February to April. In the system of Köppen, the climate is indicated as Af, and further south as Am. The 30-day totals in the dry seasons in some years can be reduced to values far below the 60 mm limit for dry months assumed in the Köppen system.

Relative air humidity is high, about 80%, but decreases in the daytime and often rises to almost 100% at night. The wind blows regularly from the northeast or the southeast or inbetween, depending on season and time of the day. Immediately before and during rainstorms, sudden and relatively strong squalls often uproot big trees, which is an important factor in forest regeneration.

1.2 Forestry Belt

Vink (1970, p. 13) defined the Exploitable Forest Belt as 'a 10-40 km wide forest zone south of the Zanderij Belt with its low-value forest, and north of the rugged hill country and the rapids. In this zone the high tropical lowland forest on unbleached Zanderij soils and Basement soils attains its best development on relatively level, readily exploitable terrain, within economic reach of the wood-consuming centres in the coastal area. The forest belt comprises some 1.4 million ha, but in view of topography and stand composition only some 600 000 ha are considered (potentially) productive, including some xerophytic forest north of the actual belt.' The Exploitable Forest Belt is referred to in this study as the Forestry Belt (see figure 1.1).

According to Vink (1970), about four-fifths of the *Virola* stands in the swamp forests on the coastal plain, half of the marsh forest, and one-third of the Forestry Belt had been partly exploited. The area of potentially manageable forest for timber production is quite small in comparison with the total area of Suriname of approximately 16 million ha. This area is also of little importance for hydrology and nature conservation because most of it is level or slightly undulating, and does not have outstanding vegetation.

The mesophytic forest in the Forestry Belt grows on freely draining soils which have good water storage capacity. Many tree species are present, and generally no species predominate, although patches of forest occur in which one species occurs in high frequency. The height of the forest varies from 25-38 m with an occasional tree reaching more than 50 m (Schulz, 1960). An indication of the floristic composition of this forest type can be obtained from the list of species harvested in the Weyerhaeuser Sample, (see Appendix III).

This mesophytic forest in the Forestry Belt is the source of most timber and some plywood logs used in Suriname (Boerboom, 1964; Vink, 1970). These products can bear some transport cost, and are hauled as logs to Paramaribo over distances in excess of 200 km. The market for poles, fuelwood and other forest products is limited, because of the small population especially in the Forestry Belt, and the relatively high cost to transport these products to the coastal area.

Little forest has been cleared for regular farming in the Forestry Belt, except for traditional slash-and-burn subsistence farming, because much potentially arable soil is available in the coastal area. Recently, oil palm plantations extending over thousands of hectares have been established in the Forestry Belt. Since 1950 the Forestry Belt has been opened up by a network of gravel all-weather roads which now comprises more than 2000 km.

'There is no officially formulated Forest Legislation in the proper sense. No Forest Reserves have been legally constituted as yet and there is no legislation concerning the definition and delimitation of forest lands'. (Vink, 1970, p. 31). In 1947, the Timber Ordinance together with other regulations concerning the forest estate was passed. This ordinance regulates exploitation of timber and forest products except for balata on government land, by granting timber concessions and licences to collect other products (Vink, 1970). According to Fraser (1973), this system 'regulating' the exploitation of timber and other products should be revised. Most land in the Forestry Belt is government owned.

A reason to establish plantations has been the lack of legal control over the harvest in the country's forest estate (Fraser, 1973). This seemed the only way for the Forest Service to guarantee future timber supplies.

1.3 Silvicultural systems in Suriname

Several approaches have been adopted in Suriname to obtain forest stands which are economically more productive than the high mesophytic forest after exploitation. Few of these approaches have passed the first screening tests, and have been applied to extensive areas. They can be classified roughly into three categories: uniform plantations after clearing; strip planting in partly exploited forest; and natural regeneration systems. These three categories have been discussed in very early publications (Plasschaert, 1910).

1.3.1 Uniform plantations

Uniform stands in single species are very attractive from the point of view of forest management, and silviculturists have often tried to create such forests to replace the species-rich and bewilderingly complex tropical rain forest.

There are examples of natural high forest stands consisting of only a very few species, such as the *Mora* sp. forests along the Corantijn River, the *Eperua* sp. forest along water courses, and the *Dimorphandra conjugata* stands on very poor white sands which are subject to periodical burning. Often the extreme site conditions allow for the supremacy of one or a few species, excluding the usual mixture of species which grows on well-drained soils in this climate.

The most conspicuous forest cultures seen on visits to the Forestry Belt are the plantations of *Pinus caribaea* Morelet (Barrett and Golfari, 1962). The variety most planted is *P. caribaea var. hondurensis* (Vink, 1970). Started as an attempt to grow cheap pulpwood on easily cleared soils under savannah brush, the system has evolved into one of timber producing plantations on cleared soils previously under high forest. The pine is grown in even-aged monocultures. The major problem is the vulnerability of young cultures to weed growth, including secondary forest tree species and lianas. The weeds remain a problem even in older stands, especially after thinning. Further information about this pine culture can be found in Vink (1970) and de Vries et al. (1978). Clearing for pine planting was done with bulldozers, and became very expensive after the oil crisis in 1973. Since then, wages have continued to rise and productivity of labour to fall considerably (Fraser et al., 1977) with the result that pine planting has ceased. By 1977, about 8000 ha of pine cultures had been successfully established.

Uncertainty has been expressed about the feasibility of sustained yields of this crop (Lundgren, 1980; Boxman, 1982). Clearing of the high forest with heavy machinery, such as D-8 bulldozers, is destructive to the soil structure especially in wet conditions, and also disturbs the nutrient cycle which is very important on these poor soils. Clearing by hand, as for example was done in the Jari Enterprise in Brazil, does not disturb the soil structure, but upsets the nutrient cycle to some extent. Leaving the residue of the burned vegetation scattered over the area is preferable to pushing the vegetation into windrows to be burned. Nevertheless, the nutrient cycle is disturbed and the pine has to start its own cycle, which it does, otherwise it would not continue to grow. The final clear felling again has a heavy impact on the nutrient cycle (Lundgren, 1980). As yet no decisive results have been obtained from studies on yield of this pine planting system over a second rotation, let alone several rotations.

1.3.2 Strip planting

A silvicultural system applied to areas of several thousand hectares is strip planting (Vink, 1970). This system was first introduced on a commercial scale in 1969. Young plants of a valuable timber species are planted in strips running east-west, which have been cleared by hand in exploited forest. The distance between the strips is 7 to 10 m, and distance between the plants or groups of plants in the strip a few metres. To provide enough light, the upper storey is killed with arboricides, and as a result a thicket full of lianas develops between the strips. Frequent weeding is required in the strips. In this system the degree of destruction of the original forest is not so important, and previous heavy exploitation has the advantage that it reduces the need for canopy opening.

A variety of tree species, some exotic but mostly local species, have been tried in Suriname. Of the exotic species, *Cordia alliodora* was successful in its early years. Other species which were reasonably successful were *Virola surinamensis*, *Simarouba amara*, *Sterculia* spp., *Cedrela* spp. and *Bagassa tiliaefolia*.

Strip planting requires rapid growing and valuable timber species to restrict the need for maintenance and to compensate for the relatively high cost. The native *Cedrela odorata* and other *Cedrela* species are examples of such valuable timber species, but they are not easily grown in uniform and healthy stands, partly because of the ubiquitous shoot borer of the Meliaceae. Strip planting is less feasible for less valuable species. Vink (1970) estimated the costs at 50 man-days per ha for a rotation of 25 years, plus the cost of more than 100 litres arboricide mixture. Vega (1981) made a similar estimate. Because of the frequent treatment required, this system is difficult to organize over large areas necessary for commercial production. The openness of the stand necessary for rapid growth of the trees stimulates a dense growth of lianas which is a constant threat to the stand. Even with adequate tending, growth seems to slow down quite early.

In the system of enrichment planting, which is similar to strip planting, use is made of advance growth of valuable species in the exploited forest. This advance growth is tended together with the planted individuals to form a uniform crop after about 40 years, and includes trees of intermediate size, which are not yet harvestable. If plentiful, they tend to suppress the plantation below. Planted seedlings or saplings do not get a good start in the highly competitive environment. It has often been observed that growth is more rapid in naturally seeded individuals than in planted individuals. A uniform stand at the end of the rotation will not be obtained, because the larger trees grow much faster than the small trees.

Although intended as uniform stands, they will eventually become heterogeneous forest, resembling naturally regenerated forest. An important difference is the large investment made in the planted individuals. Early estimates of productivity were quite optimistic and indicated a larger final volume of timber than originally present in virgin forest, as about 300 m^3/ha or about 150 trees of 2 m^3 volume each were expected to be grown in 40 to 50 years (Vink, 1970). The rapid growth during first years partly as a result of intensive care may have led to this assumption.

Thus in summary, it is not clear whether sustained yield is possible with intensive systems such as in the planting of pine and other monocultures. Strip planting leaves virtually nothing of the original tree vegetation except an abundance of weeds. Mechanical damage to the soil structure is negligible because all work is done manually and chemically. Further, the original forest is eliminated over a period of several years which makes changes less abrupt. However, the nutrient cycle is disrupted considerably compared with the original situation, although in the enrichment planting system the disturbance is less severe than in most other systems of planting.

It is debatable whether strip planting and enrichment planting are really separate systems. Both require intensive treatments, and have in common the assumption that spontaneous forest regeneration is not a sufficient basis for silviculture. Both systems lead to monocyclic management aimed at establishing a close stand of large trees to be harvested in one operation. In Suriname, both have been introduced in only partly exploited forests, which provide much dead organic matter in the first few years. Only strip planting is possible after heavy harvesting, as was done for example in the Weyerhaeuser Operations in 1969/1970. On the other hand, when more experience has been gained with forest enrichment systems, the shift may be to a system of full natural regeneration. This is because underplanting the existing vegetation with its established trees will not improve the volume production very much in the first two decades, even after drastic opening of the canopy. Increment will concentrate on the large trees already dominating the site (see also the experimental results in Part III).

1.3.3 Natural regeneration

This is another approach to forest regeneration. In Suriname, the term natural regeneration is often used to refer to any treatment of the original forest in order to grow more timber without additional planting. As this system is the main subject of this book, it is reviewed only very briefly in this chapter. Natural regeneration techniques have been applied in Suriname on a very limited scale, over areas of several hundreds of hectares only.

Early research led to a silvicultural treatment scheme which was too expensive to apply extensively on a commercial basis in Suriname (Vink, 1970). However, natural regeneration has continued to be of interest as it was known that this approach may result in appropriate extensive management methods. Such a system has advantages on poor soils with very limited prospects for development, as over large areas of Suriname (see also Synnott and Kemp, 1976).

The basis of this system is the process of regeneration in natural forest, going on before exploitation or other human interference. In this system of forest management, processes are directed and stimulated but not excessively; the greatest restriction is on harvesting.

1.4 Need for management of tropical rain forest

'Dagoe abi foeroe masra, go slibi angri' (A dog with many masters goes to sleep hungry; Surinamese proverb).

Why not refrain from interfering in the remaining areas of virgin or lightly exploited tropical rain forest? This ecosystem does not require management in the same way as the semi-natural landscapes in North America and Europe. For many people the demand for timber is not a legitimate reason to attack these forests.

The first task of forest management is conservation, but funds are required for this purpose. Such funds can be raised by levying visitors to outstanding nature reserves, but this is not possible in most tropical rain forest areas. Moreover, most countries with large areas of tropical rain forest cannot afford to use much taxpayers' money for forest conservation. Therefore, forest management must be financed by the sale of forest products.

A well-designed silvicultural system can assist forest conservation by guaranteeing the source of valuable products. A plundered forest is one large step nearer to destruction by shifting cultivation, other agricultural use, or plantations, than a forest with a good store of timber. In practice, timber concessionaires lose interest in their concession areas once the timber has been harvested. Even nature conservationists have little interest in such areas, and often only the silviculturist and the forest manager are interested in them to restore productiveness by systematic management.

Having an ecologically and financially acceptable silvicultural system at their disposal means that foresters, debating land use planning, need not immediately retreat when more intensive land use is proposed by agriculturists. Economic feasibility of forest management is a good shield against forest destruction.

Thus the most important factor preventing degradation of forests is the economic benefit to be gained from maintaining them, for example for the production of timber or other products, or prevention of erosion of catchment areas. Soils suitable for other forms of rural production, such as pastures or cropping, in the long term can only be kept under forest provided the forest offers greater economic return. If not, then the forest area will be reduced to an absolute minimum, that is to protection forest and nature reserves.

This does not mean that other motives are not important, but that these may be diminished under the constant pressure of the economic needs. Forest legislation that compels a landowner to maintain forested areas and even to replant certain areas, may greatly assist forest conservation in the short term, but may also develop into a straight-jacket, taking away the co-operative spirit. Enthusiasm is required, not aversion, to obtain or maintain good productive forest.

Silviculture is caught between the minimum requirements of the exploitation, harvesting timber and other products to pay for management, and the ecologically limited elasticity of the forest ecosystem to bear exploitation and the other manipulations necessary for management. This is the management problem which silviculture must try to bridge.

The need for sound silvicultural systems is clear. Once a practicable system is found, forest management can expand and have a functional place in society. When the local population derives its main income from the forest thus managed, the forest is safeguarded far better than by strong legislation without effective local support. A strategy of wise use is more effective for conservation than a purely defensive strategy. Pressure for agricultural land often forces governments to issue land which is unsuited to such purposes. However, with greater consideration; land use based on forestry may be established to provide employment, with less ecological damage and perhaps with higher return on the capital and labour invested. The optimum situation would be not to have individuals grow their own food, but to provide an adequate income for everyone.

Natural allies of the forester should be the timber industries, because they are very dependent on the forest resources. Better education should make short-term views obsolete.

The semi-natural forests created by the type of silviculture described in this book will blend better with interspersed virgin forest reserves than do other economically productive forms of land use. This view is supported by many, including Baur (1964), Goodland and Irwin (1975), and Poore (1976).

Part II

Celos Silvicultural System

2 Celos Silvicultural System: basic concepts

2.1 Development of a silvicultural system

In this chapter, criteria are discussed for the selection of a silvicultural approach to the mesophytic high forest in the Forestry Belt of Suriname. Silviculture may be defined as the handling, including the design and establishment, of forest ecosystems, to produce the forest products and services required. A silvicultural system is then the way in which silviculture is organized. These definitions are pretentious; silviculture can probably never give more than a simplified manual for handling a complicated ecosystem that possibly can never tbe fully understood, and which can only be directed in part. In the definition, producing is not a synonym for harvesting; forest exploitation does not produce wood, it transforms standing trees into logs on the landing. Often exploitation plays a prominent role in a silvicultural system, especially in the system proposed in this book, but it is the tree that produces timber. In the case of tropical rain forest, many tree species probably need a fairly complete forest ecosystem to finish their life cycle, and thus silviculture is not simply the manipulation of trees only.

A silvicultural system is usually developed in practice, arising out of a need to find solutions to practical problems. This can lead to a system which is little more than a patchwork of ad hoc solutions. Theoretical systems, on the other hand, can be useful to set thoughts, but often flounder on the many obstacles presented in practice. The Celos Silvicultural System presented here has been developed from results of small-scale experiments, subsequently tested on a semi-practical scale for several years, and should now be tested on a large scale.

A silvicultural system is only part of the whole complex of forest management, although lying at its base. Forest management itself needs to be directed by a clearly formulated forest policy, and to be supported by legislation. Especially in Suriname now, legislation on forest management needs to be strengthened (Fraser, 1973).

In management planning of an existing forest area, firstly a decision has to be made on which part of the forest is to be managed permanently, or which part will be managed temporarily until another type of land use has been established. Then the choice has to be made between the diverse management options available to fulfil the development strategies for the demarcated forest estates.

The Celos Silvicultural System was designed to produce timber logs and peeler wood, in a forest estate large enough to feed an economically viable timber processing unit. Production of pulpwood or fuelwood was not envisaged, and even does not fit into the concept. Another type of silvicultural system must be applied to produce these raw materials.

A silvicultural system must balance socio-economic and ecological requirements in a technically feasible way. These three aspects govern the choices to be made, and absolute priority given to one may affect deleteriously the ultimate result. Purely ecological aspects do not change with time as much as socio-economic aspects, which depend on changes in society.

Reactions of the ecosystem to certain interference can be tested theoretically and described, and the information can be used to design a silvicultural system, once present socio-economic requirements have been formulated. With changing socio-economic circumstances, the ecological aspects can be re-arranged and a system designed more appropriate to the actual situation. From this it follows that a silvicultural system needs to be flexible, also because it needs to function for long periods, in large, often little known, forest areas, and for a constantly changing timber market. Research in ecology should establish the limits to manipulation of the forest ecosystem to guarantee the sustained yield.

The problem with this approach is that socio-economic requirements tend to override ecological constraints. Time is always short, and degradation of forest ecosystems becomes acutely manifest only in extreme cases. In western society man has become so accustomed to adapting the environment to his needs, that he no longer considers adapting himself to the environment. On the other hand, research to provide a sound silvicultural system, with sustained yield, must not degenerate into seeking the solution that does no harm to the original ecosystem, especially in forest areas still untouched, but destined for permanent timber production. Inevitably a compromise must be made. A certain guarantee for soundness is derived from adhering closely to the natural processes in the virgin forest, which is probably in good ecological balance.

2.1.1 Socio-economic considerations

In Suriname the socio-economic considerations determining the selection of a silvicultural system are the need to safeguard resources of timber logs and peeler wood, and the low population density in the Forestry Belt. The forest should provide employment, but forest labour is relatively expensive, because labourers have to be transported into the forests and provided with living quarters and facilities. A large area of forest has been selectively felled once, and even though only lightly disturbed, this forest now has a low productivity per hectare. Transport cost largely determines the cost of logs at the sawmill, and extensive felling in ever more remote areas increases these costs (Vink, 1970). Thus productivity needs to be enhanced in the forest areas opened up by roads but which at present are largely unmanaged.

The level of education of potential forest labourers is low, and qualified staff is scarce. Abundance of forest, shortage of staff and capital, and extensive exploitation methods, all point to an extensive management system with a low input per hectare.

2.1.2 Ecological constraints

Ecological constraints to silvicultural interference in the mesophytic forests of the Forestry Belt need not be sought in the climate. The relatively short dry periods do little damage to the tree population, and the heavy rainfall is generally favourable to vegetation growth. Windthrow rarely occurs in whole stands, but mostly in individual trees in poor condition. Forest regeneration mainly occurs in small gaps made by the death of individual trees.

Clear felling of this forest results in serious silvicultural problems. Harvesting large amounts of biomass not only removes much of the available nutrients, but leads also to rapid development of secondary forest of low economic value. Advance growth and seedlings of desirable species left after clear felling do not compete well with the secondary vegetation. Re-establishment of desirable primary or late secondary species is difficult in large clear felled areas which create large distances to seed bearers in less disturbed forest. Establishing plantations is labour intensive under these conditions, because without intensive weed control secondary succession takes over. Pests and diseases can become serious problems in this climate.

The success of plantations and annual cropping systems depends largely on the fertility and physical conditions of the soil, but the development of native forest in Suriname seems to depend mainly on the water-holding capacity of the soil and its aeration (Schulz, 1960). This is probably because the nutrient cycle of the forest is more important than the soil as a source of nutrients. Evidence of this is the overlapping of high forest on small patches of bleached sand surrounded by high forest on less degraded soil. Such patches show up clearly on aerial photographs after deforestation and replanting with pine. This overlapping has originally been ascribed to the effect of the subsoil (Schulz, 1960).

In the hot humid climate of Suriname, chemical and biological processes in the soil proceed much faster than in temperate regions. Recent studies in Suriname and also in other tropical countries with poor soils have shown that most of the available nutrient store in the forest ecosystem is located in the living forest and also in the dead timber in it (Ohler, 1980; Schmidt, in press). Recent studies in the northern hardwood forest of the USA indicate that in a temperate forest there is a large store of nutrients in the forest floor and in the mineral soil and subsoil. This store is not removed when clear felling occurs, but forms a reserve, which is depleted in the phase of the 'Aggrading ecosystem' in which the forest ecosystem rebuilds (Bormann and Likens, 1979).

In Europe, as early as the nineteenth century, it was argued that the forest floor should remain in the forest, and not be sold to horticulturists and farmers. However, it was assumed that all timber could be removed because it was a readily saleable product. Only recently, in Europe and USA, the role of the dead timber in the forest ecosystem has been reconsidered at a scientific level.

Nutrient reserves of the forest ecosystem are supplemented with nutrients filtered from air and rain by the living and dead biomass. Deeply weathered soils play a minor role in increasing the nutrient store in the forest. Periodic enrichment of forest ecosystems by dust, especially volcanic dust, may be an important source of nutrients, even when volcanoes are remote and eruptions rare. The more the forest is developed, the better its filtering and retaining capacity become.

Overall temperature and location of nutrient store are some of the main differences between the forest of Hubbard Brook in which the work of Bormann and Likens (1979) was carried out, and the mesophytic forest in Suriname. The high temperatures together with the poverty of the soil and subsoil in the Forestry Belt menace the long-term productivity of the soil under a system of clear felling (Boxman, 1982). The only way to maintain the nutrient store in the original ecosystem seems to be to maintain a large biomass, which slowly releases and recycles its nutrients and which has a high filtering activity. This is the concept of *biomass-dependent site quality.*

Silvicultural manipulations have to be compatible with this. Consequently uniform plantation methods, which require the removal or killing of most or almost all biomass above ground before planting and at harvesting the plantation, are less well adapted to the soil and climate than, for example, polycyclic fellings together with silvicultural manipulation of the stand. (See also Uhl, Jordan and Herrera, 1982).

Polycyclic systems, in which only part of the timber is harvested at one time, are often considered to be second rate in comparison with monocyclic high forest systems (Dawkins, 1958; Synnott and Kemp, 1976; Assmann, 1970). Polycyclic systems are considered by some to lead to degradation of the forest within a few felling cycles. The risk of forest plunder is introduced into the forest with every cyclic felling, whereas in monocyclic systems the impact of clear felling is felt only once in a long period of time.

Often, monocyclic systems are preferred in newly opened tropical forest regions to be managed, simply because they allow harvesting of all naturally grown timber at one time. Short-term profit then may supercede long-term considerations. To save some of the timber reserves from liquidation, that is to leave timber trees to reap a better harvest in the future at lower cost of growing, is a test of the credibility of intentions about forest conservation.

2.1.3 Technical feasibility

In Suriname, a technically feasible solution must be relatively easy to put into practice and also to administer, because forest management is not as yet well developed. In addition, after some years, this basic simplicity may be encumbered with procedures needed to correct management errors. A more productive silvicultural system, which requires intricate procedures, may not be suitable because of its complexity and high demands on staff. According to Brasnett (1953), a practicable system of management is important '..... because while management which is not based on good silviculture definitely harms a forest, silviculture which is not organized in a manageable manner breaks down and leads to nothing but confusion'.

A single approach by a research worker probably will not lead immediately to a satisfactory silvicultural system. According to Troup (1928), a good silvicultural system evolves rather than is designed.

Several stages in development of the management of a previously unmanaged forest can be distinguished. Exploitation of existing timber resources is usually the first step to regular forest management. The large investments in infrastructure necessary for exploitation, together with future perspectives for the timber and forest-based industry, require careful consideration to be given to possible sustained yield of the forest areas opened up.

The two-cycle method described by Brasnett (1953) may be used to regulate the yield of less accessible forest with low timber volumes for the initial exploitation but with a reasonable stock of middle-sized trees to be harvested in several decades to come. This system has been worked out for Suriname by Bauer et al. (1975). The main problem in this approach is that in Suriname the low annual volume increment of desirable species in only lightly exploited but untreated forest makes the cycles quite long. The expensive infrastructure required will become a heavy burden, because of the frequent maintenance required for roads, bridges, camp sites, etc. Patrolling extensively used and large forest areas is also relatively expensive. Assumptions about growth and mortality, and especially about the marketability of species, tend to be unreliable over such long periods. The whole approach lends itself to over felling in the stand, because intensive control is not possible. Annual harvest of timber logs would be about 12 500 m^3 from an area of 50 000 ha (Bauer et al., 1975), that is about 0.25 m^3 per ha on an annual basis. This is in agreement with the increment found in CELOS research in lightly exploited forest (see Chapter 6).

Higher production per ha is required, and can be attained with an adequate silvicultural system, such as is described in this book. This system was developed from the results of experiments carried out in the Mapane and Coesewijne Region (see Fig. 1.1) over a period of about 15 years. These experiments are discussed in Part III. The system is still basically a general and simple approach to be improved on the basis of further experiments.

2.2 Brief review of experimental results.

Silvicultural research carried out by the Forest Service before 1965 had shown that the increment of desirable species can be increased by applying refinement and liberation treatments to exploited forest. Refinement and liberation both reduce competition in the stand by selectively favouring desirable species. The concepts of refinement and liberation accepted in Suriname were those defined by Dawkins (1958, p. 104). Refinement is 'The general removal of weeds, defectives and proscripts (whether they are impeding desirables or not), in the interest of complete utilization of the site by the desirable crop', and liberation is 'The freeing of desirables from inferior competitors, by removal of impeders, within the limits appropriate for their age and size'. In certain cases the operations are identical, as is shown in the discussion of experiments. From the beginning the meaning of refinement even may have shifted between 'eradication of all non-commercial species' and 'general removal of unwanted vegetation'. The latter is preferred, as more insight into the ecological balance should make one cautious of declaring a species of no use or even harmful to some commercial objectives. Use of the site for exclusive production of commercial timber species only, may in the long term be unwise, as this could lead to reduced stability of the ecosystem (see also Section 2.4). Refinement means killing of vegetation, mostly trees and lianas which have no value for the future crop. Sometimes trees can be killed by girdling alone, but usually they have to be killed by a combination of girdling and application of arboricide. Lianas are killed by cutting, and occasionally arboricide is required. A certain diameter limit is kept with this work. Dawkins (1958) refers to removal, but here the biomass killed is left in the stand to decompose.

Early research in Suriname had shown that large numbers of saplings and small trees could be obtained from existing natural regeneration. Growth was stimulated selectively by an initial refinement, in which the overstorey of non-commercial tree species was killed. This had to be followed by a series of liberations. Treatments to induce seeding and seedling establishment were not considered to be necessary. On the basis of these early results, monocyclic systems were assumed to be the most suitable to obtain a large volume per hectare of commercial timber and plywood logs, in a rotation of 60 to 80 years. Arguments used in favour of the monocyclic approach were that this approach permitted free manipulation of the canopy to obtain optimum growth of the young stand of desirable species, and eliminated the devastating effect of harvesting in a polycyclic system (Boerboom, 1964). As the diameter increment was almost the same for most young trees in heavily treated stands, it was assumed that one diameter class would predominate the whole cycle in regenerated forest stands. An intermediate yield of light hardwood species, rapidly grown, was expected to be possible in about year 30. The high cost of the early treatments, bearing much compound interest over the long cycle, probably could be reduced with a less intensive schedule of treatments (Boerboom, 1964), but such a schedule would have to be based on further research.

These early reports do not mention the problem of regeneration of the forest after the final harvest. Growing a high volume of commercial timber (more than 200 m^3/ha) over such a long cycle ends in harvesting this volume by clear felling, followed by rapid development of a secondary forest, in which the commercial species do not compete well without expensive silvicultural treatment. The first cycle was started in forests which had been only lightly exploited, and the effects of initial refinement were far less damaging to the remaining forest than a heavy exploitation. This is the case even when the amount of biomass killed is about the same. In 1969, heavy exploitation of about 200 m^3/ha of timber was carried out as an experiment on about 30 hectares in the Mapane area, and the remaining vegetation showed little promise of producing a second crop of valuable timber (see also Fig. 2.11)

The results of a number of experiments initiated since 1965 form the basis for a new approach to forest management. In total, four field experiments were started in the Mapane and Coesewijne region in the period 1965 to 1976. The results of these experiments will be discussed briefly in this section, and in more detail in Part III.

Monitoring the developments in lightly exploited forest (Expt 67/2) over a period of nine years without the application of silvicultural treatments, has confirmed that these forests are of very low economic production. Volume increments on remaining trees of commercial species were low, about 0.2 m^3/ha annually. A stock of second quality trees of commercial species of harvestable size was retained, but competition was high, and many of the best producing individuals had been removed in the harvest. The mortality rate had considerable effect on the development of exploitable timber stock, and seemed not to have been affected very much by harvesting. Annual mortality was about 2% for all diameter classes above 15 cm diameter at breast height (dbh). The stem-diameter distributions of timber species groups showed a slight trend to revert to pre-exploitation values. The changes brought by the exploitation were small: total basal area was reduced from about 30 m^2 to about 24 or 27 m^2/ha, depending on location.

A complex experiment was carried out in the Mapane area to determine the best liberation schedule (Expt 65/3). Plots received heavy silvicultural treatments, that is refinement and liberation, to reduce the population of non-commercial tree species. The original basal area of 28 m^2/ha after light exploitation was reduced to about 7 m^2/ha in the lightest refinement and to about 4 m^2/ha in the heaviest refinement. The resulting rapid growth of seedlings, saplings and trees of commercial species was accompanied by heavy regrowth of unwanted vegetation. The trend towards original basal area values was very rapid in the early years, and total stem volume regrowth was about 10 m^3/ha annually in the first 12 years in plots left untreated after the initial heavy refinement. The commercial species accounted for only a small proportion of the total volume increment when no selective treatment was given, but when an optimum schedule of liberations was applied, thus permitting maximum growth, the annual volume increment of commercial species ranged from 2 to 4½ m^3/ha, depending on the list of species.

Although in general the number of trees of commercial species was promoted by the treatments, the mortality rate of these species was also increased considerably. Many carefully tended small individuals were lost, either because of being crushed by falling dead timber or because of severe competition. Even in heavily treated plots with an intensive schedule of liberation, the trees differentiated in size steadily, and stem-diameter distribution was soon similar to that of the lower diameter classes in the original forest. There were only a few trees with large diameters, because all trees above 20 cm dbh had been killed to obtain greater uniformity at the commencement of the experiment.

This experiment showed that it is difficult to establish an unimodal stem-diameter distribution as desired in monocyclic systems, starting with the normal decreasing stem-diameter distribution of the original high forest. After ten years it was possible to predict that, within 30 years from initial treatment, a considerable number of fast-growing trees would reach harvestable sizes above 40 cm dbh in Expt 65/3. However, in other experiments a comparable quantity of harvestable timber trees was produced with less intensive treatment if fore-runners had not been killed at the start.

In Expt 67/9 A, a series of silvicultural techniques to promote increment of the population of commercial trees in lightly exploited forest was tested. Treatment schedules were less intensive and treatments lighter than applied in Expt 65/3. An initial refinement which reduced the total basal area from about 28 m^2/ha to between 17 and 7 m^2/ha, followed by a second modified refinement in the eighth year, was the minimum requirement for good development of the commercial tree population, as indicated by the average girth increment. More frequent treatment would have increased the number of trees of commercial species further, but in terms of timber volume produced this was not economically feasible.

The optimum treatment as indicated by the results of Expt 67/9 A was applied in 1975 on a larger scale to 25 ha in nearby forest. In this experiment (Expt 67/9 B), a population of more than 1000 trees of commercial species with diameters over 15 cm dbh were monitored. The initial refinement in this lightly exploited forest reduced the total basal area from about 28 m^2/ha to about 10 m^2. Girth and volume increment in the first seven years was better than anticipated on the basis of the preceding experiment (Expt 67/9 A), and the mortality rate was lower. Volume production was estimated to be 2 m^3/ha annually, but this largely depends on the numbers of large individual trees of commercial species in the stand.

In 1982, developments in Expt 67/9 A, which was eight years in advance of Expt 67/9 B, indicated the need for a third interference in the sixteenth year of the cycle after the initial refinement. Access to the stand showed promise of being good in the twentieth year, even with a light treatment four years before the second harvest.

The cost of treatments was studied on several occasions, and the cost of refinement was found to be comparable with the cost of refinement carried out by the Forest Service in strip planting programmes.

The experimental results indicated that a polycyclic silvicultural system was preferable. In such systems, the harvesting damage affects the future volumes to be taken from the forest. Very little research on this had been carried out in Suriname until recently, when several large experiments were started (de Graaf, 1982b; Hendrison, in press; Jonkers, in press). Observations (de Graaf and Geerts, 1976; Mellink, 1980) indicated as suggested by Dawkins (1958) that a polycyclic system may be feasible for an annual production of less than 1-2 m^3/ha. However, the volume removed also had to be restricted for other reasons, for example to reduce removal of nutrients from the forest.

A target log volume of about 20 m^3/ha to be felled and removed seemed reasonable, being more than the average volume usually taken at present in such exploitation. For a harvest of 20 m^3/ha, a standing volume of stems of commercial tree species of 40 m^3/ha was considered desirable to permit selection from standing stock including hollow or otherwise defect stems. The experiments in the Mapane region had shown an increment of about 2 m^3/ha annually with the treatment preferred, and thus a felling cycle of 20 years seemed feasible. The real value for a forest compartment or timber estate varied with the stand.

Cycle length was also determined by accessibility. Movement of machinery and people through the forest is hampered by the vegetation, and also by large dead logs, which can be of considerable length, and thus obstruct the skidder. These are expensive to clear, because pathways have to be cut with powersaws. The initial refinement greatly increases the number of these logs, which will decay and partly sink in the soil in no less than a 15-20 year cycle.

With restricted volumes to be harvested in each cycle, the best way to improve economic results was, and is, to produce logs of high quality. Thus, growth of the tree population must be concentrated on the best individuals of desirable species. At the same time, the recruitment of young vigorous trees must be continued to ensure that the number of timber producing trees is maintained after each harvest. Results of the various experiments have indicated this to be feasible at a reasonable cost.

2.3 Celos Silvicultural System

The Celos Silvicultural System is a method of growing good quality timber in relatively short felling cycles in previously lightly exploited or undisturbed high mesophytic forest in Suriname. This system can be classified as polycyclic. No pulpwood, wood for charcoal or other wood assortment of low unit value is grown deliberately. Forest severely devastated by for example heavy exploitation, cannot be upgraded cheaply and easily by this system, and restrictions on the exploited volume and exploitation methods must be enforced to safeguard the forest.

In addition to economic considerations about the price of the timber grown and the employment provided, the system has several other aspects:

- by retaining much of the original all-aged structure of the forest, many management options are kept open;
- forest thus managed is not very vulnerable to neglect, which reduces increment of valuable timber, but does not endanger the structure, whereas neglected plantations may be easily smothered in weeds, even at an advanced age;
- little risk of forest fire because there is little dry slash, as even heavily refined forest remains damp and cannot be kindled easily;
- pests and diseases are 'calculated risks' as in the original forest;

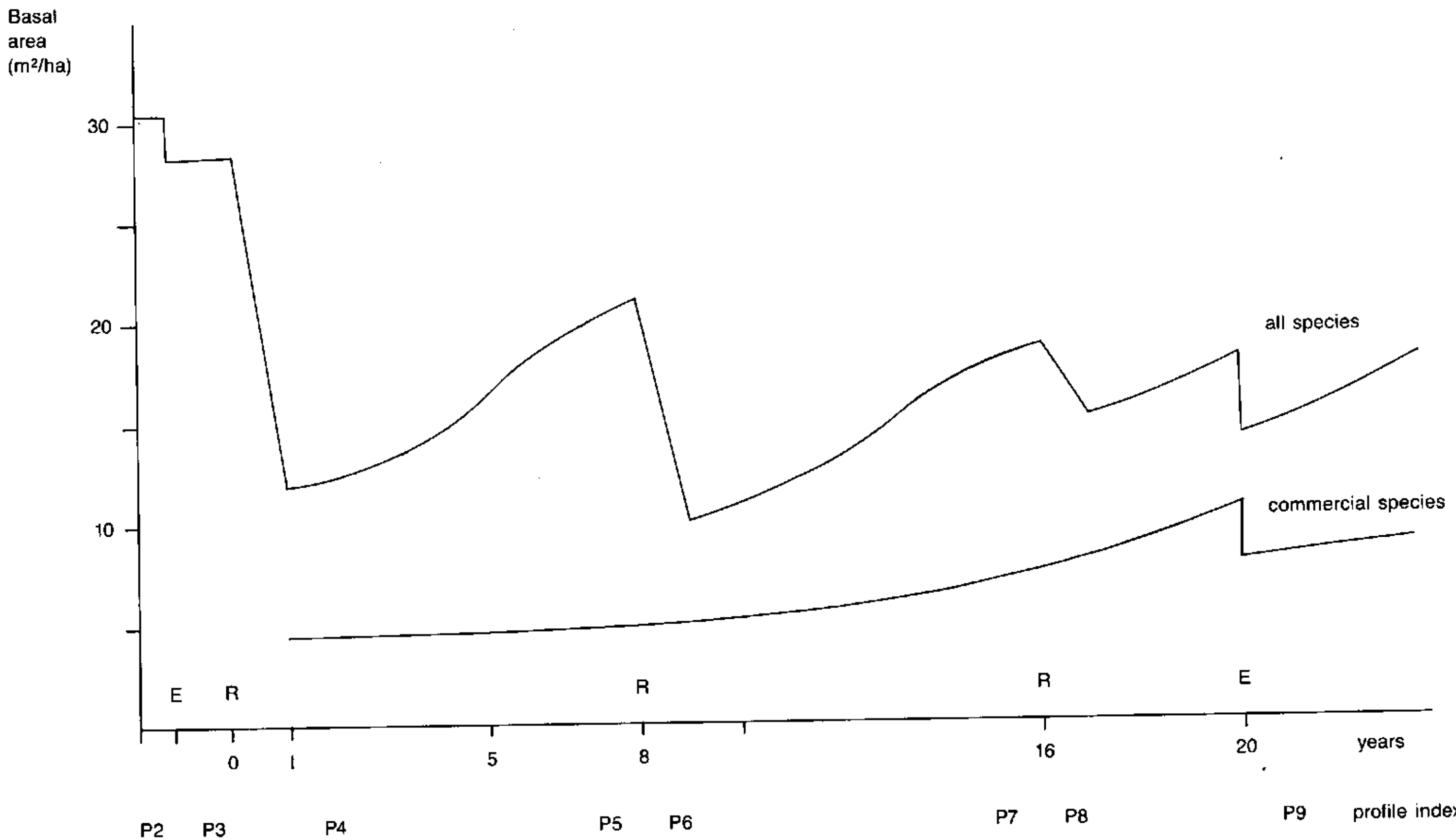


Fig. 2.1 Projected development of basal area of all species and of basal area of commercial species, under the Celos Silvicultural System proposed for the Mapane region. Time of: exploitation = E; refinement = R; forest profile diagrams = P_{2-9}.

– restricted changes in the vegetation are less destructive to the fauna and flora than the radical treatments to obtain uniform plantations;
– the nutrient store in the biomass, and the filtering function of the forest are only partly disturbed by the treatments prescribed, and thus replenishment of the nutrient store by aerial input is maintained;
– changes in evapotranspiration and hydrology are probably minimal (Poels, in press);
– many subsidiary forest products still can be harvested and produced as in forest without silvicultural treatment.

The treatments to be applied in the first silvicultural cycle of 20 years are three refinements, in year 0, year 8 and year 16. The basal area reductions obtained are considered to be optimal for the Mapane region, where the experimental plots were located (see Fig. 2.1). These reductions would have to be modified for other regions and species lists.

To illustrate the changes to be expected as a result of the treatments, a series of forest profile diagrams is presented in Figs 2.2 to 2.10. The original profile P 1 (Fig. 2.2) was drawn from a strip of undisturbed forest (see Chapter 7). Profile P 2 (Fig. 2.3) is a simplification of P 1, and is the first of a series of hypothetic profiles, showing the changes caused by the three refinements and the logging operations in a 20 year cycle. These profiles condense the results of the experiments discussed

Fig. 2.2 Forest profile diagram (P_1) of an undisturbed forest plot of 20 × 50 m, in the Mapane region. The relatively open structure results from the drawing method used, e.g. small trees have been drawn only in part of the area, to avoid congestion in the diagram (for further details, see Fig. 7.15).

in Part III, as does the scheme of changes in basal area shown in Fig. 2.1. Aerial and terrestrial stereophotographs showing aspects of the forest under treatment are also presented in Part III.

The method used to draw these profiles has led to some distortions. For instance, in Fig. 2.2, in half of the plot area only trees above diameter limit 15 cm are drawn. (See Fig. 7.15.) This means that the lower diameter for recruitment is 15 cm dbh, and explains the appearance of quite large trees in Fig. 2.8. These profile diagrams cannot be used for diameter distribution counts.

The profile series shows clearly that the forest will not become uniform as a result of the treatments. There will always be a mixture of small and large trees, and the height of the stand will be maintained, even though the forest will become more open in structure.

Figs 2.2 to 2.10 have been constructed with aid of the girth increment per diameter curve for certain treatment schemes in Expt 67/9 A. While girth increment indicated the development of trees after each interference in the cycle, this series is based largely on the views of the author. Trees of the commercial species have been drawn with hatched crowns. The species and diameter at breast height of the trees in profile diagram P 1 (see Fig. 2.2) are given in Gelens (1983). Treatments and changes in the forest are discussed below in more detail.

Exploitation. The 20 × 50 m plot on which the profile series is based has more than the average number of large trees of commercial species for the region (see also Section 6.5). It is difficult to get a fair representation in a drawing covering only a tenth of a hectare in well-developed and highly variable forest. The current harvest does not include all trees of commercial species of harvestable size. Two trees were logged in year 0, and on a hectare basis this is 10 trees/ha. Generally, exploitation should take about 5 to 10 stems/ha depending on size, with a total volume of about 20 m^3/ha; the basal area reduction being 2 to 3 m^2/ha for the trees felled or destroyed by felling damage (Fig. 2.1). Often, this is the second exploitation, the first being a creaming operation in which a concessionaire has removed some prime class stems, before real forest management has been initiated.

Initial refinement. Growth conditions of the remaining population of commercial tree species are not improved greatly by this light exploitation, and therefore it should be followed by refinement. The situation immediately after initial refinement as presented in Fig. 2.5 shows that a number of large trees of non-commercial species have been killed, and the large and medium-sized trees of commercial species have been freed largely from competition for light, and partly from root competition. The diameter limit for this initial refinement was 30 cm, and basal area was reduced from about 28 m^2/ha to about 12 m^2/ha (see Fig. 2.1), indicating that more than half of the tree biomass was killed. As a result of decreased competition and the large increase in nutrients and water available, the average girth increment increased considerably. Changes in diameter distribution after the initial refinement are presented in Table 2.1. Death of trees as a result of

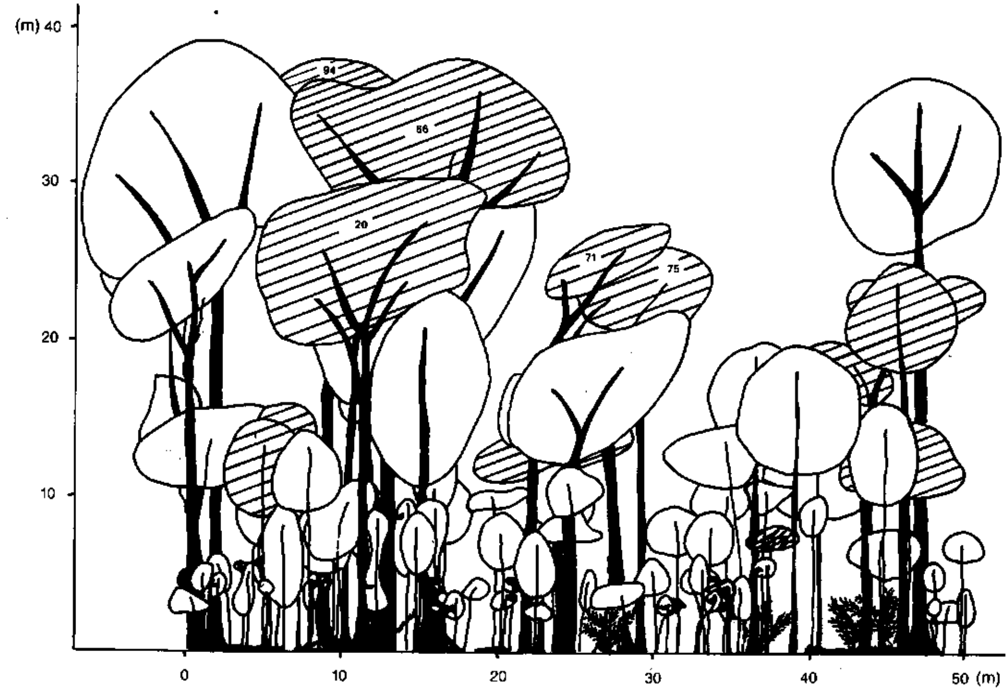


Fig. 2.3 Simplified forest profile diagram (P_2) of plot in Fig. 2.2. The hatched crowns are the commercial species.

Fig. 2.4 Forest profile diagram (P_3) showing the hypothetical effects of a light harvesting of two trees (no. 66 and 75).

Fig. 2.5 Forest profile diagram (P_4) of the hypothetical managed forest in year 2 after refinement in which all non-commercial species above 30 cm dbh have been killed to provide growing space for remaining trees.

Fig. 2.6 Forest profile diagram (P_5) of hypothetical managed forest in year 7, immediately prior to second refinement: most dead trees have fallen; commercial species have grown considerably; and also non-commercial species have increased, which need to be reduced in number to improve increment and recruitment of commercial species.

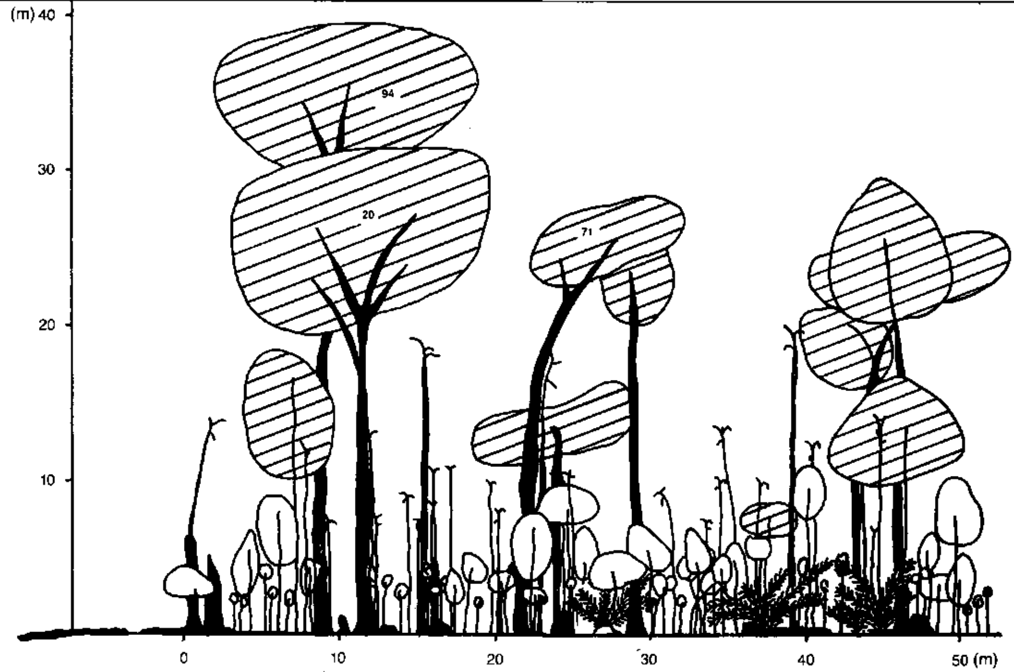


Fig. 2.7 Forest profile diagram (P_6) of hypothetical managed forest in year 9, after second refinement in which all non-commercial species above 10 cm dbh have been killed. The method of drawing leads to underrepresentation of small trees.

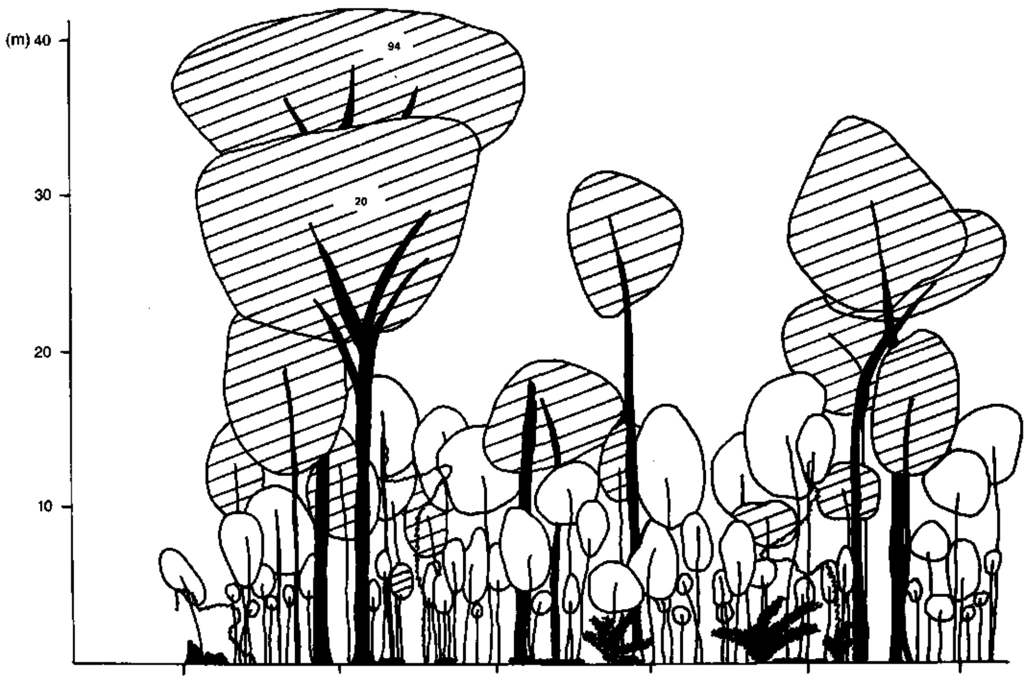


Fig. 2.8 Forest profile diagram (P_7) of hypothetical forest in year 15, immediately before a third, light, refinement: trees have increased in size and numbers, and much recruitment has passed the diameter limit for representation in this type of profile diagram, in sharp contrast to the forest profile in Fig. 2.7. Note the broken stump of a large commercial tree (no. 71) and the lianas which will be a potential hazard to small trees in the subsequent harvest.

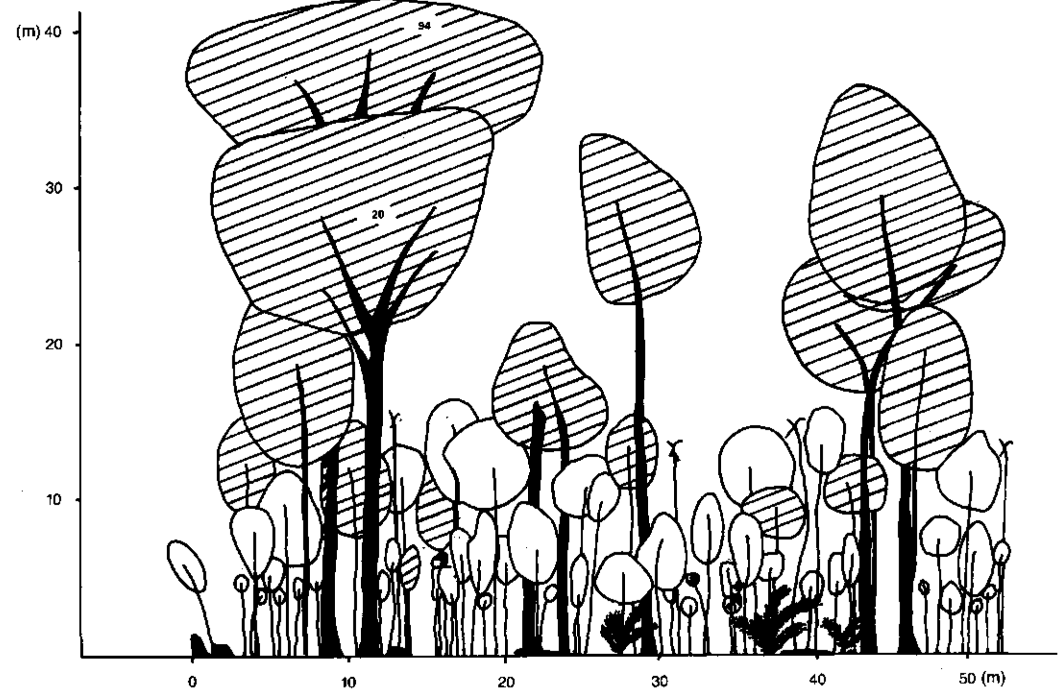


Fig. 2.9 Forest profile diagram (P_8) of hypothetical managed forest in year 17, after third light refinement, eliminating mainly lianas and a few small trees of undesirable species.

Fig. 2.10 Forest profile diagram (P_9) of hypothetical managed forest in year 20, after a second light exploitation, removing two trees (no. 20 and 94); the stumps are about 15 m apart; the falling trees caused notable damage. The height of the forest is comparable with the original forest, but the more open structure indicates less competition; commercial species dominate the stand, but in the lower strata non-commercial species are still represented.

Fig. 2.11 The Weyerhaeuser Sample area in 1982, showing the development of secondary vegetation since 1970. The original forest was largely destroyed by harvesting about 200 m^3/ha bole volume. The vegetation is much infested with lianas; even the *Cecropia* sp. in the background is overgrown with climbers, and in the foreground the author is standing in front of a wall of liana tangle. The plot was not fully cleared in 1969/1970, because some trees with badly formed stems were not felled and also all crowns of trees harvested were left. In other places the secondary forest has developed better, with less dominance of lianas. Ten years after rigorous exploitation, although biomass is building up again rapidly, the resulting secondary forest is far less valuable than the original, especially with regard to commercial timber production.

refinement is in many cases a slow process, and it may take a full year to reach the target basal area (see Fig. 2.1).

Especially after the initial refinement, some trees which should have been eliminated may be left because of either neglect or resistance to the methods used. These lone trees have little effect on the development of the stand, except that large trees when they fall may destroy many smaller trees of desirable species. These trees should be treated again in the subsequent refinement, but not neccessarily immediately after the first year.

TABLE 2.1 Changes in stem-diameter distribution after refinement (number of trees per hectare)

Species	Period in relation to refinement	Diameter class (cm dbh)							Sample area (ha)
		5.0–14.9	15.0–29.9	30.0–44.9	45.0–59.9	60.0–74.9	75.0–89.9	≥90.0	
All	before	559	173	55	22.6	13.8	4.8	0.9	10
	4 years after	360	150	24.6	5.9	1.3	0.2	0.2	12
	6 years after	1 138	191	25	14	1	0	0	1
Commercial	before	72	10.9	7.2	2.4	0.4	0.06	0.06	16
	4 years after	n.a.	12.0	9.6	3.1	0.6	0	0	16
	7 years after	81	10.1	11.5	4.0	0.8	0.2	0	16

Second refinement. After a number of years the girth increment slows down, as competition again reaches a high level. The situation just before the second refinement is represented in Fig. 2.6. Basal area has increased from about 12 to about 20 m^2/ha by year 8, and should be reduced to about 10 m^2/ha (Fig. 2.1). Most dead trees have already fallen, although an occasional branchless dead bole or a short stump has been left standing.

The second refinement is carried out especially to relieve saplings and small trees of commercial species from competition. Because these are very vulnerable to felling damage in the subsequent exploitation, an increase in numbers is most desirable to achieve a more balanced diameter distribution. A diameter limit of 10 cm was applied in this second refinement, and again much biomass was killed, but less than in the initial refinement.

The profile diagram in Fig. 2.7 shows the stand immediately after the second refinement, and demonstrates the extent to which the proportion of non-commercial species has been reduced, leaving only small trees and saplings and seedlings in this case. Often such a heavy reduction is necessary to improve economic productivity, and the treatment should only be lighter when research has shown that certain non-commercial trees are to be spared because they are essential to the ecological balance.

The stand remaining after the second refinement continues to develop, and the results in year 15 are shown in Fig. 2.8. Commercial tree species clearly dominate the stand, but ecological diversity has been reduced only partly. Young trees of non-commercial species are still pushing upward, and when left unharmed by further silvicultural interference could eventually reach the upper strata of the profile. The large number of saplings and young trees in this profile diagram may be explained partly by the method used to draw the profile diagram. As these trees have passed diameter limits in their zones, they suddenly appear.

Third refinement. Lianas and increased basal area are the main reasons for a third refinement in the sixteenth year. This treatment is light (Fig. 2.1), killing mostly small trees, and an occasional larger tree, but mainly concentrating on removing lianas to reduce felling damage to trees bound together by them.

To date, a third refinement has not been carried out on any of the experimental plots. As a rough estimate, total basal area in year 16 will be about 18 m^2/ha, and should be reduced to about 15 m^2/ha. The relative openness of the undergrowth, as acquired in the period after the second refinement, should be maintained because this greatly facilitates harvesting. In the profile diagram (see Fig. 2.9) the few trees killed are visible, and no large lianas are left.

Second harvest. Finally, enough standing commercial timber has grown to make a second harvest of timber feasible in year 20. In the profile diagram of Figure 2.10 two trees have been harvested. The second harvest is also quite heavy because of the high number of large trees of commercial species in this plot.

Developments in the second cycle. In the second felling cycle, competition cannot be reduced by eliminating trees of non-commercial species only. At this stage, when the group of commercial species dominates, an additional *thinning* is required. This means selecting individuals in the group of commercial species. In forest regions where there are more trees of commercial species per hectare than in the Mapane region, the thinning stage may be reached in the first felling cycle. Probably thinning will be done to waste, that is trees will be killed by arboricide application

Thinning will require more trained labour than the refinement. Malformed or defective individuals of desirable species are the first to be eliminated, unless they are to be reserved for special reasons, such as a tree of a rare species has to be kept as a seed tree, or a hollow tree harbouring many animals, for example bats. Slow-growing trees often can be recognized by bark symptoms or architecture, and if obviously not suffering high competition could be marked for removal by harvesting or killing with arboricide. As yet no experience has been gained with thinning, and criteria have yet to be developed.

The optimal stem-diameter distribution in the second felling cycle may be similar to that in undisturbed forest, with only a few trees above 50 cm dbh and with a total basal area not far above 20 m^2/ha in the Mapane region. The gaps caused by exploitation will be new foci of growth, and in addition, periodic reduction of basal area is considered to be necessary to keep the trees in a good condition. As few large trees will die naturally, the natural gap-forming processes will almost stop, and this is detrimental to the development of seedlings and saplings. The stand should be irregular and varied, having an abundance of seedlings, saplings and small trees, even if this means less volume increment than the maximum possible. It makes no sense to grow more timber than can be harvested, when sustained yield is determined largely by prevention of harvesting damage.

Skid roads, not to be confused with temporary skid tracks, should be permanent, as should be log landings. This infrastructure will be used in subsequent cycles and thus does not need to be reforested.

The feasibility of changing to a true selection felling system when the group of desirable species has become dominant in the stand depends to a certain extent on the timber prices. Harvesting small volumes per hectare, that is taking individual trees dispersed throughout the forest, is more expensive than harvesting a relatively large volume once in a 20 year cycle. In addition, harvesting damage could be considerable because distances covered by the skidder are much greater per m^3 timber taken.

2.4 The polycyclic approach

In this section the interference made by the management in the forest is compared with the naturally occurring disturbances in 'undisturbed' forest. It has been concluded that simple harvesting of timber in a polycyclic system, leaving the forest to regenerate without further silvicultural assistance is not a satisfactory approach. In the long-term this management system is not feasible, because production of saleable timber per hectare is economically too low. Therefore, silvicultural treatment to attain higher yields per hectare is essential. Silvicultural aspects of the human interference are discussed first, and then the aspects of natural processes which the human interference closely resembles.

2.4.1 Silvicultural aspects

The main objectives of silvicultural treatments in polycyclic felling systems are:
- promotion of volume increment of desirable species;
- regeneration of desirable species and recruitment of saplings into the higher diameter classes;
- balancing of the ecology of the stand to safeguard sustained yield.

Promotion of volume increment of valuable timber begins with exploitation conditions and methods in the polycyclic system. Usually, individual increment is highest in the largest trees (see Chapter 8), and therefore it is worthwhile sparing from exploitation trees of harvestable dimensions of desirable species. This probably is cheaper and more cost effective than raising a new population of trees with aid of silvicultural treatments. Positive selection felling instead of selective creaming is the first step to promote volume increment of desirable species. Another way to promote volume increment of desirable species is refinement, which as discussed earlier, frees to a certain extent desirable trees from competition.

Both selection felling and refinement promote growth and regeneration of desirable species, but also promote growth and regeneration of undesirable species, and therefore refinement has to be repeated periodically. The goal of refinement should not be to eradicate undesirable species, but to reduce their proportion in the stand, and to insure that individuals do not become unduly competitive.

Regeneration of desirable species was considered to be very important in research carried out in Suriname before 1965, and a method was sought to promote it in order to make a monocyclic management system possible. In a polycyclic system the large amounts of regeneration and recruitment required for clear felling systems are not essential, only welcome. The minimum regeneration required is that necessary to maintain a fairly stable stand table. In the experiments carried out in Suriname, in spite of all upward shifts of trees in the diameter classes, the total number of trees of desirable species in the lowest class was not diminishing under optimal treatment schemes, but increasing, be it very slowly. The losses of small trees as a result of repeated logging need to be compensated by the recruitment of saplings of desirable species, and more of these than the original number as present in undisturbed and balanced forest seems to be necessary in managed forest. Specific treatments have been shown to be quite effective to promote recruitment of saplings from seedling populations.

In a silvicultural system with a multitude of species much attention cannot be given to single species. Perhaps it is only possible to pay special attention to regeneration of a few species which are very valuable and not too difficult to handle. An example is the artificial seeding of *Vouacapoua americana.* Schulz (1960) observed *Vouacapoua* seeds remaining on top of the soil did not germinate but that most seeds germinated when pressed into the soil. Rodents feeding on seeds may play a role in burying some, as is the case with *Quercus* seeds in Europe. Many species germinated better when seeds were covered by earth (Schulz, 1960), and most tree species of mesophytic forest in Suriname have seed dispersal by animals. Perhaps seeds of very valuable species should be collected and brought into the soil in stands under treatment. On the other hand, it may be preferable to prevent the natural allies of the forester, the forest animals, from being hunted, to achieve seed dispersal for natural regeneration by natural means.

Balancing the ecology of the stand is a very complex matter, with many unknown long-term effects. Projection of trends discerned over a number of years of research into periods of several decades should be done with caution. The strong dependence of tree growth upon the nutrient cycle in the forest is important in the silvicultural system to be applied. The fauna, both large and small, are essential not only to seed dispersal (van Roosmalen, 1980) and other aspects of regeneration, but also to the litter decomposition and soil processes. Working as closely as possible to the natural processes, and maintaining the forest in as natural a state as possible, is some guarantee for a good ecological balance. As already stated, undesirable species should not be eradicated, at least not before it is known whether they are essential to the forest ecosystem. Deliberately leaving pockets of untreated forest can help prevent loss of species, even within forest compartments. Possible degrading effects caused by eradication of tree or animal species cannot be detected easily on relatively small experimental areas, as the surrounding ecosystem, still largely intact, has a compensating influence. However, it may be expected that the tropical rain forest ecosystem has some resilience to artificial disturbances.

Extensive forms of silviculture may be the best means to achieve the objectives. According to Schulz (1960, p. 216): 'It is very unlikely that the ecological study of the Suriname rain forest will ever provide the silviculturist with more than some general information; the large number of local communities and the manysided interrelations between the numerous associates found in the latter as well as between them and the environmental factors, are by far too complex to allow an exact *prediction* of the effects of far-reaching regeneration operations'. The most that can be done is to favour the recruitment and growth of desirable species at the expense of the population of trees of unwanted species. The self-regulating forces in the forest ecosystem should be left intact wherever possible.

Silvicultural assistance to desirable trees has to destroy part of the surrounding vegetation, to provide an opening, that is more growing space, for the particular individual. In the Celos Silvicultural System these openings, other than purely natural openings, are made by exploitation, and by refinement.

Exploitation. The area covered by a tree felled in exploitation varies from 100 to 600 m^2 and sometimes more. The average in a study at Patamaka, Suriname (Mellink, 1980) was 225 m^2, but the area covered by a single fallen tree varied considerably, and the relationship between diameter at breast height and crown size or inflicted damage could not be determined.

Felling of ten trees per hectare will cover at least a quarter of an hectare with fallen crowns. The area of these gaps cannot be added up to determine a theoretical clear felled area, because border effects of gaps are important. In addition, estimates of felling damage, for example by Dawkins (1958), depend on the tree model used. Damaged area summing methods seem to assume that a tree has a cylindrical growing space, and that the tree is damaged or destroyed by destructive events occurring within this space. However, a model for the development of a tree from seedling to fully grown tree, has to take into account that often trees share much of their growing space.

There seem as yet to be no clear rules to indicate or decide felling and logging damage. Recording on an area basis or recording of damaged individuals of advance regeneration do not encompass the borderline effects on trees left in and around the gaps made by exploitation. There are no such clear boundaries as suggested in area methods, and the grid used is often very rough, for example 10 × 10 m. Losses of advance regeneration are indicative, but do not predict reliably development of the population of commercial tree species. Methods that combine area and tree-by-tree damage often suffer from lack of clarity as they produce cumbersome masses of parameters and data. An index method must be rigidly standardized, at least within the region of application, to yield consistent results over long periods.

Gaps caused by one fallen tree are closed fairly quickly, mainly by the sideways growth of surrounding trees, but also by seedlings and saplings in the gap. Secondary species and lianas do not develop easily in small gaps. The microclimate in larger gaps caused by the felling of several trees differs from that of small gaps (Schulz, 1960). Small gaps or large gaps often become swamped with secondary vegetation, resulting in a long unproductive period as regards timber production.

Selective exploitation does not make a forest more uniform, although it may remove the largest trees, thus bringing those remaining nearer to the average. When felling trees, no efforts should be made to concentrate crowns in certain areas, in an attempt to restrict felling damage. Even when small in area, such gaps with piled-up crowns are covered with extraordinary amounts of dead organic matter, and do not regenerate easily into 'normal' forest vegetation. They are often colonized by biological specialists, such as lianas.

The height of the forest immediately surrounding the gap affects light conditions and root competition in the gap (see also Florence, 1981). Specifications for maximum and minimum diameters of gaps should also refer to forest height around the gap, and in the case of oblong gaps, orientation to the path of the sun. Light penetrates early and late in the day in a zone east and west of the gap, and promotes growth of tree seedlings and saplings under a closed canopy which does not permit much light to enter vertically.

Refinement. As many trees included in the refinement are among the largest, this operation has some effect of making the forest more uniform. However, if the remaining population is largely a mixture of large and small trees, then the stand becomes more open but not much more uniform.

In the experimental plots in Mapane, more trees were killed in refinement than in exploitation, and often more than 50 trees per hectare, larger than 45 cm dbh were eliminated. Trees killed by arboricide do far less damage to the stand than do felled trees. The biomass killed by the refinement is spread more uniformly over the forest floor than that killed by felling. Leaves and smaller branches falling from considerable height land everywhere, but stems form more concentrated mass.

The usual annual fine litter fall from living trees is increased by the fine litter from killed trees, but as most leaves on the living trees in undisturbed forest come down as litter in one year (Schmidt, 1982), this increase will not be large for leaves. Annual litter fall in lightly exploited forest in Mapane was found to be about 11 t/ha, which represents about 3% of total biomass present (Schmidt, 1982). When an annual mortality of the total tree population of 2% is added, the regular annual deposit of fine and coarse litter is about 5% of the biomass. But, as fine litter is rich in nutrients, more than 5% of the nutrient store located in the biomass will circulate with normal annual litter fall and mortality of trees.

When refinement as described in this book, reduces the total basal area from about 28 m^2/ha to about 12 m^2/ha, approximately 60% of total biomass is killed in one year. The small litter from this comes down in a period of a few months to a year, and the coarse litter in a period of five to ten years, with a peak in the first five years. Thus the more than twelve-fold increase in organic matter coming down on the forest floor is spread over a considerable period, and perhaps is at most five times the normal annual supply per hectare. This is considered to be comparable with the effect of local peak supplies from fallen trees in virgin forest.

The coarse litter decomposes at varying rates, as it varies in size and durability.

Large logs may take several years to several decades to rot. Thus, the nutrient supply from the large amount of dead timber fallen in the first five years after refinement extends beyond the first ten years. However, dead timber contains less nutrients than fine litter. Ecological studies were carried out to quantify these effects (Schmidt, in press). An evaluation of nutrient cycling in forest stands under various treatments indicated that nutrient cycling increases with increasing intensity of the disturbances in the forest stands (Voordouw, 1982).

In the initial refinement, small trees are not killed, except those hit by falling coarse litter. In subsequent treatments the forest undergrowth should not be slashed and opened up for the sake of 'cleaning up'. Apart from being expensive, this will probably only disturb the ecosystem and will not contribute much to the regeneration and increment of desirable species. Thus, below a certain diameter limit, all trees and saplings or seedlings should be left undisturbed as far as possible.

Refinement is a uniform treatment, and therefore is relatively cheap and simple to carry out. However, this treatment does not necessarily lead to uniform stands, and in fact it should not. Uniformity of a stand means synchronized growth, which is undesirable because of the demands placed on nutrient reserves. Additional to this such uniform forest stands provoke very undesirable management with final clear felling. In the Celos Silvicultural System, refinement does not lead to uniformity. Trees of commercial species often occur in groups and the total basal area after refinement can be high over small areas, whereas total basal area in nearby areas is much lower than the average used to calculate the diameter limit for refinement (see Section 3.1). Serious weed problems did not occur in the experimental plots where the basal area was about 10 m^2/ha measured in a sample of at least ¼ ha. However, where the average basal area was about 7 m^2/ha, weed problems could occur in isolated spots where unwanted secondary tree species readily established.

These data, together with the upper limit for the total basal area in stands under management (see Chapter 7) confirm the rule of thumb of Dawkins (1958) that fluctuations in basal area should be maintained within the limits of one-third to two-thirds of the original total basal area of undisturbed forest, the latter being about 31 m^2/ha for the Mapane region.

The initial refinement applied in the system discussed, seems quite a serious interference to the nutrient cycle, but a much lighter initial refinement was found not to be very effective (see Chapter 7).

Where intermediate or even small trees of desirable species are absent in areas of say more than a hectare, consideration could be given to leaving these areas untreated, but this should be done only if this not disorganizes the field work. A reason to treat such areas may be that treatment will stimulate recruitment of new individuals of desirable species. Without refinement, recruitment depends on slow natural processes. Local absence of desirable species was not found in the relatively restricted area covered by the experimental plots.

2.4.2 *Aspects of natural processes*

Silvicultural treatments in the Celos Silvicultural System are considered to be similar to the natural processes in undisturbed forest. Regeneration goes on continuously in undisturbed forest, mainly in and around gaps or 'chablis', as called when these gaps originate from naturally fallen trees (Hallé, Oldeman and Tomlinson, 1978). Reduced competition from trees weakened for example by disease or rot, also permits development of previously suppressed trees and saplings. Stimulation of volume production and regeneration by silvicultural measures does not negate these processes, but overrules them in case of very intensive treatments.

The extent to which deliberate disturbance by silviculture can be considered to resemble nature is disputable. Recent work on primeval forest in Central Europe in mountain forests of mixed coniferous and deciduous species, indicates a number of phases in natural forest succession, discernable over areas of at least several acres, but usually larger, up to more than a hectare (Leibundgut, 1982). Thus in those forests in Europe, neither selection forest systems nor clear felling high forest systems can be viewed exclusively as either natural or unnatural systems of management. Both have a place as silvicultural systems adapted to particular circumstances.

In the undisturbed high mesophytic forest of Suriname, natural regeneration processes are speeded up mostly in the small spaces where one or occasionally several trees died standing or were thrown over. There is little evidence of large-scale windthrow being important in the high mesophytic forest of Suriname, as may be the case in other humid tropical regions. Areas with larger numbers of big overturned trees occur occasionally, and groups of trees of species having an extreme demand for light, such as *Goupia glabra*, indicate such heavy disturbance in the past, but the usual pattern is the formation of small gaps by the falling of one or several trees. The idea of Bauer (1964) that 'chablis' give rise to a mosaic of essentially even-aged patches of regenerating forest is somewhat misleading. In Suriname in most places in the forest a population of seedlings and saplings of several and widely varying age classes waits for opportunities to flourish once a gap is formed. This population is only partly killed or disturbed by gap forming when a tree falls or sheds large dead branches. Small and coarse litter provides nutrients, and this, together with the increase in light and water, grossly stimulates growth of surviving individuals.

The resulting vegetation in the gap is not homogeneous or even-aged. Oldeman (1983), who introduced the concept of the eco-unit, defined this as a vegetation unit that has started to grow at a well-defined time on a well-defined surface. This description may be viewed as identical to the idea of Bauer (1964). However, this start of an eco-unit should be understood as the sudden accelerated development of an existing part of the vegetation (R.A.A. Oldeman, personal communication).

Following the natural regeneration processes in the mesophytic forest of

Suriname means that silvicultural treatments should selectively stimulate growth of individual trees, and that efforts should not be directed to produce uniform stands, even if this were possible. Instead, a constant supply of nutrients from litter should be maintained, to guarantee good growth throughout the whole cycle. In this essentially uneven-aged stand, large trees should be present to provide the required volume production, together with a host of smaller trees and saplings and seedlings, ready to fill the gaps caused by large trees falling, dying standing or being felled. As seeding and seedling establishment takes place continuously, timing of stand treatments to benefit from seed years is not necessary. Forest regeneration and building phases and forest breakdown phases should not be separated widely in space and time, mainly because of the nutrient cycle which has its main store of nutrients in the biomass. The poor soil does not have the reserves to bridge an interruption in the litter supply for more than a few years of forest growth. Under such an uneven-aged forest cover, the ecosystem is assured of a tight nutrient cycle as under natural conditions.

Natural mortality in 10 ha of lightly exploited mesophytic forest was found to be about 2% annually for all diameter classes above 15 cm dbh (Expt 67/2). In undisturbed forest, mortality may be somewhat lower. Small dying trees, either left standing or falling in full leaf, do not make real gaps in the vegetation structure, only trees above a certain size, say, 45 cm dbh. The term canopy is not used here, as it usually assumes a closed layer of crowns, which is not the case in mesophytic high forest in Suriname.

Data are not available for Suriname on the rate of trees falling with living crowns or dying while still standing. However, it is thought that a very large proportion of trees which fall have living crowns (see also Hallé, Oldeman and Tomlinson, 1978), at least half of all mortalities. On the basis of data on diameter distributions in mesophytic forest, given in Chapter 6, this would mean a falling rate of one large tree per hectare every two or three years. In a period of 20 years this means seven to ten trees per hectare falling, out of a total mortality of 14 to 20 trees larger than 45 cm dbh per ha. While this may be considered to be very high for undisturbed or lightly disturbed forest, other observations indicate this to be realistic. Riera (1982) found 17 gaps (chablis) had formed in one year in an area of 20 ha of the mesophytic forest of French Guiana. He supposed tree falls were caused by the extra weight of water on them during periods of high rainfall. It can be added that roots may not be well anchored in soils drenched by heavy rain, and that trees often have asymmetric crowns.

Cyclic logging of, say, 10 trees of 2 m^3 log volume each, once in 20 years, increases mortality. Moreover, exploitation tends to take the very best and most vital trees. Even though the disturbance caused by selective exploitation exceeds that of natural processes, it is closer to these natural processes than clear felling. The openings made by light exploitation are not unnaturally large.

Another important disturbance occurring in this polycyclic system is the death of large trees in refinements, which is similar to the natural death of trees remaining standing. Such trees do far less damage to the surrounding vegetation than do falling trees with living crowns, and only occasionally a real gap is formed when masses of large dead branches from big trees come down in a short period.

When kept within the limits indicated, the impact of light exploitation and of refinement is similar to natural processes. However, there may be risk of degradation of the site by nutrient losses exceeding the natural level, but research on catchment areas so far has revealed that nutrient leaching in refined stands is minimal (Poels, in press).

Evapotranspiration rates will change little when biomass is kept high throughout the management. This may be important on sites with restricted drainage of otherwise reasonably functioning soils under high forest. High evapotranspiration rates maintain water output via streams at a reduced level, thus reducing the output of dissolved nutrients (Bormann and Likens, 1979).

Very little research has been carried out on the effect of the reduced tree species list in treated forest stands on the multitude of organisms and their functions in the ecosystem. The idea that the lives of all living beings in this mesophytic forest are so interwoven that no species can be missed from those present in the virgin forest needs more proof than theoretical reasonings can give. A recent study has indicated some changes in bird populations after refinement (de Jong, 1982). Arboreal animals may be handicapped for lack of contact between tree crowns in recently refined forest. Food problems may be expected for specialized species when essential tree and liana species become less frequent or even locally absent. A detailed study of the spider monkey (*Ateles paniscus*) in Suriname (van Roosmalen, 1980), has shown this monkey to be dependent on fruit production. On the long list of species providing food many commercial timber species are found. Exploitation of these can be considered to be negative, and a refinement, which improves growth and also fruit production as was observed for *Tetragastris altissima* in Expt 67/9 B, could improve the situation. However, the main problem for this spider monkey is the heavy hunting pressure, which eradicates whole groups. The strict protection needed can only be given in well managed and controlled forest areas; a silvicultural motive to protect the species is its effectiveness as a seed dispersal agent.

Fluctuations in species populations are known to be more detrimental to highly dependent species than to species not closely linked (Margalef, 1968). In a complicated ecosystem with many interdependent species large fluctuations should be avoided. A large flow of energy triggered by large changes produces a high risk of losses. Sensitivity of ecosystems to disturbance has also been discussed by O'Neill and Reichle (1980), who have postulated that nutrient cycling processes are relatively sensitive to disturbing influences and indicate stress earlier than does the tree population. Finally, the trees also show stress, but in management it is important to find reliable indicators of stress that will give signals in an early stage.

A distinction has to be made between parallel and cyclic processes, both of which are present in ecosystems. The parallel configuration allows essential processes to be taken over by one population of organisms from another, but this cannot occur in the cyclic configuration. A disturbance in a cyclic configuration is more damaging to the whole ecosystem than is a disturbance in a parallel configuration. Cyclic configurations can be expected in nutrient cycling or in decomposition of complex substrates (O'Neill and Reichle, 1980).

These authors also stress the importance of redundancy, that is the presence of many species in the system. Having a number of species, all performing the same critical function in a similar way (such a group is called a guild), permits a shift from one species to another in case of emergency. Thus, redundancy in the forest is insurance against major collapse of the system in case of perturbation. Therefore, the silvicultural system should include as many species as provide marketable timber or perform key functions in the ecosystem. The minimum requirement probably can be determined only empirically, over quite large areas of several hundreds of hectares. This will take a considerable amount of time, perhaps a full felling cycle of 20 years. In the meantime, large-scale operations which change the forest greatly should be planned with caution, This means that no species should be eradicated over large areas, and that only reduction of abundance of unmarketable species is allowed. This fits in well with the concept of the Celos Silvicultural System.

Natural selection of trees on increment rate and marketable form is done mainly by the ecosystem itself in the early years of the individual. In the undergrowth and lower strata, which are kept closed under the Celos Silvicultural System, the large number of seedlings arising each year is reduced to a few survivors growing to pole-sized trees. The selective pressure leaves the most vigorous individuals. Only when trees reach a size above, say, 10 or 20 cm dbh, are they selectively promoted or eliminated by silvicultural treatments. Genetic erosion is not considered to be important as compared with other threats to the existence of the productive forest. With very heavy felling genetic erosion may be much stronger because of strong pressure on the populations of desirable species.

2.5 Comparison with related silvicultural systems

Most systems with heavy interferences in high forest are monocyclic, and thus comparison with the CELOS System is only of restricted value.

Lichtwuchsbetrieb. The 'Lichtwuchsbetrieb' (increment felling) for beech (*Fagus sylvatica*) in Europe involves a very heavy thinning in monocyclic high forest stands to stimulate individual increment of selected trees (Assmann, 1970). This is done to produce heavy timber in a short period in existing high forest, and the resulting loss in volume productivity on a hectare basis is accepted. This heavy interference removes about half the standing volume, and the stand remains open for several decades during which regeneration of beech and other tree species occurs. However, his regeneration is used only as soil cover. Special regeneration techniques enable the establishment of a new beech forest with the final felling, whereas in Suriname after clear felling a secondary forest stage has to be taken into account.

Uniformisation par le haut. The 'Uniformisation par le haut' (Donis and Maudoux, 1951; Baur, 1964) practised in the former Belgian Congo, has been referred to as being related to early natural forest regeneration experiments in Suriname (Schulz, 1960). Uniformisation would make the untouched stand more productive, and in due time even suitable for a system of management coming close to a selection system. A light refinement should be given 10 or 20 years before the first exploitation to increase the exploitable volume. According to Donis and Maudoux (1951), liana cutting is the strongest intervention in the system, and the refinement diameter limit for trees is quite high, about 50 cm dbh. In addition, understorey trees are destroyed and light intensity penetrating to the forest floor is reported to be 30-40% of the full daylight. This must have been a rapidly changing situation, because such forests usually close again within a few years. No data are given on basal area or volume increment by either Donis and Maudoux or Baur.

Uniformisation aimed to make the forest more uniform whereas the Celos Silvicultural System aims at sustained valuable timber production, which is not necessarily best in uniform stands. According to Baur (1964), Uniformisation cannot be classified as a sustained yield system, but mainly as a stand improvement system. No prescription is given for the stimulation of regeneration of desirable species, and treatments are too light to encourage the recruitment of saplings from regeneration.

Selection System in Ghana. In Ghana a selection system is pursued mainly in semi-deciduous forest, where the annual rainfall is 1250 to 1750 mm. The system has the objective of increasing the development of immature valuable timber trees. In the 'typical rain forest areas', where the annual rainfall is 1750 to 3000 mm, the forest is considered to be very poor and here 'exploitation is on a salvage basis, as the dearth of trees in the smaller girth classes rules out any hope of working such forest by any of the natural systems, and the policy is to convert these forests by artificial means' (Baidoe 1970). This may change when more species become acceptable.

In the selection system in Ghana, a stock map is prepared for all economic trees over seven feet girth; an improvement thinning of the immature stock is carried out, and selective felling on a 25 year cycle is practised, with a calculated yield. From this brief outline it would seem that this system is similar to the Celos Silvicultural System, but there are differences.

In 1968, economic trees in Ghana were considered to be over seven or even nine feet girth, which is much larger than the limit applied in Suriname, being 45 cm diameter. Improvement thinning is applied to individual trees, over an area of 12 feet radius at the tree base, while in the Celos Silvicultural System the treatment is uniform. In Ghana the cost of treatment is stated as 1½ man-days per acre (3.7 man-days per ha), and there is experience with the system on a large scale since 1958.

Yield regulation is by area method, minimum girth limits and maximum basal area. Felling cycle is normally 25 years. Yield selection is done from stock maps, so that remaining stock is well distributed throughout the compartment. Even large trees may be left as seedbearers. Lower girth limits for felling (nine and seven feet) are rigid. The calculated yield makes no allowance for defective trees. All felled trees are recorded in a felling register.

There are one or two exploitable trees per acre (2.5 to 5 per ha), which are fairly large and contain much timber individually as compared with the trees commonly harvested in Suriname. These large trees have a high unit value, and therefore probably justify the considerable administrative work per individual. A stock of at least 22 economic trees per ha below exploitation size, usually in the class 1-9 feet girth, is necessary to make the system applicable. Stand tables for all tree species show that the rain forest in Suriname compares favourably with that in Ghana (in numbers per ha) except possibly in the largest diameters.

In Ghana the selection system assumes a non-variable list of commercial species, and extensive change to this list may upset management. Baidoe (1970) refers to the low volumes usually removed by the contractors, even lower than permitted by the yield regulation. Recently, the Ghana Timber Marketing Board (1982) has made proposals to promote the use of lesser known species. Baidoe (1970) called for more information on ecology and silviculture of marketable species, and also on increment, mortality and rotation length. The feasibility of collecting these data depends on the intensity of management. With the low increment and yield as found possible in managed mesophytic forest in Suriname, this information may well be too expensive to collect.

The amount of regeneration occurring in forests in Ghana under the selection system was not quantified by Baidoe (1970). On the basis of experience in mesophytic forest in Suriname, it would seem that treatments are too light for sufficient increment of established regeneration. Experiments on manipulation of stands are needed to provide conclusive information.

Selection system in Puerto Rico. This system has been described by Baur (1964). Factors which led to the use of a selection system in the Luquillo Mountains were the need for soil protection in catchment areas, the vulnerability of even-aged stands to cyclones, and the scenic value. Many of the main species are partially shade-bearers, while others are light demanding and prefer large gaps. Felling cycles are either five or ten year, and in the first cycle improvement has priority to timber yield or regeneration. The ideal composition of the forest stand is indicated in Table 2.2. Basal area is kept at about 18.4 m^2/ha. In each felling cycle, the forest is treated by poisoning unwanted trees, removing trees with the crowns in contact, and avoiding gaps in excess of 25 feet. The remaining trees should have a free zone around their crowns of about six feet. Removal is concentrated on the poorer species and larger sizes.

According to Baur (1964) a deliberate effort is made to retain a fairly continuous canopy, and these systems are similar to single-tree selection systems in Europe. Operations aimed to improve the stand, by removing useless stems and vines, receive much attention.

On the whole, the system of Puerto Rico is similar to the Celos Silvicultural

TABLE 2.2. Ideal stand composition after treatment in forests in Luquillo Mountains, Puerto Rico

Diameter class (cm dbh)	Number of stems per hectare			
	1st class Saw timber species	2nd class Saw timber species	Pole species	Total
10.0–17.7	111	74	35	220
17.8–25.3	64	25	12	101
25.4–40.5	59	12	0	71
40.6–53.3	42	0	0	42
Total	276	111	47	434

Source: Baur, 1964.

System, but it would seem that it is not directed principally to producing timber at commercial prices. The frequent harvesting and tending required are likely to be expensive. Amounts of timber taken are not indicated. Only a small area of several hundreds of hectares of forest under this management is primary forest, most of the area is secondary forest or areas which have been heavily logged.

Although the factors influencing tree growth rate in the Luquillo Mountains are difficult to identify, bolder treatments could improve mean growth rates (Crow and Weaver, 1970). Yet present growth rates are similar to those found in Suriname. While treatments may be improved, nutrient deficiencies in trees may account for the variation in growth observed, together with the crown position found to be important by Crow and Weaver.

The ideal stand table for Puerto Rico (Table 2.2) indicates the absence in Puerto Rico of large trees (above 53 cm dbh). In the Celos Silvicultural System, larger diameters will occur at the end of the first circle, and the upper limit can be set at 75 cm, but at this stage it is premature to set such a limit.

Selection system in North Queensland, Australia. In the selection system applied to the forest in North Queensland described by Baur (1964), total basal area is reduced from initially very high values of up to 80.5 m^2/ha to a residual basal area of only 12.5 m^2/ha. Although the last value is much in accordance with the residual basal area maintained in some experiments in Suriname, the removal of such a very high volume makes comparison difficult. Baur (1964) has compared the stand in Queensland after the basal area reductions to a park forest. Such drastic treatments cannot be undertaken in the management of high forests in Suriname, because weeds will take over immediately, and biomass reduction would be too large to safeguard the nutrient store.

Liberation thinning in Mixed Dipterocarp Forests of Sarawak. This recently developed system (Hutchinson, 1982) aims at liberating individually selected trees of desirable species in recently exploited Dipterocarp-rich forests in South-east Asia. Next harvest of timber is expected within thirty years, and liberation thinning is intended to be applied only once in the felling cycle, a few years after first exploitation. The intensity of treatment is roughly comparable with that in the Celos Silvicultural System, as is also the amount of manpower needed. The remaining total basal area of all species seems to be proportionally somewhat higher than in the Celos Silvicultural System, but as the species composition is quite different, the two systems cannot be easily compared in detail.

Prescriptions for treatment tend to be complicated, and detailed instructions have been prepared to cover all possible situations with the individual trees to be liberated. Field staff require a high level of training and this may result in relatively high costs.

2.6 Attitudes in management

On ne connaît que les choses que l'on apprivoise, dit le renard. Les hommes n'ont plus le temps de rien connaître (Antoine de Saint-Exupéry, cited by Dubos, 1981).

The silvicultural system presented in this book is an initial approach to improved management of timber estates in the rain forest in Suriname. This approach will be modified as it is applied in practice over large areas, but improvements will only be made if the manager and his team are deeply involved with the work.

Planning of land use also means planning the way of life of many people. The attitude of the people towards the forests around them is important, because the view one has on the subject on which one works largely determines the quality of the ultimate results. Working in a forest and living near to it is not attractive to everyone. To be a good forester, caring for the forest one helps to manage, and not simply surviving the time spent there to be promoted to a more attractive job, one has to see the forest as something respectable. The reasoning that the forest is one's source of income ultimately, will not be enough, and some integration with one's life is needed. For example the horse-riding nomads not only use the horse, but were and are themselves deeply influenced by this animal which has helped shape their culture. The same way, the civilization of the more developed countries which formerly had a non-nomadic and mainly agricultural traditional style of life, has become a mining-dependent society which derives its main wealth from digging up fossile fuel and mineral deposits. This deeply influenced the ideas of society, and even agriculture has been changed much by this mining attitude. In forestry, a mining attitude is pernicious in the long term, but is easily assumed and brazened out in the situation of still much forest to be depleted of timber, and much lack of fundamental knowledge of the ecosystem. General civilisation is promoting this, with its short-term policies and buy-now-pay-later philosophies. Only with people working in the forests who are committed to the forest, will such situations be ordered for the best. This is something else than claiming nature reserves, in which mankind is felt to be not a legitimate inhabitant. People do not belong in these reserves, and only visit to be spectators.

The writer and ecologist Dubos, (1984) was convinced 'that the best policy of conservation is to intervene carefully, yet creatively, in the existing order of things. .....Experience shows that alterations of natural ecosystems need not be destructive and may indeed be highly creative. The guiding principle for success is that artificial ecosystems should be as compatible as possible with the prevailing ecological characteristics of the regions in which they are created'.

With this approach there is the opportunity to create an environment in which the tropical rain forest is not used as a timber quarry, but safeguarded as a source of many products perhaps with timber and watershed protection being the first priority in most regions.

As man is originally a 'semitropical savanna animal' (Dubos, 1981), he has the inclination to create open landscapes littered with trees, similar to the landscape in which he developed as a species. This inclination needs to be resisted in case of the management of humid tropical rain forest, because it can only be kept well as closed high forest, as was discussed in this chapter.

To promote deep involvement with his work, the forest manager should live preferably in his forest, or as near to it as possible. After all, Machiavelli in the fifteenth century stated that to dominate a conquered nation, the conquerer must settle in the land. This way developments can be followed closely, not only to consolidate, but also to prevent the region to become a squeezed province.

The manager should have both biological and technical training, to be able to work on both sides of the management problem as mentioned in Section 1.4. Such people are not the easily reared product of industrial schooling or of conservation movements, but have to be trained for their function quite a long time, to reach the necessary level.

3 Celos Silvicultural System: practical aspects

3.1 Operations in the Celos Silvicultural System

A provisional list of operations for harvesting and other tasks in treatments in the Celos Silvicultural System is presented in this chapter. Many of these operations have developed from research carried out by CELOS, and others are already used by the Forest Service. More is required to establish and manage timber estates than the items listed, but discussion has been restricted to these.

Firstly overall maps of the region should be prepared with the aid of aerial photographs and forest surveys. Subsequently, management areas are planned and demarcated on the maps, to form blocks and compartments (Fraser, 1973). The length of the felling cycle determines the number of blocks, and cannot be changed without administrative problems, and probably appreciable losses in productivity. Compartment size is usually in the order of hundreds of hectares, preferably with natural borders. The all-weather main roads are then planned and constructed, and also secondary roads, to open up groups of compartments for harvesting timber. An inviolate virgin forest reserve should be planned, to occupy *at least* 5% of the management area, as proposed by Oldeman and Boerboom (1982). It should be located centrally, well demarcated and protected, and have limited access.

3.1.1 List of operations

Operations proposed for the period before and immediately after the first harvest and initial refinement in managed forest are discussed below. Some will be repeated in the eighth and sixteenth year, assuming a 20 year cycle. The reductions of total basal area for the Mapane region have been given in Fig. 2.1. Some of the estimated numbers of man-days per hectare of managed forest as given were taken from de Vletter (1980).

a) Opening up the forest within the compartments. This is done by cutting lines 1 to 2 m wide through the vegetation in both a north-south and an east-west direction to divide each compartment into plots of 400 × 250 m. It is estimated that a team of five men can cut 2.5 km line per day, thus the estimated number of man-days per hectare is 0.20.

b) Enumeration and mapping of potentially harvestable trees and sampling of advance growth of desirable species and of the total tree population. The number of man-days per hectare for enumeration is estimated to be 0.25 and for sampling 0.10. A system of full enumeration originally developed in West-Africa was implemented in about 1970 for the Bruynzeel Timber Co. (Noelmans, 1979), and was planned also for use in the Mapane region. These proposals did not include assessment of allowable cut but this can be fitted in quite well. The system is roughly as follows. A gang of five men, with the foreman centrally positioned and flanked by two tree spotters, moves in a straight line across the 400 × 250 m plot. They maintain a distance of 10 m apart and thus cover 40 m. The team starts in one corner of the plot, and works its way across the plot, parallel to the short side. The man on the plot line checks the distances covered, and the one on the other side cuts a temporary line to be used as the base for the next turn. During the survey all trees of exploitable size and species are calipered and log volume is estimated. All data are recorded by the foreman, including the location of the numbered trees on a field map. It is suggested that the scale of this map be 1 : 1000. The trees recorded receive a number, written in advance on a small piece of plastic, to be fixed to the tree with a thumb tack. Topographic features, such as creeks, gullies, rock outcrops and skid roads, are marked on the map. The team moves through the 400 × 250 m plot in ten turns, and covers 20 ha per day. Approximately 150-200 trees are recorded per 10 ha plot.

Full enumeration permits better planning of harvesting operations, and saves much money and time. Sampling of advance growth of desirable species could be done in one full turn of 40 × 250 m. As 10% sampling seems quite intensive, de Vletter (1980) proposed that it be restricted, using a 10 cm dbh lower limit, and that all desirable species be grouped together. Recording could be done with an angled caliper. Sampling methods should permit estimation of the diameter distribution, and not only of total basal area.

Sampling of the total tree population could be done simultaneously in one 40 × 250 m turn. Silvicultural treatment is decided on the basis of these sampling data. The maps are kept as documents, and a copy is later given to the forest guard to check the harvesting operations. The information presented on these hand-made maps could in future be processed and stored in a computer data base, from which up-to-date maps and lists can be produced.

c) Establishment of permanent sample plots. The estimated number of man-days per hectare is 0.12 and the work requires a special team. A series of permanent sample plots is essential to monitor developments in the managed forest. De Vletter (1980) proposed that 2 one-hectare plots per compartment of 300 to 400 ha be established, as was put forward by Synnott (1980). In experimental forests the sampling percentage should be much higher. A six-man team can establish and record a one-hectare plot in two days of field-work, and recording requires one day's team work.

d) Assessment of allowable cut. This should be done on the basis of the field-map and sampling data. The trees to be harvested should be marked on the map in ink, and in the forest with paint and hammer-marks. No estimate of the time required has been made. The trees to be harvested should not be located in dense groups. Hammer-marks and paint marks should be made on both bole and stump to make supervision easier for the forest guard. Stems should be checked for rot, which in many cases can be done by hitting the tree trunk with an axe and listening to the sound. Trees with extensive rot and consequently little timber value should not be felled, but killed during refinement, to avoid felling damage, or be left as seedbearers in special cases.

e) Planning of skid roads and felling direction of individual trees. No estimate of the number of man-days required has been made. Where feasible, individual trees of desirable species should be marked with red paint in an endeavour to reduce harvesting damage. This operation is estimated to take approximately 0.33 man-days per hectare. No efforts should be made to concentrate crowns of felled trees in open spots by directed felling. It is preferable to fell trees in the direction most useful for transport, and safest for felling operators. Efforts to avoid crushing a promising desirable tree should not have priority above safety. The crowns of felled trees should be well dispersed throughout the forest compartment, each creating its own relatively small gap.

f) Felling and harvesting operations. Felling in particular should be carried out by experienced labourers. No estimate of the time required is given. Hauling by machines should be controlled strictly to reduce damage to soil and stand, and to reduce costs. Felling and hauling damage is often overrated on visual inspection, especially by inexperienced visitors moving through open parts of the stand. Sampling along straight lines gives a more reliable indication, because these traverse also less affected parts of the vegetation. Detailed studies carried out recently (Hendrison, 1984; Hendrison, in press) may lead to correction of this approach.

g) Sampling to determine diameter distribution and total basal area. The estimated number of man-days per hectare is 0.13. This sampling cannot be combined with that carried out to estimate advance growth of desirable species and total tree population, as long as logging damage is unpredictable. The diameter limit for refinement is determined using the diameter or basal area distributions of the listed commercial species and of all species. The limit is placed where basal area of all species remaining under the said limit, plus the basal area of the commercial trees remaining above the limit, result in the target total basal area.

h) Additional line cutting. Extra lines are cut to form north-south strips 125 or 62.5 m wide. The estimated number of man-days per hectare required for the first option is 0.15. The strips should not be too wide for inexperienced labour. The north-south lines can be demarcated more clearly by a conspicuous line, for example those laid out by the portable distance measuring device used by the French Forest Service (Topochaix). This saves much line clearing, and also reduces problems in administration of tasks performed.

i) Marking, frilling and spraying trees to be killed in refinement, and liana cutting. The men work east-west and west-east direction, in a zigzag through the strip. Marking should be carried out by trained labourers or tree spotters, and is estimated to take about 0.33 man-days per hectare. The bark should be marked with paint and not with slashes, because these are not conspicuous enough in many species, especially after several weeks. This work is good training for tree spotters. It can be modified in many ways, and is essential to the silvicultural processes. Prescriptions should be kept simple as long as the consequences have not been tested for more complicated instructions.

Frilling and spraying can be done by contract labour and are estimated to take 1.80 man-days per hectare (Staudt, 1976). These operations can be carried out by a gang of three men, two cutting and one spraying. It is advisable to rotate these operations within the team. Supervision is easier when a colouring agent is mixed in the arboricide. All lianas of a diameter at ground level above a certain limit, say 2 or 3 cm, should be slashed, which takes about 0.33 man-days per hectare.

Refinement operations should be done shortly after logging has been completed, because regrowth on lines, in gaps and on skid roads makes access difficult. Refinement cannot be done before logging, because when logging is delayed the numerous dead trees can cause accidents.

j) Second recording of permanent sample plots. This is estimated to take 0.06 man-days per hectare.

Summary of inputs, and further recommendations. For the initial silvicultural treatment 3½-4 man-days and 20 litres arboricide mixture per hectare are estimated to be required. In year 8 and 16, operations a, g, h, i, and j will have to be repeated, which will take about 3 man-days per hectare. Item i on this occasion will probably take less time than during first refinement, as there will be few large undesirable trees. Amount of arboricide used will also be less, about 10 litres per ha. The data given above can be considered as maxima rather than averages for a well-managed timber estate. It is probably preferable to contract labour for relatively simple and easily supervised tasks, such as line cutting and frilling and arboricide spraying, payment being based on productivity per kilometre or per hectare.

While the list of desirable species alters with the years, and stem defects in the stand are largely uncertain, the yield from a forest stand is quite variable. If such factors are unknown, then detailed computerized methods to predict volume production are of little use and simple and cheap methods such as a modified Brandis method (Osmaston, 1968) will do. When finally the forest manager has come to terms with the many factors influencing management results then higher precision methods to predict volume and to meet local circumstances can be developed.

Accurate large-scale maps are essential for extensive management. If necessary, maps should be improved using information from the simple enumeration maps for exploitation.

Visual inspection is not very helpful for estimating present standing volumes, and is useless for assessing increment. A simple inventory technique, using permanent sample plots is essential. A special inventory team seems to be the best and cheapest solution. The need for liana cutting can be assessed visually but large distances in the compartments have to be covered to obtain a reasonable impression. If liana cutting before the first harvest is advisable, the field operations could be combined with a or b, but supervision will be difficult at this stage.

3.2 The use of arboricides

From several points of view the use of arboricides is debatable, and objections of, for example, environmentalists to refinement often concentrate on the use of poisons to kill trees. A much used term for the technique described below is 'poison girdling' in which arsenic compounds are applied in a ring cut around the stem base of a tree. Modern hormonal arboricides hardly warrant the name poison, because of their relatively low toxicity to animals, but these chemicals are specifically poisonous to trees.

A poison can be defined as a chemical substance which in relatively low dosage kills an organism. This definition assumes that the dosage and concentration are important. The way in which a tree-killing chemical is used, the quantity required, and the toxicity and persistence largely determine whether a particular substance is to be used. Aerial spraying of herbicides differs greatly from manual application of such chemicals to tree trunks, and further, the chemicals used vary widely in composition and action.

Toxic substances in the forest. Firstly, the issue should be raised whether it is acceptable to use toxic chemicals in the management of timber estates in tropical rain forests even if used only in minimal quantities, as in the Celos Silvicultural System. Not all substances naturally circulating and deposited in living and dead components of the forest are harmless. The forests in Suriname are full of substances that can be classified as poisons to a certain degree, ranging from toxic components of heartwood of durable species and bark of many trees, to snake venom. The large amount of vegetation biomass in the tropical rain forest, and low animal biomass as compared with other mature ecosystems, probably is at least partly the result of the relative indigestability of the vegetation components (Margalef, 1968). This is certainly enhanced by the many toxins in the plants. Without such toxic components, the forest would not exist in its present form. The amount of these toxins should not be underrated, but more importantly, these chemicals are an essential part of the system, and obviously play a role in regulating internal relationships. (Brünig, 1983).

It is essential that chemicals brought into the forest do not extend their action beyond the intended goals. They should work with precision, which means that they should work only where intended and then decompose into harmless components or become harmless by storage, for example by irreversible adsorption to soil components.

Tree killing methods. Apart from the application of arboricide, standing trees can be killed by mechanical girdling. This is done by cutting through the cambium and often even through the sapwood, or by other physical attacks, such as heating the bark and cambium around the tree base, as practised by shifting cultivators on a tree too large to fell. However, such methods are labour intensive. The use of powered tools for girdling is quite imposing for the person handling them, and comparable to the use of a powersaw. Moreover, not all tree species can be killed by mechanical girdling, because of multiple incidence of included phloem inside the stem, or a highly irregular stem section.

Arboricides can be easily tested initially in short-term field experiments to determine the special treatments required for certain tree species, the chemicals and formulations most suitable, and the quantity required. Usually most of the necessary information can be obtained within one to two years. A reduction in the amount of chemical used can often be achieved by applying only mechanical girdles on tree species that can be killed in this way.

Method used in the CELOS research. The arboricide used by the Forest Service in Suriname, and also in the experiments described in this book, was the well-known 2,4,5-T weed killer. It was used in various formulations, often combined with 2,4-D, and mostly used in a solution in diesel oil of 5% or 3%. This arboricide acts as a phytohormone, and when administered in sufficient quantity disorganizes the cambial tissues of the plant. The arboricide is well-established, and has a long history (Hartley and West, 1969). It is very effective when applied correctly, and a kilogram of the pure chemical can kill hundreds of trees. In 1978 the price of one litre unmixed arboricide was roughly equivalent to a day's wage for unskilled labour in Suriname. The toxicity of this chemical is relatively low in animals (UNESCO, 1978; Advisory Committee on Pesticides, 1980).

A solution of the arboricide in diesel oil penetrates plant tissues better than does an emulsion in water. Application of the mixture on unbroken bark of the trees in early experiments was not as effective as when used in combination with girdling. A frill is made around the tree base, by making connected cuts in the bark and sapwood that open slightly to receive the chemical. A small hand-axe with narrow blade is preferred. A machete is less suitable for large trees, especially those with an irregular stem section, but using a machete saves carrying the axe when mainly small trees have to be killed, as in second and third refinements. A continuous line of cuts should be made as low as possible around the base of the tree, because the arboricide works best close to the root system (Schulz, 1967). It is not necessary to make very deep cuts, but they should penetrate the bark and the cambium, and end in the sapwood. Deep cuts allow the arboricide to enter the heartwood, where it is not effective; the cambial layer and the phloem should be disorganized. There are indications that resistant trees disperse the 2,4,5-T arboricide more easily through their xylem vessels than do sensitive trees, which retain the arboricide in phloem tissues (Sundaram, 1965).

Trees with extensive buttresses should preferably be girdled low. Deeply fluted stems should receive an extra wide band of arboricide of 30 cm or more, sprayed onto the intact bark, without much effort being made to frill inside the flutes. For some tree species, such as the *Cecropia* species, with large aerial root systems, frilling is not necessary, because these are highly susceptible to the arboricide; a band sprayed around the stem above the root system is all that is required.

The arboricide is sprayed on the tree normally in a 10 cm wide band directly above the frill, and the bark should be thoroughly wetted. The frill should then be filled up, going around the tree for a second time. Resistant species should receive a wider band, or more arboricide in the frill. It is useful to have labourers who can spot common resistant trees, because these trees then can be treated more intensely, and thus the mortality rate can be increased. A simple code in marking the trees can specify treatment for special cases.

Quantities of arboricide needed are variable. According to Schulz (1967), 30 litres/ha of arboricide mixture (5%) and 4.5 man-days/ha are required for initial refinement. This is for quite a heavy refinement, and recently about 16 litres of 5% mixture per ha for a light refinement over more than hundred hectares has been reported (Poels, 1982).

Stemless palms, such as *Astrocaryum paramaca*, can be killed by applying a little arboricide on the youngest leaf, so that the chemical can reach the meristem of the palm easily. This is not easily done with palms having long stems. The Forest Service has experimented with spraying liberal amounts of 2,4,5-T mixture on exposed parts of the root systems of palms, which proved succesful in killing. Palms should only be killed when they are very abundant, and labourers will often object to killing useful species, because they provide several by-products of direct use.

More than 85% success rate in killing trees after two years has been reported by Schulz (1967). Trees not killed in initial refinement should be treated again in the second refinement, that is after about eight years in the Celos Silvicultural System, and then they usually succumb. Repeating treatment within one or two years to obtain almost 100% kill is unnecessary and quite expensive, and was not done on most of the experimental plots discussed, because the success rate in initial treatment was more than 90%. Preferably, frilling and spraying should be done in dry weather because then penetration of the arboricide is optimal. A dry period after the refinement makes the treatment most effective, probably because of the water stress. Further research on refinement in wet periods may indicate whether operations can be spread out over the year. This would help with more efficient planning of operations.

It is preferable to purchase the arboricide for large-scale application in large batches, in high-quality non-corroding tanks. Ordinary oil drums are unsuitable for long distance transport and for long-term storage of the undiluted arboricide. A sample from the batch should be analysed to determine whether contamination (with dioxine) is not above the acceptable level. The chemical should be transported from the main store to the forest station preferably in well sealed, small but strong containers, for example in strong plastic jerricans, as used in the CELOS experiments (de Graaf and Geerts, 1976). This reduces possible losses in accidents. The pure arboricide should be stored at the forest station in the same strong containers used for transport. The extra cost is well justified by the prevention of losses due to leakage.

An emulsion of 2,4,5-T with water, as is possible with some formulations, may fail to work on certain resistant tree species. The arboricide does not mix easily, especially with water, and should be agitated vigorously before being distributed to other containers.

For application on the trees a knapsack sprayer is most suitable. It should be compact, light in weight, uncomplicated, and strong. Above all, it should not soil with its contents the person carrying it. A knapsack sprayer was constructed at CELOS (de Graaf and Geerts, 1976), using strong plastic 10-litre jerricans as easily replaceable refills. This simple sprayer works with a siphon instead of a pressure-action sprayer, which has the danger that the operator may inhale the spray mist and that chemicals can be wasted or that they reach unintended places in the forest. Jerricans for refills can be filled in the herbicide yard at the forest station, to provide a full day's load, or refilled by the roadside from a barrel with screw-in tap positioned above a soil pit to accommodate the jerrican. Filling should always be done with a filter funnel. The administrator should not try to economize on jerricans, which should be marked clearly as company property, and numbered, because they are popular for private use.

Safety. The arboricide 2,4,5-T is not very persistent in the environment, and its half-life on plants in Great Britain has been estimated to be 1.6 to 2.6 weeks. Usually, in soil it does not carry over from one season to another, its half-life being up to ten weeks. (Advisory Committee on Pesticides, 1980). The amount of the highly toxic TCDD (dioxin) contaminant in the arboricide should be as low as possible, according to the Advisory Committee on Pesticides (1980) below 0.01 ppm. TCDD is relatively immobile in the soil, and is not likely to contaminate groundwater. Its half-life in the soil is probably one year in temperate regions and may be shorter in soils of higher temperatures. The risk of TCDD being formed by burning brush that has been sprayed with 2,4,5-T is insignificant (Advisory Committee on Pesticides, 1980).

The effect of the arboricide treatments on the tropical rain forest ecosystem with regard to residuals in dead trees, soil and water, has not as yet been studied in

Suriname. Contamination of food webs may occur, for example, via insects feeding on parts of the tree directly treated with the arboricide. When following the correct spraying procedure only a few drops of the arboricide reach the soil. Contamination of streams can be prevented by not treating forest types that are periodical inundated, and by transporting chemicals and mixture in adequate containers. Further, contamination is less likely to occur from regular use than from accidental spillage and abuse. The arboricide cannot be used for illegal fishing as may aldrin and dieldrin, but a diesel mixture may be stolen to kindle fires to burn off shifting cultivation plots. Mixing a colouring agent in the arboricide will help detect such abuse, and will also assist to check the quality of spraying work.

No evidence of a detrimental effect on animal life in forest areas of Suriname has been observed of regular application of commercially available formulations of 2,4,5-T. Its use in Vietnam War has aroused much publicity, but the two cases are not comparable as the dosage was much higher in Vietnam, being about 28 litres of undiluted product per ha, and the application methods, mainly aerial spraying (von Meyenfeldt et al., 1978), were very different from those used in CELOS research. Contamination with dioxine of the arboricide used in Vietnam was very high compared with standards as set by the Advisory Committee on Pesticides (1980).

More important than the probably very restricted damage to the environment of using arboricide in timber estates, may be the effects on the humans handling the chemicals. Reduction of dosage per ha will reduce environmental problems, but exposure of workers to the chemicals is not reduced automatically with the quantity per ha. Measures to safeguard workers from excessive contact with the arboricide are needed, and those working with it should receive clear instructions on its safe use. Workers should be alerted to the dangers of skin contact with the chemical and of leaking knapsack sprayers. Acceptable daily intakes have been published recently by the Advisory Committee on Pesticides (1980). Chemicals and mixtures should be stored in a separate locked enclosure which is not located close to streams or living quarters.

The dangers of chemicals should be understood but not exaggerated. Workers should also be alerted to other dangers, such as occur when driving cars or felling large trees with powersaws. There is some danger in visiting recently refined stands, where many dead trees looming above may fall in a sudden wind squall or rainstorm. Wearing safety helmets can only partly reduce this danger.

3.3 List of preferred species

The point of view that all timber-size trees will be valuable in the future is questionable for many tropical species which do not have special qualities and which are hard to work. The list of preferred species should not aim to increase volumes of timber being logged per hectare without limit. To reduce harvesting damage, a restricted volume should be taken out in each felling cycle. This strategy makes harvesting and growing of first-class timber more worthwhile than if all saleable timber were removed at once, whatever the standing volume per hectare. Usually harvesting is cheaper when a large volume per hectare can be taken, but a better price per log can compensate for restrictions in volume.

The list of preferred commercial species as drawn up by CELOS is presented in Table 3.1. Species of first-class timber should not be confused with the classical luxury species used for cabinet-making. The list contains a large number of timber species used mainly for general construction purposes or for plywood (see also Vink, 1977). It is by no means complete, but should be extended only with species that will bring good prices, especially in the future. From the point of view of ecology, the list of commercial species should be large, as the original forest is multi-species and as far as possible should remain so. However, a long list of species is economically not viable, because the timber industry prefers to work with a restricted number.

The timber industry can shift its preference for certain species as soon as the more preferred species are 'depleted'. This usually lowers the quality of the end product, or raises the price of those products, because more expensive technology is necessary. In the end the wood product may be less competitive on the market. It may be feasible to group a number of species that are technically acceptable for a specified use. Thus the timber industry would not sell products of a certain timber species, but an assortment of timber for specified uses. This not only opens ways to harvest and market the lesser known species, but also widens the scope in silvicultural measures in the forest.

TABLE 3.1 List of commercial species used by CELOS

Family and species	Code	Local name	Trade name	Code number
Anacardiaceae				
Loxopterygium sagotii	SLA	Slangenhout		31
Annonaceae				
Xylopia aromatica	PEP	Pegrekoepisi		24
Araliaceae				
Didymopanax morototoni	KAS	Kasavehout		36
Schefflera paraënsis	MOR	Morototo		39
Bignoniaceae				
Jacaranda copaia	GOE	Goebaja		48
Tabebuia serratifolia	GRO	Groenhart	Tabebuia	17
Burseraceae				
Protium insigne	GTI	Tingimoni-grootbladig		45
Protium neglectum	HTI	Tingimoni-harde bast		44
Tetragastris altissima	SAL	Rode sali		40
Tetragastris hostmannii	TIS	Tingimonisali		47
Trattinickia burserifolia *Trattinickia rhoifolia*	ATI	Ajawatingimoni		46
Celastraceae				
Goupia glabra	KOP	Kopi	Goupie	21

Guttiferae				
Platonia insignis,				
Rheedia sp.	GEE	Geelhart; Pakoeli		55
Symphonia globulifera	MAT	Mataki	Manni	50
Humiriaceae				
Humiria balsamifera	MER	Meri; Blakberi		56
Lauraceae				
Licaria cayennensis	KAN	Kaneelhart		20
Nectandra grandis	ZPG	Pisi, zwarte, grootbladige		27
Ocotea glomerata	ZPK	Pisi, zwarte, kleinbladige		28
Ocotea petalanthera	WIP	Pisi, witte		26
Ocotea sp.	WAP	Pisi, wana		25
Ocotea rubra	WAN	Wana	Red Louro	33
Lecythidaceae				
Lecythis davisii	KWA	Kwatapatoe		49
Meliaceae				
Carapa procera	KRA	Krapa	Andiroba	37
Cedrela odorata	CED	Ceder	Cedar	16
Moraceae				
Brosimum paraënse	SAT	Satijnhout	Satiné	30
Piratinera sp.	LET	Letterhout	Snakewood	22
Mimosaceae				
Parkia nitida	AGR	Agrobigi		54
Myristicaceae				
Virola melinonii	HBA	Hoogland baboen	Baboen	11
Virola surinamensis	LBA	Laagland baboen	Baboen	12
Papilionaceae				
Andira spp.	RKA	Rode kabbes	Angelin	18
Dicorynia guianensis	BAS	Basralokus	Angélique	13
Diplotropis purpurea	ZKA	Zwarte kabbes	Tabatu	19
Dipteryx odorata	TON	Tonka		57
Hymenaea courbaril	RLO	Rode lokus	Courbaril	23
Mora excelsa	MRA	Mora		53
Peltogyne spp.	PUR	Purperhart	Purpleheart	59
Platymiscium spp.	KOE	Koenatepi		58
Vouacapoua americana	BRU	Bruinhart	Wacapou	15
Rutaceae				
Fagara pentandra	PRI	Pritijari		29
Sapotaceae				
Manilkara bidentata	BOL	Bolletri	Balata	14
Micropholis guyanensis	RIW	Riemhout, wit		51
Pouteria engleri	RIZ	Riemhout, zwart		52
Simaroubaceae				
Simarouba amara	SOE	Soemaroeba		32
Sterculiaceae				
Sterculia spp.	OKR	Okerhout		42
Vochysiaceae				
Qualea albiflora	HGR	Hoogland gronfoeloe		35
Qualea coerulea	LGR	Laagland gronfoeloe		41
Qualea rosea	BGR	Berg gronfoeloe		34
Vochysia guianensis	WIS	Wiswiskwari		38
Vochysia tomentosa	WAK	Wanakwari		43

Source: de Graaf, 1982; Lindeman and Mennega, 1963.

The silvicultural advantage of this must be to reduce the impact of selective exploitation on desired first class species. A large and sound tree of lesser known species can be taken instead of a number of small trees of prime species left after first creaming operations. The total volume to be harvested per cycle should remain about the same as before extension of the list of species, because of the logging damage inflicted on the stand.

The list in Table 3.1 covers an ecologically broad spectrum, and diversity in the managed forest is thus largely maintained, even when all species forming large trees but not listed are eradicated.

3.4 Cost

Total cost of a system of silvicultural treatments is usually expressed in money units. Because of inflation and changing exchange rates it is useful in the long-term to express productivity also in timber volume per man-day spent on production, and in materials and machine hours used. Both methods are used here.

Comparison of systems in Suriname. In the Mapane region, under the Celos Silvicultural System, the production of 20 m^3 timber net volume over 20 years requires an input of about 10 man-days and about 40 litres of arboricide mixture. Assuming that the stand would have produced only 2 m^3 net without treatment, the extra net increment as a result of the treatments is 18 m^3/ha. When discounted at 4% interest rate, the inputs are 0.95 man-days and 4.09 litres arboricide mixture per m^3 timber, which can be set at about Sf 12 plus Sf 8 totalling Sf 20. This is 25-30% of the 1982 prices for common quality saw logs at the mill. In a forest estate, annual inputs over a 20-year cycle would be 0.5 man-day and 2 litres arboricide mixture, on a hectare basis, for an annual output of 0.9 m^3 timber. This does not take into account that the treatments are also an investment in trees to be harvested in subsequent cycles, which is not the case in monocyclic systems.

It is difficult to compare data for the Celos Silvicultural System with the known inputs and outputs of the pine planting system in Suriname, because of the use of large expensive machinery in the latter system, and the lack of comparability of the end products. Pine plantations produce mainly pulpwood, and only a small proportion is expected to be used for sawn timber (Fraser et al., 1977), at least while minimum diameter specifications for saw logs in Suriname remain as high as 37 cm dbh.

Establishment costs for a pine plantation are presented in Table 3.2. On the assumption that the production is about 450 m^3 in 30 years, the return is high per man-day. However, cost per machine hour for a D8 bulldozer was very high, about 180 Sf/h in 1977. According to Fraser (1973), maintenance in a pine plantation requires 7.1 man-day/ha annually for the first 13 years. With an annual increment of about 10-15 m^3/ha, this is a production of about 2 m^3 per man-day, but this estimate only includes maintenance, and not clearing and planting costs. Twelve

TABLE 3.2 Establishment costs per ha of pine plantations in Suriname

	Manual labour (man-days)	D 8 bull-dozer (hours)	Wheel-tractor (hours)	Chemicals
Site preparation and planting	6	12	4	0
Tending over 10 years including ant control and rotary slashing, etc.	54	0	12	7 kg Mirex 260 litres 5% 2,4,5-T in diesel

Source: Vink, 1970.

hours clearing with a D8 bulldozer (see Table 3.2) are not equivalent to 120 man-days hand clearing, but the comparison gives an indication of cost of replacing labour by machines. Calculated on this basis, volume production of pine timber per man-day would be very low, mainly because of the high clearing cost.

The costs for strip planting methods are fairly well known for the first decade, but final volume production cannot be estimated easily. Gross volume produced is sometimes referred to as net volume, because no allowance is made for defects in these plantation trees. Estimates for *Cordia alliodora* plantations were given as 130-150 trees of 1.5-1.8 m^3 each, for a rotation of 25 years (Vega, 1981). This would result in a final volume of about 200 m^3/ha composed of large sizes, and supposes quite a high annual volume production of about 8 m^3/ha. This volume would have been produced with an input of about 50 man-days and more than 100 litres arboricide mixture per hectare (Vega, 1981). When discounted at 4% interest rate, the inputs are about 0.64 man-days and 1.45 litres arboricide mixture per m^3 timber. Almost half of the expenditure occurs in the first five years, which is a disadvantage in investments over long periods, as every treatment that can be delayed without drawbacks to production becomes cheaper.

It remains to be seen whether these volumes as predicted will be produced. General ecological theory about nutrient cycling suggests that growth is slowed down when nutrient supplies from the organic matter left from the original vegetation are exhausted. Total bole volume production in heavily refined forest with subsequent natural regrowth has been assessed in Chapter 5. The partly secondary vegetation after such heavy interference in Expt 65/3 produced about 10 m^3/ha annually in the first decade. Thus, high volume production after the forest has been severely disturbed is possible, but it should not be assumed that this is a sustained yield to be harvested at will.

According to a detailed economic appraisal of silvicultural systems, carried out by Fraser et al., (1977), for the pine planting to show promise of economic viability the cost of clearing of the original forest should be zero, and additional income from cattle grazing in the young plantations is highly desirable. However, cattle grazing in Suriname is still in an experimental stage. Reduction in growth by trampling of the roots may be compensated for by a reduction of weed growth. According to Fraser et al. (1977), plantations of *Cordia alliodora* and *Cedrela* species look promising, depending on the prices to be obtained for good hardwood peeling logs. The uncertainty of volume production was noted; standing values per m^3 required to break even at 8% interest were Sf 17 to Sf 44 for the two species, depending on the details in the systems applied.

For the appraisal of natural regeneration models, Fraser et al. (1977), used an optimistic and a pessimistic model with two rates of interest, 4% and 8%. Required stumpage prices per m^3 ranged from Sf 9 to Sf 47.50. A harvest of 30 m^3/ha in a cycle of 15 or 25 years was assumed. In financial terms the Celos Silvicultural System in 1977, at that time not yet well described and tested, was rated as being at least competitive with pine timber and pulpwood production already discussed.

Overhead costs. Overhead expenditures per ha for plantations should be below Sf 100 (Fraser et al., 1977). A large proportion of overhead cost for forest management is for road making and maintenance. In plantations, costs of roads are lower per m^3 produced than in low-yielding naturally regenerated forest. About 6.5 m/ha of truck road is necessary for exploitation in the natural forest in the Mapane region (Noelmans, 1979). Even if the establishment cost can be written off in the first exploitation, the maintenance cost must be included in subsequent treatments and second exploitation. These maintenance costs are estimated at Sf 500/km annually, which in the Mapane region is about Sf 3.25 per ha, or the same per m^3 timber grown. It is assumed that skid roads are infrastructure not essential for the silvicultural operations.

Transport cost of labourers and materials in extensive land use systems is relatively high. In a managed forest as hypothesized by de Graaf (1982a) of 50 000 ha net productive forest area, an annual coupe of 2500 ha would be planned in a 20-year cycle. Annually an area of 2500 ha would require silvicultural treatment during the first eight years, and double this amount after this period, with an additional third area after the sixteenth year. Transport requirements are greatly reduced by establishing camping sites to serve an area treated in an eight-year period, thus about 20 000 ha. This assumes transport in an area with a radius of 8 km, but in practice the distance will be more, because roads are winding. Part of the route will have to be covered on foot, but a simple two-wheel drive truck would save time and would also be useful for inspection and other duties. Three such trucks in the forest estate may easily clock up 50 000 km annually, which at a cost of Sf 1 per km is the same Sf 1 for a m^3 of timber grown. Reasonably maintained roads make the use of expensive four-wheel drive vehicles unnecessary; labourers should not be transported by car along skid roads, as the risk of getting stuck is high.

Permanent camp buildings with a serviceable life of 20 years, for a group of ten labourers may cost Sf 10000 to establish. For the 150 people needed in the managed forest discussed, this means an investment of Sf 150000 to be written off over a full cycle. To this, maintenance costs should be added at 10%, being Sf 15000. An annual expenditure of Sf 8250 for housing means a fraction of a

Suriname guilder per m^3 timber grown. These data give only an indication of costs. (In 1982 the value of one Sf was about US $ 0.56)

Cost of silviculture in other regions. A very rough comparison is made only with forestry in Europe, on the basis of data given by Mayer (1968). A selection forest, which is the system most related to the Celos Silvicultural System, is assumed to have reached a balanced state. The forest under the Celos Silvicultural System in the first cycle is still subjected to necessary initial changes which are relatively expensive to establish. In the data given by Mayer, the use of machinery such as powersaws for silvicultural purposes makes it difficult to compare results. He gives as productivity 1.4 m^3 per man-day for clear felling systems, and 2.6 m^3 per man-day for group selection felling (Femelschlag). Separate data for silvicultural treatment of selection forest are not given. Compared with this, 1.8 m^3 per man-day in the Celos Silvicultural System is quite acceptable for a system not yet fully evolved. Further the labour cost is very much lower in Suriname than in Europe. However, this is somewhat balanced by the relatively high stumpage price obtained for timber in Europe. Mayer (1968) discusses the profitability of growing valuable timber as opposed to low value wood products, and favours selection forests for the production of good quality big timber.

A low volume production per hectare has the disadvantage that long distances have to be covered and large areas supervised. Close supervision of labour gangs is almost impossible, and contract labour seems essential to obtain economically viable results. An annual volume production of only 1 m^3/ha in most managed forests in Europe would be reason enough to discontinue silviculture for production purposes; usually average annual volume production is higher than 4 m^3/ha. In Scandinavia an annual productivity of between 1 and 2 m^3/ha is usual (Mayer, 1968), but a large proportion is pulpwood, which makes comparison difficult.

Because conditions are different, these comparisons can only be illustrative. In Mapane the annual volume production of commercial timber is from only a small number of trees in the stand, whereas in managed forests in Europe most trees produce saleable timber, even though sometimes it may be low priced assortment.

The proportion of the total cost of the timber logs delivered at the factory which is spent on silvicultural measures, varies from about 10% in Scandinavia to about 30% in Germany (Mayer, 1968). In Suriname, the present-day price of sawn timber is derived from very low royalties, costs of harvesting, transport, and industrial processing, plus a certain profit, without much consideration to the cost of growing the trees in the future. Market prices of timber logs being determined largely by harvesting and transport cost, the price developments in the near future will be more similar to those in the mining industry than in agriculture. Inevitably, timber prices will increase as sources are depleted, and when this happens in a short period there is no time to develop a forest estate. When selective felling is the usual practice, as in Suriname, other species are harvested after preferred timber species have been depleted, and this could continue until the market will not accept the ever decreasing quality. In Suriname, the transport cost of logs from virgin forests over long distances has already reached the point where it would seem to be cheaper to grow quality timber (for example, with the Celos Silvicultural System) in less remote forests.

The more depleted the forest, the less attractive it is for polycyclic management. In fact, it is preferable to introduce this type of system immediately in virgin forests destined for timber production, where timber resources are highest. Then it would be easier to set aside funds for silvicultural work and other management measures to conserve the timber resources.

PART III

Silvicultural experiments

4 Introduction and methodology

4.1 Review of research before 1965

From its inception in 1904, the Forest Service of Suriname has given close attention not only to forest inventory and exploitation but also to forest regeneration. A very early report by Berkhout (1903, in Gonggrijp and Burger, 1948) proposed for the mesophytic forest in the Forestry Belt an exploitation system of clear felling to be followed by artificial regeneration using taungya methods or management by selection felling ('plenterhieb'). In a later report, Berkhout (1910, in Gonggrijp and Burger, 1948) rejected selection felling on the basis of a report by Plasschaert (1910), who concluded that this system was not beneficial to natural regeneration of commercial species. This is now confirmed by the results of Expt 67/2. Plasschaert considered that artificially regenerated forest, having one or at most only a few timber species, would suffice with regular forest management, and that such a forest could be obtained only by clear felling and replanting or artificial seeding.

Logging methods influence silvicultural practices significantly. At that time, mechanical logging had not been developed in Suriname. Later, Pfeiffer (1929, in Gonggrijp and Burger, 1948) indicated that a minimum of 100 m^3/ha of exploitable timber was necessary for economic mechanical logging of selected forest complexes. Ultimately in 1970, 20 m^3/ha was considered to be sufficient to permit skidding with wheeled skidders, as has been amply demonstrated in practice (Vink, 1970).

These early attempts at forest regeneration contributed little to knowledge of the dynamics of the forest vegetation (Boerboom, 1964). In general, silvicultural practices aimed to obtain a stand of as much useful timber as possible, preferably of only a few, or even one, very valuable species. This was considered to be quite possible, even though the natural virgin forest was composed of a multitude of species. A background of European forestry, and perhaps to a greater extent management experience gained in Southeast Asia, especially in the teak forests in Java, may have influenced the direction of forest management in Suriname during the period 1904-1926. The intensity of treatment advocated, and investment per ha in those systems were much greater than is proposed in this book for this type of forest. The experiments on natural regeneration discussed by Plasschaert (1910) were mainly on *Manilkara bidentata*, a species much sought after because of the balata yield. At that time, the balata industry was far more important than the timber industry, and in some years provided employment for more than 7000 out of a population of less than 100 000. Today, the value of the timber exceeds that of the balata to be bled from the tree. Because bleeding leads to a high degree of mortality, and in surviving trees considerably reduces the future timber quality, the regulations restricting logging of *M. bidentata* trees should be revised (Gonggrijp and Burger, 1948).

Plasschaert (1910) did not indicate why experiments on regeneration of *M. bidentata* failed. Treatment consisted of felling or girdling all vegetation in the experimental area of several hectares, leaving only seed trees of *M. bidentata*. Even in years of abundant seed, no new seedlings were found, and establishment of a seed-bed by cultivating the soil, as suggested by Plasschaert (1910), was not destined to be successful as is now known. The treatment probably changed the environment so radically that the seeds did not germinate. The cost of more intensive treatment was found to be prohibitive.

The planting experiments done later at Zanderij Station were much more informative about regeneration, but many of the plantations established have been destroyed. Present day research on these plantations is not very promising because the condition of the forest and soil at planting is not known. The growth of plantations on the poor soils at Zanderij is slow. However, study of these plantations may indicate whether synchronization of growth, especially in a single species stand, is deleterious to growth.

Gonggrijp and Burger (1948) paid considerable attention to the important timber species of Suriname, especially those occurring in considerable quantities per hectare, namely: *Vouacapoua americana, Dicorynia guianensis, Goupia glabra, Hura crepitans, Carapa procera* and *C. surinamensis*, and the *Mora* spp. Most stands containing a high volume of any of these species were limited in area to only a few thousand hectares, but were attractive because of the relatively high volume of exploitable timber.

Gonggrijp and Burger (1948) gave little information about the mixed forest on dry land, that is the mesophytic forest, which covers most of the interior of Suriname. The productive forests in the lowland area, about 2 million hectares, were estimated to contain about 200 million m^3 timber of all species. This estimate was based on branchless boles of trees of 30 cm or more in diameter at breast height. The annual potential increment was estimated to be at least 1 m^3/ha. Thus, the minimum allowable amount of timber to be felled was 2 million m^3 per year. These estimates are similar to those of Vink (1970), although these were based on different assumptions about exploitation methods, timber species logged, and silvicultural methods applied.

Estimates of forest productivity after clear felling which were made after World War II were quite optimistic. For example, in a paper on the use of firewood as the source of fuel for the aluminium industry, Gonggrijp (1956) stated:

'After cutting the natural stands, regeneration is estimated to result in more homogeneous and much more valuable forests, with an increment of at least 5 tons of firewood per ha/year, which implicates the attainment again of the present volume of 200 tons/ha in a period of 40 years. It may be discovered that it is of advantage to proceed to convert the natural stands into more productive homogeneous stands. In which case a rotation of much more than 40 years can be attained'.

The soil was considered to be able to maintain such a yield. Sustained yield was assumed to be assured as soon as sufficient forest regeneration had occurred. Such an assumption was not novel then nor is it at the present time. Ultimately, it was decided not to consume wood for energy production, but to convert a large forested area to a shallow artificial lake, Van Blommestein or Brokopondo Lake, for the generation of hydro-electricity for the industry.

The emphasis on artificial regeneration and the desire to harvest large volumes of timber have influenced forest regeneration systems developed since World War II. The feasibility of harvesting and interfering with the mesophytic forest increased with the introduction of more modern road-making and logging equipment, availability of relatively cheap fossil fuel oil, and powerful synthetic arboricides. When the Forest Service was re-established in 1947, it began to open up the Forestry Belt by constructing a network of all-weather truck roads. The timber boom after World War II opened up attractive markets for a number of species hitherto of no commercial value.

Forest regeneration research was again directed to the establishment of a silvicultural basis for management planning. In addition to experimental planting of a number of local and exotic species, experiments on natural regeneration of the mesophytic forest and other forest types were set up. Of the various forest stations, Kamp 8 became the most important centre for experiments on the mesophytic forest.

The ecological studies of Schulz (1960) changed the direction of silvicultural research in Suriname from being species oriented to ecosystem oriented. After several years of open-minded experimentation, the research objectives and methods were defined by Schulz (1960, 1967) and Boerboom (1964). Prompted by the ideas of Dawkins (1958) on management of tropical mixed forest, a monocyclic system was considered to be essential for efficient timber production. Boerboom (1964) concluded that it was possible to obtain prolific recruitment of saplings of commercial species from the seedling population naturally present in the mesophytic forest of Suriname. He proposed that further research on liberation systems and time schedules for liberation be undertaken, especially to determine the minimum level of maintenance required for an acceptable stand of regenerated forest. Further he proposed that attention be given to developing criteria for the minimum dimension of regeneration acceptable for treatment, and to assessing the feasibility of liberating only those trees which could be classified as 'leading desirables'. This resulted in the experiments discussed in following chapters.

The cost of the treatments at that time, as now, was a deciding factor in establishing a management system. According to Vink (1970), the system of natural regeneration of the mesophytic forest proposed at that time 'would hardly make the system an economic proposition'. It was considered to be too expensive and complicated to organize, because skilled and even literate labourers were required for the frequent liberations.

Neither Schulz (1967) nor Boerboom (1965) discussed in detail the serious problem of forest regeneration after the final harvest at the end of the first monocyclic rotation. This problem was remote in time in such long rotations. Yet, present-day experience of fully logged forest areas indicates that this problem is almost insurmountable. The regeneration of commercial species present in restricted quantities requires elaborate silvicultural aid in order to compete with the vigorous secondary vegetation arising after such drastic interference. The solution may be artificial regeneration, or a shift to partial harvesting, in other words, to adopting a polycyclic approach. Schulz (1967) referred to the introduction of a polycyclic system in his plea for more research on logging damage. The mesophytic forest in Suriname produces relatively small logs, and conclusions about polycyclic logging based mainly on African and Southeast Asian conditions should not be unconditionally accepted. Recent research on logging has indicated that damage could be fairly well restricted (Hendrison, 1984; Hendrison, in press).

The need for a polycyclic approach places the results of the research carried out between about 1945 and 1965 in another light. Stocking percentages, the need for large numbers of saplings per hectare, increment data over the first periods and treatment frequency are all interpreted differently and are given another order of priority in a polycyclic approach. Views on treatments such as pruning and thinning change when species lists are changed. With infrequent and inexpensive silvicultural treatment, regeneration can keep pace with exploitation, which harvests several thousands of hectares annually.

While the Centre for Agricultural Research in Suriname (CELOS) carried out the experiments discussed in this book, the Silvicultural Research Department of the Forest Service continued its work on natural regeneration in a series of experiments established in the 1960s (de Vletter, 1976). Recently, a large field trial on polycylic management commenced in the Mapane region near to Expt 67/9 B (de Vletter, 1980). The large silvicultural experiment on polycyclic management (Expt 78/5) which was set up by the author in the Kabo region in 1978 (de Graaf, 1982b) will be discussed in a later publication in this series (Jonkers, in press).

4.2 Methodology

Silvicultural research in highly mixed natural forests can concentrate on either individual tree species or on whole stands composed of many species. The individual species approach was considered to be unsatisfactory, particularly in the early stages of this study. Where possible, autecological information about important tree species was sought, but priority was given to finding economically and ecologically feasible forest treatments to manipulate the whole forest for the best result. Especially when effects of certain treatments are to be studied in numerical terms, large experimental plots are required in order to collect sufficient data about individual species.

A useful way to begin a study of a complex ecosystem, such as tropical rain forest, is to observe a limited disturbance, preferably a well defined and repeatable disturbance, or even to create it. This is the 'black box' approach (Margalef, 1968), in which a consistent reaction in the system, even if not understood, assists in defining percepts of the system. When a satisfactory general management approach has been found empirically, details may be studied in an endeavour to explain reaction in the ecosystem.

Most of the silvicultural experiments were started more than 15 years ago, when less emphasis was placed on general ecology. At the commencement of the studies the effect of animals on the forest ecosystem, and the nutrient store and nutrient cycling which are now considered to be essential, were not taken into consideration. In the last 15 years the view of ecology has widened considerably, and the silvicultural systems devised from the experimental results have to be tested on aspects largely neglected in the first years of experimentation.

In 1965 emphasis was given to the scheme of the treatments to be applied in the first 15 years of the rotation. Volume production and cost per m^3 timber produced was not expected to be known early, because the system was monocyclic, and the rotation more than 60 years. Cost of treatment over such a long period could only be estimated roughly. Harvesting damage to the remaining stand was considered to be less important in the monocyclic system as conceived in 1965 than such damage is now in a polycyclic system. This aspect is being investigated in experiments set up since 1977 (for a list, see Project LH/UvS 01, 1984).

Research discussed here began with the concept of a field experiment, and mostly ideas were tried out on plots staked out in selected forest areas. In these plots, parameters of the tree population, particularly commercial species, were recorded mostly annually to monitor developments. Recording of all trees of all species is a formidable task in large plots of several hectares, the more so when done annually. Such intensive recording of all trees could only be started in more recent experiments. An intensive scheme of recording is not only very expensive, but increases the risk of breakdown for the experiment if the schedule cannot be reduced without considerable loss of data in case of budget cuts. These experiments have to continue for long periods, often with uncertain financing.

Usually, the conceptual framework for an experiment in silviculture is limited by factors such as the minimum timber volume necessary for the following exploitation to be economically feasible and the maximum price per m^3. However, such factors tend to change over a long period of time with technological and economic changes. The basic assumption in these experiments was that a quality product should be grown, that is saw logs or plywood logs of fairly large dimensions, over 45 cm dbh (Boerboom, 1964). This assumption is still valid because there is plenty of second class timber in the relatively large area of accessible forest in Suriname. The cost of harvesting and transport is an important limiting factor.

Silvicultural research should not strive simply to estimate the timber increment during a certain period after a particular type of exploitation and silvicultural treatment. It should endeavour to explain how to handle the forest, so that it is not destroyed but kept in good productive order. Further, research should not be limited only to reactions of the tree population to silvicultural interference. Ecological evidence suggests that in complex ecosystems the tree population may not be as good an indicator of stress as, for example, changes in soil nutrient cycling, in which processes may be more sensitive than growth of the trees (O'Neill and Reichle, 1980). As tree development studies take time, information about degenerative processes may be obtained more rapidly by studying other parts of the ecosystem. Therefore, detailed study of nutrient cycling and related aspects was carried out (see also Schmidt, in press).

The methods used in the experiments described in this book, are discussed under the following headings: recording of trees; other observations; plot treatments; data processing; interpretation of data.

4.2.1 Recording of trees

Trees which were recorded regularly, that is mainly trees of commercial species, were given a permanent number. Plastic tags were wrapped around saplings, and on larger trees aluminium tags were fixed with a nail or a number was painted on the bark. At the point of measurement, preferably at breast height, epiphytes and loose bark were removed, and the bole marked with a red paint ring one to two cm wide. This allowed quite accurate measurement of annual girth increment to be made. Girth was measured in millimetres. The lower diameter limit for recording ranged from 2.0 to 15.0 cm dbh, depending on the requirement of the particular experiment. The expression dbh indicates diameter at reference height, which in most cases was 1.30 m above ground level. For trees with buttresses or a very irregular stem section, often the reference height was much higher, but always at the same fixed point throughout the experiment.

The species of each tree was identified by trained treespotters. They gave the local name of the tree, which was then related to the scientific name as far as was known. This posed no special problem for most commercial species. Mostly, the handbook of Lindeman and Mennega (1963) was used. Such identifications are not absolute, but meet most requirements.

Trees of commercial species were classified into quality classes in various ways during the long experimental period. Only two of these classifications have been used for interpretation, that is form class I comprising trees of good overall stem and crown form, and form class III comprising all trees of either good or bad form.

Recording of non-commercial tree species was considered to be too laborious for the small team of workers in the first years of the experiments. Moreover, according to the silvicultural concept underlying these older experiments, most of the non-commercial tree species would be eliminated in the more intensive treatments. In later years, overall sampling of diameter distributions was carried out several times using a girth tape or an angled caliper with paper strip to record the number of trees per five-centimetre diameter class. This caliper saved much time, but was only introduced in 1978. Data on total basal area obtained are reasonably accurate except for the very large trees which could not be measured with this instrument. These trees were measured with the Biltmore stick, which was placed on a pole to reach above high buttresses. Measurements with this stick are less accurate but are done more quickly. Prism sampling was tried several times but was found not to be satisfactory, because it could not be used in small plots. Furthermore, it depended heavily on visibility in the case of large trees at a distance in densely vegetated plots.

Height measurements were seldom carried out because of poor visibility, and as disturbance to the vegetation had to be limited to the prescribed treatment the vegetation could not be cut to increase visibility. This situation differed from that in temporary plots for large-scale inventories, where such disturbance is acceptable. In Expt 67/9 B, the period shortly after refinement when all leaves had fallen from killed trees provided opportunity for height measurements. From the bole lengths measured at that time, the volume tariff used for volume calculations was constructed (see Appendix VII).

Mortality was registered at each recording, and where possible the cause was specified. Damage to the trees, and pests and diseases were recorded.

Most field experiments were carried out on well-demarcated plots of various sizes which were bounded by lines 1.0 to 1.5 m wide cut in the undergrowth. The corners of plots were marked with plastic pipes of 4 cm diameter and 1.30 m long and protruding one metre from the soil. These pipes were widely used in CELOS silvicultural experiments. They are light and durable, and easily carried in large numbers by one person over large distances, but are somewhat expensive. They were installed with a soil auger, and aluminium tags were attached in sawn slots.

Measuring trees even for simple parameters, such as girth increment at breast height, is strenuous exercise in the hot and humid atmosphere of the tropical rain forest. Walking through the forest with obscured view, crossing fallen logs, tracing dispersed trees in dense forest often in disturbed and thus poorly accessible vegetation, carrying a ladder to reach high measurement points above buttresses, enduring bloodsucking insects, and waiting for hours perched under an improvised shelter of palm thatch for the heavy rain to cease, all place excessive demands on the energy of those recording trees, and all accumulate to produce a low data output per man-day input. A recording team of four to five men, comprising a foreman/recorder, two men to measure tree girths with tapes, one man to carry the aluminium ladder and to help to clear the measurement point, plus a man to wield the paint brush, recorded 100 to 200 trees, which already carried a permanent number, in one working day. This however, is only an indication, as time required varied, due to field conditions. Data were collected on more than 10 000 trees over a period of ten years or more.

Irregular stem sections at the measurement point could not always be avoided. Absolute values, for example for total basal area of a stand, could not be as exact and reliable as for most forests of temperate regions having trees with regular round stem sections and no extensive buttresses. However, as a series, the girth measurements are precise and have been used to study developments in girth over periods before and after treatments. As increment boring of stems was not possible because of the absence of annual growth rings, periodical or even annual recording was used to monitor the reactions of trees to treatments.

4.2.2 Other observations

Observations were made on other aspects, including accessibility, labour cost and material used for treatments, and organization of the work. As treatments were infrequent, there were few occasions for such observations. Accessibility is affected by the frequency of visits to plots, especially if the machete is used liberally. This is an anathema, especially in small plots, because it is an unscheduled treatment which disturbs the experiment.

Few data only have been collected about soils. The experimental plots were laid out in as homogeneous forest as possible on slightly sloping terrain (see Figs 6.1 and 6.2), and soil maps, if made, seldom showed salient differences within an experiment.

4.2.3 Plot treatments

In the experiments started before 1977, controlled exploitation was not carried out, and experimental plots were demarcated in lightly exploited forest. Exploitation of these plots was quantified by measuring the remaining stumps, and mapping skid tracks and gaps. Treatments were applied only in the experiment plots. As the Forest Service at that time did not practice large-scale natural regeneration, these treatments had to be organized by the research silviculturist with generous assistance from the Forest Service.

Experimental treatments should be simple for better understanding of what is really done. Also, treatments should be quantifiable, otherwise they cannot be reproduced. For treatments which are difficult to express in numbers, such as liana cutting, calculation of correlations with increment is almost impossible.

The two silvicultural treatments applied were refinement and liberation. These were applied in several different schedules. No planting was done and no artificial seeding, not even deliberate seedbearer treatments. Attention was focussed on the naturally established seedlings, saplings and juvenile and adult trees in the experimental plots.

The concepts of refinement and liberation used in these experiments are as defined by Dawkins (1958) and adopted in Suriname. These have already been discussed in Chapter 2.

Refinement was always defined with a lower diameter limit for trees to be eliminated. At first the trees to be spared, that is the commercial species, were marked with red paint, but later, after 1979, trees to be killed were marked, with blue paint. This was clearer for the unskilled labourers treating the trees, and prevented accidental killing of commercial species. This change in approach was possible because of the lighter interference required in later experiments, which made higher diameter limits the rule, and resulted in smaller numbers of trees to be killed. Marking requires knowledge of at least all commercial tree species.

Refinement with a diameter limit can be expressed numerically as basal area, timber volume or biomass units killed or left alive. For this, a stand table derived from inventory data is necessary. Trees to be eliminated were poison-girdled. Use was made of the sodium ester of trichlorophenoxyacetic acid, the well known 2,4,5-T, as a 5% solution in diesel oil. Refinement included cutting lianas to a specified thickness. (For details about tree killing techniques, see Chapter 3).

Liberation was done with machete (cutlass) and larger trees were killed by poison-girdling. Liberation is not easily quantified or even standardized for field instructions. In the early research plot treatments this sometimes led to the slashing of all 'weed' vegetation and the killing of all trees of non-commercial species during the liberations prescribed. Such treatment aggravated the weed problem considerably, until the stand of saplings closed its canopy. The more individual approach of treating each tree according to its needs has to be carried out by experienced labourers, and has proved to be very expensive for saplings in terms of cost per m^3 timber produced finally. The advance of management as meant by Dawkins (see Chapter 2), in Suriname was that refinement became a lighter interference than in early years, and that subsequent treatments (liberations) were postponed until year eight. This resulted in the merging of refinement and liberation, until only refinement treatments were to be applied, with a variable lower diameter limit. This simplified work and field instructions considerably. By keeping the stand fairly closed, slashing of weeds became unnecessary, as vegetation other than trees, saplings and seedlings became less important. In Suriname this was even the case with lianas and climbers.

4.2.4 Data processing

The large amount of data recorded was processed on IBM 1130 computer made available by the Government of Suriname. Most important operations were: the filing of the data; sorting of this file in several ways; and calculation of stem numbers and of basal area per tree, per selected diameter class and per species and tree qualification groups. Periodic girth increment was calculated for selected classes and groups, combined with sorting out of trees that died during the period stated.

Basically, the diameter classes were set at 5 cm intervals commencing with class 0.0-4.9 cm. For discussion these have been condensed, and the series 5.0-14.9, 15.0-29.9, 30.0-44.9 cm, etc. was preferred. Thus the first class did not span 14.9 cm, but only 9.9 cm, and trees smaller than 5.0 cm were not included. These wide classes were necessary for the experiments having small numbers per treatment, for example Expt 65/3 and 67/9 A, to provide enough data in the higher diameter classes, the minimum number of trees per class being fixed at five. For standardization this series also had to be used for the other experiments, even if these had many trees in the larger diameter classes. Thus, precision was partially sacrificed to facilitate comparison between experiments.

Girth increment per diameter class was classified according to the diameter class of the tree at the start of the period stated. In most cases, recording was scheduled to result in periods of one year or a number of full years between recordings in order to facilitate calculations. Data could not always be presented for periods of the same length.

A differentiation was made between true and false recruitment, the latter being composed of individuals too large to assume that they had grown into the size class within the period stated. Usually these were trees overlooked during previous recordings. These data were not used in studies on changes in diameter distribution, but were used in girth increment studies to increase the small numbers of trees in a class.

In several cases bole volume in m^3 over bark was estimated. Basal area data from computer outputs and a simple volume tariff (see Appendix VII) constructed from data from Expt 67/9 B were used. The calculations were done with the aid of a pocket calculator. Volume data thus found cannot be exact, but can be used for comparative purposes. The volumes found are less accurate for the group of all species in the stand than those for the commercial species group. A considerable number of non-commercial species have highly irregular stem forms, for example deeply fluted trunks, very high buttresses, or even perforations throughout the stem. For comparative purposes the volume produced is a most important variable, and also, volume is the unit for sale of timber. Ecological studies use units of weight, preferably dry weight.

Mortality was calculated from the number of trees found dead in the period stated, and was presented as a proportion of the population present and living at first date of recording for the period stated.

4.2.5 Interpretation of data

In interpretation of the data, use was made of the following variables:
- stem-diameter distributions of selected groups of species;
- basal areas of selected groups;
- bole volumes of selected groups, if and when available;
- periodic annual girth increments for selected groups;

– mortality rates.

These variables are discussed for each experiment in the relevant chapters. The group of the commercial species 11-41 consists of species which have been accepted by the timber trade since 1967. This group is not a botanical entity but is composed of species from 15 families. Species composition of the forest varies between experiment locations, but also within one location, thus resulting in variation between plots of one experiment. The reactions of the group of commercial species to treatment were determined more by abundant species, such as *Tetragastris altissima*, than by rare species. Even when there was considerable variation in the species composition, reactions to treatments were fairly uniform.

Further, use was made of information about geology, soils, topography, rainfall, cost of silvicultural treatments, and of quantitative but non-numerical information from forest profile diagrams drawn to scale in selected plots, and also stereophotographs. The silvicultural system as presented in Part II was derived from all experimental data. Assumptions about processes in the forest, especially in the later years of a felling cycle, which have not yet been observed, have been made by extrapolating from data about known processes.

The polycyclic approach makes the use of well-trodden paths of silvicultural research rather difficult. Experiments on uniform even-aged stands tend to monitor a generation of trees, if possible the whole life cycle. Many research methods are adapted to this approach, and have a high degree of accuracy, but are less applicable in a polycyclic approach.

Instead of following a generation of trees in the experiments, the population was put into a framework of diameter classes independent of age. In the fundamentally uneven-aged mesophytic forest in Suriname, the life stage of the tree, that is its 'ecological age', was assumed to be related more to its size and competitive status than to its 'chronological' age, which is mostly unknown. The methods used by Hallé, Oldeman and Tomlinson (1978) to identify the stage and status of trees by their architecture, could not be incorporated in this research work, but should be tried in future work.

Statistical tests were used in only a few cases. This is related to the early stage of experimentation. In fact, in the allied agricultural field research, working with far less complicated ecosystems, experiments which are intended to yield data for statistical testing are seldom the first done on the subject. Mostly agricultural experiments are repeated frequently, and can be designed especially to test relationships already known from foregoing research. Repeating experiments during a period of only a few years is easy with annual crops but is not possible in long-term silvicultural experiments.

In first generation long-term silvicultural experiments, the first need is not to test largely unknown effects very precisely, but to find a path through the maze of phenomena. Many replications are desirable to obtain better estimates of important factors, but trees are large creatures, and establishing and monitoring plots is expensive and labour intensive. A host of treatments, the results of which are difficult to interpret, does not help in increasing understanding of principles in ecosystem reactions in a mixed forest. Thus, for these experiments only a few treatments and variables have been used in interpretation.

5 Experiment 65/3: growth and mortality in naturally regenerated mesophytic forest

5.1 Summary

Expt 65/3 was set up to study the effects of delay of maintenance after an initial heavy refinement, because frequent maintenance was very expensive. The heavy silvicultural interferences in this experiment were preceded by light exploitation, taking about 14 m^3/ha, mainly as logs from quite large trees.

Total basal area in the two large experimental blocks A and B was reduced by refinement to one-fourth and one-seventh respectively of the value beforehand. Subsequent maintenance followed different time schedules for liberation of mostly the small individuals of commercial tree species. In zero maintenance plots, that is those which received an initial refinement but no subsequent liberation treatments, the vegetation consisted mainly of non-commercial tree species and lianas. Growth of individual trees of commercial species was favoured each time a liberation treatment was given, and recruitment of saplings from existing populations of seedlings was promoted, but mortality was higher than in untreated forest. Basal area of the group of commercial tree species increased almost tenfold in 13 years in the most intensive treatments, and less in the less intensive treatment schemes. There was a close relationship between girth increment and total basal area.

Annual bole volume increments of the commercial species in the most intensive treatment ranged from 2 to 4½ m^3/ha, depending on the list of accepted species. This volume production occurred mostly on small trees during the first 14 years. Total bole volume of all species in the most intensive treatments increased from about 20 m^3/ha in 1966 to about 110 m^3/ha in 1978, which is equivalent to a periodic annual volume increment of about 9 m^3/ha. In zero maintenance plots regrowth of all species was better, but volume production of commercial timber species was considerably lower than in the intensive treatments.

The experiment was set up for a monocyclic system, with a rotation of not less than 60 years, and the cost of intensive treatment over this long felling cycle was very high. The less intensive treatments were much cheaper but also less effective. Probably, the most important conclusion to be drawn from Expt 65/3 is that it is not worthwhile trying to create uniform even-aged stands, because the intensive treatments required are not economically feasible over the 60 years required to produce timber-size trees. Further, the ultimate clear felling planned would create

massive problems for forest regeneration, because of extensive harvesting damage and vigorous growth of secondary forest after such heavy disturbance.

5.2 Introduction

According to Boerboom (1964) who set up Expt 65/3, the objectives were to study the effects of delayed liberation treatments on populations of valuable young trees in refined mesophytic forest stands. These objectives must be viewed in terms of the basic approach at that time to silvicultural conversion of a forest. Exploitation specialists preferred large volumes of timber per hectare to allow inexpensive harvesting as in the Malayan Uniform System, which was a silvicultural system well developed in Southeast Asia. The creation of a fairly uniform and even-aged young stand of valuable species by harsh refinements of only lightly exploited mesophytic forest in Suriname had been shown to be possible in earlier experiments (Boerboom, 1964). However, the main problem was the high cost of intensive liberations required afterwards to prevent the valuable regeneration being swamped by weed vegetation springing up after opening of the canopy. The harvesting cycle in this type of monocyclic system must be at least 60 years, with the result that the expensive early treatments led to financial problems. Expt 65/3 was set up to provide the theoretical basis for delaying early liberation treatments without undue loss of regeneration.

Expt 65/3 was located on a reasonably flat plateau close to Kamp 8, where several studies had been carried out by Schulz (1960). On the general soil map of Mapane (Fig. 6.1), the experiment is located on the transitional zone between the cover landscape (Zanderij landscape) and the residual soils of the interior on units 40 and 54. Unit 40, in the cover landscape, comprises 'Slope and plateau soils, moderately well and imperfectly drained loamy sand to sandy clay, locally somewhat excessively drained (bleached) medium and coarse sand'. In the experimental area no specific excessively drained sandy soils are found. Unit 54 is in the Rama landscape, with 'Hilltop and plateau soils, well drained mostly gravelly clay'. The experimental area is dissected by only one small gully which is mostly dry, and which is located in the surround strips between block A and B of the experiment. Rainfall data for Kamp 8 are given in Appendix I.

5.3 Experimental lay-out

The design of Expt 65/3 was a balanced incomplete block design, consisting of two blocks, A and B, each subdivided into six subblocks each of eight recording plots. Thus, blocks A and B each consisted of 48 plots, that is six treatments with eight replications. The total area of each block was about 10 ha, the area of each treatment plot was 35 × 50 m, and of each recording plot 20 × 35 m. The field lay-out is presented diagrammatically in Fig. 5.1. During the period 1965-1971, a

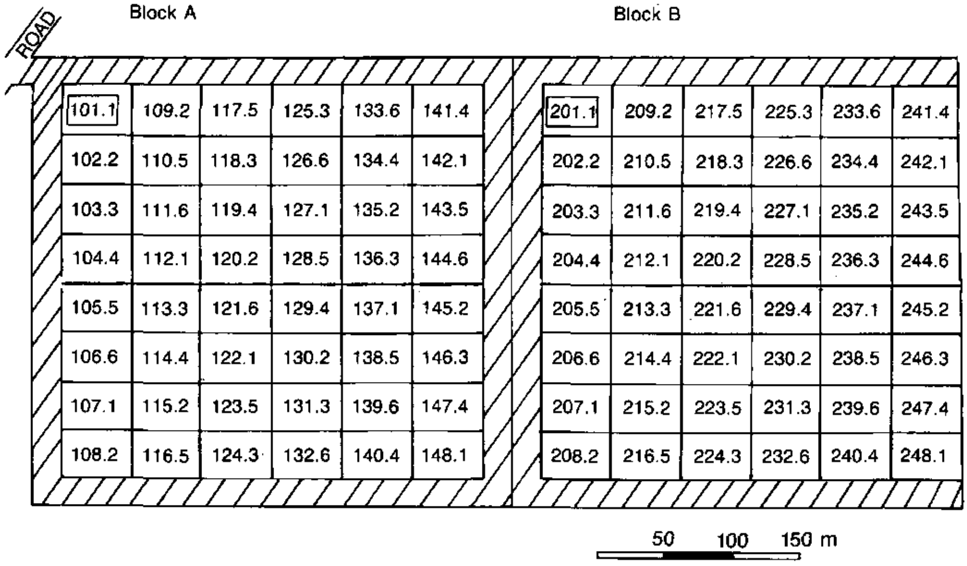


Fig. 5.1 Expt 65/3: field lay-out. Refinement limit in block A 10 cm dbh, and in block B 20 cm dbh. Last figure of the plot number indicates the treatment, the hatched zone indicates the 20 m wide surround.

centrally located plot (2 × 20 m) was used to record seedlings in each treatment plot.

Blocks A and B differed only in diameter limit for refinement, being 10 cm and 20 cm for block A and B respectively. Treatments within blocks differed in the time schedule for liberation treatments (see Table 5.1). The schedule of liberation treatments was revised several times during the experiment.

As this experiment was set up mainly to monitor changes in the population of seedlings, saplings and small trees, the relatively small size of the plots was not a

TABLE 5.1. Expt 65/3: scheme of liberation treatment schedules* and recordings

Treatment code	Years after initial refinement													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A,B 1			x	x	x		x			x				
2			x		x				x					
3				x	x					x				
4							x							
5														
6														
Recording (years)	'66	'67	'68	'69	'70	'71		'73	'74		'76	'77	'78	'79

* This scheme was followed in both block A and B and was revised in 1972.

problem. For trees larger than say 30 cm dbh, the recording plot surround of only 7.5 m was not satisfactory. These large trees were less important in number than in volume produced. However, after 14 years, the number of large trees increased, and precision in defining treatments was reduced. The complicated lay-out made treatment somewhat difficult to apply and to supervise.

5.4 Exploitation

Exploitation in the concession compartment in which the experimental area was located, was completed in 1964, one year before the experiment began. An inventory done shortly after exploitation showed that about 2.7 trees per hectare had been taken (Sterringa, 1968a). Over the 19.2 ha experimental area, a total of 52 trees had been logged, including 21 *Ocotea rubra* trees (see also Table 3.1) and 11 *Virola melinonii* trees. They varied in size from 45 cm dbh to more than 90 cm dbh, with no stem-diameter classes predominating. On the basis of a mean stem diameter at breast height of 72.5 cm and 18 m log length, the estimated mean log volume felled was 5.3 m^3, thus resulting in a harvest of about 14 m^3 per ha. Trees were large, and their crowns must have covered large areas after felling, say 300 m^2 per tree, thus covering about one-tenth hectare with three trees per hectare. In this intensively treated experimental area, no obvious signs of exploitation damage were visible several years after refinement, because secondary species appeared almost everywhere as a result of the heavy treatments.

5.5 Silvicultural treatments

In Expt 65/3 two minimum stem-diameter limits were used for refinement (Boerboom, 1964), because degree of refinement had a large effect on the regrowth of weed species. The heaviest refinement was done in block A with a stem-diameter limit of 10 cm dbh. This reduced the total basal area above 5.0 cm dbh from about 28 m^2/ha in the exploited forest to about 4 m^2/ha. This estimate is based on reconstructed stem-diameter distributions. In block B the diameter limit was 20 cm dbh for weed tree species, resulting in reduction of total basal area from 28 to about 7 m^2/ha. In both blocks, all trees of valuable species above 20 cm dbh were also killed to obtain more uniform stands. This was very counterproductive in terms of volume production of timber size logs.

Refinement cost given by Sterringa (1968a) was 5.0 man-days and 58 litres arboricide mixture per ha for the 10 cm stem-diameter limit, and 3.6 man-days and 44 litres arboricide mixture for the 20 cm limit. Arboricide mixture used was Esteron 2,4,5-T, 5% solution in diesel oil. Quantification of refinement treatment in terms of biomass is difficult. After refinement it is estimated that less than one-tenth of total biomass was left alive. However, it should be conceded that much standing biomass already had a large proportion of (dead) heartwood, often partly rotting and decomposing. Volume estimates are given in Section 5.7.

Quantification of refinement treatment is difficult, but quantification of liberation treatment is almost impossible. In Expt 65/3, liberation treatments aimed to remove only weed trees and lianas directly threatening those trees recognized as being valuable, even those not marked previously. The individuals to be liberated had to be at least 2 cm dbh. Thus no seedlings were liberated, but where possible they were saved. Small weed trees were eliminated by simple cutting, and larger trees by killing with arboricide, with or without a frill.

In the intensive treatments, for example A 1 and B 1 (see Table 5.1), after two liberations the remaining total basal area may have been almost as low as immediately after refinement, notwithstanding the very rapid regrowth of secondary species during the first two years. Reliable data on total basal area are only available for 1974, 1975 and 1978.

The lightest treatment schedule, B 5, is comparable with treatment schedule 20 + 0 in Expt 67/9 A, which now in 1985 is considered to be quite a heavy interference. Thus the treatment schedules of Expt 65/3 are now of little practical use, but the systematic and statistically reliable set-up of the experiment make the results useful in understanding the induced changes.

In the first few years of the experiment, liberation treatments required approximately 8 man-days and about 11 litres arboricide per hectare per treatment (Sterringa, 1968a). More experienced labourers required less time to do the work, but more importantly, the period of time required was greatly affected by the delimitation of the stands into 50 × 35 m treatment plots. The labourers probably did set a standard of time required per plot, irrespective of treatment prescriptions, and thus the real effect of effort required was obscured (Wiersum, 1970). In ergonomic studies on forest operations large and quite homogeneous stands are required to enable labourers to establish a realistic rhythm in their daily work, and to receive training before measurements commence.

In 1975, von Meyenfeldt tried to standardize and quantify the liberation treatments, by constructing four simple forest models and using a five-point scale of forest accessibility. Intensity of treatment was expressed by the numbers of trees killed or remaining alive, and in terms of corresponding total basal area killed or remaining. Use was made of filler trees of non-commercial species to avoid real gaps forming as a result of treatment. These treatments were closer to a subsequent refinement with a low stem-diameter limit than to a differentiating individual liberation. Treatments were quite heavy. The plots under treatment schedule A 3 in 1975 had a total basal area of 16.1 m^2/ha before treatment. After treatment, 4.0 m^2/ha of commercial species remained, and 2.3 m^2/ha of filler trees, in total 6.3 m^2/ha.

In plots under treatment schedule B 3, total basal areas were somewhat lower after treatment, with 3.2 m^2/ha of commercial trees, and 2.3 m^2/ha of filler trees remaining, resulting in a total basal area of 5.5 m^2/ha after treatment. Because of the vitality of many small trees in these stands, this low basal area did not lead to invasion of weed and lianas in subsequent years.

From these models, von Meyenfeldt established a range of 2.4 to 5.9 man-days per ha for all work involved in liberation treatments, including tree marking. The labour cost depended largely on the number of trees to be eliminated and on accessibility, and decreased with time elapsed since last treatment. Thus not only the number of liberations, but also the situation in the stand to be liberated is important. The amounts of arboricide used were not given in these studies. (von Meyenfeldt, 1975).

5.6 Stem-diameter distributions

The number per 320 m^2 of seedlings and saplings of commercial species accepted in 1970 (5-200 cm height) in the 2 × 20 m plots and also the mortality rate for the period 1965-1971, are presented in Table 5.2. The decrease in numbers recorded in the early years of the experiment continued, with the lowest figures being recorded in 1971, after which recording in the 2 × 20 m plots was discontinued. Growth of many surviving seedlings, saplings and trees has been stimulated grossly by the refinement, but seed production, dispersal, germination and seedling establishment have not provided recruitment fast enough to replenish the store of seedlings in these years. The estimated numbers of plants of commercial timber species in five stands under different treatments are given in Table 5.3. The group of larger seedlings and of saplings increased with increasing intensity of treatment schedule. In less

TABLE 5.2. Expt 65/3: number of seedlings and saplings (5 to 200 cm height) of commercial species accepted in 1970, and mortality rate

Treatment code	Year of recording*			Mean annual mortality rate (%)	
	1965	1968	1970	1965–70	1970–71
A 1	222	247	212	8	23
2	263	259	207	10	20
3	255	229	202	10	19
4	299	291	187	11	15
5	398	380	334	7	17
6	259	225	178	10	16
B 1	227	217	137	12	n.a.
2	241	260	186	11	n.a.
3	207	217	135	13	n.a.
4	200	158	113	13	n.a.
5	295	269	145	13	n.a.
6	198	183	152	11	n.a.

Source: Wiersum, 1970, and Zondervan, 1972.

* Data per eight plots each of 40 m^2, in total 0.032 ha.

TABLE 5.3 Expt 65/3: estimated number of individuals per ha of commercial timber species in five stands under different treatments, in 1970

Plant height (cm) or diameter (cm dbh)	Treatment code				Virgin forest
	A1	A6	B1	B6	
5– 50	1 000	2 600	1 400	1 400	10 000
50–100	2 000	1 000	1 150	1 500	1 250
100–200	3 000	800	1 050	1 200	520
200– 5 cm dbh	1 500	650	490	410	250
≥5 cm dbh	200	140	160	90	110

Source: Wiersum, 1970.

intensively treated stands and in virgin forest, competition from the large trees was responsible for the relative shortage of seedlings and saplings.

Larger individuals, that is the saplings and small trees above 90 mm girth at breast height (gbh) of commercial species, were monitored throughout the experimental period 1966-1979 in the 20 × 35 m recording plots. The change in numbers in the group of commercial species 11-41 form class I (only well-formed individuals) is shown in Fig. 5.2. Numerical data are given in Table 5.4. The initial sharp increase which occurred under the most intensive treatment schedules 1, 2 and 3 until 1973, was followed by a decrease, which was greatest in the first three treatment schedules. Data for a wider group of commercial species, that is species 11-58, form class III (of all categories of stems and crowns) are presented in Table 5.5. A much larger increase in this species group occurred under intensive treatment schedules, but no clear decrease after 1973 was observed. The success of the treatments was more obvious for this group of species, but data are distorted because many of these species were considered to be weed during the first years of the experiment. Under the intensive treatment schedules, many individuals must have been killed by man. The large decrease in numbers after 1973 for species 11-41 form class I may be related to the strict selection on form. As competition and mortality increase, the number of badly formed individuals can be expected to increase, thus reducing the number of first-class trees.

The number of trees per hectare of all species in 1978, which was derived from a caliper inventory, is presented in Table 5.6. The stem-diameter distribution shows many small and only a few large trees, which generally grow faster and will retain this lead. This stand is not uniform like even-aged monocultures of pine or eucalyptus, and cannot be made so without killing the best trees. Treatment schedules A 3 and B 3 reduced the number of trees of all species, especially in diameter class 2 (15.0-29.9 cm). The stem-diameter distribution was similar in plots under treatment schedules A 1 and B 1 and A 5 and B 5. However, from the data in Table 5.5 it is known that there were many more commercial trees in plots under treatment schedule A 1 and B 1 than under treatment schedule A 5 and B 5, as a result of the intensive treatments.

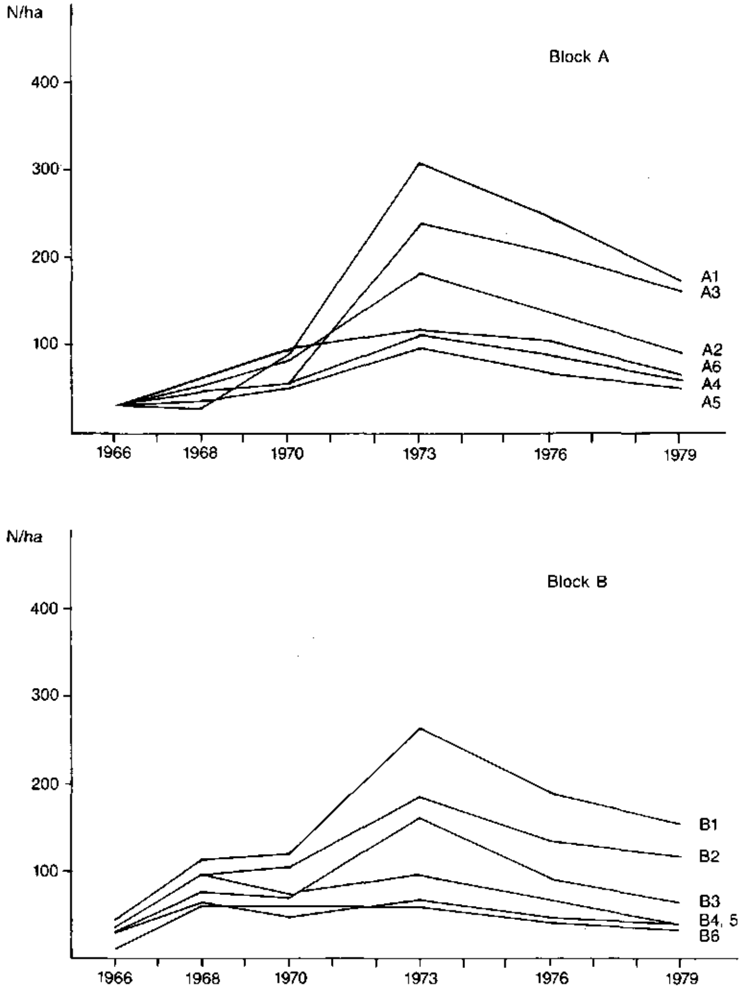


Fig. 5.2 Expt 65/3: increase in numbers (N/ha) of trees of commercial species 11-41 form class I under six treatment schedules, each with eight replications in blocks A and B.

Numbers of commercial trees above 90 mm gbh of species 11-41 form class I in 1967 and 1973 were used for a statistical test, assuming a balanced incomplete block design. Firstly, the number of trees per plot in 1967 was subjected to Fisher's F test. Data are not given here. No clear subblock or treatment effect was found at the 10% level of significance, for either block A or block B. Thus, it is probable that no soil and vegetation effects were present at the commencement of the experiment, and that treatment had little effect on numbers of saplings in 1967.

Secondly, the statistical significance of the increase in number of trees per plot in the period 1967-1973 was tested. Data are not given here. A considerable treatment effect was found, as may be expected from examination of Fig. 5.2. No subblock effects were found at the 10% level of significance. Repeating this test with subblocks of four produced similar results.

TABLE 5.4 Expt 65/3: development of number of trees of commercial species per ha (species 11 – 41, form class I*) for twelve treatment schedules

Treatment code		Years after initial refinement**					
		1 (1966)	3 (1968)	5 (1970)	8 (1973)	11 (1976)	14 (1979)
A	1	34	29	90	312	247	175
	2	34	52	88	183	138	93
	3	34	38	56	242	208	161
	4	32	50	56	115	91	64
	5	36	41	52	98	70	54
	6	39	64	100	150	134	104
B	1	43	115	120	267	192	156
	2	36	97	104	186	134	118
	3	30	77	68	163	93	63
	4	36	95	73	98	64	38
	5	30	66	48	63	43	39
	6	13	61	57	61	41	32

* Only well-shaped individuals.
** Lower recording limit in 1966 was 157 mm gbh and was reduced subsequently to 90 mm gbh.

TABLE 5.5 Expt 65/3: development of number of trees per ha of commercial species 11 – 58, form class III* for 12 treatment schedules

Treatment code		Years after initial refinement**					
		1 (1966)	3 (1968)	5 (1970)	8 (1973)	11 (1976)	14 (1979)
A	1	55	115	243	634	567	639
	2	59	140	245	405	383	413
	3	52	152	192	618	573	666
	4	39	107	152	269	256	288
	5	41	124	174	290	243	247
	6	48	131	226	297	265	272
B	1	55	179	254	562	510	494
	2	43	145	220	403	387	385
	3	50	163	188	356	333	315
	4	55	166	188	272	245	226
	5	45	109	120	186	179	172
	6	32	124	154	204	188	172

* Includes well, moderately and badly shaped individuals.
** Lower recording limit in 1966 was 157 mm ghb and was reduced subsequently to 90 mm gbh.

TABLE 5.6 Expt 65/3: numbers of trees per ha in 1978 of all species in four diameter classes under six treatment schedules*

Treatment code	Diameter class (cm dbh)				Total
	1 (5.0–14.9)	2 (15.0–29.9)	3 (30.0–44.9)	4 (≥45.0)	
A 1	825	225	10.8	3.6	1 064
3	682	145	12.6	0	840
5	828	228	34.2	5.4	1 096
B 1	766	264	16.2	0	1 046
3	607	108	16.2	0	732
5	716	290	32.2	9	1 047

* Mean of eight plots per treatment schedule.

5.7 Basal area and bole volume

The decrease in numbers since 1973 does not necessarily indicate a decrease in the dominance of commercial trees, when the stem-diameter distribution is not given. Basal area developments, which are better indicators, are given for species 11-41 form class I in Table 5.7 and Fig. 5.3. In the intensive liberation treatment

TABLE 5.7 Expt 65/3: development of basal area (m^2/ha) of trees of commercial species 11–41, form class I under 12 treatment schedules

Treatment code	Years after initial refinement**					
	1 (1966)	3 (1968)	5 (1970)	8 (1973)	11 (1976)	14 (1979)
A 1	0.23	0.19	0.46	2.12	2.73	3.17
2	0.25	0.30	0.41	1.39	1.76	1.85
3	0.36	0.44	0.54	2.00	2.69	3.24
4	0.30	0.31	0.38	0.75	0.97	1.07
5	0.34	0.41	0.44	0.85	0.87	0.78
6	0.44	0.44	0.99	1.44	1.66	1.96
B 1	0.56	0.32	1.20	2.47	3.11	4.01
2	0.60	0.67	1.02	1.93	2.10	2.58
3	0.37	0.57	0.68	1.61	1.86	1.88
4	0.31	0.50	0.57	0.87	0.93	0.92
5	0.19	0.20	0.24	0.37	0.37	0.28
6	0.15	0.25	0.28	0.39	0.40	0.39

* Only well shaped individuals.
** Lower recording limit in 1966 was 157 mm gbh and reduced subsequently to 90 mm gbh.

schedules 1, 2 and 3, the trend was upwards after 1973. For the wider group, species 11-58 form class III data in Table 5.8 show an even larger increase. In Fig. 5.3, the change after 1973 indicates severe competition, causing reduction of numbers of first-class trees.

Thus, it may be concluded that the most intensive liberation treatment schedules were successful in increasing the proportion of commercial trees. Liberation treatment schedule 3 was still effective, and better than treatment schedule 4. Fig. 5.3 indicates that refinement should be followed a few years later by a liberation treatment, and that this should not be delayed too long if a good proportion of commercial species is to be established in the stand.

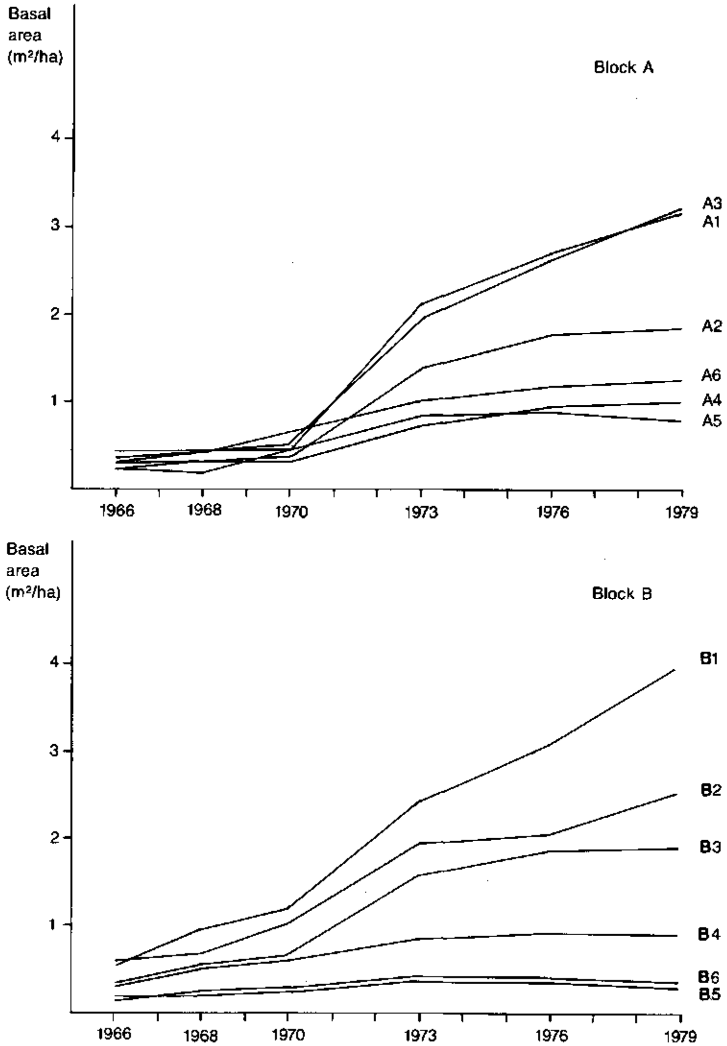


Fig. 5.3 Expt 65/3: development of basal area of commercial species 11-41 form class I under six treatment schedules in blocks A and B.

TABLE 5.8. Expt 65/3: development of basal area (m^2/ha) of trees of commercial species 11–58, form class III* under 12 treatment schedules

Treatment code	Years after initial refinement**					
	1 (1966)	3 (1968)	5 (1970)	8 (1973)	11 (1976)	14 (1979)
A 1	0.31	0.48	1.10	4.07	6.13	9.91
2	0.36	0.63	1.24	2.70	3.87	5.41
3	0.48	0.74	1.11	3.81	5.84	7.86
4	0.35	0.56	0.84	1.50	2.34	3.17
5	0.40	0.62	0.80	1.64	1.90	2.46
6	0.34	0.76	1.24	1.81	2.16	2.55
B 1	0.65	1.20	1.83	4.50	6.49	8.87
2	0.63	1.48	1.43	3.05	4.44	5.88
3	0.50	0.81	1.24	2.84	3.98	5.88
4	0.46	0.76	1.22	2.13	3.02	3.47
5	0.36	0.48	0.62	1.26	1.49	1.50
6	0.30	0.48	0.61	1.16	1.27	1.26

* Includes well, moderately and badly shaped individuals.
** Lower recording limit in 1966 was 157 mm gbh and reduced subsequently to 90 mm gbh.

The proportion of non-commercial species was reduced considerably by the intensive treatment schedules (see Table 5.9). By 1974, the plots under treatment schedule A 1 had received four liberation treatments, and the total basal area was approximately 9.0 m^2/ha, almost half of which was composed of commercial trees of wide specification (for values for 1973, see Table 5.8). Growth in the remaining tree population was vigorous, attaining a total basal area of 15.0 m^2/ha within five years. The situation was similar for those plots undergoing treatment schedule B 1.

By 1974, plots under treatment schedule A 2 were ready for further treatment (see Table 5.1), having reached a total basal area of 14.1 m^2 per ha. The liberation treatment in 1974 could not be quantified, but can be estimated to have been very light. The situation was similar for plots under treatment schedule B 2.

In 1975, the plots under treatment schedule A 3 were submitted to a third liberation treatment, which was quite heavy. Total basal area was reduced from more than 13.4 to 6.3 m^2/ha, and by 1978, had increased again to 11.4 m^2/ha. Under treatment schedule B 3, reduction of total basal area in 1975 was greater, and recovery not as good as under treatment schedule A 3, even though it was more than one m^2 per ha per year. From Tables 5.7 and 5.8, the plots under treatment schedule A 4 and B 4 do not show promising development. The single liberation treatment in 1972 does not seem to have been effective, although basal area of all species was reduced considerably.

Total basal area for all species per treatment schedule for 1974 was measured by

TABLE 5.9 Expt 65/3: development of total basal area (m^2/ha) of all species under 12 treatment schedules

Treatment code	Year		
	1974*	1975**	1978***
A 1	9.0	n.a.	15.0
2	14.1	n.a.	17.6
3	13.4	6.3	11.4
4	9.8	n.a.	12.0
5	14.7	n.a.	18.5
6	15.1	n.a.	18.4
B 1	11.0	n.a.	15.6
2	14.9	n.a.	17.3
3	14.3	5.5	8.8
4	10.6	n.a.	13.5
5	18.4	n.a.	19.8
6	18.1	n.a.	18.7

* From Scheltens (1975), lower girth limit 90 mm gbh, girth tape.

** From von Meyenfeldt (1975), lower diameter limit 2 cm dbh, girth tape.

*** Lower diameter limit 5 cm dbh, angled caliper recording.

girthing all trees in four plots (Scheltens, 1975) and for 1975 in three plots (von Meyenfeldt, 1975). In 1978, total basal area was measured in all 20 × 35 m recording plots with the aid of an angled caliper with paper strip to score the numbers of trees per five-centimetre diameter class.

Bole volumes of all species were calculated from basal area data obtained in 1978, using the mean values per five-centimetre class and the tariff presented in Appendix VII. Bole volumes for four stem-diameter classes are presented in Table 5.10. This table gives a better indication than basal area of the situation in this forest of decreasing stem-diameter distribution.

The low total basal areas in plots under treatment schedules A 3 and B 3 in 1978 (Table 5.9) are reflected in Table 5.10 by much reduced volumes compared with, for example, those under treatment schedules A 1 and A 5. The high volume in plots under treatment schedules A 5 and B 5 was the result of undisturbed development after harsh refinement in 1965. It is assumed that in block A, refinement with a stem-diameter limit of 10 cm for non-commercial species and 20 cm for commercial species left only 20 m^3 living bole volume per ha in 1966. In block B, which underwent refinement with a higher stem-diameter limit of 20 cm dbh, about 30 m^3 may have been left. The volumes attained in 1978 in plots under treatment schedules A 5 and B 5 support a considerable volume regrowth of about 120 m^3 in 12 years in both cases. This is 10 m^3 per year, but was probably less in

TABLE 5.10 Expt 65/3: bole volume (m^3/ha) in 1978 of all species in four diameter classes under six treatment schedules

Treatment code	Diameter class (cm dbh)				Total
	1 (5.0–14.9)	2 (15.0–29.9)	3 (30.0–44.9)	4 (≥45.0)	
A 1	31	66	11	10	118 (108)*
3	24	51	16	0	91 (91)
5	30	72	39	19	160 (141)
B 1	32	72	17	0	121 (121)
3	20	30	16	0	66 (66)
5	27	90	34	22	173 (151)

* Total volume excluding trees partly killed in initial refinement (mainly resistant trees ≥45 cm dbh) given between parentheses.

the first few years, and more in subsequent years. This is not total biomass production, but only wood production in trees still alive in 1978, measured as bole volume up to the first major branch. Total standing biomass (branches, roots, leaves) may have been twice as much, and further, the volume of trees which died before 1978 has not been included.

In Expt 67/9 A (Chapter 7), treatment 20 + 0, which is comparable with treatment schedule B 5 in Expt 65/3, was found to have increased volume from about 50 m^3 after refinement to about 180 m^3/ha in 12 years, thus producing a slightly higher volume than in plots under treatment schedule B 5. These volume estimates cannot be converted easily into dry weight estimates, because the specific gravities of the multitude of species are not known.

Table 5.11 gives the volumes of commercial species in the plots under treatment schedule A 1, which produced one of the highest volumes of valuable timber. Basal area data are accurate, and in this case the volume tariff is applicable with less reserves, because it was prepared for a selection of commercial species, be it in another location. Bole volumes for 1979 are given in Fig. 5.4. The volume increment of the commercial species is only a small proportion of the total volume.

TABLE 5.11 Expt 65/3: development of bole volume (m^3/ha) per diameter class of commercial species 11–41, form class I, and of commercial species 11–58, form class III, in plots under treatment A1 schedule

Diameter class (cm dbh)	Species 11–41, I			Species 11–58, III		
	1966	1973	1979	1966	1973	1979
1 (5.0–14.9)	0.7	5.0	3.3	1.0	6.7	10.3
2 (15.0–29.9)	0.7	8.5	17.1	0.7	7.9	23.4
3 (30.0–44.9)	0.0	0.0	7.7	0.0	2.3	11.0
Total	1.4	13.5	28.1	1.7	16.9	44.7

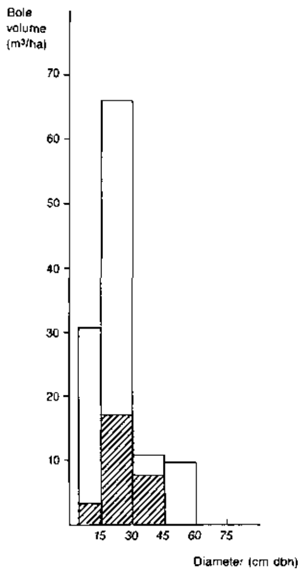


Fig. 5.4 Expt 65/3: bole volume per diameter class (m^3/ha) for only commercial species 11-41 form class I in 1979 (hatched columns, total volume 28 m^3/ha); and other trees in 1978 (unhatched columns). Total volume of commercial plus other species 110 m^3/ha.

For the wider selection of commercial trees of species 11-58 form class III (see Table 5.11), the volume increment is higher, as could be expected.

Under treatment schedule A 1, annual production of commercial volume was about 2.0 to 4.6 m^3/ha (see Table 5.11), but even in 1979 there was still no commercial volume above the felling limit of 45 cm dbh. In addition, the volumes given are gross volumes, of which ultimately only half may be harvestable, because of rot and malformed stems. Treatment schedule A 1 was not cheap. Other treatment schedules in Expt 65/3 were less productive than A 1 and its counterpart B 1, or only slightly cheaper, as were treatment schedule A 3 and B 3.

As total volume in 1979 was quite low in comparison with that of the original virgin forest, it could be expected that the volume would continue to increase. Above a basal area of, say 22 m^2/ha competition can be expected to increase so much that volume increment will concentrate on large trees, as in Expt 67/2 (Chapter 6).

5.8 Periodic annual increment of girth

In Fig. 5.5, periodic annual increments of girth are presented for selected treatment schedules for the group of commercial species 11-41 form class I. Stem-diameter class 2 is not represented in every treatment and period, because of the small sample available, for example in treatment schedule B 5, and also in the first years of treatment A 4. Periodic annual increments of girth before refinement in 1965 are not shown in Fig. 5.5, but were probably about 5 to 10 mm per year, as in Expt 67/9 A (Chapter 7). In the period 1966-1968, immediately after refinement, girth increment increased considerably under all treatment schedules. In plots under treatment schedules A 5 and B 5, because no subsequent liberations were

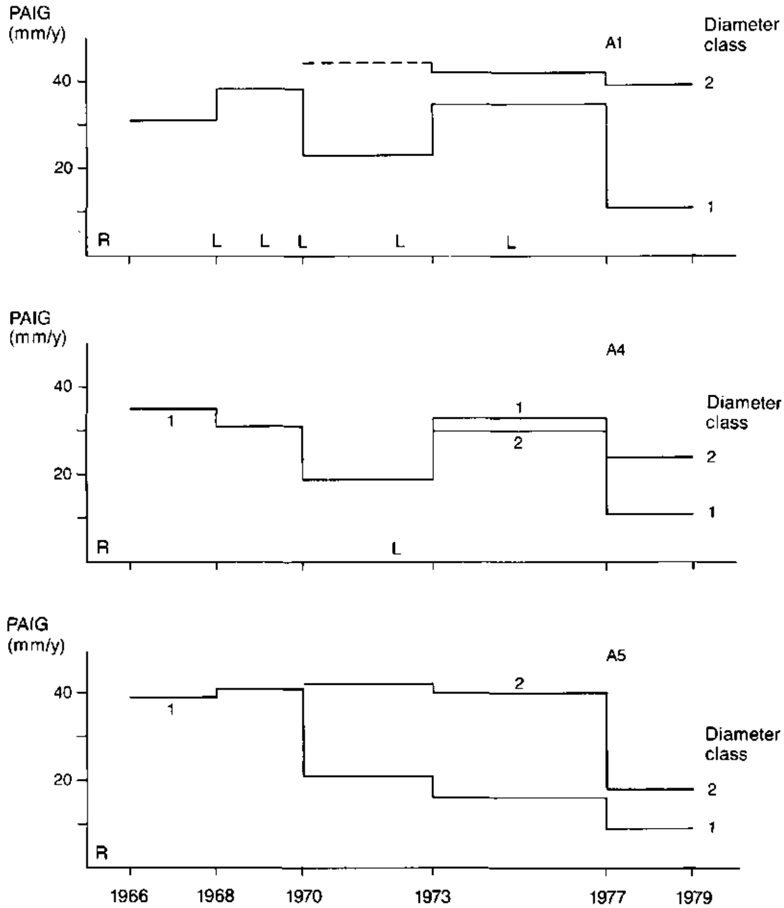
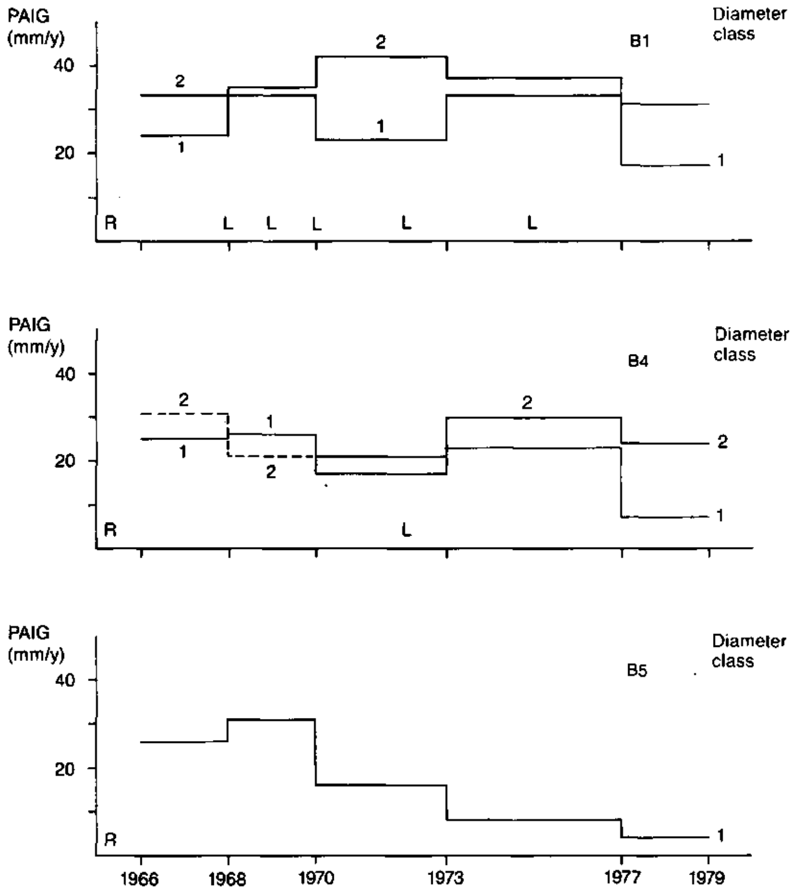


Fig. 5.5 Expt 65/3: periodic annual increment of girth (PAIG) in mm/y, for species 11-41 form class I in two diameter classes (1, 5.0-14.9 cm dbh; and 2, 15.0-29.9 cm dbh) under six selected treatment schedules (see Table 5.1). Year of treatment is indicated by R (refinement) or L (liberation). ⟶

carried out, a gradual decrease in girth increment was manifest in stem-diameter class 1 after the first five years, and in diameter class 2 several years later. The same effect was found with treatment 20 + 0 in Expt 67/9 A. The decrease in girth increment for diameter class 1 under all treatment schedules in the period 1977-1979 cannot be ascribed simply to climatic influences. Small trees especially suffer from increased competition in uniform and closed stands. In the plots under treatment schedulesA 4 and B 4, the total basal area in 1978 was not as high as in those under treatment schedulesA 1 and B 1 or A 5 and B 5 (see Table 5.9).

Of the five liberation treatments in A 1 and B 1, that undertaken in 1972 especially had a favourable effect on trees in diameter class 1, but not on trees in class 2. Trees in diameter class 2 dominated this stand, and clearly did not require liberation. Under treatment schedule A 4, trees in diameter class 1 reacted favourably to the heavy liberation in 1972, and diameter class 2 was absent until



1973. Under treatment schedule B 4, trees in diameter class 1 reacted very little, and those in diameter class 2 much more. This may be explained by the fact that under both treatment schedules the weed trees had become more dominant in the seven years after refinement, because selective treatment had not been given as under the more intensive treatment schedules such as A 1. The heavy liberation treatment in 1972 removed many of these dominant weed trees, and because of suppression in former years, few vital individuals of commercial species were present to fill the gaps. This would explain the slow increase in total basal area after 1974 as shown in Table 5.9. In treatment schedules A 1, B 1 and other intensive treatment schedules, frequent liberations, which increased the mean girth increment of small trees (diameter class 1 and smaller), helped to recruit vital individuals, thus resulting in more resilient stands, apart from increasing volume production.

Interrelated with the effects of liberations on girth increment were the effects of rainfall and the graduation from diameter class 1 to class 2 of successful trees. Even though the diameter classes are broad and periods short, this shift may be of interest in future studies.

Statements about the best time for first liberation in practical applications cannot be made on the basis of these girth increment analyses, because the silvicultural approach has changed considerably since Expt 65/3 was set up.

In 1974, data have been available (Scheltens, 1975) to study regression of periodic annual girth increment on total basal area. The ten best growing trees per 20 × 35 m plot (140 trees/ha) were selected in a way similar to the leading desirable selection system (Dawkins, 1958). The results for the twelve treatments are shown in Fig. 5.6. The high coefficients of determination suggest that this approach may be useful to quantify reactions to competition in the experimental stands. However, for non-selected trees of commercial species 11-41 form class I in two diameter classes (5.0-14.9 cm and 15.0-29.9 cm), the regression of periodic annual girth increment during 1977-1979 on total basal area in 1978 was found to be different, with $R^2 = 0.38$ and $y = -0.66\ x + 20.7$ for diameter class 1 and $R^2 = 0.31$ and $y = -1.79\ x + 55.2$ for diameter class 2. This would indicate that small trees (diameter class 1) are less affected by basal area changes than are larger trees (diameter class 2), which seems unlikely.

Attempts to find regression of girth increment of species 11-41 form class I on total basal area data for 1974, were hampered by problems with the girth increment data. These were available for 1973-1977, but in this period several liberation treatments were carried out, with those in A 3 and B 3 in 1975 being the heaviest. Omitting data for treatment schedules A 3 and B 3, a regression equation was found for diameter class 1, with $R^2 = 0.71$ and $y = -2.51\ x + 56.6$ (see Fig. 5.6), and for diameter class 2 another with $R^2 = 0.06$ (for girth increment values per treatment, see Appendix IV).

Thus the regression of periodic annual increment of girth of non-selected small trees on total basal area showed reactions to changes in total basal area that were not as strong as for leading desirables (see Fig. 5.6). The poor coefficient of determination for diameter class 2 may have been due to the very small sample of trees for which increment data are available, and also to the small effect total basal area had on growth of large trees in the range studied, not exceeding 20 m^2/ha.

In similar studies in Expt 67/9 A (see Chapter 7), with a much larger range in total basal area, regression lines for diameter class 1 and class 2 were parallel, with class 1 below class 2. This indicates that small trees suffered earlier from increase in total basal area. The slope of the regression was not as steep as that for leading desirables in Expt 65/3.

The weaker coefficient of determination for species 11-41 form class I in 1978 than in 1974, may be explained by the time lapse since treatment (see Table 5.1). During this long period, total basal area increased and the range became narrower. Only plots under treatments 3 and 4 had a low total basal area in 1978 (see Table 5.9).

Stands in Expt 65/3 were more uniform and 'even-aged' than for example, those in Expt 67/9 A, and a total basal area value which includes many small and often young and vital trees cannot be compared with a basal area value composed of a mixture of small, often suppressed, trees and large trees either vital or stagnating.

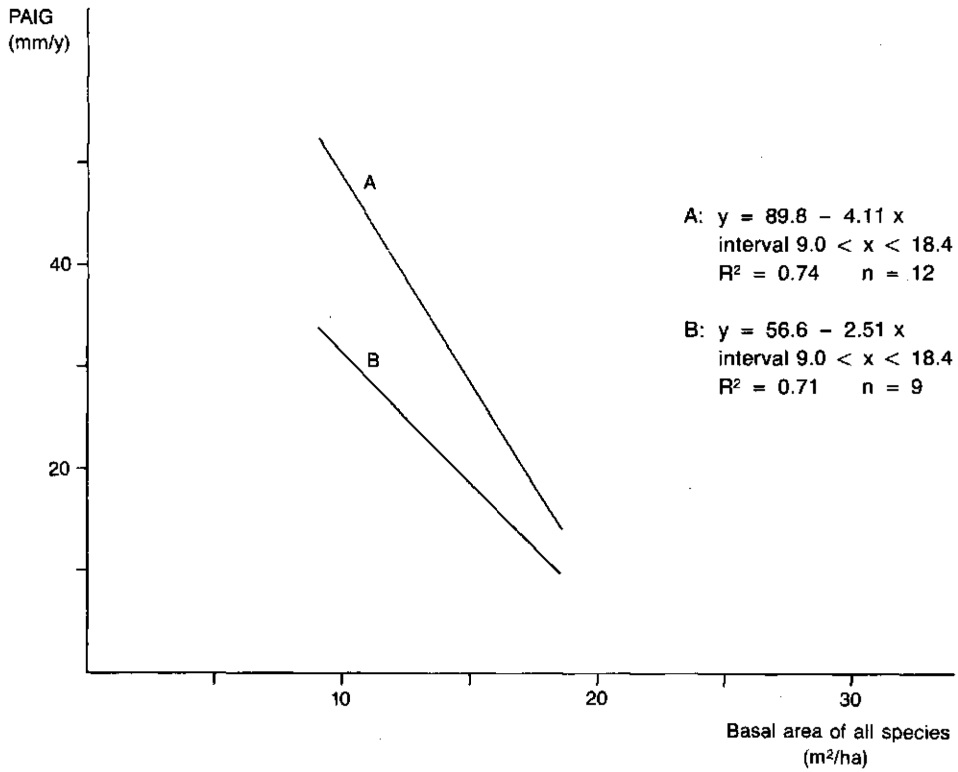


Fig. 5.6 Expt 65/3: regression of periodic annual increment of girth (PAIG) in mm/y on total basal area (m^2/ha) in 1974: A. PAIG of selected trees of all commercial species in all 12 treatments in the period 1973-1974, only four plots used per treatment. B. PAIG of non-selected trees of commercial species 11-41 form class I, diameter class 5.0-14.9 cm dbh in the period 1973-1977.

Apparently, the effect of total basal area on girth increment is greater in uniform even-aged stands than in more uneven-aged stands. Thus, a reduction of total basal area is compensated more rapidly, which is also supported by data in Expt 67/9 A.

5.9 Mortality

Data on mortality of seedlings and saplings 5-200 cm high have been included in Table 5.2. The annual mortality rate ranged from 7 to 13% in the period 1965-1970 immediately after refinement, with the mean for block A and B being 9% and 12% respectively. Boerboom (1969) estimated the annual mortality rate to be about 15% for individuals of the same size, for all species in virgin forest plots. Mortality was higher for very young seedlings, which were not established, up to 50% in the first year in closed virgin forest plots. Further, height growth of these plants was very slow in these closed plots with no gaps in the canopy (Boerboom, 1969).

The annual mortality rates for trees larger than 5 cm dbh of species 11-41 form class I for two diameter classes and for the period 1966-1979 are given per

TABLE 5.12 Expt 65/3: development of periodic annual mortality rate (%) for commercial species 11-41, form class I, under six treatment schedules

Treatment code	Diameter class*	Recording period**					Mean rate
		1966–1968	1968–1970	1970–1973	1973–1977	1977–1979	
A 1	1	16.6	7.2	1.0	3.3	3.9	6.4
	2	0	0	0	0	0	n.a.
A 2	1	6.3	0	2.0	1.9	0	2.0
	2	0	0	0	0	0	n.a.
A 3	1	16.7	5.6	0.8	1.8	2.9	5.5
	2	16.7	0	0	0	4.6	4.2
A 4	1	20.0	5.6	0	1.5	2.6	5.9
	2	n.a.	16.6	0	0	0	3.3
A 5	1	7.7	4.2	1.5	2.6	0	3.2
	2	n.a.	n.a.	0	0	0	n.a.
A 6	1	5.6	2.6	1.0	2.4	0	2.3
	2	n.a.	10.0	0	2.5	n.a.	2.5
Mean	1	12.1	4.2	1.0	2.2	1.6	4.3
B 1	1	0	3.9	0	4.1	2.1	2.0
	2	0	4.6	0	1.4	0	1.2
B 2	1	4.2	0	0.8	0.7	0	1.1
	2	0	0	0	0	0	0
B 3	1	0	3.1	0	1.5	2.5	1.4
	2	0	0	0	0	0	0
B 4	1	4.6	0	3.2	1.9	4.2	2.8
	2	0	0	4.2	0	0	0.8
B 5	1	15.4	12.5	0	0	0	5.6
	2	n.a.	n.a.	n.a.	n.a.	n.a.	
B 6	1	0	0	9.1	6.3	0	3.1
	2	n.a.	(25.0)***	n.a.	n.a.	n.a.	(5.0)
Mean	1	4.0	3.3	2.2	2.4	1.5	2.7

* See Table 5.10.
** Period reckoned from month of first recording to month of last recording.
*** Very small sample.

treatment schedule in Table 5.12. The data show large variation, because of the small populations recorded. The mortality rate in the period 1966-1968, before liberation treatments, should theoretically have been the same for all treatment schedules within a block, but this was not the case. In block A the mortality rate was much higher than in subsequent years, and this may well be attributed to the exposure shock caused by the refinement, and the destruction caused by large amounts of falling timber. The higher mortality rate in first years was less obvious in block B where refinement was lighter, leaving more cover for seedlings and saplings not accustomed to full sunlight. Differences in biomass coming down were too small between block A and B to explain this lower mortality by mechanical damage alone.

In both blocks, overall mortality rates decreased with time, and were especially low in the period 1970-1973. The mortality rate may well be related to rainfall, because the period 1970-1973 was generally humid and favoured growth, while in the periods 1968-1970 and 1973-1977 there were several dry years (see Appendix I). Five years after refinement most dead timber had fallen, and thus after this period the effect on mortality rate must have been reduced. However, death as a result of competition will have increased, because a heavy thicket of many tree species had developed.

In block A, over the entire period 1966-1979, the treatment schedules with liberations seem to have the highest mortality, except for treatment schedule A 2. Diameter class 1 has suffered most. In block B, mortality rates were highest under the treatment schedules without liberations, that is B 5 and B 6, but were even more irregular than those for block A.

Under treatment schedules A 1 and A 3, the increasing mortality after 1973, as shown in Table 5.12, probably has reduced the number of trees larger than 5 cm dbh (see also Table 5.4). Under treatment schedule B 1 and B 3 this relationship was less visible. The rapid increase in numbers of trees during the period 1970-1973 (Table 5.4) corresponded closely with the low mortality rate during that period (Table 5.12).

In Expt 65/3, because of the sample size, few data are available on mortality for diameter class 2 and above. This problem of sample size for mortality studies is discussed in detail for Expt 67/2 in Chapter 6.

5.10 Conclusions

Early selective liberation treatments which favour vigorous trees, can create a rapidly growing mixed stand containing a high proportion of trees of valuable species. These stands can produce a reasonable total volume of all species as compared with stands left untreated after an initial heavy interference. The exception are the plots under treatment schedule 4, which in 1972 received only one liberation treatment seven years after refinement, and apparently required much time to regenerate total basal area. Because of this slow regeneration under treatment schedule 4, the liberation system with filler trees was introduced in 1975 (von Meyenfeldt, 1975). Filler trees prevented the development of definite gaps, even with a heavy liberation treatment. This has resulted in rapid regrowth under treatment schedule 3 as compared with treatment schedule 4.

The well-known German slogan on thinning: 'Früh, oft und mässig' (early, frequently, and moderate), is confirmed here. Repeated selective treatments should not be confused with indiscriminate slashing of weed species, with the danger of killing young valuable regeneration which has not been marked as such. Experienced labourers are required for selective treatments. This, plus the high cost of repeated treatments, are the most valid arguments against intensive treatments as applied in Expt 65/3. A further argument against the fairly uniform stands created in Expt 65/3 is the short length of the boles grown. In the absence of large trees which provide a better environment for height growth without forming thick branches, the frequent liberations in young stands favour early development of large crowns. This causes considerable reduction in log length.

In Expt 65/3 efforts were made to establish uniform even-aged stands of commercial timber trees. A relatively high volume production was achieved, recruitment was promoted considerably by early and frequent liberations, and success was proportional to input of labour and arboricide. However, the diameter distribution in the stands tended to decrease, as usual in mesophytic forest, with only few large and many smaller trees. This is due to the large differences in growth rate of adjacent trees. Low thinning to compensate for this was not introduced, because after 1979 the experiment became obsolete.

Even if it were possible to create highly productive uniform stands at a reasonable cost per m^3 timber produced ultimately, which seems less likely now than it did in 1965, serious problems are inherent in this approach. Harvesting large volumes of timber at the end of the first rotation will destroy the forest vegetation to such an extent that a secondary succession is inevitable. Valuable regeneration after exploitation will have to compete with a multitude of weed species, which can be suppressed but not eradicated at high labour cost, and this makes management very expensive. The only way to prevent such a change to secondary forest management is careful harvesting of only a restricted amount of timber, preferably of high quality to compensate for the costs. This means changing to polycyclic management, with production of relatively low quantities of high-value timber in large dimensions.

6 Experiment 67/2: forest succession in mesophytic high forest after light exploitation

6.1 Summary

In this experiment developments were studied in high mesophytic forest after light exploitation and without subsequent silvicultural treatment. The tree population at two locations, Sarwa and Goliath, both on an area of 5 ha, was monitored for almost a decade to yield information about basal area development, volume increment and mortality of small and large trees. This provided information about what happens in exploited concessions left by the loggers, and not brought under management. Data from this experiment strengthen the data base for zero treatment plots in other experiments with silvicultural treatments.

The mean timber volume harvested was 21 m^3/ha and 32 m^3/ha at Sarwa and Goliath respectively, of the total standing volume of about 250-300 m^3/ha. Data on logging damage are presented. Vegetation structure partly recovered during the decade of observation, but the losses in the population of commercial tree species were not compensated. Stem diameter distributions discussed show that both series of experimental plots at Sarwa and Goliath had smaller numbers of large trees than the regional average. The proportion of commercial species in the stem-diameter distributions increased with increasing stem diameter.

Total basal area did not change greatly during the decade after the exploitation, and only a slight trend to pre-exploitation values was discerned. Changes in basal area distribution were found in all stem-diameter classes. Basal area of higher stem-diameter classes increased, but in most of the lower diameter classes basal areas were reduced. Individual trees of commercial species left in the stand grew reasonably well compared with non-commercial species, but in this lightly exploited forest only the class of large trees, above 45 cm dbh, increased in volume. Because of their reduced number above 45 cm as a result of exploitation, volume of commercial trees increased little in this class. Average volume increment per hectare of commercial species was affected considerably by the death of large trees, which occurred irregularly in the relatively small populations observed. Annual volume increment monitored in the group of listed commercial species was approximately 0.2 m^3/ha in Sarwa, and approximately 0.9 m^3/ha in Goliath. Data for Sarwa were more suitable for extrapolation to large forest areas, because those for Goliath were affected by unusually low mortality rates.

Average annual mortality rate for all species was approximately 2% for stem-

diameter classes above 25 cm dbh. For the commercial species mortality rates were less reliable, because of the relatively few trees in this group. However, the mortality rate of the commercial species was assumed not to differ from that of all species.

Periodic annual increment of girth, known from other experiments to be a sensitive indicator of treatment intensity, was constantly low throughout the period of observation. In this forest girth increment was found to increase with increasing stem diameter, and the group of commercial species seemed to grow slightly better than the group of non-commercial species. Volume increment in the commercial species will probably increase when competition from non-commercial trees is reduced.

6.2 Introduction

Expt 67/2, which is a study of forest succession in mesophytic high forest after light exploitation, was initiated in 1967, 'to investigate the effects of the exploitation on the forest' (Boerboom, 1969). Little was known about the effects of light selective exploitation on the remaining forest, but annually many thousands of hectares of mesophytic forest in the Forestry Belt were exploited in this way. For instance, effects could be expected in the vegetation structure, the volume increment of the remaining trees, and the species composition of the stand. For future management, it was important to know more about the development of the commercial species in forests after light exploitation and no subsequent silvicultural treatments. As it was intended to observe only, study plots of 5 ha per location were marked out in two relatively large areas of recently exploited forest in which harvesting damage could still be assessed (Sterringa, 1968b). Such large plots permit quantification of effects of relevance to future management.

The experimental areas, Sarwa and Goliath, were located in the Mapane and Coesewijne regions respectively (see Figs 6.1 and 6.2). The Sarwa plots were on soil unit 44, the Tibiti landscape, which is imperfectly and moderately well-drained sandy (clay) loam and (sandy) clay, locally with gravel surface. This landscape is more undulating and dissected than the Coesewijne region. It forms a transitional zone between the large sandy savannah area to the north, which is drained by the Sarwa and the Cassewinica creeks, and the area of residual soils to the south mainly on Armina schists (Dienst Bodemkartering Suriname, 1977) which is drained by the Mapane river. Soils at Sarwa have a higher loam content than have those at Goliath. Rock outcrops just outside the experimental plots at Sarwa indicate the partly residual character of these soils. Since the 1960s, strip plantations and land clearing for charcoal production and subsequently *Pinus caribaea* planting have increased in this region, as has hunting pressure.

The Goliath plots were on soil unit 36 in the cover landscape, which consists of well-drained medium and coarse sand to sandy clay loam. The region was being cleared, mainly for pine planting and cattle raising, and since the road was constructed in 1957, much of the original mesophytic forest had been destroyed,

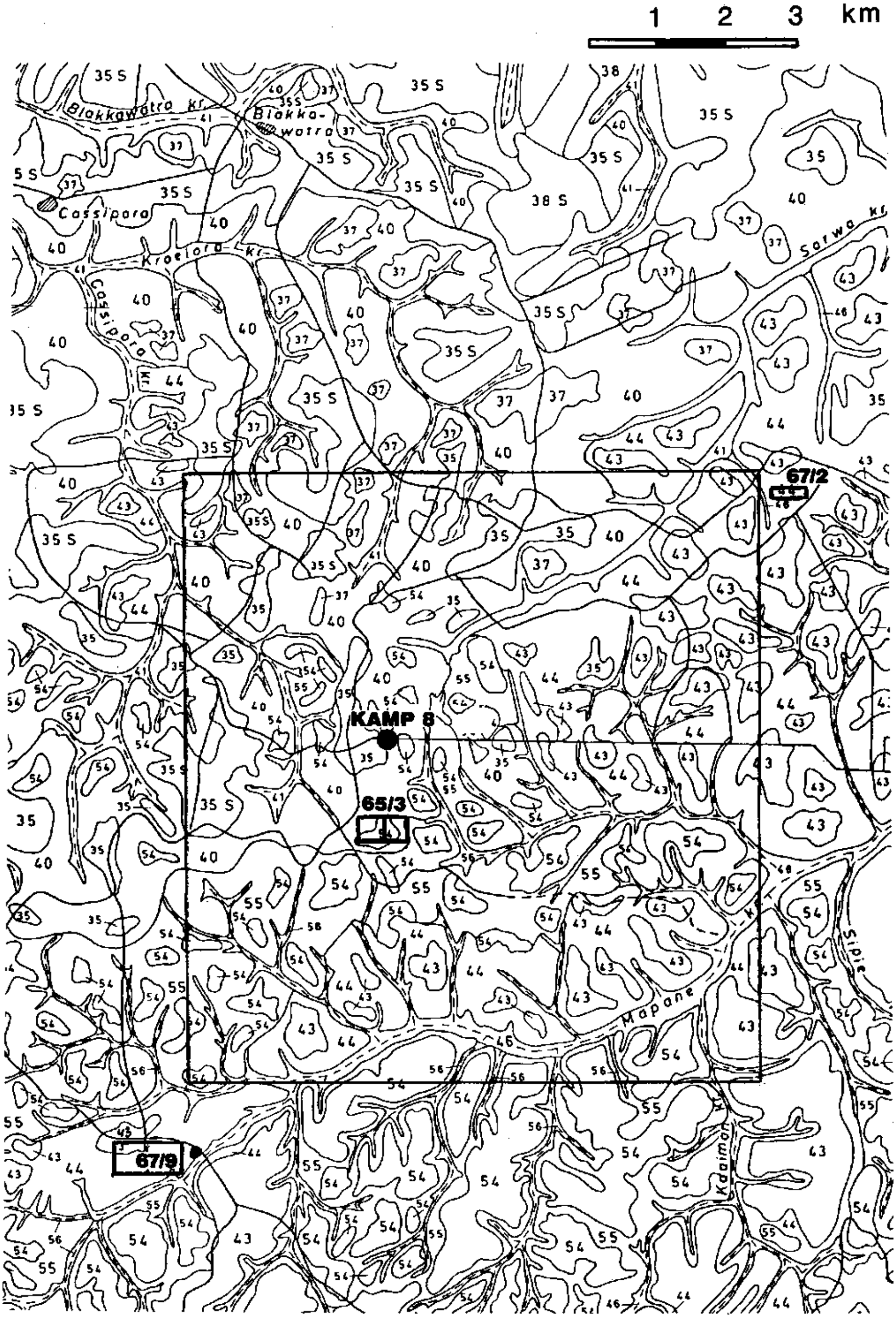


Fig. 6.1 Soil survey map of Mapane area, northern Suriname. The large rectangle indicates the area mapped by Schulz (1960; Fig. 4.6). From: Dienst Bodemkartering Suriname, (1977), sheet 22.

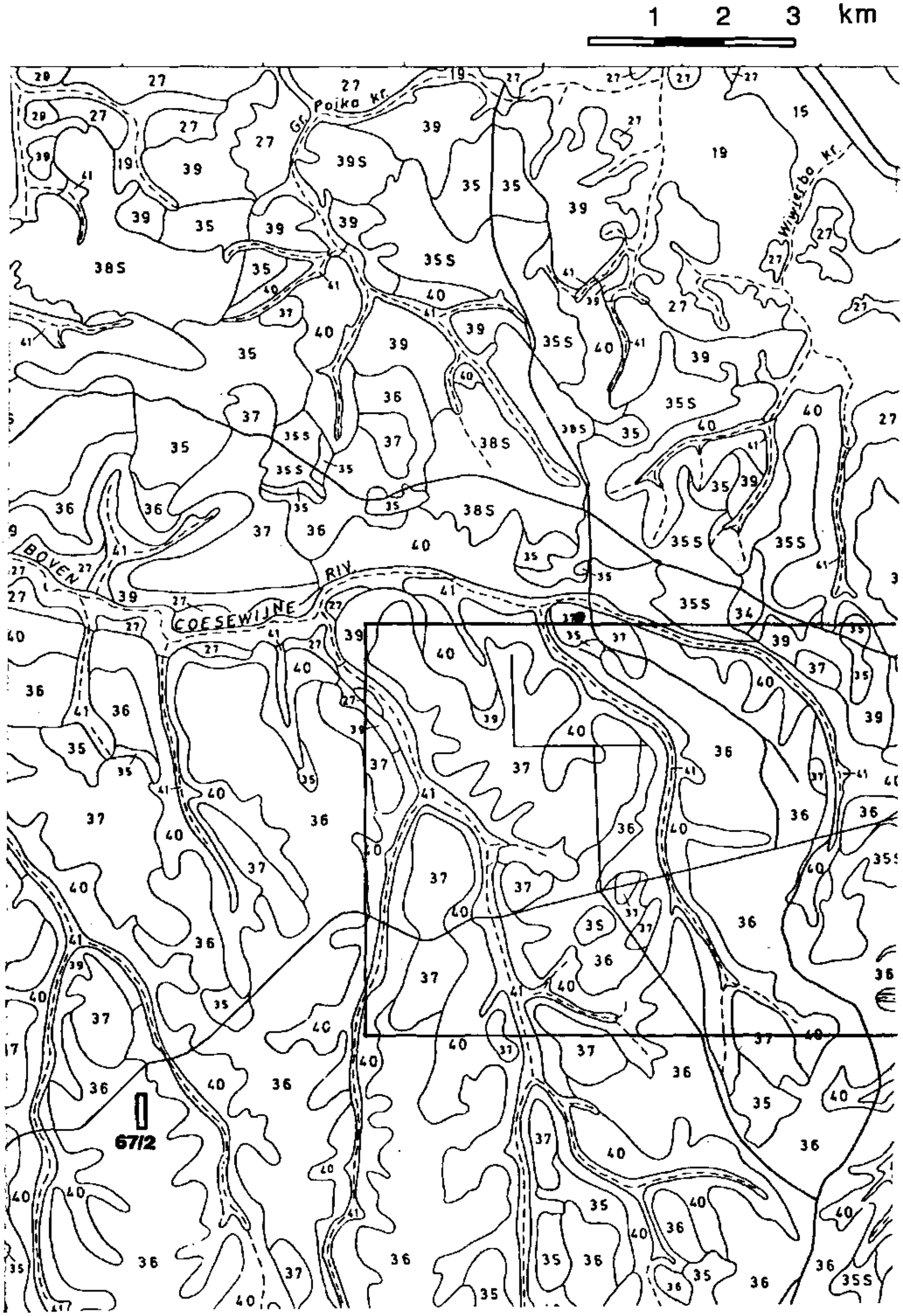


Fig. 6.2 Soil survey map of Coesewijne area, northern Suriname. The large rectangle indicates the area mapped by Schulz (1960; Fig. 5.3). From: Dienst Bodemkartering Suriname, (1977), sheet 21.

leaving strips of creek forest and scattered remnants of over-exploited mesophytic forest.

Both series of experimental plots were surrounded by at least about 50 hectares of only lightly disturbed forest, but beyond this, a road, a cleared area, or a pine plantation isolated the plots from other mesophytic forest. Hunting pressure was relatively high. In spite of such negative effects on succession processes, these two series of experimental plots were very valuable because they were the only study areas of such size for succession in exploited forest.

6.3 Experimental layout

The layout of Expt 67/2 at both locations was a row of five one-hectare plots as shown in Figs 6.3 and 6.4. A buffer zone was not marked. A numbered aluminium tag was nailed to each tree 10 cm below the point of measurement. Thus, measurements were reasonably consistent throughout the period of observation, but less precise than had a ring been painted at the point of measurement. The tree species was registered under the local name given by the treespotter, and the measured girth was recorded, but trees were not classified by stem and crown, and no height measurement was made. Recruitment was recorded except in 1977. Mortality of registered trees was recorded, but no data were collected on how and why trees died.

At the time the plots were laid out, the forest had already been exploited. Stumps of trees felled and logged were measured and identified by the local name of the species. Several years after the Goliath plots were marked out, a secondary road was constructed quite close to the western border. This road was only 10 m from the border in the north and 70 m in the south. This should have affected conditions in plots 1 and 2, especially light penetration, (van 't Leven, 1974) but no evidence of this was found.

In 1969 and 1979, forest profile diagrams were drawn of an extra plot located close to the five-hectare plots at Sarwa (Sterringa, 1971; van Bodegom, 1981). A modification of the method of Lindeman and Molenaar (1959), was used to draw the profiles. This extra plot of 20 × 100 m was rather heavily exploited with three trees removed, that is about 15 trees per ha, and changes during the ten-year period of observation were considerable in this 0.2 ha strip (van Bodegom, 1981). Part of the profile diagram drawn in 1979 is reproduced in Fig. 6.5. Two pairs of terrestrial stereophotographs, the orientation of which is shown on the plot lay-out for Sarwa (Fig. 6.3) are shown in Figs 6.6 and 6.7

6.4 Exploitation

The main period of exploitation in the experimental areas was 1964 to 1966. Operations were terminated in 1966 in Goliath and in 1968 in Sarwa. Skid tracks,

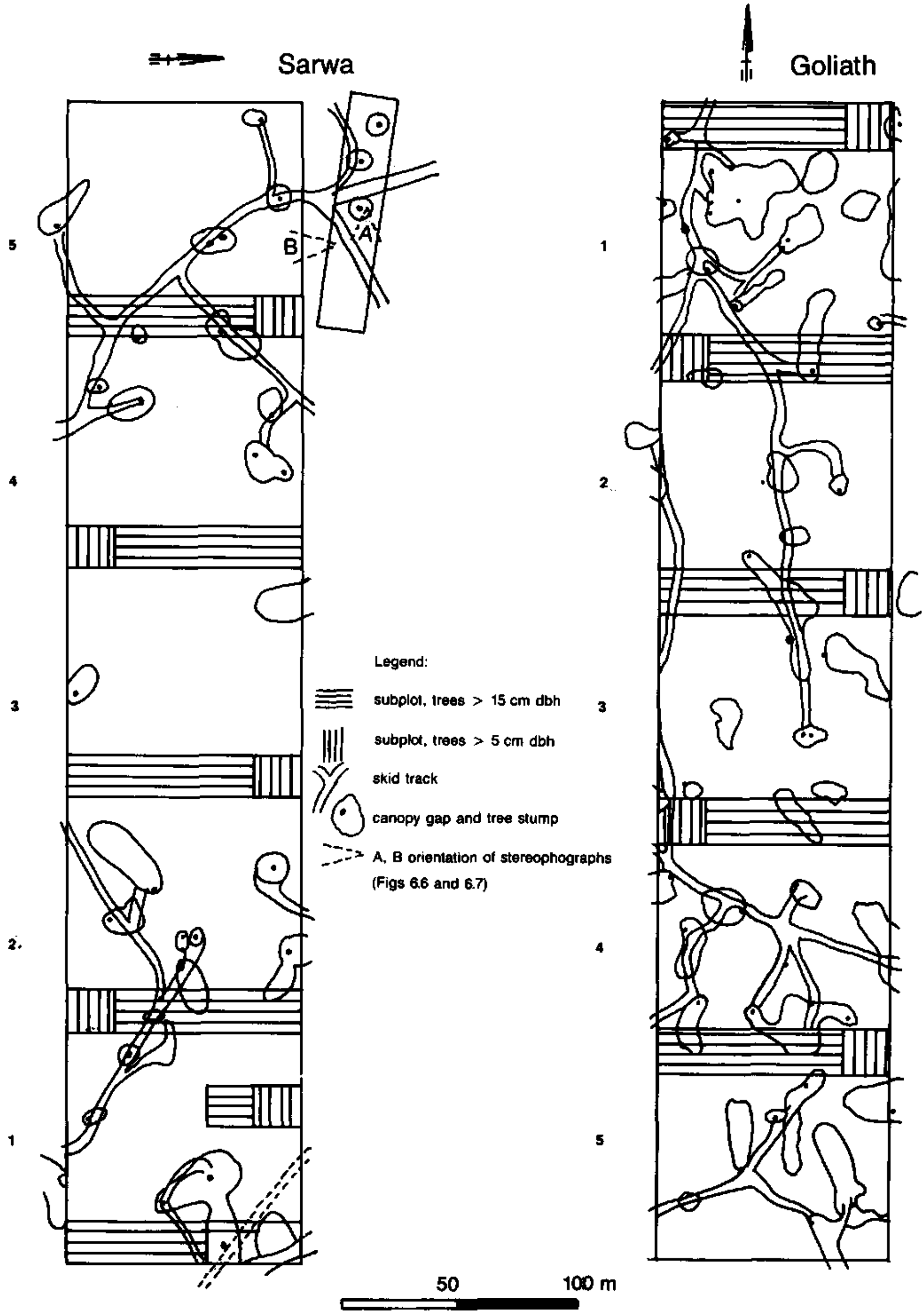


Fig. 6.3 Expt 67/2: lay-out at Sarwa; five one-ha plots, oriented east-west. Based on the drawing prepared by Sterringa (1968). A forest profile diagram drawn in the study area north of plot 5 is shown in Fig. 6.5.

Fig. 6.4 Expt 67/2: lay-out at Goliath; five one-ha plots, oriented north-south. Based on the drawing prepared by Sterringa (1968).

Fig. 6.5 Forest profile diagram of half of the study area near Expt 67/2 at Sarwa, (van Bodegom, 1981). For location see Fig. 6.3.

Fig. 6.6 Expt 67/2; at Sarwa, 1982 (photo by author). (For location of photograph see Figure 6.3 at A, near plot 5). The large tree is no. 2841 drawn on Fig. 6.5, as photographed from the west. It is *Pithecellobium pedicellare (tamaren prokoni)* and has a stem diameter of approximately 60 cm. In the background a gap in the rain forest is visible. Stereophotographs should be studied with aid of a pocket stereoscope.

stumps and openings in the forest were mapped in 1968 (see Figs 6.3 and 6.4). Trees were felled and bucked with powersaws, and skidded with a light bulldozer along the tracks mapped. At Sarwa, a few extra trees were taken from plot 1 and 2 some time after stumps and tracks had been mapped. Mean volume exploited in Sarwa was 21 m^3/ha (Table 6.1), and in Goliath 33 m^3/ha (Table 6.2). These have been calculated from basal area felled using the tariff in Appendix VII. Usually bucking was done in such a way that it led to considerable wastage. In addition, the felling cut was usually made below breast height, and this resulted in a measurement height of less than 1.30 m, thus leading to over-estimation of the basal area felled. Mean measurement height of stumps was 112 cm in Sarwa, and 106 cm in Goliath. Presumably, only two-thirds of bole volume felled has been skidded away, resulting in a mean harvested volume of about 15 m^3 and 22 m^3 respectively. At both locations, the main species harvested were *Ocotea rubra, Goupia glabra* and *Dicorynia guianensis* (see also Table 3.1). Mean potential log volume is estimated to have been about 4 m^3 per tree, taking into account the restrictions given above. The actual mean volume of removed logs was probably 3 to 3.5 m^3.

The area of openings in the forest and skid tracks is given in Table 6.3. The crawler has gone from stump to stump, picking up logs, with the result that there

Fig. 6.7 Expt 67/2; at Sarwa, 1982 (photo by author). (Location of photograph, see Fig. 6.3, at B, near plot 5.) The medium-sized tree in the background is located just beyond the northern boundary of plot 5. The open structure of the undergrowth is similar to that in unexploited forest.

was less area of skid tracks than in Expt 78/5 at Kabo (Jonkers, in press), where skidding followed a planned dendritic pattern. In Sarwa and Goliath, the same tracks have been used frequently and thus have developed into skid roads, which were still visible in many places even after 15 years of vegetation regrowth. This testifies to the heavy damage done to soil and roots by skid roads. In Expt 78/5, skid roads were planned as permanent, and skid tracks as temporary in the 20-30 year exploitation cycle envisaged.

TABLE 6.1 Expt 67/2: number, basal area and estimated volume of stems felled in exploitation in 5 one-ha plots at Sarwa

Plot no	N/ha	Basal area (m^2/ha)	Estimated volume (m^3/ha)
1	5	1.0	13
2	8	2.66	34
3	1	0.29	4
4	6	1.76	22
5	6	2.43	31
Mean	5.2	1.6	21

TABLE 6.2. Expt 67/2: number, basal area and estimated volume of stems felled in exploitation in 5 one-ha plots at Goliath

Plot no	N/ha	Basal area (m^2/ha)	Estimated volume (m^3/ha)
1	15	4.36	56
2	6	2.13	27
3	4	1.02	13
4	10	3.10	39
5	6	2.22	28
Mean	8.2	2.6	33

The area of openings in the forest given in Table 6.3 did not correspond closely to the area covered by fallen crowns, which was more than 15% when 5 to 8 large trees per ha were felled. A more recent study on felling damage in mesophytic forest in Suriname (Mellink, 1979) has indicated that the mean area covered by the crowns of felled trees was about 225 m^2, but the range was wide, and trees in this study were relatively small. For every m^2 basal area of commercial trees felled, about 1 m^2 basal area of other trees, usually with much smaller diameters was damaged. As small trees have less height, the volume felled was much larger than that damaged by the felled trees. Only about 35 trees could be studied, which was not sufficient for a precise estimate.

Exploitation damage in Expt 67/2 as evaluated 15 years later, in 1982, was tolerable for the vegetation as a whole, but the effect on the subpopulation of commercial species was considerable and mostly negative. Few trees of secondary species have established after exploitation, and only in heavily damaged and widely opened areas, usually along the skid tracks. In 1981 a large group of *Palicourea* spp. and *Cecropia* spp. was still present in Goliath plot number 1, as a result of heavy local disturbance by logging. Almost half of the original stand of

TABLE 6.3 Expt 67/2: exploitation effects for the Sarwa and Goliath plots

	Sarwa	Goliath
Felled stems		
(N/ha)	5.2	8.2
(m^3/ha)	21	33
Skid tracks		
(m^2/ha)	483	739
Canopy openings		
(m^2/ha)	734	1 243

Source: Sterringa, 1968.

trees larger than 45 cm dbh had been felled in plot 1 in the period 1964-1966 (see Fig. 6.4, and Table 6.9).

6.5 Stem-diameter distributions

Stem-diameter distributions for all species in high mesophytic forest in Mapane and Coesewijne regions are presented in Tables 6.4 and 6.5. The 2% samples cover the largest areas, and therefore can be regarded as being fairly representative. However, averages over such large sampling areas combine extremes into a stand table representing a non-existing synthesized forest, whereas averages from small samples present data only valid for local vegetation. The mesophytic forest is quite variable, and the data presented can only give a general indication of stem-diameter distributions. Thus data for several experimental areas outside Expt 67/2 have been presented to indicate this variability.

The stem-diameter distribution for all species in the Sarwa plots, reconstructed as it was before exploitation (see Sarwa R, Table 6.4), had fewer large trees than the 2% sample of the virgin forest in the Mapane region. This indicates that the Sarwa

TABLE 6.4 Expt 67/2: stem-diameter distribution (N/ha) for all species in a number of sample areas in the Mapane region

Diameter class (cm dbh)	Mapane* 2% sample	Sarwa R** 5 ha	Sarwa E*** 5 ha 1968	67/9B† 10 ha 1975	67/9A†† 3.2 ha 1980	Procter's††† bosje, 5 ha 1981
5.0–14.9	n.a.	n.a.	925	559	485	762
15.0–24.9	n.a.	n.a.	183	137	172	150
25.0–34.9	62.0	n.a.	68.2	61	70	69.4
35.0–44.9	32.5	n.a.	38.6	30	41	32.6
45.0–54.9	18.6	15.4	15.2	27.2	35.1	14.8
55.0–64.9	10.8	10.0	7.4	9.9	5.9	6.8
65.0–74.9	6.1	2.8	2.2	9.3	4.4	5.0
75.0–84.9	3.5	1.8	0.6	4.2	1.2	3.6
85.0–94.9	2.0	0.2	0.2	0.9	2.8	2.8
≥95	2.3	0.4	0.4	0.6	0.3	3.8
≥65	13.9	5.2	3.4	15.0	8.7	15.2
≥45	43.3	30.6	26.0	52.1	49.7	36.8
≥25	137.8	n.a.	132.8	143.1	160.7	138.8

* Line sample of 486 ha in virgin forest in the Mapane region, covering more than 20 000 ha (Boerboom, 1964).
** Expt 67/2, reconstruction of stand before exploitation.
*** Expt 67/2, after exploitation.
† Expt 67/9B, full inventory of 2 strips 100 × 500 m in lightly exploited forest, using girth tape.
†† Expt 67/9A, full inventory of lightly exploited forest, using angled caliper and Biltmore Stick.
††† Full inventory of lightly exploited forest south of Expt 67/9A, using girth tape.

TABLE 6.5 Expt 67/2: stem-diameter distribution (N/ha) for all species in sample areas in the Coesewijne region

Diameter class (cm dbh)	Coesewijne 2% sample*	Goliath R 5 ha**	Goliath E 5 ha 1968***
5.0–14.9	n.a.	n.a.	870
15.0–24.9	n.a.	n.a.	154
25.0–34.9	63.3	n.a.	74.8
35.0–44.9	35.7	29.6	29.0
45.0–54.9	19.6	12.4	11.2
55.0–64.9	10.3	10.8	6.6
65.0–74.9	5.5	4.1	2.9
75.0–84.9	2.5	1.4	0.6
85.0–94.9	1.4	0.2	0
≥95	1.5	0.2	0.2
≥65	10.9	5.9	3.7
≥45	40.8	29.1	21.5
≥25	139.8	n.a.	125.3

* Line sample of 550 ha in virgin forest in the Coesewijne region, covering more than 27 000 ha (Boerboom, 1964).
** Expt 67/2, reconstruction of stand before exploitation.
*** Expt 67/2, after exploitation.

plots were in a lighter forest type. The stem-diameter distributions for Expt 67/9A and B (Table 6.4) were similar to the 2% Mapane sample, although both had fewer trees above 95 cm dbh, and Expt 67/9A even less above the 65 cm dbh limit. For trees above 65 cm dbh, the sample from Procter's Bosje (Table 6.4) is slightly above the 2% Mapane sample. All these variations cannot be ascribed to exploitation effects only. The reconstructed stem-diameter distribution for all species in the Goliath plots (Goliath R, in Table 6.5) also had fewer large trees than the regional 2% Coesewijne sample. Presumably, both Sarwa and Goliath plots were located in transitional forest, between xerophytic forest on sandy soils in the north, and truly mesophytic forest on residual soils in the south. Generally the presence of large trees indicates good soil conditions for tree growth and survival, and thus good production potential for timber.

There were more large trees at all diameter limits above 45 cm dbh in the Mapane 2% sample, than in the 2% sample for Coesewijne (see Tables 6.4 and 6.5). The stem-diameter distribution for all species in Sarwa plots differed less from that in Goliath plots than from the regional values of the 2% samples.

Stem-diameter distributions for commercial species (Tables 6.6 and 6.7) indicate that the Coesewijne region (2% sample) had slightly more trees of commercial species above 45 cm dbh than the Mapane region. Similarly, the Goliath plots (Goliath R, Table 6.7) had more large trees of commercial species than did the Sarwa plots (Sarwa R, Table 6.6). This is confirmed by the exploitation data:

TABLE 6.6 Expt 67/2: stem-diameter distribution (N/ha) for commercial species 11-41, form class III, in sample areas in the Mapane region

Diameter class (cm dbh)	Mapane 2% sample*	Sarwa R 5 ha	Sarwa E 5 ha 1968	67/9B 16 ha 1976	67/9A 3.2 ha 1968
5.0–14.9	n.a.	n.a.	60	72.4	65.0
15.0–24.9	n.a.	n.a.	40	15.7	13.7
25.0–34.9	9.06	n.a.	19.2	12.5	6.9
35.0–44.9	5.72	9.4	9.4	7.7	4.4
45.0–54.9	4.14	3.4	3.2	2.7	2.8
55.0–64.9	2.56	5.0	2.4	1.1	0
65.0–74.9	1.67	1.0	0.4	0.3	0
75.0–84.9	0.90	1.6	0.4	0.2	0
85.0–94.9	0.54	0	0	0.1	0
≥95	0.58	0	0	0	0
≥65	3.7	2.6	0.8	0.6	0
≥45	10.4	11.0	6.4	4.4	2.8
≥25	25.2	n.a.	35.0	24.6	14.1

* See Table 6.4, species group similar to species 11-41, form class III.

Coesewijne was more attractive than Mapane for exploitation, especially because of the large number of big trees of *Ocotea rubra, Goupia glabra* and *Dicorynia guianensis*, three important commercial species.

The proportion of commercial species increased with increasing stem-diameter;

TABLE 6.7 Expt 67/2: stem-diameter distribution (N/ha) for commercial species 11-41, form class III, in sample areas in the Coesewijne region

Diameter class (cm dbh)	Coesewijne 2% sample*	Goliath R 5 ha	Goliath E 5 ha 1968
5.0–14.9	n.a.	n.a.	25
15.0–24.9	n.a.	n.a.	36
25.0–34.9	5.67	n.a.	13.4
35.0–44.9	5.08	8.2	7.6
45.0–54.9	4.23	5.8	4.6
55.0–64.9	3.06	5.4	1.2
65.0–74.9	1.97	2.6	1.4
75.0–84.9	1.10	1.4	0.6
85.0–94.9	0.63	0.2	0
≥95	0.63	0	0
≥65	4.3	4.2	2.0
≥45	11.6	15.4	7.8
≥25	22.4	n.a.	28.8

* See Table 6.5, species group similar to species 11-41, form class III.

TABLE 6.8 Expt 67/2: number of trees per ha, of the three main commercial species in 1972

Species	Diameter class (cm dbh)					
	5.0–14.9		15.0–24.9		above 25.0	
	Sarwa	Goliath	Sarwa	Goliath	Sarwa	Goliath
Ocotea rubra	0	15	5	11	2.8 (7.8)*	14.2 (18)
Goupia glabra	0	0	2	0	6.2 (7.0)	1.0 (2.2)
Dicorynia guianensis	5	20	3	9	3.4 (4.0)	5.0 (10)

Source: de Vletter, 1972.

* Number before exploitation in brackets.

18% above 25 cm dbh; 24% above 45 cm dbh; and 27% above 65 cm dbh for Mapane (see Tables 6.4 and 6.6). From this it is argued that the commercial species require less advance regeneration than the group of all species. Usually the reverse argument is put forward, that presumably there is a lack of advance regeneration for the commercial species group, but in fact, many non-commercial species remain small, crowding lower diameter classes. (Preferably, a commercial timber species should reach diameters of more than 45 cm dbh easily, as this is the minimum size accepted by most mills.) This optimistic view on the need of advance regeneration of commercial species does not include the results of selective exploitation without silvicultural assistance to individuals of commercial species.

The stem-diameter distributions of three commercial species in Sarwa and Goliath are given in Table 6.8. As changes in these distributions during the observation period are not shown reliably in such small population samples, only data for 1972 are given. The species *Ocotea rubra* was abundant in Goliath, and *Goupia glabra* in Sarwa, while *Dicorynia guianensis* was reasonably well represented at both locations. The small trees to be considered as regeneration were few, especially *Goupia glabra*, which is known to be a secondary or at least light-demanding species, and in its initial development stages to require large gaps in the canopy to survive (Schulz, 1960).

6.6 Basal area and bole volume

Basal area in Expt 67/2 could not be compared easily with data from other experimental plots, because for many trees reference height for measurement was far above breast height, especially in the Sarwa plots, where many *Antonia ovata*, Loganiaceae, trees occur, with highly irregular stem sections. The exploited basal area in 1967 and the development of basal area during the period 1968-1977 at Sarwa are given in Table 6.9. For Goliath additional data for 1982 were available from Oesterholt (1983) (see Table 6.10). Mortality in the period 1968-1977 is given

TABLE 6.9 Expt 67/2: basal area of exploited trees of commercial species, development of basal area of all species above 25 cm dbh, and mortality of all trees above 45 cm dbh in the period 1968–77 in the Sarwa plots

Plot no	Exploited basal area (m^2/ha)	Total basal area all species above 25 cm dbh (m^2/ha)*				Number of dead trees above 45 cm dbh, 1968–77
		July 1968	June 1972	May 1974	May 1977	
1	1.0	17.38	16.55	16.08	16.16	6
2	2.66	15.47	15.78	16.09	13.62	10
3	0.29	15.19	15.92	16.97	17.24	1
4	1.76	15.47	14.75	15.39	15.48	4
5	2.43	16.61	17.05	17.89	17.33	6
Mean	1.6	16.03	16.01	16.63	15.97	5.4
SD	0.99	0.93	0.87	0.97	1.52	

* Mean basal area of commercial species 11–41, form class III, above 25 cm dbh was 4.13 m^2/ha and 4.22 m^2/ha in 1968 and 1977 respectively.

as numbers of large trees per plot. In both areas recruitment was not recorded in 1977, but is estimated to have been no more than about 0.25 m^2/ha.

In Sarwa, considerable variation in basal area occurred, but only a slight trend was discernible in almost a decade of recording. At Goliath a more definite upward

TABLE 6.10 Expt 67/2: basal area of exploited trees of commercial species, development of basal area of all species above 25 cm dbh, and mortality of all trees above 45 cm dbh in the period 1968–77 in the Goliath plots

Plot no	Exploited basal area (m^2/ha)	Total basal area all species above 25 cm dbh (m^2/ha)*					Number of dead trees above 45 cm dbh, 1968–77
		July 1968	June 1972	May 1974	May 1977	March 1982	
1	4.36	13.50	14.45	14.43	14.98	n.a.	2
2	2.13	14.26	15.14	15.46	15.72	n.a.	3
3	1.02	15.45	15.99	16.27	15.54	n.a.	9
4	3.10	12.63	12.59	12.77	12.39	n.a.	7
5	2.22	13.87	14.82	15.07	14.64	n.a.	5
Mean	2.6	13.94	14.60	14.80	14.65	15.0	5.2
SD	1.25	1.04	1.26	1.32	1.34	n.a.	

* Mean basal area of commercial species 11–41, form class III, above 25 cm dbh was 3.87 m^2/ha and 4.36 m^2/ha in 1968 and 1977 respectively.

TABLE 6.11 Expt 67/2: reconstruction of mean basal area (m^2/ha) of all species ≥5 cm dbh before exploitation in Sarwa and Goliath plots

Categories	Sarwa	Goliath
Trees <25 cm dbh (1968)*	10.6	10.2
Trees ≥25 cm dbh (1968)**	16.0	13.9
Exploited	1.6	2.6
Killed by exploitation	1.5	2.5
	29.7	29.2

* Data from 4% and 20% sample.
** Data from 100% sample.

trend was discernible. Variations in the subplots were remarkable and testified to the low reliability of mean values from hectare plots to determine changes in basal area, in forest containing relatively few large trees, which provide a large proportion of the total basal area. Mortality of large trees is not conducive to high total basal area increments, but in Tables 6.9 and 6.10 this relationship was not always obvious.

The estimated total basal area of all species in various stem-diameter classes before and after exploitation at both Sarwa and Goliath are given in Table 6.11. Exploitation reduced total basal area more at Goliath than at Sarwa.

Changes within certain stem-diameter classes are shown in Table 6.12. In 1977, total basal area of all species of diameters above 5 cm was 26.2 m^2/ha in Sarwa, and 24.5 m^2/ha in Goliath. Thus, total values have changed little since 1968. In Sarwa, only the class of trees larger than 45 cm dbh increased in basal area in the period 1968-1977, by 0.7 m^2/ha, that is about 10%. This corresponds roughly with a bole volume of $0.7 \times 12.7 = 9$ m^3/ha, when the volume tariff is used (see Appendix VII) for this species group for which it was not made. In Goliath, the basal area for the class of trees larger than 45 cm dbh increased by 20% during 1968-1977, and then was reduced by the same amount in the period 1977-1982.

TABLE 6.12 Expt 67/2: development of mean basal area (m^2/ha) of all species in several diameter classes, after exploitation in Sarwa and Goliath plots

Diameter class (cm dbh)	Sarwa		Goliath		
	1968	1977	1968	1977	1982
≥45.0	6.5	7.2	5.2	6.2	5.2
25.0–44.9	9.6	8.8	8.8	8.4	9.8
15.0–24.9	5.3	4.6	4.7	4.7	4.8
5.0–14.9*	5.3	5.7	5.5	5.2	n.a.
>5.0	26.6	26.2	24.2	24.5	n.a.

* Data from 4% sample.

TABLE 6.13 Expt 67/2: development of mean basal area (m^2/ha) of commercial species 11–41, form class III, in several diameter classes, after exploitation in Sarwa and Goliath plots

Diameter class (cm dbh)	Sarwa		Goliath	
	1968	1977	1968	1977
≥45.0	1.6	1.8	2.0	2.6
25.0–44.9	2.5	2.4	1.9	1.7
15.0–24.9	1.2	0.9	0.8	0.7
5.0–14.9*	0.4	0.3	0.1	0.1
≥5.0	5.7	5.4	4.8	5.1

* Data from 4% sample.

Apparently, the class of trees 25.0 to 44.9 cm dbh benefited from events during the period 1977-1982. The class with even smaller trees benefited very little.

Changes in basal area of the commercial species are given in Table 6.13. Only the class of trees larger than 45 cm dbh increased in basal area, at Sarwa more than 10%, and in Goliath even more than 30%.

With the aid of the volume tariff (Appendix VII), the commercial volumes at Sarwa and Goliath were calculated from the basal areas known (see Table 6.14). This indicates developments in a stand more clearly than basal area which is more abstract. After exploitation a considerable volume of commercial species above the 45 cm dbh limit was still present in the stand. However, this consisted of stems that contained second-class logs, because initial exploitation had creamed the forest, being highly selective of species, size, and log quality. A notable volume increment was shown only in the class of the largest trees. Annual increment was highest in Goliath, as was also the annual increment in basal area. The Sarwa data appear to be more consistent with the overall development of the stand, and may be considered to give the most realistic indication of general situation after harvest.

TABLE 6.14 Expt 67/2: development of bole volume (m^3/ha) of commercial species 11–41, form class III, in Sarwa and Goliath plots

Diameter class (cm dbh)	Sarwa			Goliath		
	1968	1977	Annual increment (%)*	1968	1977	Annual increment (%)*
≥45.0	21	23	+1.1	26	33	+3.4
25.0–44.9	29	28	-0.3	22	21	-0.7
15.0–24.9	11	8	-2.6	7	6	-1.3
≥15.0	60	59	-0.2	54	60	+1.2

* Proportion of initial volume.

The close relationship between volume increment and mortality and sample size seriously restricts the reliability of production forecasts in these small populations. Additional data on stem-diameter distributions and basal area are presented in Appendix V.

The situation after a possible second exploitation which will remove the most productive large trees of commercial species can be speculated. The gaps caused by the first light exploitation did not contribute greatly to increase increment on the smaller trees of commercial species. It is also unlikely that gaps caused by the second exploitation will contribute much. To be productive, the population of commercial species must be represented in the upper storey of the forest, but after repeated negative selection, it takes time to enter this storey again. This leads to the idea that the mortality rate of trees of non-commercial species, especially of the dominant trees, should be increased artificially, as was tested in Expt 67/9 A and B, and Expt 65/3.

6.7 Mortality

A possible relationship between log volume felled and subsequent mortality of large trees has been calculated from data in Tables 6.9 and 6.10. For Sarwa, a positive relationship was found between log volume felled and subsequent mortality of trees larger than 45 cm dbh in the period 1968 to 1977 (R^2 = 0.67). For Goliath, a negative relationship was found for the same period, (R^2 = 0.46). These correlations are based on few data, and thus must be interpreted with caution.

The annual mortality rate for all species is given in Tables 6.15 and 6.16, and for commercial species 11-41 in Tables 6.17 and 6.18. The mean annual mortality rate for all species was similar for both Sarwa and Goliath, being 2.3 and 2.1% respectively for diameter class 25.0-74.9 cm dbh. Higher stemdiameter classes were poorly represented, and consequently, the mortality rate in these classes varied considerably; for example the rate of 33% in the highest diameter class (Table 6.15) is the result of the death of the only tree in this class. For trees with stem diameters 15.0-24.9 cm dbh, the mortality rate was much higher than average in Sarwa, but somewhat lower than average in Goliath. Sampling of trees of this stem-diameter class was done over only 20% of the area. For the group of all species, mortality was not concentrated in certain stem-diameter classes. This confirms that the stand was essentially uneven aged. There are periodic fluctuations in the data, but over the nine-year period (1968-1977) the mortality rate was reasonably uniform.

The limited reliability of the mortality data from the relatively small population of commercial trees is evident in the large variations per diameter class (Tables 6.17 and 6.18). The mean annual mortality rate for stem-diameter classes 25.0-74.9 cm dbh was 2.4% and 1.1% for Sarwa and Goliath respectively. The relatively high mortality rate in Sarwa in stem-diameter class 45.0-54.9 (Table 6.17) was caused by the death of four *Vochysia guianensis* trees in subplot 2.

TABLE 6.15 Expt 67/2: stem-diameter distribution in 1968, and development of periodic annual mortality rate (%) for all species in the Sarwa plots

Diameter class (cm dbh)	Stem-diameter distribution 1968 (N/ha)	Mortality rate (%)			
		1968–72*	1972–74	1974–77	1968–77**
5.0– 14.9	925	n.a.	n.a.	n.a.	1.6
15.0– 24.9	183	2.6	2.4	4.7	3.8
25.0– 34.9	68.2	2.9	1.7	3.2	2.8
35.0– 44.9	38.6	1.7	1.6	2.6	2.0
45.0– 54.9	15.2	1.0	1.1	3.7	2.2
55.0– 64.9	7.4	3.4	0	2.9	2.4
65.0– 74.9	2.2	2.3	0	2.6	2.0
75.0– 84.9	0.6	8.3	0	6.7	7.4
85.0– 94.9	0.2	0	0	0	0
95.0–104.9	0.2	25.0	n.a.	0	11.1
105.0–109.9	0.2	25.0	n.a.	33.3	22.2

* The number of dead trees was recorded in July 1968, June 1972, May 1974, and May 1977.

** Mean periodic annual mortality rate for diameter class 25.0–74.9 cm dbh was 2.3%.

TABLE 6.16 Expt 67/2: development of periodic annual mortality rate (%) for all species in the Goliath plots

Diameter class (cm dbh)	Mortality rate (%)				
	1968–72*	1972–74	1974–77	1968–77**	1968–82**
5.0– 14.9	n.a.	n.a.	n.a.	0.7	n.a.
15.0– 24.9	1.7	0.9	1.8	1.8	1.1
25.0– 34.9	1.9	1.6	2.6	2.1	1.2
35.0– 44.9	1.4	2.3	2.2	1.9	1.5
45.0– 54.9	1.8	2.1	2.3	2.4	2.8
55.0– 64.9	1.5	3.5	4.4	2.7	2.4
65.0– 74.9	4.6	0	0	1.5	2.7
75.0– 84.9	0	0	16.7	3.7	2.4
85.0– 94.9	n.a.	0	0	n.a.	
95.0–104.9	0	n.a.	n.a.	0	>95 cm dbh 7.3
105.0–109.9	n.a.	0	0	n.a.	

* Data of recording: see Table 6.15.

** Mean periodic annual mortality rate for diameter class 25.0–74.9 cm dbh is 2.1% for both periods 1968–77 and 1968–82.

TABLE 6.17 Expt 67/2: stem-diameter distribution in 1968, and development of periodic annual mortality rate (%) for commercial species 11–41, form class III, in the Sarwa plots

Diameter class (cm dbh)	Stem-diameter distribution 1968 (N/ha)	Mortality rate (%)			
		1968–72	1972–74	1974–77	1968–77*
5.0–14.9	60	n.a.	n.a.	n.a.	n.a.
15.0–24.9	40	1.5	4.3	4.1	3.3
25.0–34.9	19.2	3.1	0.5	3.6	2.9
35.0–44.9	9.4	1.1	2.1	3.0	1.9
45.0–54.9	3.2	1.6	2.8	6.7	4.2
55.0–64.9	2.4	6.3	0	0	2.8
65.0–74.9	0.4	0	0	0	0
75.0–84.9	0.4	12.5	0	0	5.6

* Mean periodic annual mortality rate for diameter class 25.0–74.9 cm dbh is 2.4%.

V. guianensis trees generally regenerate in groups in large gaps in the forest. These four trees may have been of similar age and phase of development. Mean mortality rate of commercial species was similar to the average for all species in Sarwa (Table 6.17) but was much lower in Goliath (Table 6.18). This has resulted in a surprisingly high volume increment in commercial species in Goliath during the period 1968-1977.

Mortality of large trees generally causes considerable losses of commercial timber. An estimated mortality rate of volume of 2% has important consequences for management, and a 2% annual loss of biomass by mortality is a considerable addition to annual litter fall. In small forest compartments the mortality rate is more irregular, and forecast of volume production is less reliable than in large

TABLE 6.18 Expt 67/2: development of periodic annual mortality rate (%) for commercial species 11–41, form class III, in the Goliath plots

Diameter class (cm dbh)	Mortality rate (%)			
	1968–72	1972–74	1974–77	1968–77*
5.0–14.9	n.a.	n.a.	n.a.	n.a.
15.0–24.9	2.5	0	1.5	0.9
25.0–34.9	1.4	2.4	1.8	1.7
35.0–44.9	0.7	0	1.8	0.9
45.0–54.9	0	0	2.9	1.5
55.0–64.9	0	0	0	0
65.0–74.9	3.6	0	0	1.6
75.0–84.9	0	0	16.7	2.0
85.0–94.9	n.a.	0	0	0

* Mean periodic annual mortality rate for diameter class 25.0–74.9 cm dbh was 1.1%.

compartments. As shown by foregoing results, monitoring for mortality rate should include several hundreds of individuals in each stem-diameter class, and for larger individuals of the commercial subpopulation a sample area of more than 10 ha, and an observation period of longer than ten years may be required for reliable estimates.

Whittaker (1975) gives the example of a reasonably large population of *Quercus alba* trees (1525 individuals, on 74 ha) in mixed forest in USA. Population age distribution could be determined from annual ring counts. A decreasing age distribution was found, which indicated an annual death rate of 0.8% for trees over 6 inches (15 cm) dbh. It was concluded that an almost constant proportion of trees per age class would die each year. In Expt 67/2, age classes could not be determined and therefore mortality and growth rates were followed over a long period, but a similar decreasing stem-diameter distribution was found. An almost constant death rate was also found for all species in the stem-diameter classes represented. This strongly suggests that individuals graduate through the stem-diameter classes over the years, as claimed for age classes in the case discussed by Whittaker (1975). The death rate can be considered to be a natural thinning regime, regardless of size and age of the trees, resulting in the decreasing diameter distribution shown.

The temptation to derive age classes from stem-diameter distributions is great, but such attempts meet with difficulties, even when girth increment over a long period is known. However, age structure is considered to be more important in management of even-aged stands than of uneven-aged stands (Leibundgut, 1982), because the development phase of the tree seems to be more decisive than its age in years. This agrees with the tripartite division of Hallé, Oldeman and Tomlinson, (1978): trees of the past, trees of the present, and trees of the future. These categories can be recognized by physiognomic signs, such as reïteration, which only loosely depend on age in years. The situation is complicated by the

TABLE 6.19. Expt 67/2: mortality rate in an 0.8 ha plot in undisturbed forest at Kamp 8, Mapane region, 1964–74

Diameter class (cm dbh)	Number of trees in 1964	Number of dead trees 1964–74	Annual mortality rate (%)
9.5–15.4	169	22	1.3
15.5–25.4	115	8	0.7
25.5–35.4	37	4	1.1
35.5–45.4	25	0	0
45.5–55.4	14	1	0.7
55.5–65.4	5	1	2.0
65.5–75.4	6	0	0
75.5–85.4	1	0	0
>85.4	2	0	0

Source: van Melle, 1975.

multitude of species, with shade bearing species limited to the lower storeys, while other species, having the potential to become large trees, wait for a gap in the forest, and do not require to be represented by a large population of small and medium-sized individuals.

In Table 6.19, the mortality rate is given in a 0.8 ha plot of virgin forest at Kamp 8, where all trees above 10 cm dbh of all species have been monitored for ten years (van Melle, 1975). The mean mortality rate of 1% is much lower than that found in Sarwa and Goliath. Few data for larger trees are presented in Table 6.19, and on the whole the population sampled seems too small to provide dependable data. Mortality rates in lightly exploited forest elsewhere in Mapane can be found in the 'zero-plots' of Expt 67/9 A (see Chapter 7), for the subpopulation of commercial species in 3.2 ha. The annual mortality rate was found to be approximately 1%, but with large variations, because of the small size of the population.

Mortality can be expected to be related to climatological variations. In Sarwa, the mortality rate was lowest in the period 1972-1974 (Table 6.15), and this may be explained in terms of rainfall. Several dry periods occurred in 1968-1972 and in 1974-1977 in the Mapane region; the period 1972-1974 was relatively humid (see Appendix I). For Goliath (Table 6.16) a periodicity in mortality rate is not obvious; rainfall records show that in 1972 and 1976 the month of October was very dry. Forest on the lighter sandy soils at Goliath may be more susceptible to drought stress than forest on loamy soils at Sarwa. Much depends on depth of root penetration in the soil profile, but no data are available on this. Such dry periods may cause directly the death of trees, especially small suppressed trees, by desiccation. However, often small trees are the victim of larger trees falling down. Large trees, in addition to physiological problems, have a larger problem of static balance, and often fall in short violent squalls preceding rainstorms when weakened by other causes. No precise data are available on how trees died, either standing or fallen, but many large trees with living crown have fallen or broken in Expt 67/2.

Usually, high annual girth increment is a sign of vitality. Data were collected about individual trees to determine the periodic annual increment of girth in the period before death (see Tables 6.20 and 6.21). Some trees were found to maintain reasonable girth increment just before death, and others were found to

TABLE 6.20 Expt 67/2: periodic annual increment of girth (mm/y) of individual trees of commercial species in the period immediately prior to death in Sarwa plots

Diameter class (cm dbh)	*Ocotea rubra*	*Dicorynia guianensis*	*Carapa procera*	*Goupia glabra*	*Virola melinonii*
15.0–29.9	14.2	15.3	45.8;1.5	4.3	7.3;16.2
	2.2		18.0;6.5		11.3;16.0
30.0–44.9	13.2	20.5	n.a.	7.5	23.0
45.0–59.9	n.a.	23.3	n.a.	2.2	n.a.

TABLE 6.21 Expt 67/2: periodic annual increment of girth (mm/y) of individual trees of commercial species in the period immediately prior to death in Goliath plots

Diameter class (cm dbh)	*Ocotea rubra*	*Micropholis guianensis*	*Qualea albiflora*
15.0–29.9	17.7	9.2;2.0	n.a.
30.0–44.9	18.8	10.3;8.0;0.0	1.5
		12.0;9.5;19.2	
45.0–59.9	23.8;22.0	5.0;9.0	
	22.0	n.a.	0.0

stagnate. Thus mortality cannot be related simply to stagnant growth.

Large trees often fall because the root system is partly decayed. In 1974, a FAO study in Suriname found that more than 10% of trees had rotten or hollow stems, and in some cases even more than 20%. The proportion was higher in commercial than in non-commercial species, or in all species; even small trees showed a high proportion of rot (de Milde and Inglis, 1974).

Such conditions must have a profound effect on the chances of a tree to survive and eventually reach large diameters. Stem rot is often accompanied by root rot, which ultimately results in windthrow of trees with outwardly intact stems. Research on windthrow or standing death of trees should include autopsy on the stem and main root system.

Selective pressure of wood-rotting fungi on tree populations can be held responsible for the evolutionary development of very durable heartwood as is present in many tree species in tropical rain forests. But even in a species with very durable heartwood, such as *Vouacapoua americana*, heart rot occurs in a remarkably high proportion of trees (de Milde and Inglis, 1974). The irregularly fluted stem of this species provides many opportunities for invasion of wood-rot fungi. The high incidence of wood rot demonstrates the close race between trees and fungi in durability versus attacking power. The lack of really large trees in the mesophytic forest of Suriname as compared with rain forests of other tropical countries (Boerboom, 1964; Schulz, 1960) may be due not only to the poverty of the soil, but also to these wood-destroying fungi.

Yet in species without durable heartwood, such as the commercially attractive *Virola surinamensis* and *V. melinonii*, the proportion of trees with stem rot is small, which is probably because these species perish easily after the onset of such decay. A large *V. melinonii*, which in the preceding year of recording had looked healthy, was found as a heap of rotting pieces of timber with the metal tag still present. Often the outward signs of decay are termite tunnels and oozing old wounds. Rain-water trickling through wounds high in the tree may promote decay, and this can result in much dirty water flowing from inside a stem when cut at harvesting. Decay can begin in extensive areas of damaged bark caused by neighbouring trees falling, and in such a way the effects of careless exploitation can extend for quite a long time.

Buttressing may allow a tree to isolate its dead core of heartwood from the fungus-ridden soil, because sapwood is an effective barrier to these fungi. The massive core of the stem of species such as *Pterocarpus* spp., *Sclerolobium* spp., *Mora* spp., and *Couratari* spp. begins far above soil level. Stilt roots may have the same advantage (*Symphonia globulifera*). These roots and buttresses may supposedly even eliminate the need for durable heartwood, but in *Mora* spp., which are known for their high proportion of internal rot, this is obviously not the case. In water-logged soil, either seasonably or only during heavy rainstorms, trees having buttresses are possibly better supported than those having regular forms of stem base, but such explanations are not fully satisfactory (Richards, 1964).

6.8 Periodic annual increment of girth

The periodic annual increment of girth for three stem-diameter classes of trees of the commercial species group 11-41 form class III is presented in Fig. 6.8. Increase in girth increment in the remaining population after light exploitation could be expected, because competition has been reduced. A comparable effect was seen in Expt 67/9A (see Chapter 7). The girth increment in period 1974-1977 may be positively biased because in 1977 girths were measured about 20 cm below the usual point. Data from unexploited forest are not available for Suriname.

Periodic annual increments of girth per diameter in the period 1968-1977 for

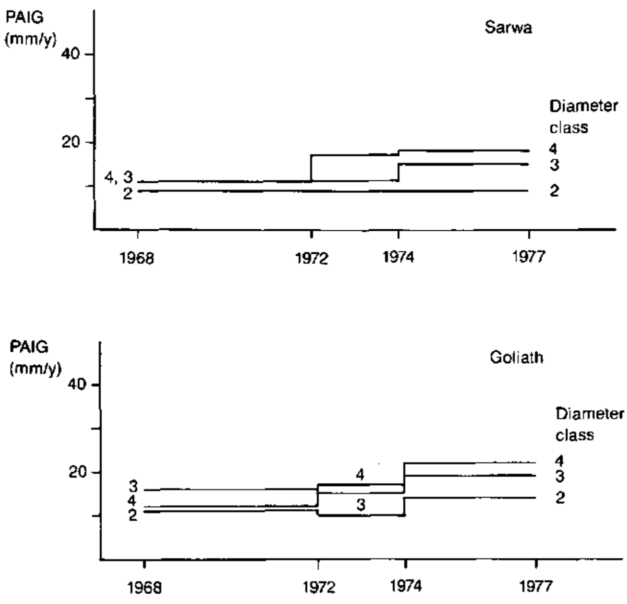


Fig. 6.8 Expt 67/2, at A. Sarwa; and B. Goliath: development of periodic annual increment of girth (PAIG) in mm/y of commercial species 11-41 form class III for diameter classes: 2, 15.0-29.9 cm dbh; 3, 30.0-44.9 cm dbh; and 4, 45.0-59.9 cm dbh.

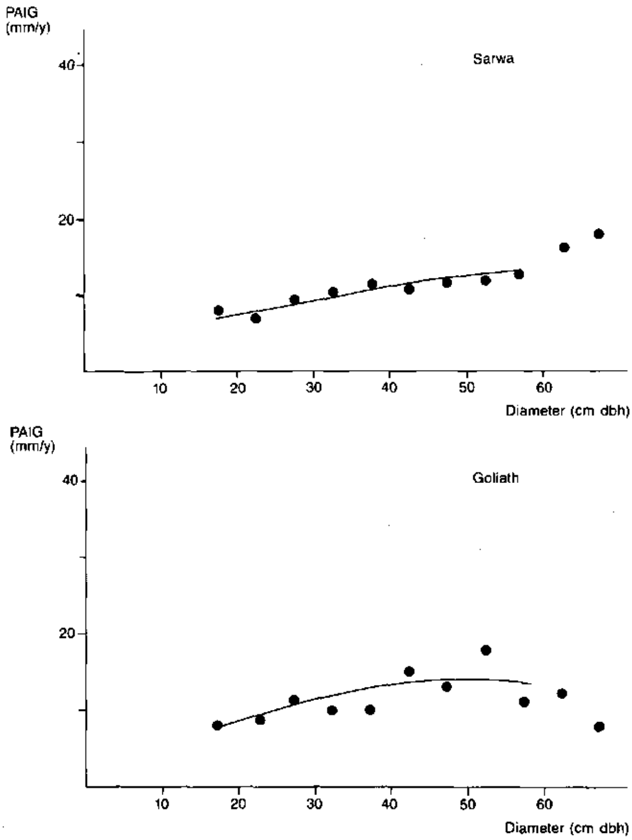


Fig. 6.9 Expt 67/2, at A. Sarwa; and B. Goliath: periodic annual increment of girth (PAIG) in mm/y per diameter for trees of all species form class III in the period 1968-1977.

Sarwa and Goliath, are presented in Figs 6.9 and 6.10. In Sarwa (Fig. 6.9 A) girth increment for all species increased with stem diameter, especially in the large diameter classes with few trees. In Goliath (Fig. 6.9 B) beyond the 50 cm limit girth increment slowed down. Beyond the 50 cm limit both trends are questionable, because the number of trees was too low to obtain a reliable estimate.

Girth increment for the populations of commercial species (Fig. 6.10) with even smaller numbers of trees slowed down earlier than that for all species, but was higher in stem-diameter classes 25-45 cm. This had been observed earlier in several commercial species by de Vletter (1972). The population of commercial species had been reduced by exploitation of individuals in the higher stem-diameter classes, but growth in the lower diameter classes of the commercial species was better than the average for all species. This is supported by data on basal area and volume developments. Girth increment was more irregular in Goliath than in Sarwa for commercial species as compared with all species. Probably this was a random effect, caused by irregularities in two or three stem-diameter classes with only 10 to 20 trees each.

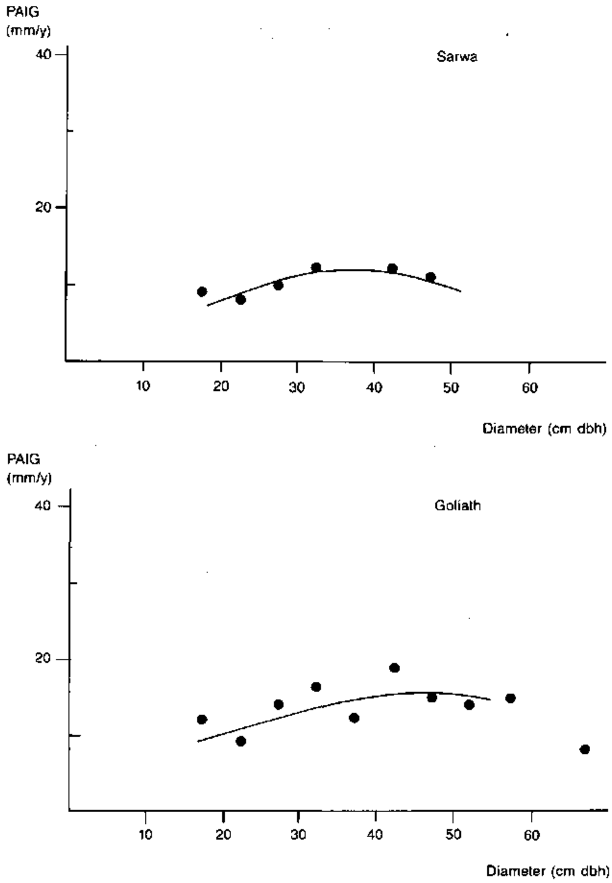


FIG. 6.10 Expt 67/2, at A. Sarwa; and B. Goliath: periodic annual increment of girth (PAIG) in mm/y per diameter for trees of commercial species 11-41 form class III in the period 1968-1977.

6.9 Conclusions

The light disturbance resulting from the low timber volumes harvested in this experiment did not profoundly disturb the forest ecosystem, and posed no threat to forest stability. Proportion of secondary species increased only slightly. However, the economic productivity of the exploited forest was very low, because of the small numbers of productive trees of commercial species, and low increment of girth in the highly competitive vegetation. A regular 2% annual mortality rate further reduced potential volume production of commercial timber. Species harvested selectively will not reach original stocking in periods of reasonable length (20-40 years), and without silvicultural treatments to increase production the future second harvest of commercial timber will be the left-over of the first exploitation, together with the minimal volume increment produced over the period between harvests.

7 Experiment 67/9 A: natural regeneration techniques

7.1 Summary

In this experiment various silvicultural techniques to stimulate growth and recruitment of desirable species have been studied using a range of maintenance schedules. As treatment plots were large (one ha), opportunity for replication was limited, thus reducing the scope for statistical testing. However, the size of the plots has made it possible to extrapolate results for practical application. From this experiment more reliable data have been obtained about the development of medium-sized and large trees which are essential to volume production in mesophytic high forest.

Exploitation in the experimental area had not been prescribed or controlled. Only a few trees per ha were taken indiscriminately throughout the area. Volume taken was estimated to be about 10 m³/ha. This light exploitation had little effect on the growth of the remaining trees, as was also the case in Expt 67/2.

Silvicultural treatments, that is refinements and liberations, subsequent to exploitation effectively increased the increment of the desirable trees in the stand. The range in intensity of treatments was lower than in Expt 65/3. The various treatments reduced total basal area of plots to different levels, and the resulting girth increment was found to be related to total basal area in certain periods after treatment.

Annual mortality rate for the commercial species increased with increasing intensity of interference in the stand, ranging from about 1% to about 2.5%, and was also affected by dry periods. Periodic annual bole volume increment of commercial species varied from about 0.7 m³/ha in plots under zero treatment to about 2.1 m³/ha in the best producing plot under the near optimum treatment schedule 40 + D 8. Volume increments were not the best indicators of success in treatment, because of the effects of irregularities in mortality and stem-diameter distribution in the plots. The lower diameter limit set for acceptable timber also affected final evaluation, because an early harvest of a low volume of large timber can outweigh a larger volume production which requires more time to produce timber above the diameter limit. Periodic annual girth increment was found to be the best indicator of success of treatment in this experiment (see also Section 5.8).

Competition for light and water, and also for nutrients from litter fall, affected volume production. A light refinement and no subsequent liberation killing half

the standing biomass resulted in about 4 m^3 periodic annual bole volume increment of all species. Heavy refinement and no subsequent liberation killing five-sixths of the original biomass resulted in a periodic annual stem volume increment of about 11 m^3/ha. These treatments also affected the tree species composition of the stand considerably.

The optimum silvicultural treatment had to produce the minimum exploitable timber volume at lowest price. Intensive treatments increased the growth of secondary weed species, both trees and climbers, which could only be controlled with high labour input. Thus, the range in basal area for optimum results was found to be between 10 to 20 m^2/ha throughout the entire production cycle. The lower limit was set by the need to prevent unwanted growth of weed trees, and the upper limit by reduced growth of desirable trees, especially the small regeneration. These values are in close agreement with those of Dawkins (1958), who prescribed a range of one-third to two-thirds of the original total basal area. Further research is required if it seems desirable to refine these estimates.

The optimum treatment, also from the financial point of view, proved to be in the range of quite extensive maintenance schemes, with interference only once in eight years, or even less frequently. This led to acceptance of the treatment scheme for Mapane as proposed in Part II.

Stereoscopic photographs, aerial and terrestrial, and also forest profile diagrams are presented to give a visual impression of treatment effects.

7.2 Introduction

Expt 67/9 A started in 1967 to study silvicultural techniques to stimulate growth and recruitment of desirable species using a range of maintenance schemes. A wider range of methods was tried than in Expt 65/3. However, Expt 67/9 A was restricted in size, number of replications, and potential treatments, because of its remote location at that time, and the limited accommodation available for staff and labourers. After layout and treatment in the first year, the work-load was borne by only one research officer assisted by students in their practical year, and a recording team of experienced labourers.

The experiment was located in Mapane region, near the old bridge over the Mapane river at Akintosoela (see Fig. 6.1 and Fig. 7.2). The geological substrate was Armina schist, which is part of the Guiana Shield of Precambrian age. Presumably the soils have developed *in situ*, unlike those of Expt 65/3 and 67/2 which were located on the border of the cover landscape. On the soil map in Fig. 6.1 the experimental area is placed in soil units 43 and 44. A detailed soil profile description from a soil pit in a zero plot of this experiment is given in Appendix VI. Soils were of low fertility and acid, and their structure vulnerable to degradation by heavy traffic. Some charcoal was found in the soil pit described, indicating human intervention in the area in the past.

The experiment was located on a long southern slope of mostly less than 10%.

Interference to rain-water percolation has been observed in well-worn footpaths and in areas disturbed by log skidding. Even in areas not directly compacted this occurred as a result of local sheet erosion, transporting muddy water to areas nearby where percolation was inhibited by the mud. This could give rise to extensive gullying, as was observed in an area of broken terrain, several hundreds of metres west of the experimental area. During and after rain, the soil in the experimental area even when undisturbed, was slippery under foot, except when gravel was present on top. The soils were quite homogeneous, and only one gully, mostly dry and not eroding, crossed plots 16, 22, 23 and 24 (see Fig. 7.1). Apparently it had very little effect on nearby vegetation, and it is not visible on the aerial photographs.

A recent detailed soil map of the experiment (van der Steege, 1983) indicates only small differences between soils in most plots, except for plot 23, half of which has dark soil, possibly deposited as a landfill by the gully crossing the plot. Just beyond the western border of the experimental area, loosely strewn schist boulders were to

TABLE 7.1 Expt 67/9A: schedule of silvicultural treatments

Plot no	Diameter limit for initial refinement (cm dbh)	First year of recording	Liberation	
			Treatment code*	Treatment schedule (years after refining)
1, 8, 15, 17, 24	none	0	0	–
3, 7	40	0	40+0	-
18	40	3	40+A3	3, 5, 8
21	40	5	40+A5	5, 8
13	40	3	40+D3	3, 5, 8
10	40	5	40+D5	5, 8
23	40	0	40+D8	8
14, 19	20	0	20+0	–
2	20	3	20+A3	3, 5, 8
20	20	5	20+A5	5, 8
9	20	3	20+D3	3, 5, 8
11	20	5	20+D5	5, 8
22	20	0	20+D8	8
5	20	3	20+S3	3, 5, 8
16	20	5	20+S5	5, 8
4, 6, 12, 25	none	0	V	0

* Code A: Leading Desirable system on 5×5 m plots.
Code D: diameter limit system on 80×80 m plots.
Code S: line system (line width 2 m, line distance 12½ m).
Code V: individual liberation of trees ≥15 cm dbh.

be seen, indicating the presence nearby of parent rock. The foundations of the bridge over the Mapane river near the camp site were on solid rock.

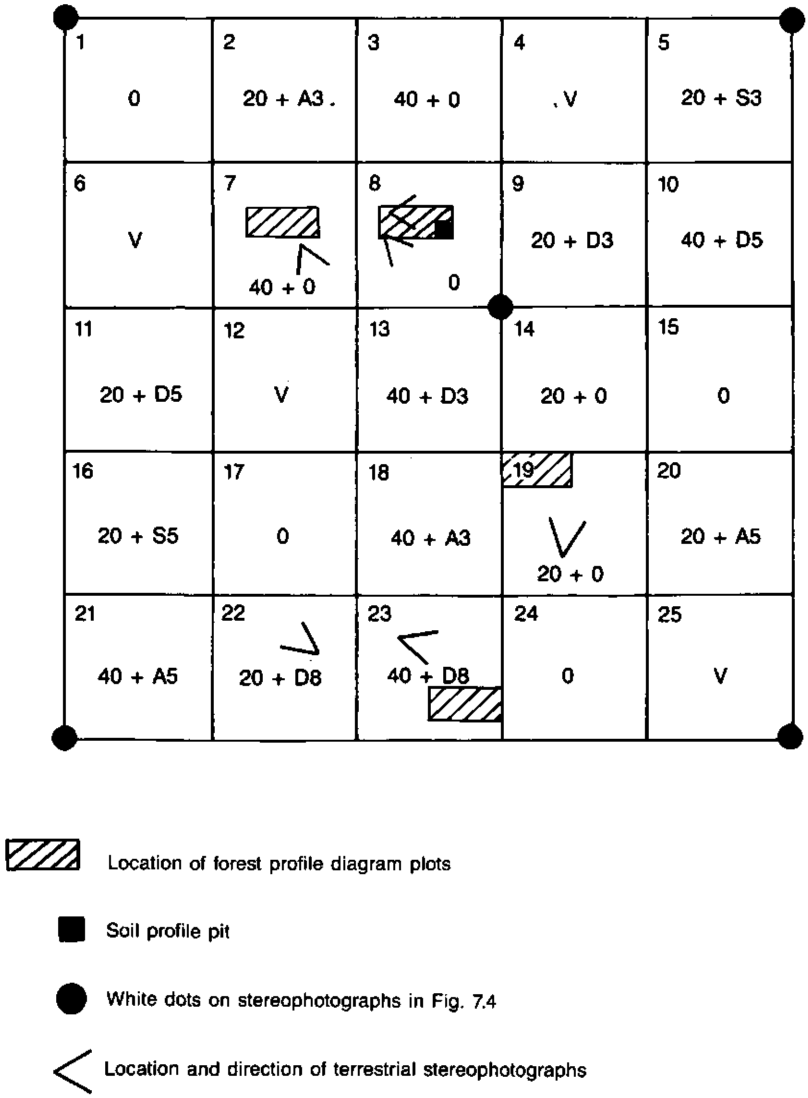


Fig. 7.1 Expt 67/9A: lay-out showing plot numbers and treatment schedule codes (see also Table 7.1). Size of treatment plots is 100 × 100 m; and recording plots are 80 × 80 m.

7.3 Experimental layout

The experiment area was 500 × 500 m, and was subdivided into 25 treatment plots each of one ha (Fig. 7.1). Distribution of treatments was random. The four types of basic initial interferences are listed in Table 7.1, and discussed in detail under silvicultural treatments (Section 7.6). More silvicultural techniques, including a very light refinement and other interferences not usually practised, were tested in Expt 67/9 A than in Expt 65/3. Five zero plots with only light exploitation were included. As plots were much larger than in Expt 65/3, few replications could be built in the experiment, and possibilities for statistical testing of mean plot data were few. Surrounds were only 10 m wide, but recording plots were reasonably large, being 80 × 80 m, and thus interaction between plots could be largely eliminated.

7.4 Exploitation

In 1964 the area was lightly exploited for saw logs and peeler logs, and in 1968 a number of trees were felled, mainly *Eschweilera* spp. for use as jetty piles. Skidding was done with a D4 crawler. Harvesting in several operations over a prolonged period is quite common for concessionaires in Suriname. The number of logs harvested per treatment plot is given in Table 7.2. In 1968, trees were felled for jetty piles mainly in the plots not refined, because many of these trees had been poison-girdled in the refined plots. Plots 1 and 4 suffered most from harvesting in 1968, probably because of their close proximity to the road. Plot 1 under 0 treatment showed a hollow structure in following years, as most trees taken were medium-sized and these destroyed many smaller trees when they fell, but did not open the upper strata very much.

On average, harvesting was light and irregular throughout the experimental area. Average numbers of trees harvested in plots under 0 treatment were comparable with those harvested at Sarwa in Expt 67/2, being 4.8 and 5.2 respectively (see Table 7.3). Volumes harvested were lower in Expt 67/9 A, because of the small size of trees taken for jetty piles, the minimum width for squared piles being set at 25 cm. Probably the corresponding volume was about 10 m^3 per ha, less than half that taken in Sarwa.

In plots under 0 treatment, about 1 m^2 basal area was felled per ha, and 1 m^2 damaged by felling, resulting in a total basal area reduction of about 2 m^2 per ha. Presumably in the other plots basal area reduction would have been about 1 m^2/ha. These small reductions have affected forest growth only slightly, as also was the case in Expt 67/2. The slight increase in periodic girth increment in the 0 treatment plots, which for small trees (5.0-14.9 cm dbh) in subsequent years decreased slowly to 'virgin forest values', also indicated the limited effects of exploitation.

TABLE 7.2 Expt 67/9A: species and numbers of trees felled for harvesting in the 25 treatment plots, in 1964 and 1968

Plot no	1964	1968
1	1 *Ocotea rubra;* 1 *Vouacapoua americana*	10 *Eschweilera* spp.
2	1 *Virola melinonii;* 1 *Ocotea petalanthera*	2 *Eschweilera* spp.
3	1 *Virola melinonii;* 1 *Goupia glabra*	1 *Eschweilera* spp.
4	none	5 *Eschweilera* spp.
5	1 *Ocotea rubra*	none
6	none	1 *Eschweilera* spp.
7	1 *Virola melinonii;* 1 *Goupia glabra*	none
8	none	2 *Eschweilera* spp.
9	1 *Ocotea rubra*	1 *Eschweilera* spp.
10	1 *Ocotea rubra*	none
11	1 *Ocotea rubra*	1 *Eschweilera* spp.
12	1 *Virola melinonii;* 2 *Goupia glabra*	3 *Eschweilera* spp.
13	1 *Virola melinonii*	none
14	1 *Ocotea rubra*	none
15	none	none
16	1 *Goupia glabra;* 1 *Cedrela odorata*	1 *Eschweilera* spp.
17	1 *Vouacapoua americana*	3 *Eschweilera* spp.
18	none	none
19	1 *Ocotea rubra;* 1 *Dicorynia guianensis;* 1 *Simarouba amara*	1 *Eschweilera* spp.
20	1 *Virola melinonii;* 2 *Tabebuia serratifolia;* 1 *Pithecellobium* sp.	none
21	1 *Dicorynia guianensis*	none
22	1 *Virola melinonii*	1 *Eschweilera* spp.
23	none	none
24	2 *Virola melinonii;* 1 *Dicorynia guianensis;* 1 *Ocotea petalanthera*	2 *Eschweilera* spp.
25	none	none
	Total 33	Total 34

TABLE 7.3 Expt 67/9A: number of logs harvested in 1964 and 1968 in the plots under six selected treatment schedules

Treatment code	Number per plot*		Mean per ha
	1964	1968	
0	2;0;0;1;4	10;2;0;3;2	4.8
40+0	2; 2	1; 0	2.5
20+0	1; 3	0; 1	2.5
40+D8	0	0	0
20+D8	1	1	2
V	0;0;3;0	5;1;3;0	3

* Data per plot, following the order in Table 7.1.

7.5 Weyerhaeuser Sample

In 1969, in an area of about 30 ha north of Expt 67/9 A (see Fig. 7.2), all boles over 25 cm dbh were harvested to provide a sample of pulpwood for the Weyerhaeuser Company, USA. A list of species (see Appendix III) was prepared from data on living trees; their volumes were calculated from measurements on extracted numbered logs stacked along the roadside. The entire operation was organized and controlled by the Forest Service ('s Lands Bosbeheer, 1971). On average, 194 m^3 bole volume per hectare was harvested. There should be reckoned with measurement errors and harvesting losses. Not all stems were used for pulpwood, especially not those of species with deeply fluted stems, and stems

TABLE 7.4 Expt 67/9A: bole volume harvested of trees in five most abundant families in the Weyerhaeuser Sample in 1969

Tree family	Stem volume exploited	
	m^3/ha	Proportion of total (%)
Lecythidaceae	36	19
Papilionaceae	34	18
Mimosaceae	17	9
Burseraceae	20	10
Sapotaceae	13	7
Total	120	
Others	74	
Total	194	

Source: 's Lands Bosbeheer, 1971.

broken into short pieces. The bole volume of tree families yielding more than 10 m^3 per ha are given in Table 7.4. The total bole volume of commercial species on the CELOS list was about 69 m^3 per ha, of which the four most abundant commercial species contributed about 25 m^3. The area had been lightly exploited before 1969. The bole volume of Lauraceae and Vochysiaceae, both characteristic of this South American rain forest, was 7.3 and 6.0 m^3/ha respectively. The total bole volume for virgin forest in Mapane was estimated to be 243 m^3/ha above the dbh limit of 25 cm in an extensive forest inventory carried out by the Forest Service (Boerboom, 1964).

7.6 Silvicultural treatments

The silvicultural treatments and the treatment schedules in Expt 67/9 A are listed in Table 7.1. In plots under treatment 0 no silvicultural treatment was given after exploitation. Other plots received an initial refinement treatment in year zero, as set out in Table 7.1. Refinement was applied at a lower stem-diameter limit of either 40 cm dbh or 20 cm dbh, and is denoted in the treatment code as 40 and 20 respectively. Treatment 40 was very light compared with that usually applied by the Forest Service in the 1960s, and reduced total basal area from about 29 m^2/ha to about 17 m^2/ha. In the refinement with 20 cm dbh limit, basal area was reduced to about 7 m^2/ha. Basal area increased again soon after refinement but was reduced with each successive liberation treatment. Three types of liberation treatments were applied after refinement, and are denoted by the treatment code as A, D, and S respectively (Table 7.1). A fourth type of liberation treatment, denoted as V, was applied to trees of commercial species above 15 cm dbh, in plots which had not received a refinement treatment.

Liberation treatment A was applied to the most promising individuals of valuable species in each 5 × 5 m area of the relevant experiment plot. This selection corresponds roughly with the leading desirable system as described by Dawkins (1958). It has the serious drawback of being very time-consuming, and giving too much attention to relatively small individuals with little chance of survival.

In liberation treatment D a lower stem-diameter limit was applied to define the valuable trees to be liberated. All trees of stem diameter above this limit (2 or 5 cm dbh) were liberated individually, regardless of their distribution. This method is easy to apply, and is closer to the refinement method used. In fact, plots under the treatments 40 + D 8 and 20 + D 8 in 1975 were given a modified refinement, in which small non-commercial filler trees were saved, to prevent formation of permanent gaps (von Meyenfeldt, 1975). Lower stem-diameter limit for such refinement in 1975 was 3 cm dbh. The filler tree system resulted in a light continuous cover, which was effective in reducing liana and other weed growth. Non-commercial trees are preferable to lianas, but the number and size of filler trees should be checked in later years.

Liberation treatment S was similar to the system applied in the forest regeneration areas of the Forest Service in the 1960s. In this treatment, lines were cut 12½ m apart, in an east-west direction to maximize light penetration. All individuals of valuable species beyond the seedling stage within 1 to 2 m from the centre of the line were liberated. This usually provided enough regeneration to work towards a well-stocked stand (Schulz, 1967). However, after some years of neglect lines in the vegetation were lost, but in extensive maintenance schedules it was not necessary to open them again, because the lower vegetation layers had become relatively open under the closed upper storeys.

From the many treatments presented in Table 7.1, the six most interesting were selected for discussion and more intense study, namely, treatment 0, 40 + 0, 20 + 0, 40 + D 8, 20 + D 8 and V. The other treatments were quite intensive and therefore not of economic interest, and also were ecologically too destructive.

7.7 Aerial photographs

Aerial photographs of Expt 67/9 A in 1971 and 1982 are presented in Figs 7.2 and 7.4 respectively. The chessboard effect of the layout is clearly visible on both photographs, especially that taken in 1971, because of the different levels of refinement applied in 1967. Liberation treatments applied in 1970 were beginning to be effective in 1971, but cannot be discerned on this small-scale photograph.

The photograph taken in 1982 shows the results of 15 years growth and mortality. The various treatment plots may be located on the photograph with the aid of the diagram of the experimental layout presented in Fig. 7.1. The heavy refinements in 1967 have lowered the mean vegetation height considerably. Plots under treatment 0 (plots 8, 15, 17 and 24 are visible) should be viewed as original vegetation, together with the forest surrounding the experimental area, mainly visible in the south. In the refined plots, few dead trees are visible 15 years after this treatment. On these photographs with exaggerated impression of height of the vegetation, the plot size of one ha seems relatively small.

Plots under treatment 20 + D 8 and 40 + D 8 (plots 22 and 23), which are considered to be optimum treatments, had lost many trees, as indicated by the low mean height of vegetation. Other intensively treated plots look similar (plots 9, 11, 13). Plot 19 under treatment 20 + 0, and plot 20 under treatment 20 + A 5, were dominated by secondary species having relatively flat crowns, mostly *Cecropia* spp. and *Inga* spp. Few lianas were present. Plot 14, under treatment 20 + 0, differed from plot 19, in having a central group of trees that were saved from refinement, and having more gaps caused by recently fallen trees. The only plot under treatment 40 + 0 visible on Fig. 7.4 is plot 7, which, when compared with plot 8 under treatment 0, appears to have lost many large trees in the refinement in 1967.

7.8 Stem-diameter distributions

The stem-diameter distributions of all species under six treatments in 1980,

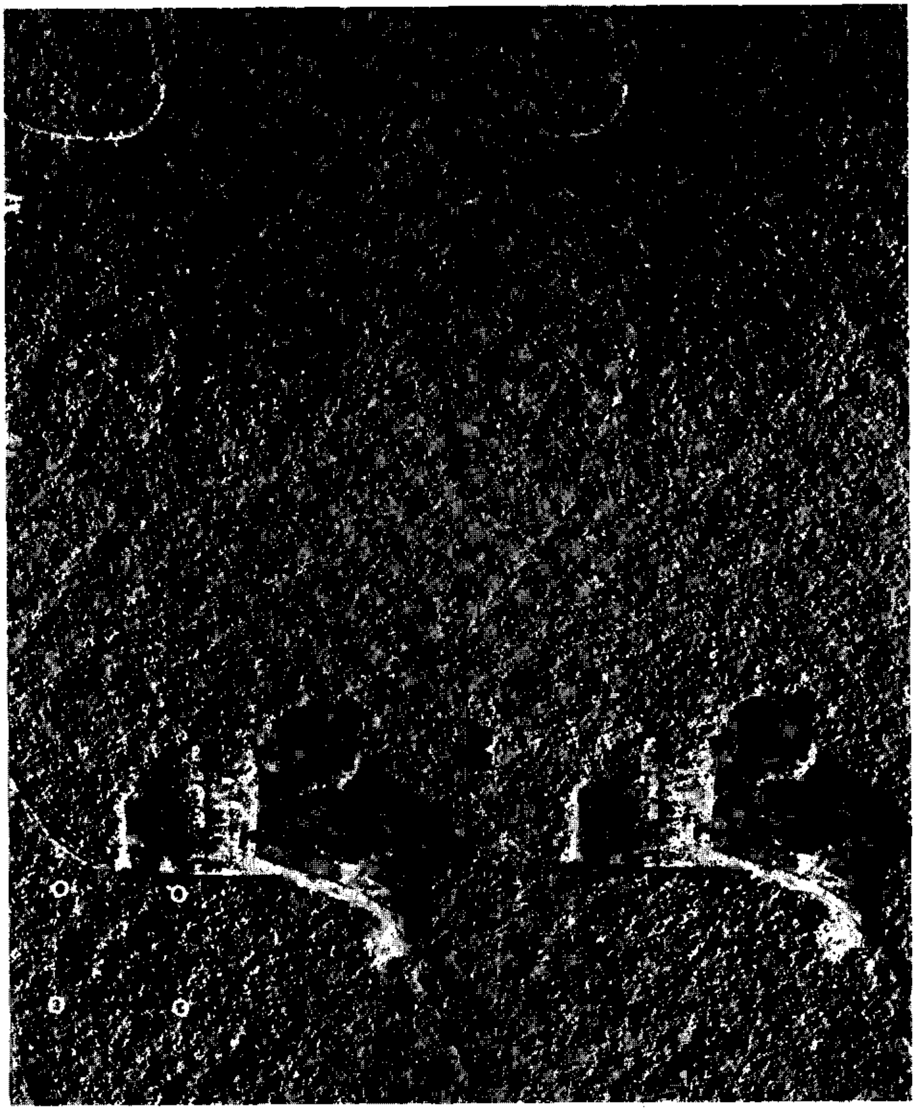


Fig. 7.2 Expt 67/9 A: aerial photograph of Mapane experimental area, taken in 1971. Scale approximately 1: 30 000. Expt 67/9 A is indicated by the four white circles in the lower left corner (see also Fig. 7.3, and the experimental lay-out in Fig. 7.1). Photo by courtesy of CBL, Suriname.

13 years after commencement of the experiment, are given in Table 7.5. The stem-diameter distribution in plots under treatment 0 has been taken as a basis. Similar to developments in Expt 67/2, the stem-diameter distribution in these plots is assumed to have changed little between 1967 and 1980. The effects of the refinements in 1967 can still be observed from the lack of large (stem-diameter classes 5, 6 and 7) and medium-sized trees (stem-diameter classes 3 and 4) in treatment 40 + 0 and 20 + 0 as compared with treatment 0. A further reduction in numbers of small trees (diameter class 2) can be seen in plots having been treated

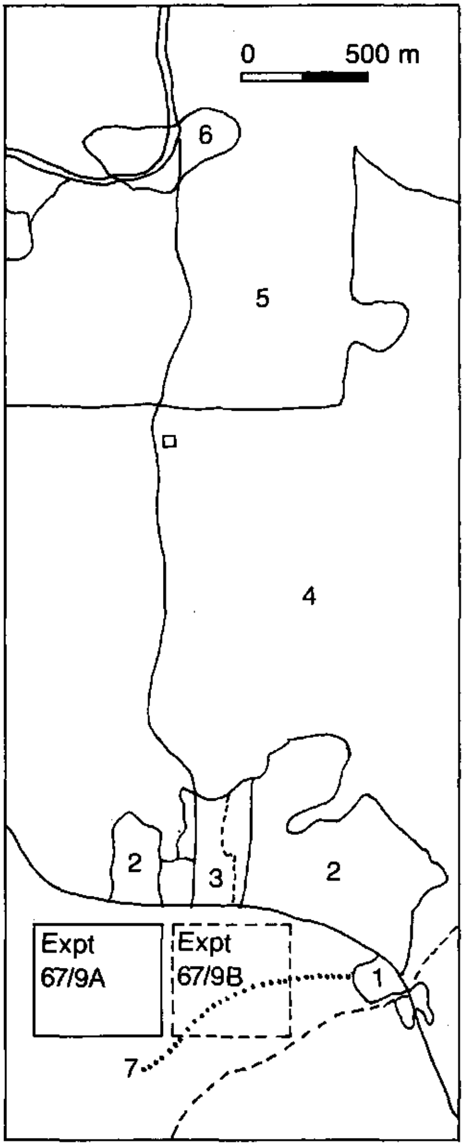


Fig. 7.3 Expt 67/9 A: lay-out of experimental area Mapane shown in the photograph in Fig. 7.2.

1. Camp site at the bridge over the Mapane river.
2. Area logged for the Weyerhaeuser Co pulpwood sample in 1969/70, and cleared afterwards for pine planting (small windrows left after burning).
3. Area logged for pulpwood (sub 2) but not cleared afterwards. Partially left as study area, partially opened up for strip planting.
4. Lightly exploited high forest on rolling terrain. Logging damage nearly unnoticeable.
5. Recently refined forest, previously lightly exploited. Here forest enrichment plantations will be established.
6. A patch of 'savanna forest' on a hillock of bleached sand.
7. (Dotted line) skidroad, crossing the area in which in 1975 the Expt 67/9 B was established.

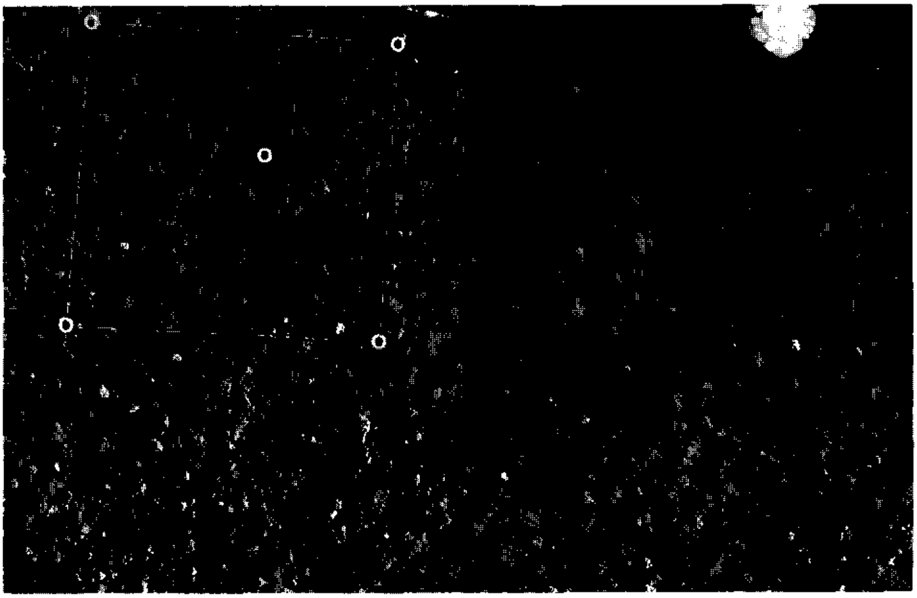


Fig. 7.4 Expt 67/9 A: aerial photograph of experimental area taken in 1982. Boundaries are indicated by white broken lines. Photo by courtesy of CBL, Suriname.

twice (40 + D 8 and 20 + D 8). Total number of trees is not indicative, and the number of trees in stem-diameter class 1 did not vary greatly between treatments (see Table 7.5). Treatment V had the least effect on stem-diameter distribution of all treatments, and most large and medium-sized trees have been retained, because in 1967 non-commercial trees only around the few medium-sized commercial trees were killed.

TABLE 7.5. Expt 67/9A: stem-diameter distribution (N/ha)* of all species under six selected treatment schedules in 1980

Treatment code	Area sampled (ha)	Diameter class**							Total
		1	2	3	4	5	6	7	
0	3.20	485	212	71	38	7.2	1.3	0.3	815
40+0	1.28	616	253	57	8.6	0.8	0	0	935
20+0	1.28	667	245	37	11	1.6	0	0	962
40+D8	0.64	539	122	24	22	1.6	0	1.6	709
20+D8	0.64	655	169	25	4.7	1.6	0	0	855
V	2.56	516	246	64	15	4.4	2.8	1.6	848

* Data obtained with angled caliper and Biltmore stick.

** Class 1, 5.0–14.9 cm dbh; class 2, 15.0–29.9 cm dbh; class 3, 30.0–44.9 cm dbh; class 4, 45.0–59.9 cm dbh; class 5, 60.0–74.9 cm dbh; class 6, 75.0–89.9 cm dbh; class 7, ≥90.0 cm dbh.

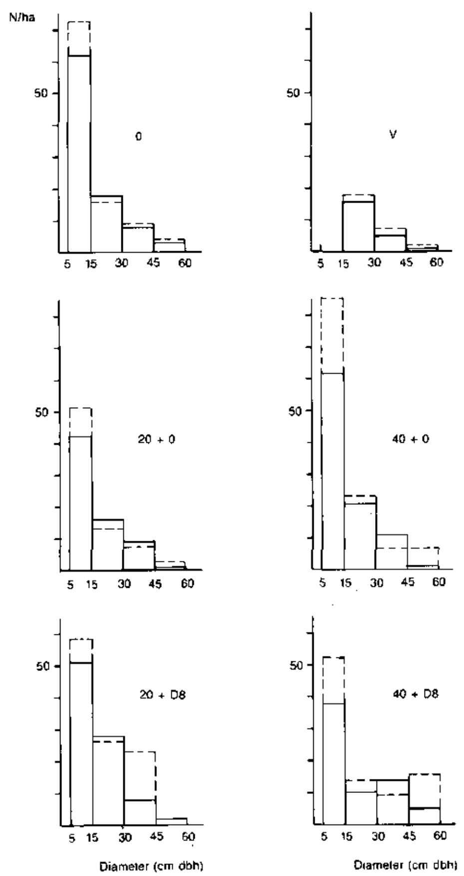


Fig. 7.5 Expt 67/9 A: stem-diameter distributions (N/ha) under six selected treatment schedules in 1968 (unbroken lines) and 1980 (broken lines), for commercial species 11-41 form class I.

The stem-diameter distribution in 1968 and 1980 of the commercial species under the six selected treatment schedules (Fig. 7.5), demonstrates the effect of the silvicultural treatments on the populations of commercial trees. Yet these graphs do not indicate the importance of large trees in the forest stand. The stem-diameter distribution for treatment 0 can be taken as the standard for the group of commercial species in lightly exploited mesophytic forest. With time, no conspicuous changes occurred in plots under treatment 0. Under treatment V, numbers increased in all classes recorded. Under treatment 20 + 0, possible recruitment induced by refinement was offset by the high mortality in later years (see Section 7.12). Under treatment 40 + 0 considerable recruitment occurred in class 1, and numbers in class 2 and 4 also increased. Under treatments 20 + D 8 and 40 + D 8 numbers increased, but not in each class, and some recruitment appeared in class 1. The entire population of class 4 under treatment 20 + D 8, being only one tree, was lost in the period 1978-1980.

In 1968, the plot under treatment 40 + D 8 had an unusual stem-diameter distribution, having very few trees in class 2 and many in class 3, compared with the stem-diameter distribution under treatment 0. This unusual distribution was due partly to the small area recorded, only 0.64 ha. The diameter distribution in 1980, with a large number of trees in class 4 was the result of successful treatment combined with the unusual abundance of trees in class 3 in 1968 (for more data, see Appendix VI).

7.9 Basal area

Total basal area developments under six selected treatments are given in Table 7.6, and in Figs 7.6-7.8. Changes over the years are indicated by smooth lines, whereas changes should be indicated by serrated lines, because of the mortality of large individuals in the relatively small plots. In Expt 67/2 total basal area of all species in lightly exploited forest did not return rapidly to pre-exploitation levels, and the same has been assumed for treatment 0 in this Expt 67/9A. Under the other treatments, the return to a high basal area was the more rapid the heavier the reduction had been. Increase in basal area was higher in plots under treatment 20 + 0 than in those under 40 + 0. In the period 1968-1976 this increase was about 10 m^2/ha, which is an annual increase of 1.25 m^2/ha. In the period 1976-1980 the annual increase was similar. In treatment 40 + 0, basal area did not change greatly after 1976, and the annual increase in the period 1968-1976 was only 0.4 m^2/ha. This difference in increment between treatments was related to a change in species composition and the vigour of the tree population. Under heavy treatments the tree population changed in composition to mainly soft secondary

TABLE 7.6 Expt 67/9A: development of estimated total basal area (m^2/ha) of trees ≥5 cm dbh of all species, under six treatment schedules

Treatment code	1967*	1968*	1975**		1976***		1978****	1980****
			before treatment	after treatment	Prism	Circular plot		
0	29	n.a.	n.a.	n.a.	n.a.	n.a.	31	29
40+0	29	17	n.a.	n.a.	21	20	19	21
20+0	29	7	n.a.	n.a.	20	18	18	20
40+D8	29	17	17	8	n.a.	n.a.	15	16
20+D8	29	7	16	5	n.a.	n.a.	12	15
V	29	21	n.a.	n.a.	n.a.	n.a.	n.a.	27

* Reconstructed from stem-diameter distribution in 1980 in treatment 0 and stem diameter limit for refinement (de Graaf, 1981).
** Based on 14% sampling with circular plots (von Meyenfeldt, 1975).
*** Data obtained using prism sampling and sampling with circular plots (Nieuwenhuis, 1977).
**** Data obtained using angled caliper and Biltmore Stick.

species with rapidly growing light wood, but in light treatments most of the original shadow-bearing tree population was retained.

Basal area of commercial species is one of the variables which were accurately determined throughout the entire experiment period. Basal area per diameter class was calculated from data from individual trees (girth in millimetres). The development in basal area of the commercial species in plots under treatment 40 + D 8 (Fig. 7.7) and 20 + D 8 (Fig. 7.8), shows a relatively slow increase. The development of basal area of commercial species under all six selected treatments is shown in Fig. 7.9 (see also Appendix VI). Treatment 40 + D 8 appears to have been optimal as regards rate of increment. In spite of its low starting value, because only trees above the 15 cm dbh limit were included, development under treatment V was also satisfactory. Such large trees are easily helped by liberation. However, just as in treatment 0, overall competition was high, because total basal area of all species was high. Small trees have difficulties in competing under such conditions, and thus only little recruitment is possible. Increment rate in treatment 0 was reasonably good, only that of 20 + 0 was lower. Basal area developments in this experiment compare favourably with those at Sarwa and Goliath in Expt 67/2.

Mean annual rate of increment for the period 1968-1980 is also given in Fig. 7.9. Extrapolation of these trends cannot be done without some indication of development in competition. The small plot area under treatment 20 + D 8 lost a large tree after 1978, but before 1978 trend in basal area increase was better than that under treatment 40 + D 8.

A better indication of the differences between treatments in this forest with decreasing stem-diameter distribution is given by volume and girth increment as discussed in following sections. The more intensive treatments as 20 + D 3 (see Table 7.1) have not been included in this discussion. As a result of intensive treatment, many small trees and saplings were established, which is comparable with what happened in Expt 65/3 as a result of intensive liberations. As mortality is high in such situations, total numbers decline when intensive treatments cease.

7.10 Bole volume

Developments in bole volume per stem-diameter class for the commercial species under the six selected treatments during the period 1968-1980 are presented in Fig. 7.10. This figure can be compared with the stem-diameter distributions shown in Fig. 7.5 (for more data, see Appendix VI). Productivity of the stand is indicated better from data on volume than on basal area growth or numbers of trees, even when these are given per stem-diameter class, but only timber in diameter class 4 and above is assumed to be saleable.

Under treatment 0 (Fig. 7.10) bole volume production occurred mainly in the highest diameter classes, as was the case in Expt 67/2. Under every treatment in Expt 67/9 A, the small trees contributed little to volume production (but were

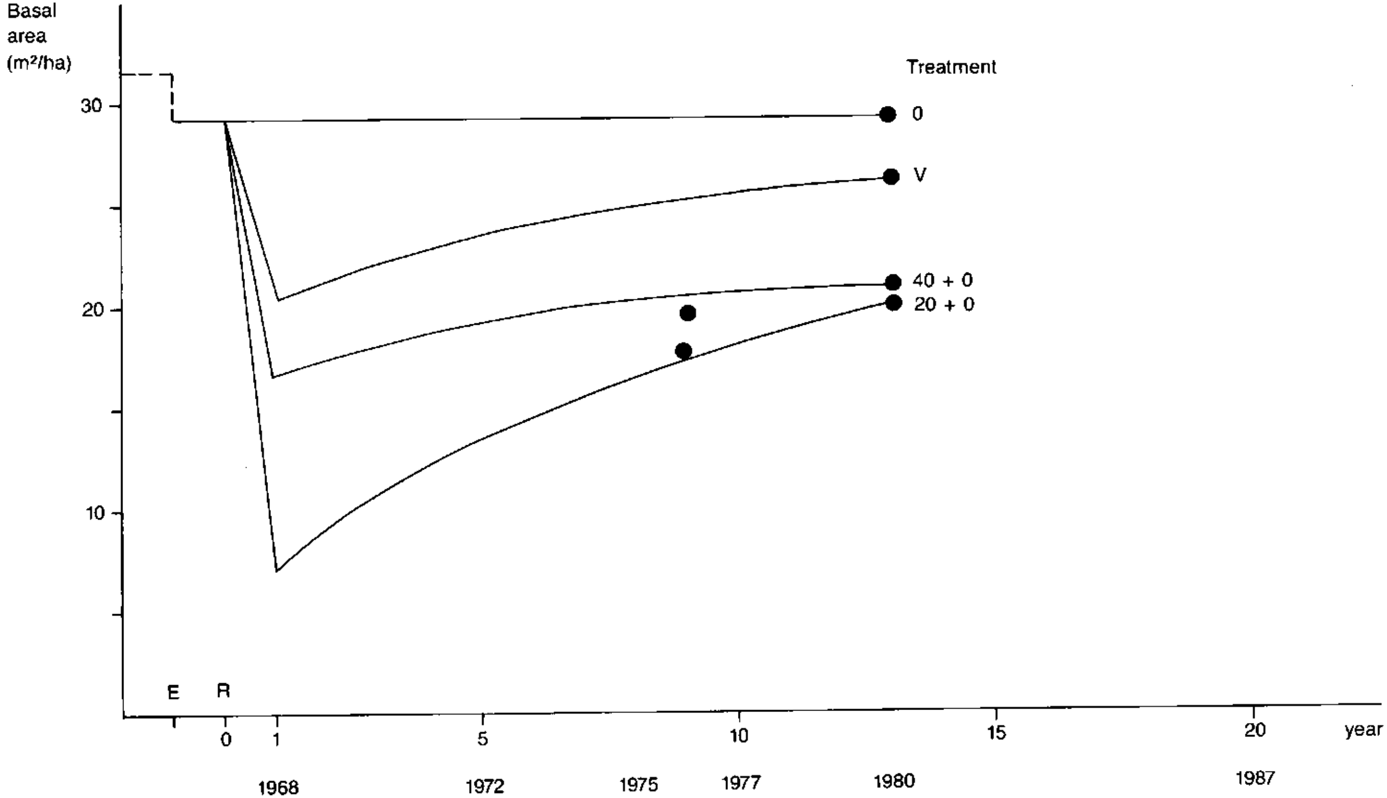


Fig. 7.6 Expt 67/9 A: development of total basal area under four treatment schedules: 0; V; 40 + 0; and 20 + 0. (For explanation of codes, see Table 7.1.)

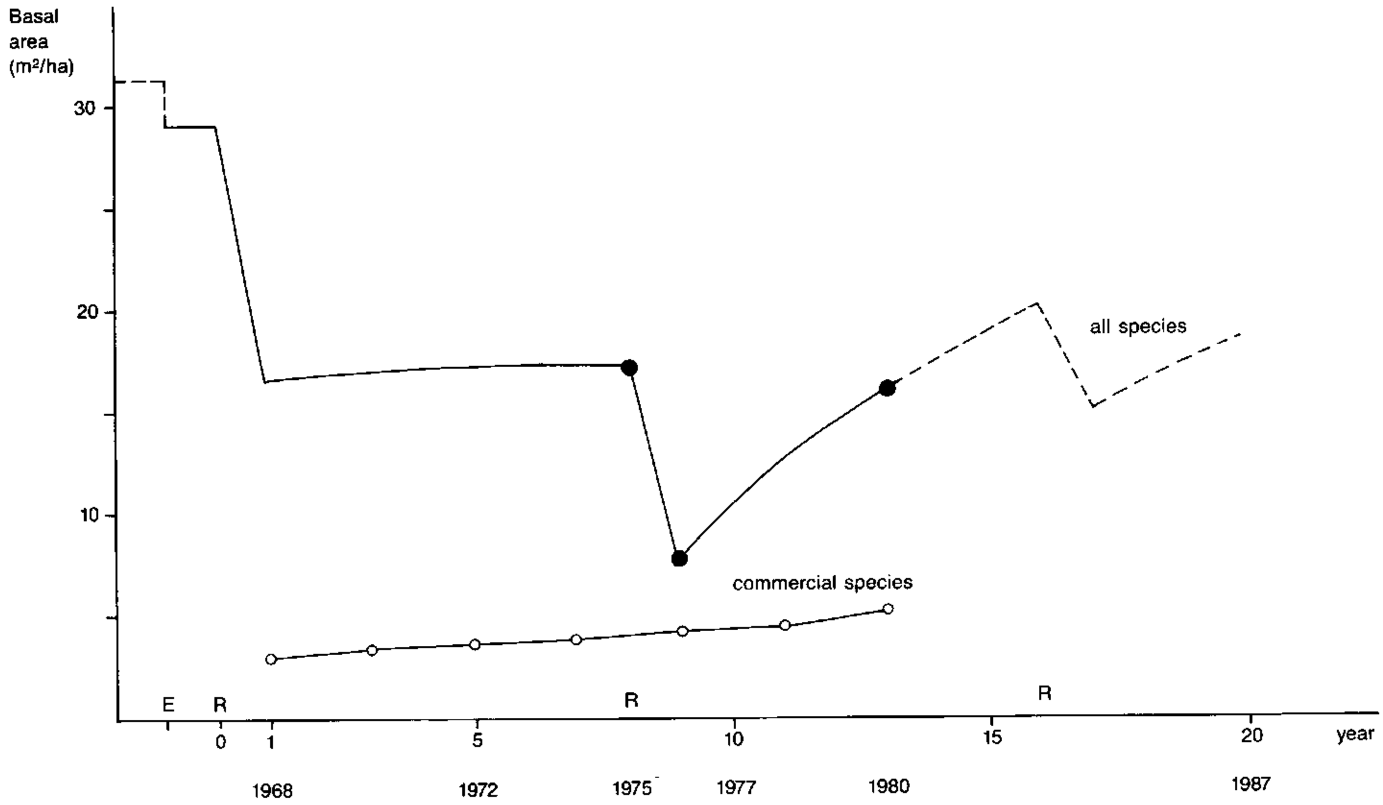


Fig. 7.7 Expt 67/9 A: development of total basal area under treatment schedule 40 + D 8, and development of basal area of commercial species 11-41 form class I.

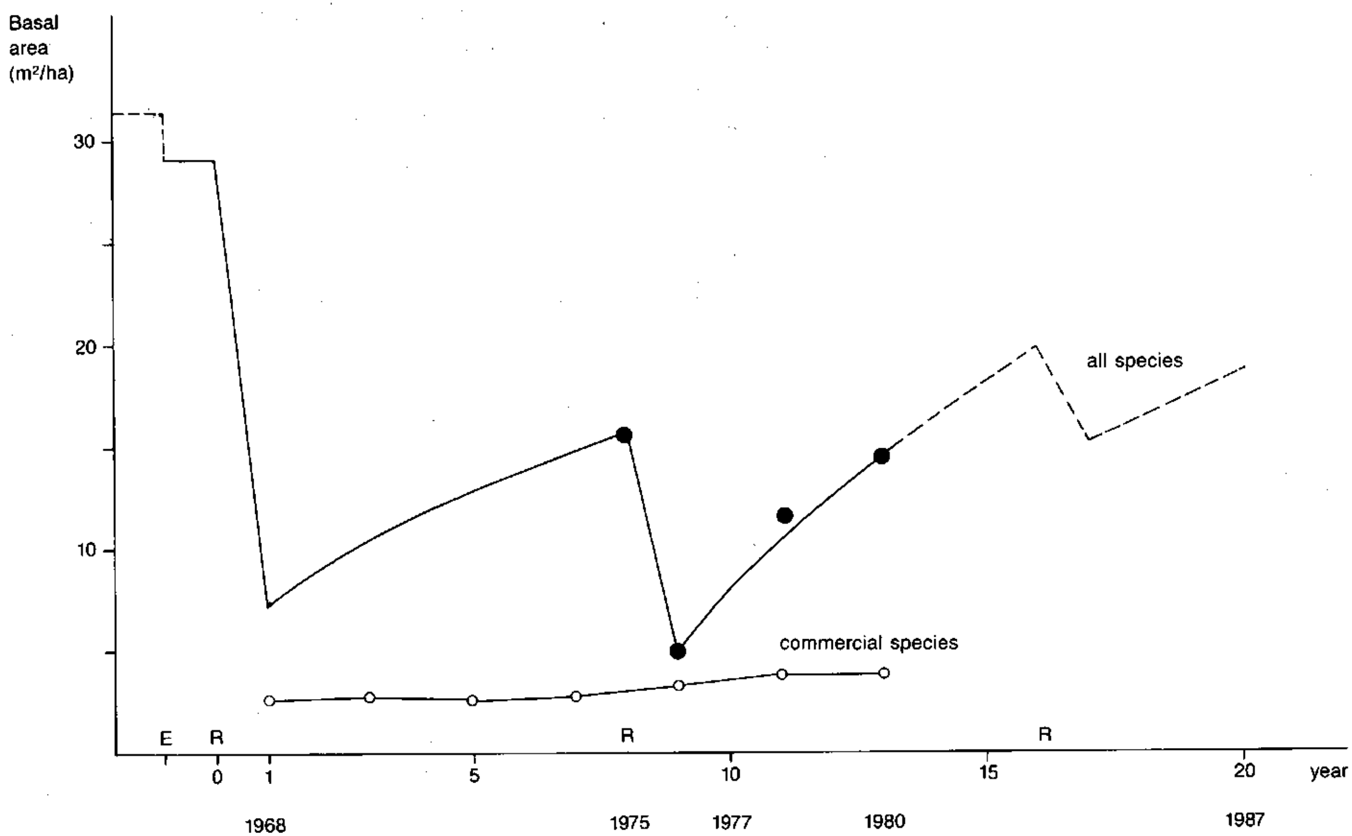


Fig. 7.8 Expt 67/9 A: development of total basal area under treatment schedule 20 + D 8, and development of basal area of commercial species 11-41 form class I.

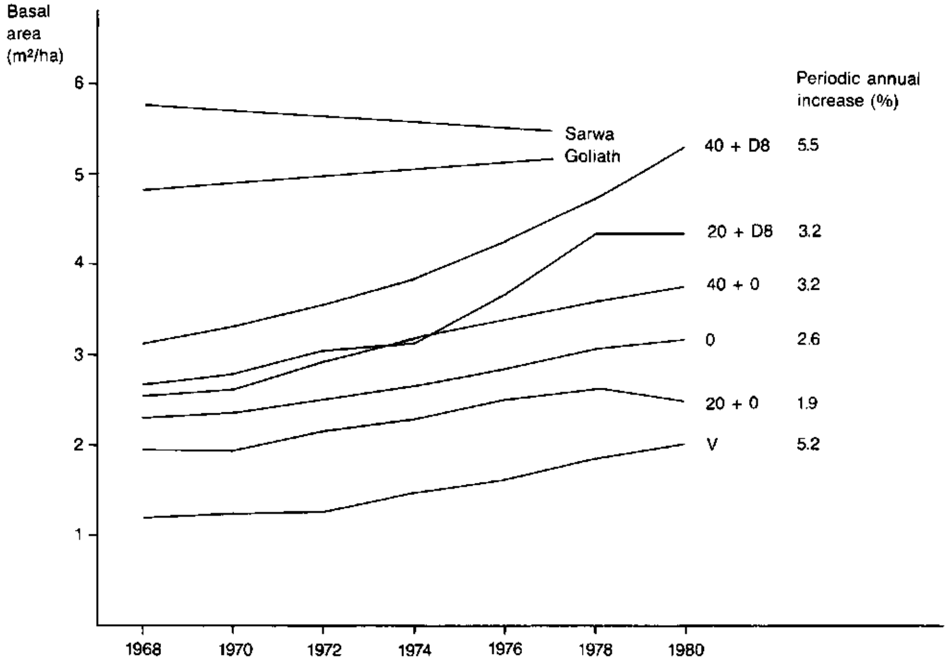


Fig. 7.9 Expt 67/9 A: development of basal area of commercial species 11-41 form class III (lower stem-diameter limit 5 cm dbh), under six selected treatment schedules. No false recruitment incorporated. Lower diameter limit for treatment schedule V differs, being 15 cm dbh. Data from Expt 67/2 at Sarwa and Goliath included for comparative purposes.

essential for recruitment to replenish the higher diameter classes). Under treatment V, volume increased in stem-diameter class 3 and 4, but volume production was no better than under treatment 0. Treatment 20 + 0 had a volume increment only in class 4, which in relation to the severity of the interference in 1967 was a minimal result. Under treatment 40 + 0, volume increased in class 4, but decreased in class 3. It may be assumed that during the 12-year period considered, many trees from class 3 passed into class 4 without being replaced by recruitment from class 2. In the plot under treatment 20 + D 8, volume increased in diameter class 3, but not in class 4, because of the death of the only large tree in this small plot. As girth increment studies (see Section 7.11) indicate a rapid and lasting growth in this treatment, it can be expected that in the near future many trees from class 3 will graduate to class 4, and thus ensure increasing volume production.

Under treatment 40 + D 8, volume production has been relatively large in the higher stem-diameter classes. About 30 m^3/ha has been produced in saleable dimensions during the 12-year period considered, more than 2 m^3/ha annually. The unusual diameter distribution in 1968, which has already been discussed, demonstrates that the largest trees have the best timber production, especially when growth is stimulated by silvicultural measures. As treatment of this plot in 1975 helped both large and small trees, in coming years larger volumes can also be

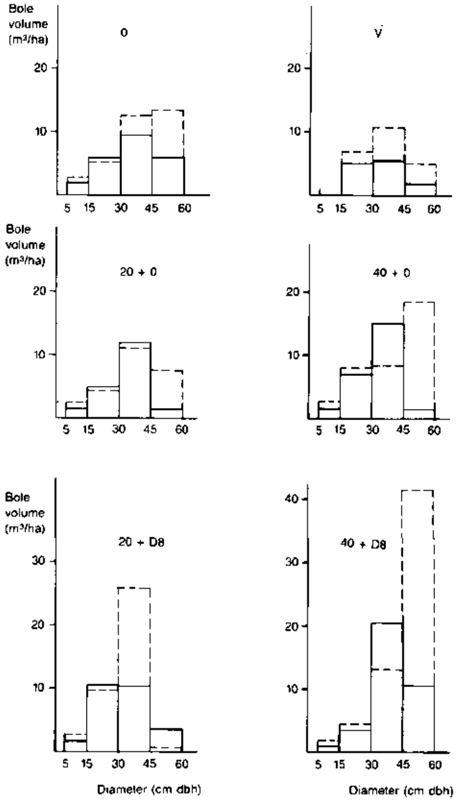


Fig. 7.10 Expt 67/9 A: bole volume (m^3/ha) per diameter class under six selected treatment schedules in 1968 (unbroken lines) and 1980 (broken lines), for commercial species 11-41 form class I.

expected in the lower diameter classes, which until now were less than satisfactory, compared with those under treatments 20 + D 8 and 0.

Bole volume increment of commercial species under six selected treatments during the periods 1968-1974 and 1974-1980 showed a remarkable increase (see Table 7.7). These data support the saying that 'timber grows on timber'. With improved stocking, and more specifically, with increased size of trees in the stand, volume production increases, until competition has reached a level so high that individual volume increment must decrease in most trees. In both periods volume increment increased most under treatment 40 + D 8. In the period 1974-1980, also under 20 + D 8 production was good, after a bad start in the first period. Plots under treatment 0 were better stocked than those under treatment 20 + 0 in the first period 1968-1974, and this, together with the high mortality under treatment 20 + 0, explains why the plots under treatment 0 do so well, compared with the plots under treatment 20 + 0, as indicated in Table 7.7. This trend of relatively high production under treatment 0 is not expected to continue in this type of forest stand with very high internal competition.

Although cheap volume production of quality timber is an important goal of management in production forest, volume production is not the best and most

TABLE 7.7 Expt 67/9A: development of bole volume increment (m³/ha) of commercial species 11-41, form class I, ≥5 cm dbh, under six treatment schedules

Treatment code	1968–1974		1974–1980	
	Total	Annual	Total	Annual
0	1.7	0.3	6.9	1.2
40+0	3.2	0.5	8.0	1.3
20+0	1.5	0.3	4.3	0.7
40+D8	9.1	1.5	16.4	2.7
20+D8	1.2	0.2	11.2	1.9
V*	1.7	0.3	7.3	1.2

* Lower diameter limit 15 cm dbh.

decisive variable on which to compare treatments in this experiment. The relatively small size of the plots, and the small population of commercial species make the volume production data susceptible to bias from factors such as erratic stocking and mortality of large commercial trees. As these disturbances have less effect on mean girth increment, this has become an important parameter in determining the success of a treatment scheme (see Section 7.11).

The bole volume distributions for all species in 1980 are given in Table 7.8. Volumes have been estimated with the aid of the bole volume tariff in Appendix VII. Of the six treatments in 1980, plots under the two most intensive treatments 40 + D 8 and 20 + D 8 had the lowest total volume (Table 7.8). Reductions in volume per stem-diameter class are also demonstrated. Also, variations in the original forest may have affected stem-diameter distributions, for example plots under treatment V had higher volume in the highest stem-diameter classes than those under treatment 0.

The changes in volume distribution of commercial species 11-41 form class I, and

TABLE 7.8 Expt 67/9A: estimated bole volume (m³/ha) in 1980 of all species under six treatment schedules

Treatment code	Diameter class*							Total
	1	2	3	4	5	6	7	
0	19	69	90	93	32	8	3	314
40+0	23	84	69	23	3	0	0	202
20+0	26	79	44	28	8	0	0	185
40+D8	19	35	30	56	8	0	13	161
20+D8	24	55	29	11	7	0	0	126
V	20	78	80	40	20	18	17	273

* See Table 7.5.

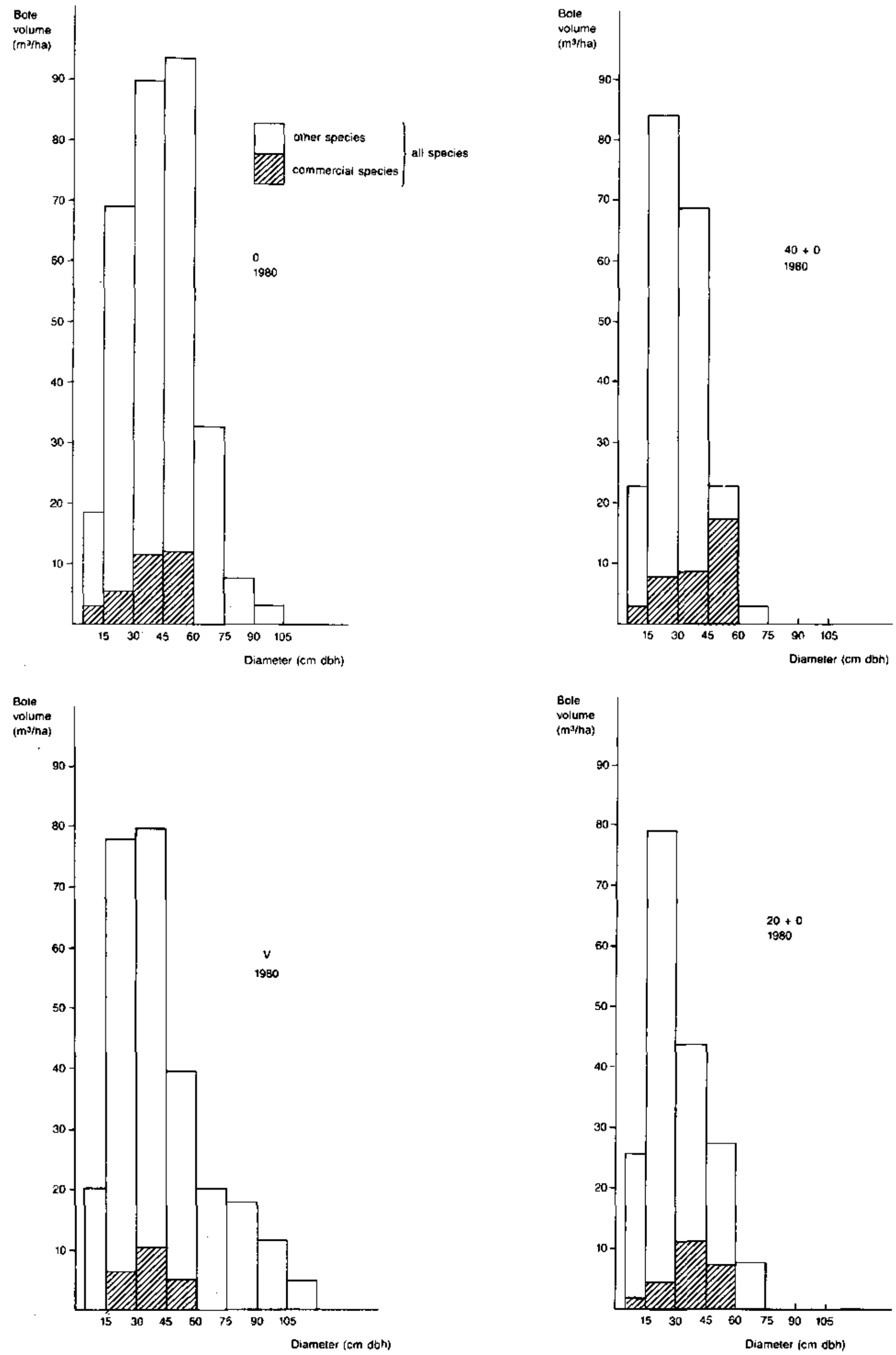
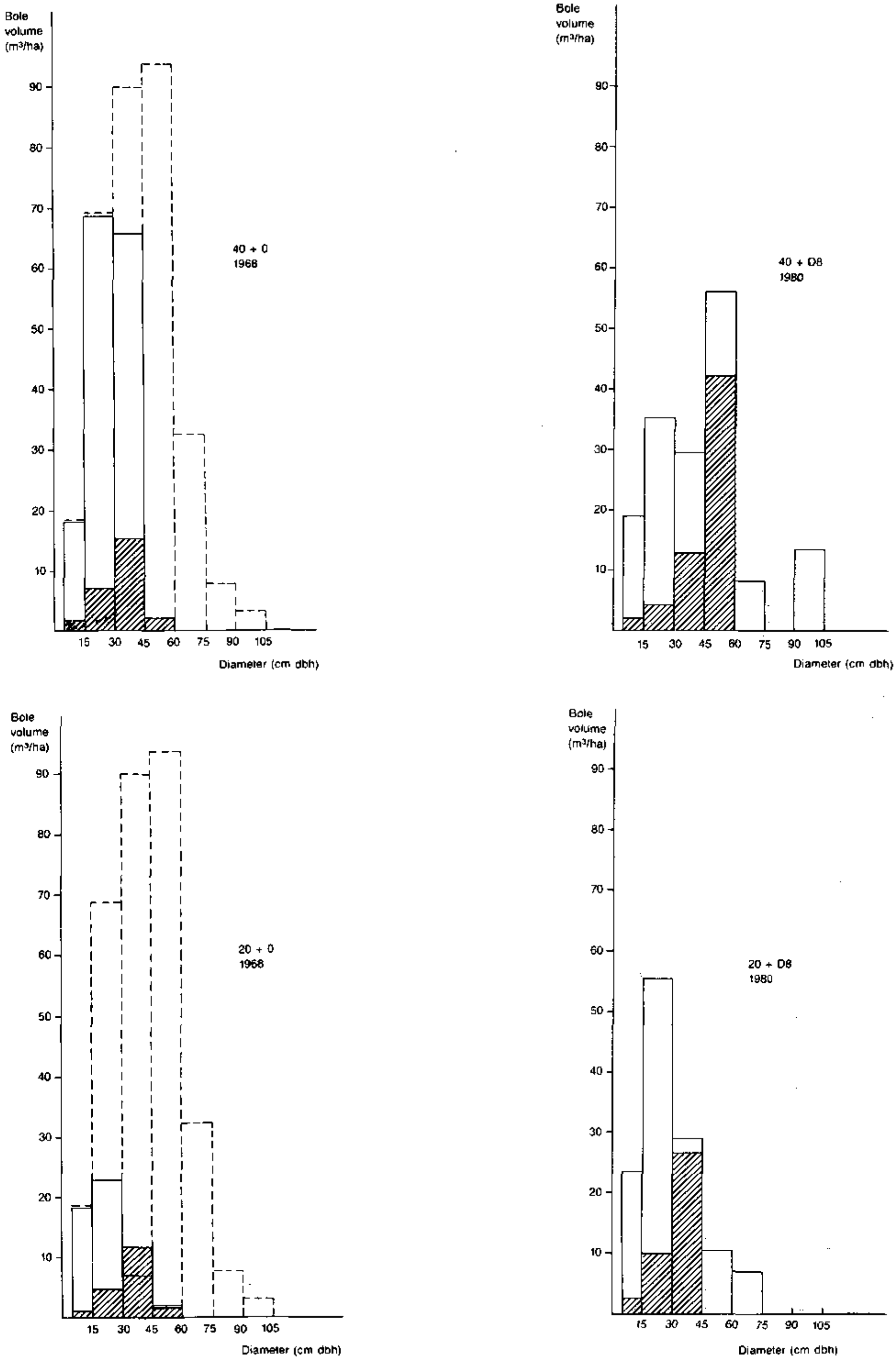


Fig. 7.11 Expt 67/9 A: bole volume (m^3/ha) per diameter class in 1980 under six selected treatment schedules and under two treatment schedules in 1968. Hatched parts of columns, commercial



species 11-41 form class I; and unhatched parts of columns, all other trees. Broken lines indicate that data have been reconstructed (see Table 7.8 and Appendix VI for numerical data).

of all species under the six treatments are presented in Fig. 7.11. The data for commercial species are the same as used in Fig. 7.10. Plots under treatment 0 are assumed not to have changed in volume distribution since 1968. The stand under this treatment had a small proportion of commercial species, which changed very little throughout the 12-year observation period. In 1980, in plots under treatment 40 + 0 the lack of large non-commercial trees as a result of the light refinement in 1967 was only partly obscured by regrowth. As the stem-diameter limit for refinement was 40 cm dbh, some non-commercial volume in diameter class 3 (30.0-44.9 cm) was left in 1967. Class 2 benefited from the refinement, as did trees in class 4, mostly commercial species.

Data for plots under treatment V in 1980 reflect the limited interference to liberate individual medium-sized and larger trees of commercial species in 1967. From the beginning there must have been more large trees (stem-diameter classes 6, 7 and 8) in these plots than in those under treatment 0. Treatment V seems to have affected mainly stem-diameter class 3 and 4.

In 1980, plots under treatment 20 + 0 still showed signs of the effect of the heavy refinement in 1967 (see Fig. 7.11). The limit for refinement was 20 cm dbh, and most trees of non-commercial species in and above diameter class 2 were killed. However, by 1980 the volume of non-commercial species had increased considerably. Most trees were fast-growing secondary species with light wood. The high non-commercial volume in stem-diameter class 4 and 5 was composed mainly of badly formed stems of species 11-41, all individuals of species 42-58, and also the very few trees of the real non-commercial species surviving the refinement. Even with the high growth rates here, these large stem diameters cannot be attained within 12 years.

The two graphs in Fig. 7.11 for treatments 40 + 0 in 1968 and 20 + 0 in 1968 are reconstructions which show the vast quantity of bole wood killed by the refinements, especially under treatment 20 + 0. Under treatment 40 + 0 about 160 m^3 stem volume was killed, that is almost half of the total. This corresponds with half the living biomass including branches, leaves, and roots. Yet this can be considered to be a light treatment according to its effects on the girth increment and volume production.

Under treatment 20 + 0 about 260 m^3/ha bole volume was killed in 1967 by refinement, leaving only 50 m^3/ha standing alive, of which about 20 m^3 was considered to be commercial volume. The 260 m^3 killed represents about five-sixths of the original volume, corresponding to five-sixths of total biomass including branches, leaves, and roots. This was a heavy treatment and affected the forest greatly. The forceful opening of the upper storeys induced abundant regeneration of secondary tree species mixed with the original surviving undergrowth. This treatment can be compared with the lightest treatment given in Expt 65/3 (Section 5.5).

Bole volume in treatment 40 + D 8 in 1980 (Fig. 7.11) shows the effect of only two interferences, initial refinement in 1967 and second refinement (liberation) in 1975. Commercial species 11-41 form class I account for more than one-third of the total volume. The situation is even more favourable when the species list is extended to species 11-58, which were saved in this stand in the second interference in 1975. At refinement in 1967, the restricted list of commercial species was used (species 11-41 form class III), but the high diameter limit for refinement saved many future commercial species not then listed. The treatment in 1975, making use of a filler tree system, (von Meyenfeldt, 1975) cannot be quantified in volume remaining, but only in total basal area remaining, as data on diameter distribution are insufficient for detailed estimates. However, from Fig. 7.11 it would seem that many trees of non-commercial species in stem-diameter classes 1, 2 and 3 must have been killed, but the vigorous regrowth obscures the extent.

The plot under treatment 20 + D 8 in 1980 was also very promising for future growth. Roughly one-third of the volume was commercial, but as with treatment 40 + D 8, much of the non-commercial volume contained valuable species which were added to the list later. As there were fewer large and dominating trees of commercial species under treatment 20 + D 8 in 1980, this stand may suffer more when neglected in the future than will the stand under treatment 40 + D 8 with a high proportion of large productive commercial species. Trees of non-commercial species in diameter class 2 will hinder commercial species in class 3 in the plot under treatment 20 + D 8, and will certainly be able to suppress trees in lower stem-diameter classes.

Bole volume of trees killed in refinement and volume increment of all species over the 12-year period for treatments 40 + 0 and 20 + 0 are given in Table 7.9. In treatment 20 + 0, annual increment was almost three times that under treatment 40 + D 8. This difference can be explained by the more vigorous regrowth of secondary species in the heavily treated 20 + 0 plots and the lower specific gravity of these species. Expressed in dry weight the differences in production between plots would be less, but still considerable. The reasons for these differences are the better conditions regarding light and water, and reduced root competition under treatment 20 + 0, and also the nutrient content of the biomass killed. The volume production given in Table 7.9 is only a rough indication of maximum productivity in moderately disturbed (treatment 40 + 0) and heavily disturbed (treatment 20 + 0) forest stands, but demonstrates that volume increment will decrease as biomass builds up and competes for nutrients and space.

TABLE 7.9 Expt 67/9A: development of estimated bole volume (m^3/ha) for all species above 5 cm dbh under two treatment schedules

Treatment code	Bole volume			Increment	
	1967 before refinement	1968 after refinement	1980	Total 1968–1980	Mean annual
40+0	314	154	202	48	4
20+0	314	54	185	131	11

7.11 Periodic annual increment of girth

Development of girth increment during the period of the experiment under six selected treatments, for trees of form class I of a group of four commercial species is shown in Fig. 7.12 and Table 7.10. This group was selected because it is well represented in all treatments, and because its numbers were not affected very much by intensive treatments. The usual group of commercial species 11-41 contains a number of secondary species, which only establish in heavily opened forest. Because of their very rapid growth, these soon penetrate the lower diameter classes, and with their rapid girth increment would create a bias in girth increment. However, the actual differences are small. (These species have been included in comparisons of volume increment). The number of trees in the sample is not as

TABLE 7.10 Expt 67/9A: development of periodic annual increment of girth (mm/y) for a group of four commercial timber species (11, 37, 40, and 24–28) under six treatment schedules

Treatment code	Diameter class*	Period**					
		I	II	III	IV	V	VI
0	1	9	7	6	8	5	4
	2	12	11	13	14	11	13
	3	11	9	14	15	12	23
	4	8	14	18	18	16	16
40 + 0	1	13	14	12	10	7	5
	2	19	19	22	24	21	17
	3	24	26	26	17	18	23
	4	n.a.	n.a.	n.a.	19	19	22
20 + 0	1	20	19	15	7	4	4
	2	25	28	36	27	13	10
	3	29	20	27	19	20	15
40 + D8	1	11	10	10	21	31	21
	2	19	15	13	23	29	(36)†
	3	25	18	21	22	29	32
20 + D8	1	20	21	21	25	28	20
	2	30	34	35	40	38	35
	3	n.a.	(30)	33	29	33	34
V	1	n.a.	n.a.	n.a.	n.a.	n.a.	10
	2	21	27	25	24	20	18
	3	20	20	27	28	23	24

* See Table 7.5.

** Period I, June 1968–July 1970; period II, July 1970–July 1972; period III, July 1972–July 1974; period IV, July 1974–July 1976; period V, July 1976–June 1978; period VI, June 1978–June 1980.

† Data between parentheses are from samples with less than five trees.

important for girth increment as it is for volume production but five trees per stem-diameter class were considered to be the minimum to obtain a reliable mean. Fast growing and also slow growing or even stagnating individuals were included but form had to be good.

In all treatment plots girth increment before 1967 is assumed to have been similar to that in plots under treatment 0. Girth increment under treatment 0 varied slightly during the period of observation (see Fig. 7.12). The downward trend in stem-diameter class 1 is mainly the result of the low value in the last period (1978-1980), which had one quite dry season. The mean annual girth increment in diameter classes 1 and 2 was 7 mm and 12 mm respectively. For diameter class 2 this is similar to the increment in the same diameter class in Expt 67/2 where exploitation was much heavier (see Chapter 6).

Under treatment V, girth increment in diameter class 2 has been promoted by the individual liberation treatment in 1967. It was some years before the maximum effect was achieved, and thereafter increment decreased slowly. The mean girth increment was about 22 mm, which is considerably less than attained under the optimum treatment for such trees.

A similar delay in response to refinement was observed in plots under treatment 40 + 0, but in diameter class 2 the peak value was reached later than it was reached in treatment V. The reaction in class 1 was not spectacular, and girth increment returned to the levels of treatment 0 in subsequent years. This light refinement did not aid these small trees greatly. Under all these six treatments girth increment initially increased more slowly in stem-diameter class 2 than in class 1, which achieved maximum increase immediately after treatment and thereafter slowed down. Probably they were overtaken by larger trees in diameter class 2, or passed into diameter class 2 because of their rapid growth.

Girth increment in the plots under treatment 20 + 0 changed very much. A mean value over the full 12-year period would have given far less information than the graph in Fig. 7.12 in which the period has been split into six two-year periods. Reactions to treatment were strong, even in the chosen group of four species, all species of 'undisturbed forest'. In period VI, 1978-1980, competition must be have been almost as high as under treatment 0, but total basal area was not as high as in that treatment. In the future, some individuals will continue to grow well, but the stand as a whole will stagnate, commercial volume production will be low, and mortality high.

Under treatment 40 + D 8, during the first three periods periodic annual girth increment was similar to that in plots under treatment 40 + 0. It was not identical, presumably because of differences between plots, for example in number of trees per species in the group selected, or perhaps a somewhat higher total basal area after refinement in 1967. In treatment 40 + D 8 the area recorded was only 0.64 ha, while under treatment 40 + 0 the recorded area was twice as large, a duplicate plot being available. On the basis of girth increment during the first six years, production was not optimal. The actual volume produced was reasonable, but was biased by the aberrant diameter distribution in this plot. The second

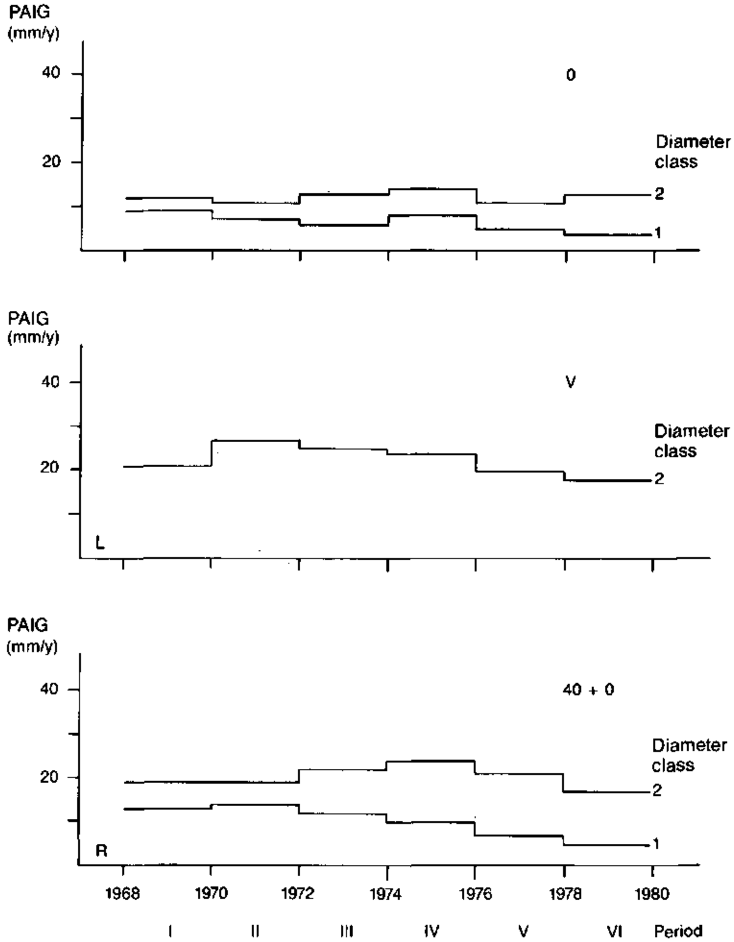
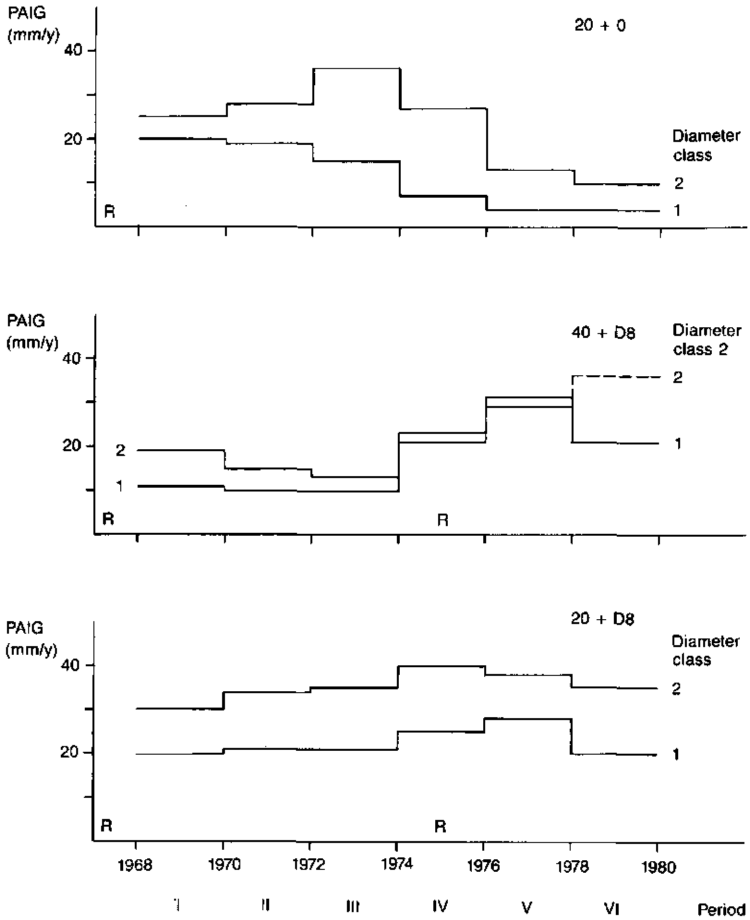


Fig. 7.12 Expt 67/9 A: development of periodic annual increment of girth (PAIG) in mm/y, for two diameter classes under six selected treatment schedules in six 2-year periods (I-VI) for a group of four commercial species, 11, 24-28, 37 and 40, all of form class I; diameter class 1, 5.0-14.9 cm dbh, and diameter class 2, 15.0-29.9 cm dbh. ⟶

silvicultural interference in 1975 with a quite heavy filler tree system treatment (von Meyenfeldt, 1975) resulted in a considerable increase in girth increment in the subsequent two periods. Thereafter girth increment decreased in trees in stem-diameter class 1, to be followed in due course by a similar future decrease in class 2.

The rapid decrease in girth increment in diameter class 1 was not only caused by increasing competition, but also by promotion of the best growing individuals to class 2, especially in periods of very good increment. This effect is less if wider diameter class limits are set and the observation period is shorter. In small populations, not having a 'normal' distribution within diameter classes (normal meaning following a decreasing rate) the effect is more erratic than in large



populations. For the indications derived in this section, this promotion effect is not important.

The plot under treatment 20 + D 8 was treated again in 1975, just in time to maintain girth increment at a high level. This treatment is considered optimal, because girth increment is closely related to volume production. However, other factors, such as the original stem-diameter distribution, stem quality, species composition and mortality rates also contribute to optimum production at a low cost.

In plots under the more intensive treatment schedules (see Table 7.11), girth increment was high, and similar to that in Expt 65/3. Most of these treatments are unnecessary to maintain good growth of saplings and small trees, but they stimulate recruitment. The plots under these intensive treatments were not recorded before first liberation in the third or fifth year. Data came from small populations, making irregularities more probable. The treatment applied in 1975 during period IV was not intensive, because these plots were treated intensively in 1970 and 1972. Also, maintaining a closed canopy was given precedence in 1975 to promotion

TABLE 7.11 Expt 67/9A: development of periodic annual increment of girth (mm/y) for a group of four commercial timber species (11, 37, 40 and 24–28) under four treatment schedules

Treatment code	Diameter class*	Period**					
		I	II	III	IV	V	VI
20+D3	1	n.a.	24	34	31	36	21
	2	n.a.	33	30	26	20	6
20+D5	1	n.a.	n.a.	(36)†	40	45	41
	2	n.a.	n.a.	30	32	43	28
40+D3	1	n.a.	38	40	43	32	22
	2	n.a.	41	31	29	21	14
40+D5	1	n.a.	n.a.	29	28	31	31
	2	n.a.	n.a.	25	26	23	13

* See Table 7.5.
** See Table 7.10.
† See Table 7.10.

of girth increment and recruitment. The intensity of treatment can be observed in the aerial photographs (Figs 7.2 and 7.4). The only light treatment in 1975, mostly liana cutting and no killing of trees, resulted in a decrease in growth in period VI (1978-1980; see Table 7.11).

It is concluded that girth increment reacts rapidly and strongly to treatment of the stand. This results in changes in the stand table, but these are only discernible after longer periods. In practice, periodic inventories only monitor changes in stand table and the underlying processes remain difficult to follow. A mean girth increment over a period of ten years or more is often meaningless, and the reasons for success of a certain treatment cannot be given in terms of changes in total basal area alone.

Development in periodic annual girth increment for the group of four commercial species shown as the relationship between girth increment and stem-diameter is given in Fig. 7.13. The downward trend in girth increment in the highest diameter classes may be caused by insufficient sampling of trees in these classes. This trend is not found in the girth increments of the large population of the area of 16 ha recorded in Expt 67/9 B.

Under treatment 0, girth increment in the higher diameter classes increased with time in the first four periods. In period V the increment declined, but in period VI it increased sharply. This presumably is the result of some trees in plot 8 reacting favourably to a gap formed just before and during this period. This gap does not show up on the aerial photographs of 1982 but it is located south of the soil pit (see also Appendix VI), and for some years to come will be marked on the ground by fallen trees. Growth increment in small trees did not change very much, because the effect was very local, and the population of small trees was dispersed over the whole area.

Under treatment V trees below the 15 cm dbh limit were recorded only during

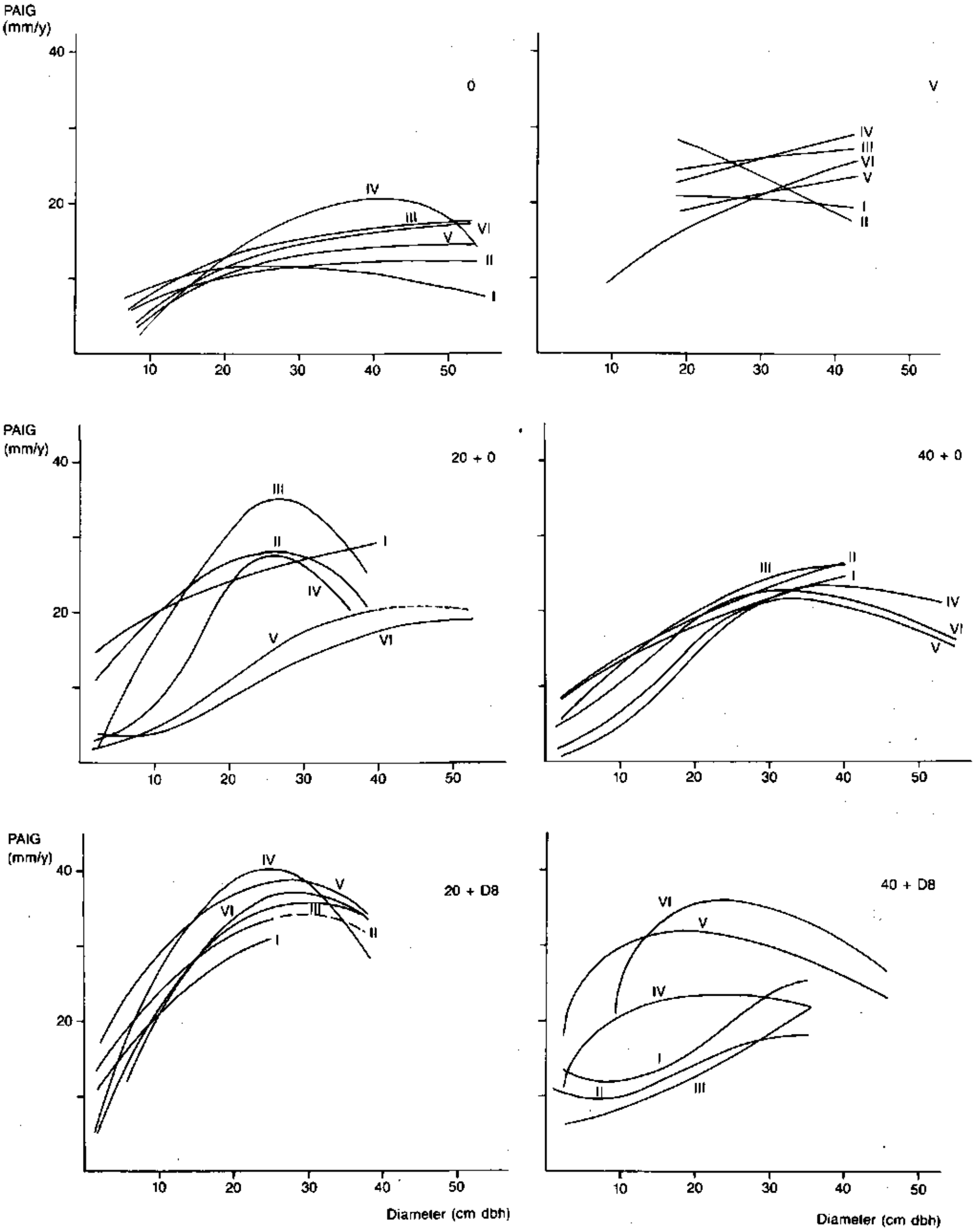


Fig. 7.13 Expt 67/9 A: periodic annual increment of girth (PAIG) in mm/y, per diameter class, under six selected treatment schedules, in six 2-year periods (I-VI), for a group of four commercial species, 11, 24-28, 37 and 40, all of form class I.

the sixth period. Increment rate did not vary greatly over the periods, although an initial rise was followed by a decrease in the last two periods.

Under treatment 40 + 0, increment increased slightly during the period of observation, and was higher than under treatment 0. The refinement in 1967 does not seem to have had as much effect as the refinement in plots under treatment 20 + 0, where large variations in increment were observed. A general trend could be observed of an initial rapid increase in girth increment in the smaller trees followed by a decline, whereas in the larger trees there was continuous increase. For trees of about 15 cm dbh there was no change in girth increment during the first three periods. The trend continued throughout the observation period, with stem-diameter limit for decline in girth increment increasing with increasing years, until finally (period VI) the increment under treatment 20 + 0 for the smallest trees was less than under treatment 0, and increment for all diameter classes took values below that of treatment 40 + 0. This stagnation at a relatively low basal area of about 18-20 m^2/ha may be explained by the close stand of the many young trees under treatment 20 + 0, with none of the usual gaps as under treatment 0. Total basal area composed of many small and mostly young trees is not comparable with total basal area composed of trees of varying age, and with a wide range of stem diameters.

Girth increment under treatment 40 + D 8 varied considerably throughout the period of observation, mainly as a result of the liberation in 1975. The unusual shape of some of the curves may be explained by the very restricted sample of trees, especially in the larger diameter classes. For other treatments (20 + 0, 40 + 0)

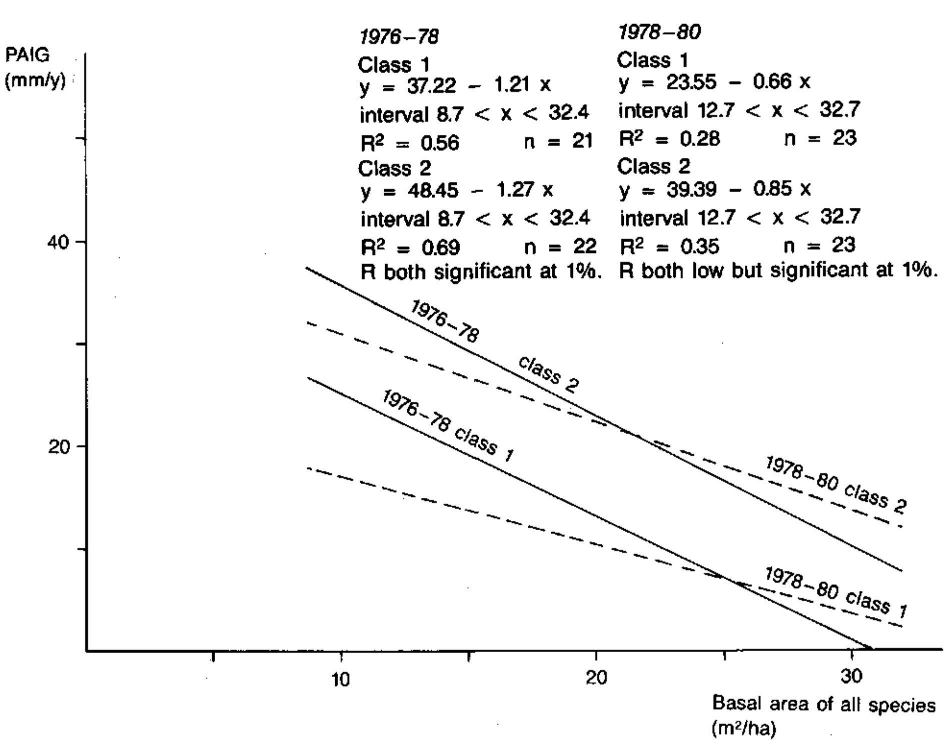


Fig. 7.14 Expt 67/9 A: regression of periodic annual increment of girth (PAIG) in mm/y on total basal area in 1978, for a group of four commercial species, 11, 24-28, 37 and 40, all of form class I, in two diameter classes (see Fig. 7.12). Girth increment periods 1976-1978 and 1978-1980.

TABLE 7.12 Expt 67/9A: statistical test of significancy of differences in periodic annual increment of girth (PAIG) for a group of four commercial timber species (11, 24–28, 37, and 40), form class I, in two diameter classes, under six treatment schedules in the period 1976–78

Treatment code	PAIG observations per plot (mm/y)											
	Diameter class 1 (5.0–14.9 cm dbh)					Mean	Diameter class 2 (15.0–29.9 cm dbh)					Mean
0	6	4	3	5	4	4.4	11	11	7	18	13	12.0
V			n.a.			n.a.	18	19	25	18		20.0
40+0	7	8				7.5	18	23				20.5
20+0	5	3				4.0	n.a.	14				14.0
40+D8	31					31.0	29					29.0
20+D8	28					28.0	38					38.0

Analysis of variance

SV	Diameter class 1					Diameter class 2				
	DF	SS	MS	F	P	DF	SS	MS	F	P
Between treatments	5	361.19	72.24	5.23	<0.025	4	1 003.03	250.76	195.9	<0.01
Within treatments	8	110.5	$s^2 = 13.81$			6	7.7	$s^2 = 1.28$		
Total	13					10				

Null hypothesis of no difference between treatments rejected.

there was a less conspicuous change in the shape of the curve from concave to convex in the lower diameter classes.

Finally, under treatment 20 + D 8 girth increment curves were similar to those under 40 + 0, but with a higher level of increment. Both small and large trees appear to have benefited from the treatments, and the stabilization of the curves over the years, expressed in the grouping of the curves, may indicate a stabilization of processes in the stand, but on a higher level of increment than for example under treatments 40 + 0 and 0.

Under an optimum treatment schedule, in the lower diameter classes rapid growth would promote strong individuals to subsequent classes, but at the same time these lower classes would be supplemented with recruitment. Without a future third liberation treatment, girth increment under all treatment regimes may become similar to that under treatment 0 or even treatment 20 + 0.

Data on periodic annual increment of girth per recording plot in the period 1976-1978 in stem-diameter classes 1 and 2 were subjected to an analysis of variance for groups with unequal replication (see also Steel and Torrie, 1981). This was done to give an example. In both diameter classes, differences between treatments were found to be statistically significant (Table 7.12). Further testing did not add more information than that already derived from the foregoing discussion.

Girth increment and total basal area data per plot (see Appendix VI) were used to determine the linear regression of periodic increment of girth on total basal area (Fig. 7.14). Regression lines for diameter class 1 and 2 have similar slopes for the same period, but slopes change with time elapsed after silvicultural treatment reduced total basal area. Also, the coefficients of determination decrease with time. The differing intercepts of the regression lines for the respective diameter classes indicate that large trees have a better girth increment rate than small trees for the same total basal area values.

An increase of regression coefficients with time to less negative values was also found in Expt 65/3, and seems to be less pronounced in uneven-aged stands with a wide range in age and stem diameters than in more even-aged stands. Heavy competition in even-aged stands results in rapid differentiation between large and small trees, until finally the stand becomes more similar to uneven-aged stands such as found in Expt 67/9 A under light treatment, and in undisturbed forest. Increase of the regression coefficient to a zero value is not plausible, because this indicates no effect of total basal area on girth increment.

7.12 Mortality

Annual mortality rate of commercial species 11-41 form class I under the six selected treatment schedules is presented in Table 7.13. The proportion of trees eliminated from form class I because of degradation of form, mainly as a result of mutilation by falling dead timber of trees killed in refinement, has not been included. The mortality rates for commercial species 11, 24-28, 37 and 40 form

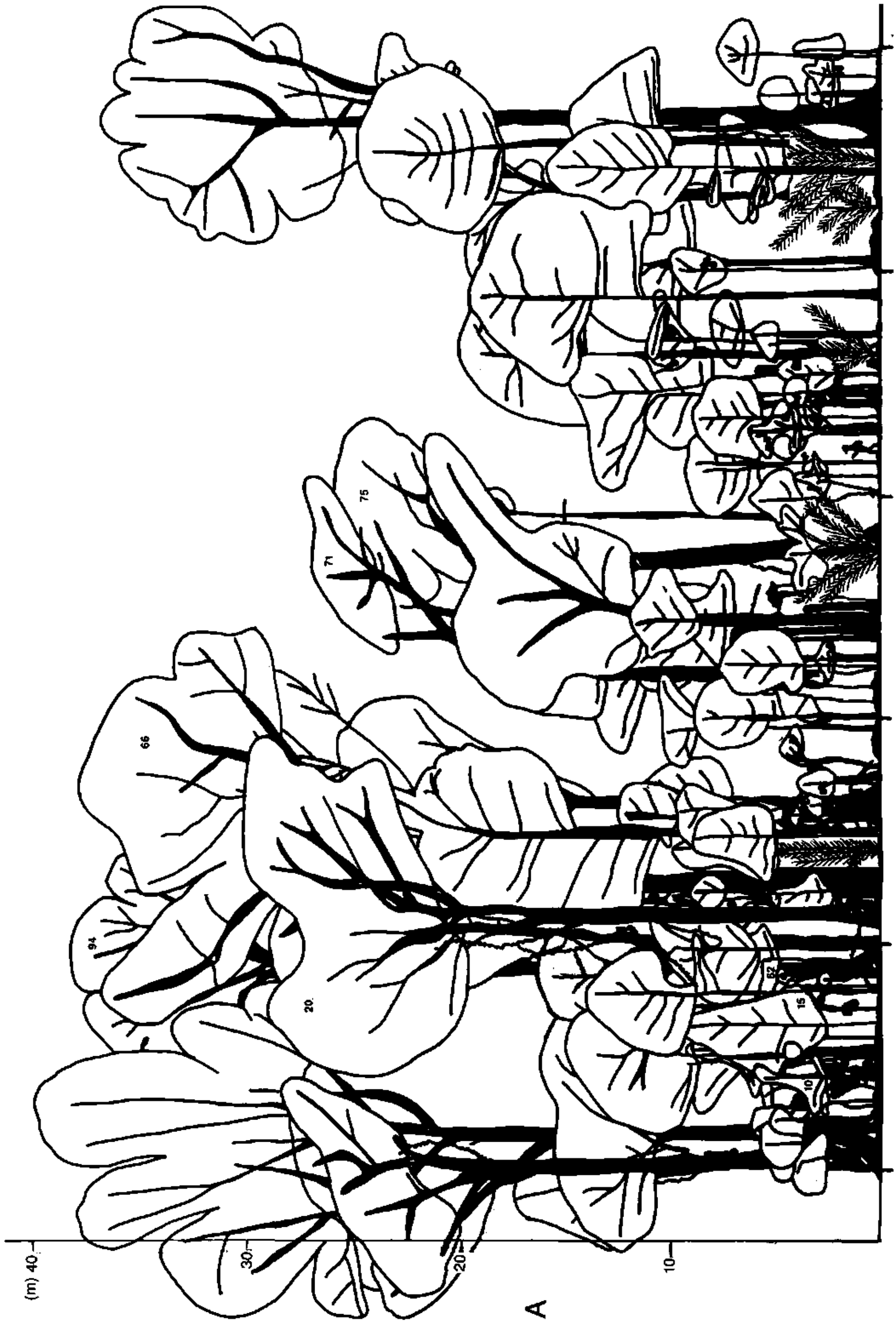
TABLE 7.13 Expt 67/9A: development of periodic annual mortality rate of commercial species 11–41, form class I, under six treatment schedules

Treatment code	Diameter class*	Period**						Mean		
		I	II	III	IV	V	VI	per class	class 1–2	class 1–3
0	1	4.8	0.5	1.3	0.5	0.2	1.8	1.5	1.3	0.9
	2	2.7	0	0	0	0.9	3.1	1.1		
	3	2.0	0	0	0	0	0	0.3		
	4	0	0	0	0	0	4.6	0.8		
	5	0	0	(50)	0	0	0	(4.2)		
40+0	1	0	2.4	1.1	0.5	0.5	1.4	1.0	0.9	1.6
	2	2.0	0	0	0	2.1	0	0.7		
	3	4.2	0	4.5	5.0	0	4.2	3.0		
	4	0	0	0	0	0	0	0		
20+0	1	2.8	1.8	3.5	3.0	1.6	2.2	2.5	2.5	2.5
	2	4.8	0	9.4	0	0	0	2.4		
	3	4.2	0	4.2	0	0	6.7	2.5		
	4	50.0	0	0	0	0	8.3	9.7		
40+D8	1	8.7	0	0	0	0	4.1	2.1	1.1	1.0
	2	0	0	0	0	0	0	0		
	3	0	0	0	0	0	5.0	0.8		
	4	0	0	0	0	0	0	0		
20+D8	1	7.8	2.1	0	1.8	1.7	3.1	2.8	1.9	2.8
	2	2.8	0	2.6	0	0	0	0.9		
	3	10.0	10.0	0	0	0	7.7	4.6		
	4	n.a.	n.a.	n.a.	n.a.	0	50.0	8.3		
V	1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		
	2	2.5	2.9	0	1.2	0	1.0	1.3	1.2	1.7
	3	4.5	0	0	0	0	2.1	1.1		
	4	0	16.7	0	0	0	0	2.8		

* See Table 7.5.
** See Table 7.10.

class I and form class III are given in Appendix VI.

The mean mortality rate for the first three stem-diameter classes was lowest under treatment 0 and also treatment 40 + D 8, but was almost three times higher in the plot under treatment 20 + D 8. This is further evidence of the highly dynamic developments in the stand under the last treatment. The small sample of trees in the higher diameter classes occasionally has resulted in high mortality rates, sometimes up to 50%. However, when mortality rates are compared using only the data from the first two diameter classes, which had a reasonably large population of trees, results are less extreme. In this case, treatment 40 + 0 and 40 + D 8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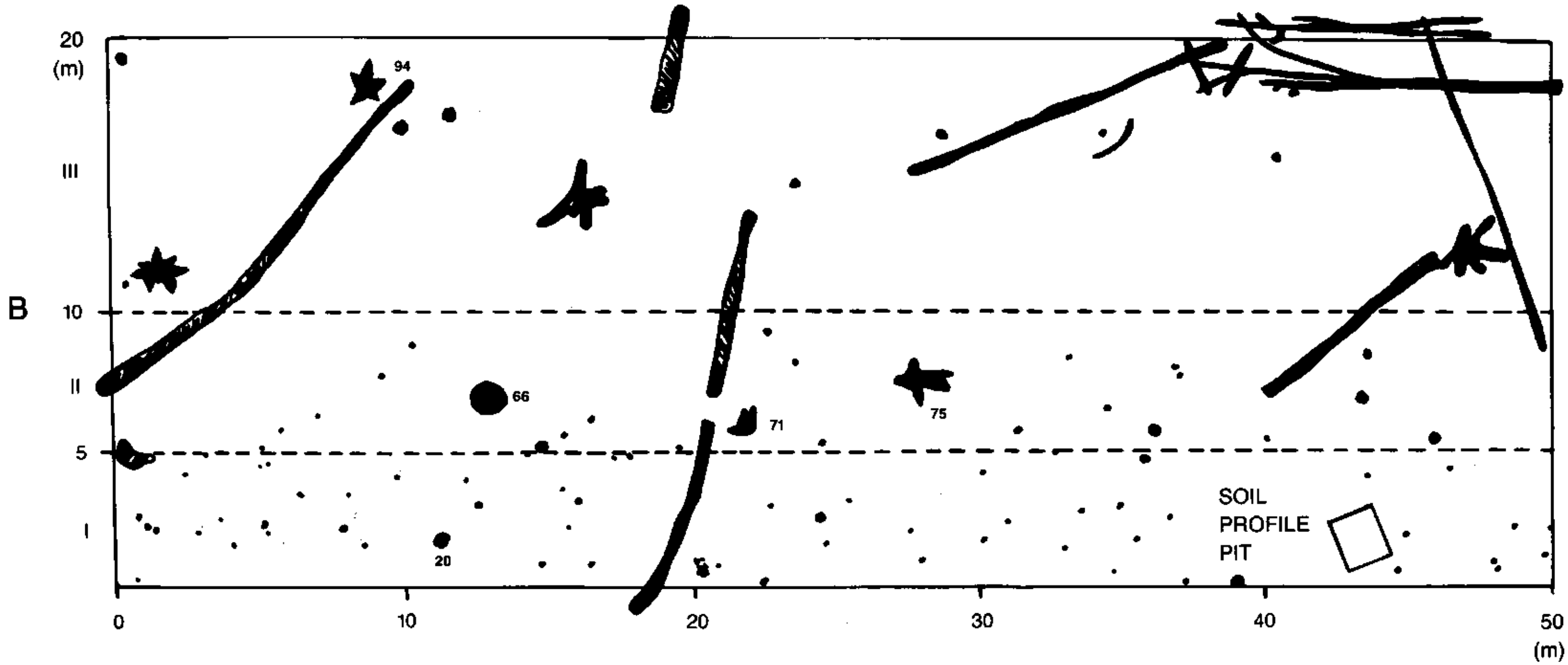

Fig. 7.15 Expt 67/9 A: plot 8 under treatment 0 in 1982. The profile diagram shows an undisturbed part of a larger plot in which only two medium-sized trees were harvested in 1968. Note the relatively open structure. A. Forest profile diagram, plot size 20 × 50 m; B. Positions of trees and dead logs in three zones of the forest profile diagram. Lower diameter or height limits for individual trees and climbers: zone I (5 × 50 m), trees 2 cm dbh, climbers 3 cm at 50 cm height, stemless palms 2 m leaf top height; zone II (5 × 50 m), trees 5 cm dbh, climbers 5 cm at 50 cm height, stemless palms 9 m leaf top height; zone III (10 × 50 m), trees 15 cm dbh, climbers 6 cm at 50 cm height. Drawing by M.F. Gelens.

showed a mortality rate similar to that of treatment 0, while treatments 20 + 0 and 20 + D 8 had a higher rate..

During the first three periods, treatment 20 + 0 was the same as 20 + D 8, and 40 + 0 the same as 40 + D 8, but mortality rates varied considerably between treatments. A comparison of mortality rates under treatment 20 + 0 and 20 + D 8 with those under treatment 40 + 0 and 40 + D 8 in the first three periods indicates that heavy refining resulted in higher mortality rates than did lighter refining, as was found in Expt 65/3 in which the range of intensities in treatment was much higher.

Mortality rates under treatment 20 + D 8 and 40 + D 8 do not seem to have been affected greatly by the second silvicultural interference in 1975. No clear difference can be discerned between plots under treatment 20 + 0 and 20 + D 8 or between plots under treatment 40 + 0 and 40 + D 8 after 1975.

Mortality rate seems to vary more with period of recording than with diameter class. Most treatments had a high mortality rate in period I and VI. For example, under treatment 40 + D 8, mortality was observed only in period I and VI which coincide with very dry periods (see rainfall data, Appendix I). Drought may have increased mortality rate, especially of small trees in highly competitive situations. Mostly, larger trees die as the result of falling in rainstorms and accompanying gusts of wind, but these details were not recorded. Further, individual windthrow or the falling of large trees in this forest is the result of a long process of weakening, and cannot be ascribed to one cause only. The high mortality rates in the plots under treatment 20 + 0 in period III stand alone and presumably are not an indication of climatic influences.

Thus, it may be concluded from Table 7.13 that refining probably increases the mortality rate in the remaining stand of commercial trees. Further, the data suggest an increasing mortality rate with increasing severity of refinement. To obtain more quantitative data, much larger populations than studied in Expt 67/9 A are required. Effects of rainfall on mortality are plausible, although the direct causes of death of trees were not assessed.

7.13 Terrestrial photographs and forest profile diagrams

A series of photographs taken in 1982, and forest profile diagrams for plots under treatments 0, 40 + 0, 20 + 0, 40 + D 8, and 20 + D 8 are presented in Figs 7.15 to 7.24. The locations of the photographs and forest profiles are given in Fig. 7.1. Evidence of preceding events in the stand often due to silvicultural interference is visible in the photographs. The profile diagrams show changes induced by the silvicultural treatments not visible on the photographs. In the forest profile diagrams only trees inside the plot have been included. Apparent gaps, for example in Fig. 7.15, in reality often were filled by crowns of large trees standing outside the profile diagram plot. Size of all plots in these diagrams was 20 × 50 m.

The genetic pattern of reactions of tree species in all stages of their life cycle is thought to have been formed largely by the natural circumstances in the regeneration processes of the forest. In this forest type these circumstances are a series of accidents and incidents during the tree-by-tree regeneration specific to this forest. Many treatment effects on the experimental stands can be understood more clearly in terms of these particular forest mosaic dynamics. In undisturbed high mesophytic forest in Suriname, gaps are continuously being formed by single trees or small groups of trees that die, for example by falling but this may not necessarily be the case always. When trees are large, their death greatly improves conditions for growth of the population of mostly slow growing or stagnating seedlings and saplings underneath (Richards, 1964). Under a heavy and homogeneous canopy, only a meagre undergrowth can survive. Seed germination, seedling establishment and recruitment of saplings are hampered if this condition does not change in time. In the long term, natural processes change this. The heavy shadow in the lower storeys is a natural condition in even-aged forest development stages, while ageing processes in large trees, and deaths finally permit more light to penetrate. The homogeneous canopy conditions occurring under several treatments in this experiment give the forest some aspects of a cultivated temperate region hardwood forest, and if regeneration and recruitment of saplings are to occur earlier than with the gaps formed by the following harvest, then silvicultural measures are required.

The photographs and profile diagrams represent a variety of stages in the natural regeneration of high mesophytic forest. An unnatural aspect is the scale, which is more extended, because many trees have been killed simultaneously in large areas. This scale makes the developments more recognizable, as they occur more synchronized, and allows mean values to be used. These homogeneous conditions cannot last long, and all plots discussed here will eventually in the very long-term become similar to plots under treatment 0, if treatment is discontinued. The success of the silvicultural treatment then is the rate at which the population of trees of commercial species has been promoted in size and volume to compensate for the decimation of their numbers by harvesting.

The forest profile diagram of plot 8 under treatment 0 in 1982, gives an impression of an undisturbed part of a lightly exploited mesophytic high forest (Fig. 7.15 A). Positions of trees have been drawn separately (Fig. 7.15 B). Conditions in the undergrowth are shown in the terrestrial stereophotographs in Fig. 7.16. A list of scientific names of the trees is given by Gelens (1983).

The forest profile diagram of plot 7 under treatment 40 + 0 in 1982, 15 years after refinement, shows a much denser mass of crowns, with a relatively smooth upper surface and reduced height (Fig. 7.17). These aspects were also shown in Fig. 7.4. After large-scale elimination of trees of non-commercial species above 40 cm dbh in 1967, very few large trees were left to continue natural gap forming. The thick canopy hindered growth of small trees, as shown in Fig. 7.18.

The profile diagram of plot 19, under treatment 20 + 0 (Fig. 7.19), shows the dense structure of the canopy. The many flat-crowned trees are short-lived secondary species, such as *Cecropia* spp. and *Inga* spp. (see also Fig. 7.20). The aerial photograph of 1982 (Fig. 7.4) shows a smooth canopy on plot 19, but gives

a somewhat different picture for plot 14, under the same treatment. Gelens (1983) did not consider the profile diagram in Fig. 7.19 to be homogeneous like the rest of the stand, because more gaps were found here than elsewhere in the plot. The trees appeared to be clustered, probably because of the light conditions necessary for establishment of true secondary species, which occur only in large gaps. Diffuse light is not adequate for such species.

The canopy of this plot will soon be opened up again either by trees falling or dying upright, because many are of short-lived secondary species. The conditions for growth of shade-bearing saplings and seedlings are gradually becoming more favourable under the canopy of secondary species. But until these large secondary trees decay, the growth of most trees in this stand will stagnate perhaps even more than under treatment 0. (see Section 7.11). In the early years of the experiment this plot was very difficult to penetrate on foot. The heavy refinement resulted in vigorous regrowth of low and dense vegetation with numerous lianas. Production of commercial timber was very low, especially as a second treatment was not applied, and the many small trees of shade-bearing species common in undisturbed forest increased overall competition, in addition to that of the secondary species and lianas.

The profile diagram of plot 23 under treatment 40 + D 8 (Fig. 7.21), shows the results of radical opening of the upper storeys in 1975. All non-commercial tree species above 3 cm dbh were killed, except filler trees mostly less than 10 cm dbh which were saved to maintain a more or less closed forest. The disturbance resulted in a dense undergrowth (Fig. 7.22). This plot had one of the highest productions of commercial timber (see Section 7.10), and most large trees were commercial tree species. Their clear bole length was not the result of the treatment, but of forest conditions before human interference.

No profile diagram is available for plot 22 under treatment 20 + D 8. The photograph of this plot (Fig. 7.23) shows a more open undergrowth than in plot 23

←

Fig. 7.16 Expt 67/9 A: plot 8 under treatment 0 in 1982 (photo by author).

A. A rather undisturbed part of the forest is shown in the foreground and lighter conditions of a gap in the background. The large tree, which is no. 66 in the profile diagram (Fig. 7.15) is *Trattinickia* sp. of almost 3 m girth. The thick tortuous liana stem in front of it is probably *Bauhinia* sp. The open undergrowth is typical of undisturbed forest. Its leaves often lose their natural gloss as they are covered with epiphyllous lichens and mosses, accentuating the long life of the leaves of these stagnating plants. The palm tree in the upper left corner is *Astrocaryum* sp. The forest floor is thinly covered with litter. The slight bends in thin stems indicate that at that height the shoot was damaged, but with continued diameter growth these soon will disappear.

B. This is taken a little to the right of A. In the background is a gap, somewhat larger than on A. The tree to the left, with holes in the stem is probably *Minquartia* sp. and not in the list of commercial species, but used locally for poles because of its durability. The fallen stems of the small trees shown will soon rot and the only remaining evidence of their existence will be the lean on saplings that have been touched. One of these saplings reacted by forming a new perpendicular shoot, which soon will be the main trunk. The marks on the black-and-white stick are 5 cm wide.

Fig. 7.17 Expt 67/9 A: plot 7 under treatment 40 + 0, forest profile diagram in 1982, 15 years after refinement. Source: Gelens, 1983. Note the continuous, closed canopy and reduced height.

Fig. 7.18 Expt 67/9 A: plot 7 under treatment 40 + 0 in 1982 (photo by author). Fifteen years after refinement the undergrowth is open as under virgin forest. The lack of large trees and the rotting timber in the foreground are the result of refinement in 1967. The slender medium-sized tree in the background is *Virola melinonii,* listed as a commercial species.

under treatment 40 + D 8. This is probably because in plot 22 the treatment in 1975 killed few large trees. In 1975, all non-commercial tree species above a 3 cm dbh limit were killed, except for the filler trees as already mentioned for treatment 40 + D 8. Under this treatment also the filler trees were mostly smaller than 10 cm dbh.

7.14 Conclusions

After the usual light exploitation and no subsequent silvicultural measures, increment on commercial species was low in the high mesophytic forest of Mapane. Heavier exploitation would not improve this situation substantially, but selective silvicultural treatments to stimulate growth of individual trees of commercial species were shown to promote production considerably. Plots under treatment 20 + D 8 and 40 + D 8 had a high volume production, and showed promise of high future increments, because numbers of well-growing medium-sized and large trees of commercial species were sufficient and increasing. Recruitment under these treatments was satisfactory but not plentiful. Most importantly, both treatment schedules were cheap and easy to apply.

Fig. 7.19 Expt 67/9 A: plot 19 under treatment 20 + 0, forest profile diagram in 1979, 12 years after refinement. Drawing by H. Armstrong. Note the very dense structure, smooth upper surface and reduced height.

Fig. 7.20 Expt 67/9 A: plot 19 under treatment 20 + 0 in 1982 (photo by author). The large piece of timber in the foreground has lost its sapwood to woodrot since it fell several years ago. The tree with stiltroots is *Cecropia* sp. and that with smooth bark behind it is *Inga* sp., both secondary species establishing in gaps. Light penetrating the canopy is more intense than in plots under treatment 40 + 0, and a profuse growth of lianas is visible in the background.

The peculiar stiltroots of *Cecropia* are the answer on a problem this secondary species often has to face after initial establishment. The very small zoochorous seed can produce only a small seedling, which is easily smothered by litter. Seedlings germinating on exposed spots like trunks or earth clods on root systems of fallen trees largely escape being covered by a dead leaf, but when growing succesfully need more support than their original stand can provide. The young tree then simply puts out extra supports in the form of roots. The rapid lengthwise growth, with a hollow stem, is essential for this gap species, because it has to reach the canopy before the gap closes. *Cecropia* trees straddling a dead log are found to be numerous in the forest, once attention of the observer is drawn to this aspect.

A treatment schedule consisting of only a single initial refinement resulted in stagnation in growth of a large proportion of the population of commercial species. Mortality increased with intensity of interference in the stand, and resulted in considerable losses in potential harvestable volume, but under optimum treatment was of restricted importance compared with the increased volume increment. Initial refinement seemed to have increased mortality more than subsequent liberation treatments, which were very effective in increasing volume production.

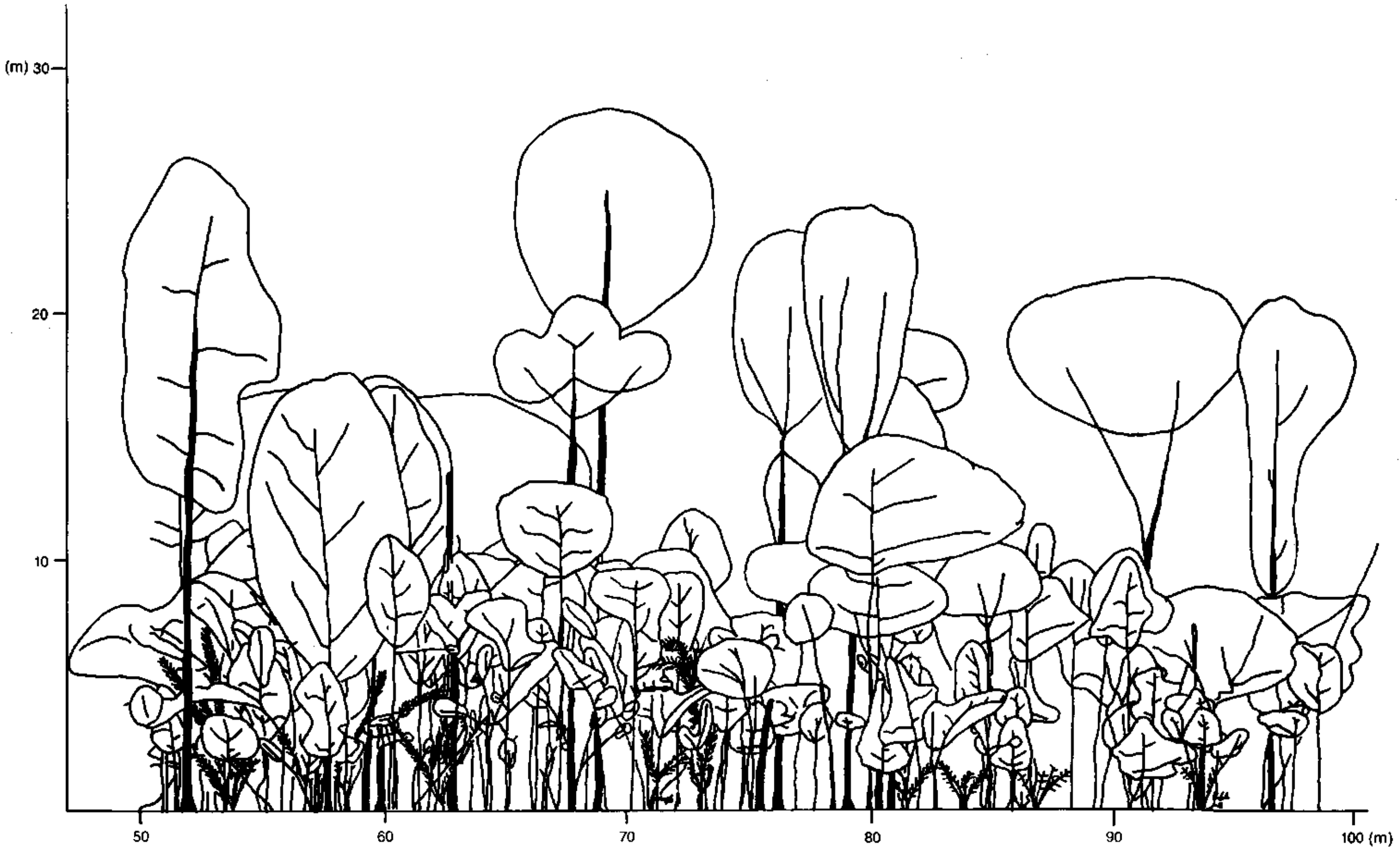

Fig. 7.21 Expt 67/9 A: plot 23 under treatment 40 + D 8, forest profile diagram in 1980. Drawing by H. van Ziel. Note the open structure above 10 m, and the dense vegetation below. Plot was refined in 1967 and liberated in 1975.

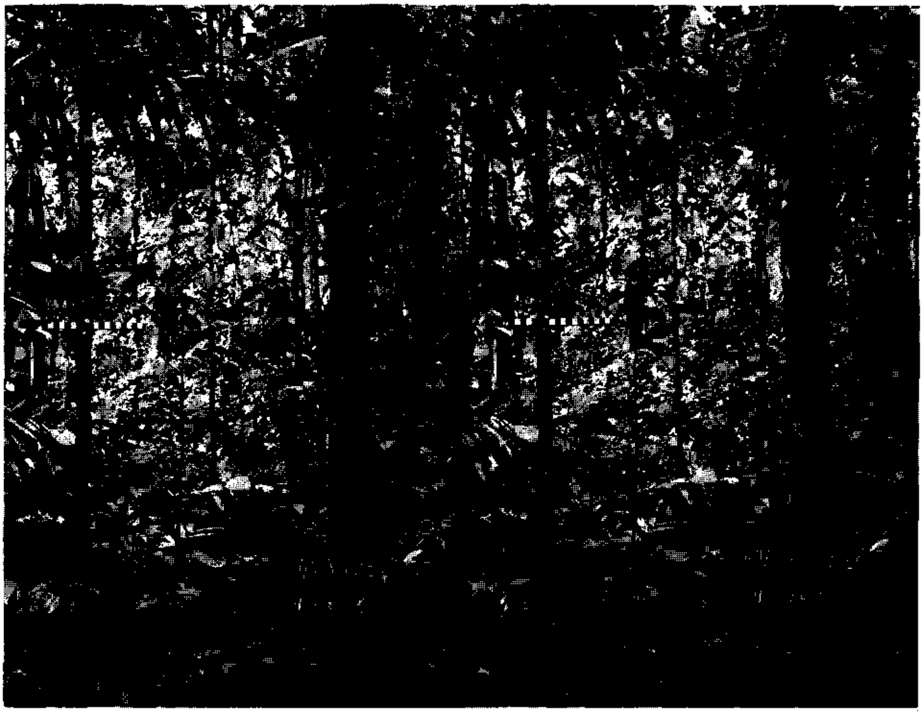

Fig. 7.22 Expt 67/9 A: plot 23 under treatment 40 + D 8 in 1982 (photo by author). The dense undergrowth is the result of liberation in 1975, which removed many medium-sized trees of non-commercial species that had been saved at initial refinement in 1967. If left untreated for a further ten years, this plot may become similar to that under treatment 40 + 0 in 1982, but with greater variation in the size of largest trees. Large trees remain hidden in this photograph.

Fig. 7.23 Expt 67/9 A: plot 22 under treatment 20 + D 8 in 1982 (photo by author). Undergrowth is more open than in plot 23 under treatment 40 + D 8, although liberation was done in the same year (1975). This is probably because the liberation resulted in less disturbance, as trees of non-commercial species larger than 20 cm dbh had been killed in the initial refinement, and had fallen in earlier years. Thus, little dead timber fell after 1975. Large trees shown on the photograph are of commercial species. The filler trees saved in the 1975 treatment were mostly smaller than 10 cm dbh.

8 Experiment 67/9 B: natural regeneration techniques; field trial

8.1 Summary

The preliminary results of Expt 67/9 A in 1975 indicated that treatment 20 + D 5 was most favourable for stimulating production of commercial species in lightly exploited forest. A large-scale trial was set up on an area of 25 ha adjacent to Expt 67/9 A to test this treatment schedule. The scheme was not rigidly prescribed, so that it could be modified if required. The large area treated, and the 16 ha measurement plot provided good opportunities to collect reliable data on stand development and labour and material costs, and organizational problems.

The area had been unevenly exploited, and an average volume of about 20 m^3/ha is estimated to have been taken over a considerably long period.

In 1975 an initial refinement was carried out, which reduced the total basal area to roughly one-third of the original value. This refinement was intermediate in intensity between the two refinements applied in Expt 67/9 A. In 1983, eight years after the first refinement, the second treatment had not yet been given. Periodic annual volume increment of commercial species after refinement was as expected, about 2 m^3/ha in the period 1976 to 1982. This increment occurred mainly in the still underrepresented large and medium-sized trees. Volume increment is expected to increase further.

Periodic annual mortality of commercial species in first years was low, about 1.4% for stem-diameter class 5.0-59.9 cm dbh, but rose to 2.6% subsequently. Mortality of commercial species, estimated to be about 2% in lightly exploited forest before silvicultural treatment, was not increased much by the refinement.

Periodic annual girth increment during the first seven years was quite high, being about 30 mm for trees above 20 cm dbh; only slightly less than with more intensive treatment schemes as in Expt 67/9 A. At this early stage of the experiment no relationship could be found between girth increment and total basal area. Recruitment kept pace with the numbers of trees that grew into higher stem-diameter classes, but was not particularly abundant, and needed to be stimulated further by treatments to compensate for future losses due to harvesting damage.

Aerial and terrestrial stereoscopic photographs presented give a visual impression of the vegetation structure. Accessibility of the stand, which is important for management, is discussed, and a scale of accessibility is presented. Variability in the stand is discussed and illustrated with sub-plot data.

It was concluded from the preliminary results in this trial that silvicultural treatment was economically feasible and ecologically acceptable.

8.2 Introduction

In 1975, results of Expt 67/9 A led to preliminary conclusions about silvicultural assistance to commercial species in lightly exploited forest (de Graaf and Geerts, 1976). At that time treatment 20 + D 5 seemed to be the most promising treatment and thus it was decided to carry out a larger scale field trial to provide better estimates of factors such as labour costs, arboricide requirements, volume increment and mortality rate. The area of 500 × 500 m selected for Expt 67/9 B was immediately east of Expt 67/9 A (see Fig. 7.3). This Expt 67/9 B was not designed to compare treatments, but mainly to quantify important parameters in silviculture which could not be studied on the relatively small plots of Expt 67/9 A.

Soils are quite comparable with those in the area under Expt 67/9 A. A gully runs through the area from the centre to the south-east corner, where it terminates in the Mapane river. This gully is mostly dry and at present is not actively eroding. Aerial photographs of the area taken in 1971 and 1982 show little variation in the forest vegetation. On the detailed soil map made in 1982 (van der Steege, 1983) only slight differentiation in soils in the 16 ha recording plot is shown. Drainage of most of the plot is satisfactory. Rainfall data are available for the period 1960-1981 (see Appendix I).

8.3 Experimental layout

Layout of the experiment is shown in Fig. 8.1. The forest was made accessible on foot by cutting lines 1-1½ m wide through the undergrowth 100 m apart in a north-south direction. This is the usual practice to gain access to forest stands. Labourers doing the refinement work had to move in east-west direction in swaths, 'weaving' between the north-south lines.

In 1975 a central recording area of 400 × 400 m was delineated. In 1978 this area was divided into twelve 1.0 ha and eight 0.5 ha plots, by cutting narrow lines in an east-west direction (see Fig. 8.1). For subsampling smaller trees, 40 circular plots evenly distributed throughout the 400 × 400 m area were marked out. The centre of these plots was marked with a plastic pipe bearing a metal number tag. The radius of each plot was planned to be 15.96 m, but was inadvertently fixed at 15 m. Total area of this subsample is 2.83 ha (17.7%), each circular plot measuring 707.5 m^2. In the 16 ha recording plot, all trees of listed species above the diameter limit of 15 cm dbh have been monitored annually; in 1975 almost 900 trees were monitored. Local name of the tree species was recorded, the tree was numbered permanently in the field, its girth at point of measurement was measured, and the tree classified according to general form of stem and crown. A subsample of trees

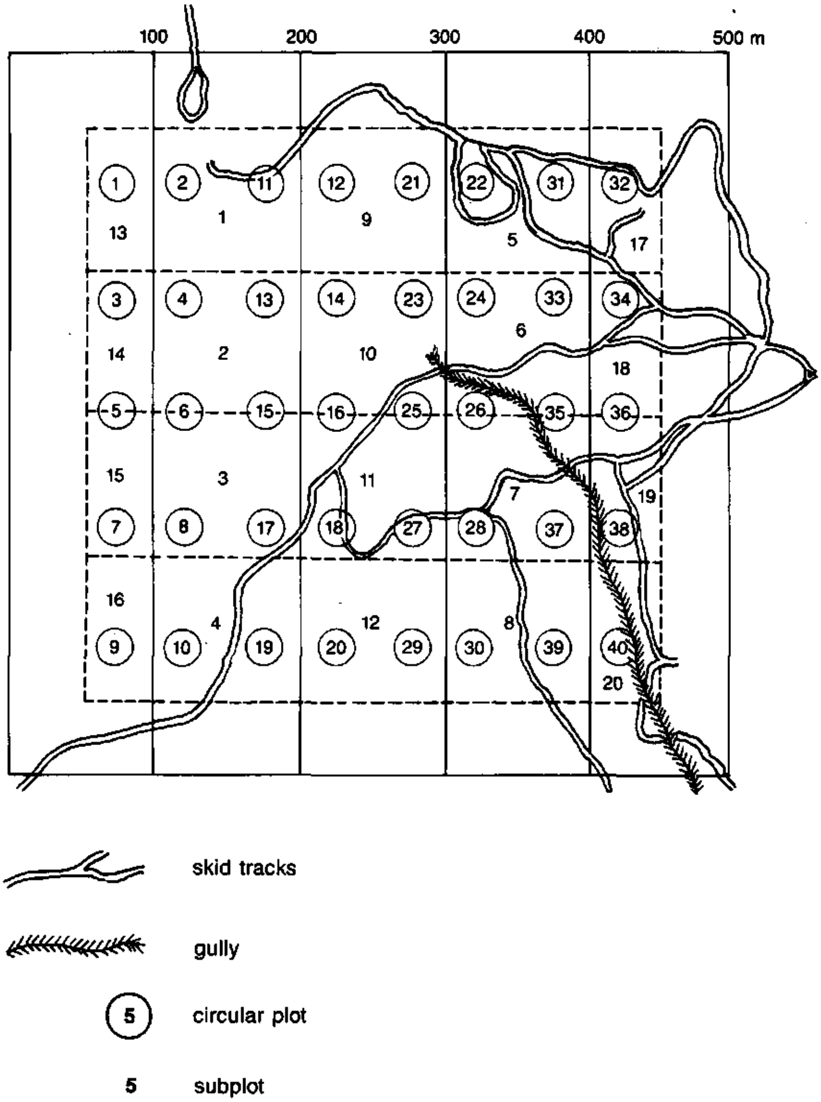

Fig. 8.1 Lay-out of Expt 67/9 B. The central 16-ha plot has 40 circular plots each of 15 m radius (707 m^2 area) for subsampling small trees, and it is also divided in 20 subplots (12 one-ha plots and 8 half-ha plots).

of 2 cm dbh and above was recorded in the 40 circular plots, each time the 16 ha area was monitored.

Bole length of standing trees of the two commercial species *Tetragastris altissima* and *Virola melinonii* was measured soon after refinement, when trees killed had shed most of their leaves (Nieuwenhuis, 1977). From these data a provisional volume tariff was prepared, see Appendix VII. No form factor was assessed, but a value of 0.7 was assumed (Gonggrijp and Burger, 1948).

8.4 Exploitation and silvicultural treatment

Exploited volume in this area could not be reconstructed in detail as was done in Expt 67/9 A, but a map showing skid tracks was drawn in 1975, the year in which light exploitation ceased (Fig. 8.1). The exploited volume can reasonably be assumed to have been on average 20 m^3/ha, but the actual volume taken could have been less, because total basal area before refinement was 28.3 m^2/ha. The stand table for commercial species 11-41 form class III shows a small loss of stems of valuable species above 45 cm dbh, as compared with the 2‰ sample of the Mapane region taken before exploitation (see Table 6.6). In 1976, the area of Expt 67/9 B carried 36 m^3/ha of the four most abundant commercial species larger than 25 cm dbh, irrespective of stem quality, as compared with 25 m^3/ha in the area of the Weyerhaeuser sample (see Section 7.5).

Areas which were disturbed very much by the logging, and in which the trees were removed over more than about 20 m width, were colonized by secondary vegetation. This trend was accelerated by the refinement. On the aerial photographs such patches can be seen. Here, regeneration of commercial species could not compete with the secondary species, except for light-loving commercial species of secondary nature, such as *Goupia glabra, Sterculia* spp., *Jacaranda copaia, Didymopanax morototoni* and *Simarouba amara*. These were the most impenetrable parts of the area during the period discussed, and were relatively unproductive with regard to valuable timber. Larger game, especially deer, favoured these patches of secondary vegetation for browsing. Apart from use of such areas for a habitat for game, this type of vegetation should be restricted in area by careful logging, and especially by avoiding the felling of groups of large trees. Artificial restocking of these areas is not feasible. It is expected that later on these patches will resemble the areas under treatment 20 + 0 in Expt 67/9 A, as shown in Fig. 7.20.

At the start of the experiment in 1975, the treatment scheme was planned to follow code 20 + D 5 (see Table 7.1). However, the second treatment has been postponed several times, because the increment of valuable trees has remained acceptable. The initial refinement was carried out in the period September to November 1975 during the dry season. As all valuable trees above 15 cm dbh had been marked with red paint, the lower diameter limit of 20 cm for killing trees of unwanted species made extra marking unnecessary. Approximately 40 litres arboricide mixture was used per ha. The mixture was a 5% solution in diesel oil of Esteron 2,4,5-T, 65%, acid equivalent 42.5, with 480 g of active ingredient per litre commercial product. After several years, more than 90% of trees treated were dead, thus no extra refinement treatment was considered to be necessary.

Total basal area was not reduced as much as under treatment 20 + 0 in Expt 67/9 A with the same lower limit for refinement, because the extended list of commercial species used in 1975 raised the basal area of trees to be spared. The total basal area after refinement, 9.8 m^2/ha, was between that under treatment 20 + 0 and that under treatment 40 + 0 in Expt 67/9 A.

The refinement cost was 14.2 man-hours per ha for treatment (walking, frilling, spraying, etc) with an additional 2 to 3 hours for liana cutting (Staudt, 1976). Cost for marking trees to be retained was about 0.33 man-days per ha, when using experienced labourers. In total, about 21 man-hours per ha were spent on refinement operations in the 25 ha area treated. No time has been allowed for line cutting and sampling in these estimates. With physiological research it was found that the work was not strenuous, and certainly less exacting than working with the power saw. Heart-beat frequency varied from 89 to 113 beats per minute for walking, frilling and spraying. The work was done by two men only, with little supervision except from the ergonomist. Both men did all tasks involved except treespotting (Staudt, 1976). Taking into account the intensity of treatment, the cost of refinement was within the generally accepted level of the Forest Service. The Forest Service used gangs of five or more men for refinement work, but usually with more specialization in the group.

Most dead timber from killed trees fell during the first four years. A number of large dead trees are discernible on aerial photographs taken in 1982 (Fig. 8.7). Such dead trees when falling do not damage the remaining stand as much as vigorously developed living trees felled during harvesting, but large timber falling from dead trees on developing stands intertwined with lianas can do considerable damage by breaking or bending smaller trees bound together by the lianas. In Expt 67/9 B tangles of lianas were not common, because of the light exploitation and subsequent relatively light refinement.

Woody parts of vegetation, such as twigs, branches and stemwood, form 90% of the above ground living phytomass of this forest. Stemwood alone has been shown to represent more than 60% of this phytomass in Mapane after the usual light initial exploitation (Schmidt, 1982). The refinement in Expt 67/9 B reduced living phytomass to about 40% of that before treatment.

8.5 Total basal area development

Early in 1976, soon after the refinement at the end of 1975, all trees above 10 cm dbh, alive or recently dead because of treatment, were tallied in an area of 10 ha, between the north-south lines 100-200 and 300-400 (see Fig. 8.1). Based on this tally, the total basal area before refinement was estimated to be 28.3 m^2/ha, which is in agreement with data from the 2% inventory of Mapane region, carried out by the Forest Service (Boerboom, 1964; see Section 6.5). The basal area was calculated from the number of trees per 5 cm stem-diameter class found with the tally, and the basal area for the tree in the middle of each 5 cm stem-diameter class.

Refinement must have reduced the living basal area to 9.8 m^2/ha, as estimated by applying the diameter limit for refinement (20 cm) to the stand table (de Graaf, 1981). Making allowance for not a 100% kill of treated trees, and for forgotten trees, remaining living basal area was estimated to be 10-11 m^2/ha. There are no data on standard deviation.

In 1979 the stand was recorded again, this time with an angled caliper and a

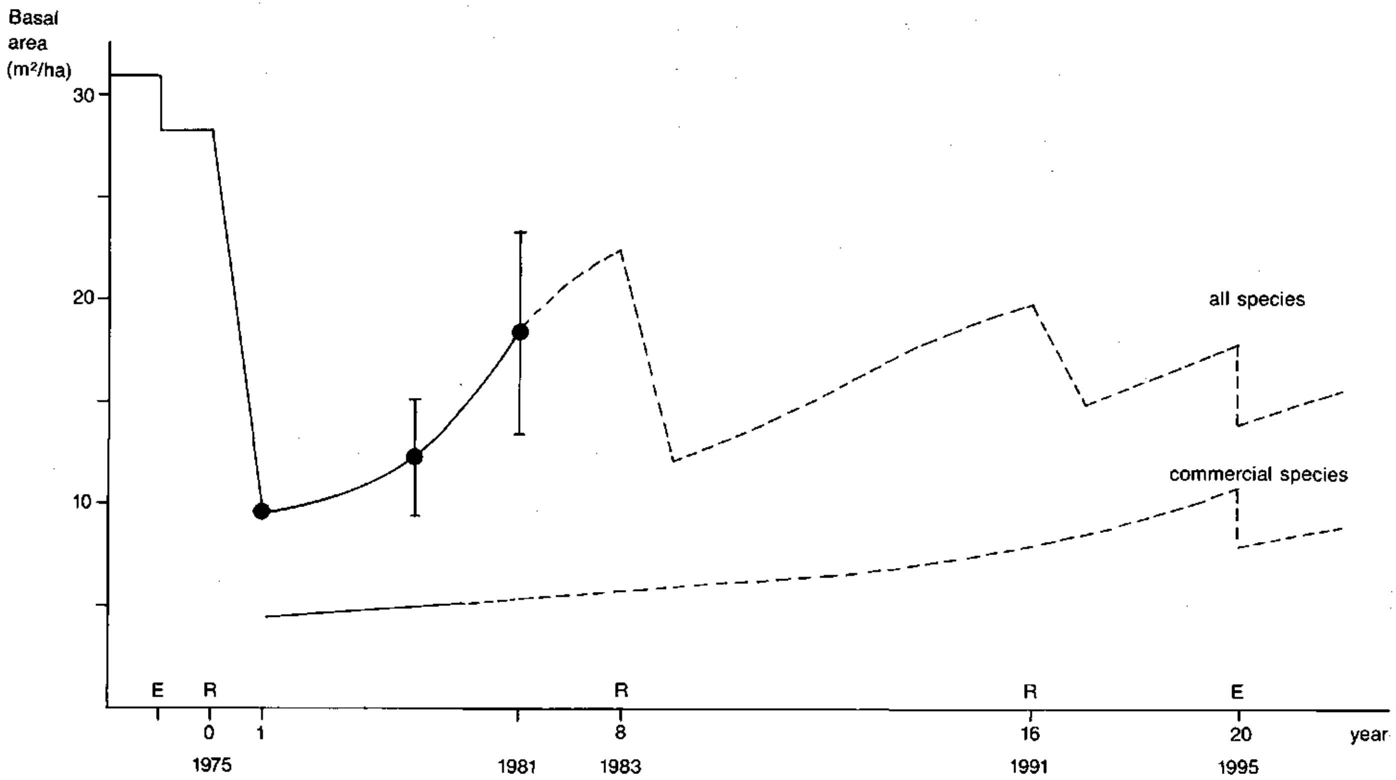

Fig. 8.2 Expt 67/9 B: development of total basal area of all species in the period 1975 to 1981, and projection to 1995 when the first cycle is completed. *Development and projection of the basal area of commercial species 11-58 form* class III is also given, for which an increment trend of 5% is assumed under the scheduled treatments.

:e stick for large diameters. The mean total basal area of living trees over elve 1.0 ha plots was 12.2 ± 2.4 m^2/ha. With the 0.5 ha plots included in thc .. mple, mean total basal area was 13.6 ±3.3 m^2/ha. In 1981 the girth of all trees in four 0.25 ha plots was recorded (Schmidt, 1981). The total living basal area was estimated to be 18.2 ± 4.1 m^2/ha. More detailed sampling was not possible at that time. Absurd data were the result of restricted sampling in early years in 20 of the 40 circular plots systematically distributed throughout the experimental area, with a total sample area of about 1½ ha. Problems arose with borderline trees in these round plots, and the small sample area probably was not representative, even though evenly distributed throughout the experimental area.

In 1976, experiments with basal area prisms, working on the renowned Bitterlich principle, gave an estimate of 14.7 ± 5.4 m^2/ha for 40 reading points with a prism of factor 2.5 (Nieuwenhuis, 1977). The difficulties encountered with prism sampling, for example poor visibility of large trees in the distance, and stem section forms deviating greatly from the basic circular concept, made this type of basal area sampling less reliable than straightforward tallying. Only a small number of trees are actually sampled with the prism method, and on a small scale the forest is reputedly variable.

Basal area development, and a future projection of this are presented in Fig. 8.2. These can be compared with basal area development in Expt 67/9 A. An increase in total basal area from about 10 m^2/ha to about 18 m^2/ha in a period of five years (1976-1981), indicates an annual increment of basal area of 1½ m^2/ha, which is more than under the heavy treatment 20 + 0 in Expt 67/9 A. This increment is likely to slow down, especially when basal area reaches 20-22 m^2/ha, as was the case in Expt 65/3 and Expt 67/9 A, although such a value is still far from the original 30 m^2/ha in virgin forest on the site. The steep increase in these first years is related to the large number of small trees, many of secondary species which have passed the 5 cm lower limit of recording since the treatment was given in 1975.

In 1982, total basal area and stem-diameter distributions were studied by Hagman and Schenk (1982) in an area of 5 ha immediately south of Expt 67/9 A. Total basal area was calculated to be 33.3 m^2/ha. For trees 5-105 cm dbh, basal area was 29.7 m^2/ha, the remaining 3.6 m^2/ha was made up of about two trees per hectare of 105-205 cm dbh. These large trees are not evenly distributed throughout the forest, even in virgin forest. The 2% inventory of Mapane (see Table 6.4) gives only 2.3 trees per ha larger than 95 cm dbh, whereas the 5 ha of Hagman and Schenk give 3.8 trees per ha above 95 cm dbh.

8.6. Stem-diameter distribution and bole volume

Stem-diameter distributions and bole volumes in Expt 67/9 B are given in Tables 8.1 and 8.2, together with data from Expt 67/9 A. Data for 1975 for all species are from lightly exploited but further untreated forest, and for 1979 are

TABLE 8.1 Expt 67/9B: comparison of development in stem-diameter distribution (N/ha) for three species groups with development under similar treatment schedules in Expt 67/9A

Treatment code	Species	Year	Diameter class*							Total	Sample area (ha)
			1	2	3	4	5	6	7		
Expt 67/9B											
20+…	all	1975	559	173	55	22.6	13.8	4.8	0.9	829	10
		1979	360	150	24.6	5.9	1.3	0.2	0.2	542	12
		1981	1 138	191	25	14	1	0	0	1 369	1
	11–41,	1976	73**	10.9	7.2	2.4	0.4	0.06	0.06	94	16
	form class I	1979	85**	12.0	9.6	3.1	0.6	0	0	110	16
		1982	80***	10.1	11.5	4.0	0.8	0.2	0	107	16
	11–58,	1976	94	29.8	17.4	5.3	1.1	0.3	0.13	148	16
	form class III	1979	115	31.2	18.8	5.8	1.4	0.3	0	173	16
		1981	114	29.0	20.6	6.2	1.4	0.6	0	172	16
Expt 67/9A											
0	11–41,	1968	61.9	17.5	7.5	2.8	0	0	0	90	3.2
	form class I	1980	73.4	16.3	9.1	4.4	0	0	0	103	3.2
40+D8	11–41,	1968	37.5	10.9	14.1	4.7	0	0	0	67	0.64
	form class I	1980	53.1	14.1	9.4	15.6	0	0	0	92	0.64
20+D8	11–41,	1968	51.6	28.1	7.8	1.6	0	0	0	89	0.64
	form class I	1980	59.4	26.6	23.4	0	0	0	0	109	0.64

* see Table 7.5.
** Data for species 11–41, form class III.
*** Data for species 11–41, form class III, 1981.

TABLE 8.2 Expt 67/9B: comparison of development in bole volume distribution (m^3/ha) for three species groups with similar treatment schedules in Expt 67/9A

Treatment code	Species	Year	Diameter class*							Total	Sample area (ha)
			1	2	3	4	5	6	7		
Expt 67/9B											
20+...	all	1975	17.4	58.5	68.6	60.0	62.5	31.1	8.6	307	10
		1979	15.4	44.0	31.0	14.9	6.0	1.0	1.4	114	12
	11–41,	1976	n.a.	4.1	9.1	6.1	2.0	0.4	0.5	22.2	16
	form class I	1979	n.a.	5.0	12.7	8.1	2.6	0	0	28.4	16
		1982	n.a.	4.5	15.0	10.4	3.1	1.1	0	34.1	16
	11–58,	1976	n.a.	11.4	21.6	13.6	4.9	2.0	1.2	54.7	16
	form class III	1979	n.a.	12.0	24.1	15.1	6.1	2.1	0	59.4	16
		1981	n.a.	11.3	26.3	16.4	6.1	3.6	0	63.7	16
Expt 67/9A											
0	11–41,	1968	2.0	5.9	9.5	5.9	0	0	0	21.3	3.2
	form class I	1980	2.6	5.7	11.7	11.9	0	0	0	29.3	3.2
40+D8	11–41,	1968	0.8	3.8	20.3	10.5	0	0	0	34.6	0.64
	form class I	1980	2.2	3.9	12.7	42.1	0	0	0	58.7	0.64
20+D8	11–41,	1968	1.9	10.4	10.3	3.5	0	0	0	24.2	0.64
	form class I	1980	2.1	9.8	26.6	0	0	0	0	36.4	0.64

* See Table 7.5.

from forest after refinement. Classification according to form class proved not to be congruent in the lowest class of both experiments. Thus in Expt 67/9 B, form class III was substituted for form class I in the lowest diameter class. In 1982, insufficient data were available for the lowest class, and here again substitution was carried out. The number and volume of trees in the higher stem-diameter classes were greatly reduced by the treatment. In 1981, large numbers of small trees appeared to have been established, mostly species of no commercial value. The 1981 sample was quite small, and the number of trees in diameter class 4 was overestimated, but the numbers in diameter classes 1, 2 and 3 agree fairly well with the other data. In future many of the small trees will die as competition increases, and often the secondary species are the first to lose this battle with the many primary species.

In Table 8.1, species group 11-41 form class I is a selection of commercial species, whereas species group 11-58 form class III covers all trees of commercial species reserved in 1975, for which reason this stem-diameter distribution above 30 cm dbh is in closer agreement with that in 1979 for all species. Sampling for all species in 1979 (see Section 8.5), covered only part of the experimental area.

The diameter distribution and volume distribution of commercial species in treatment O of Expt 67/9 A changed over the twelve years, but to a lesser extent than under treatments 40 + D 8 and 20 + D 8 (see Table 8.1). Expt 67/9 A is eight years in advance of Expt 67/9 B. The expected increase in numbers and volumes of commercial species in diameter class 3 and above could be observed within the first six years of the experiment. This increase is expected to continue because there is still an imbalance between the number of small and large trees in this forest as compared with undisturbed forest. In diameter class 1, there was a slight increase in the low number of commercial species, which indicates they are not being depleted or replenished in large amounts under the influence of the treatment. All that is required is that the numbers remain more or less constant over the felling cycle, to provide a source from which the higher diameter classes are replenished. The total number of trees (Table 8.1) is less important than the position of the smallest trees, which should not suffer too much from competition by the larger trees. It is still possible to create space for these smaller trees of commercial species by killing non-commercial species in the stand.

In 1981 an overwhelming number of trees of non-commercial species was still present in the first two stem-diameter classes as shown in Table 8.1. These trees included not only shadow-bearing species of the lower strata but also young and vital trees of emergent non-commercial species. The set-up of the experiment is such that these potential emergents should not dominate the stand, because their places should be filled by commercial species. Saving lower strata species will probably be possible without too great loss in increment for the commercial species group.

It is difficult to predict what the final situation will be when most trees of non-commercial species have been killed. Certainly the next exploitation will have an effect, creating gaps which should become new foci of regeneration. It would be desirable to have many young saplings to compensate for exploitation damage, and it is possible to obtain larger numbers, as has been shown in Exp 65/3, but it is expensive. For immediate financial results the volume production concentrated in the upper stem-diameter classes is more important.

When the list of commercial species is extended, commercial volume in the stand increases (see Table 8.2). The rate of increment for species 11-58 form class III was not as high as in the more narrowly defined group of species 11-41 form class I (van der Hout, 1982). During the period 1976 to 1981, the annual rate of increment for species 11-58 form class III was 3.3% for all trees above 15 cm dbh. This can be calculated from Table 8.2. For the period 1976 to 1982, the annual rate of increment for species 11-41 form class I was 8.9% (Table 8.4).

In 1979 the volume of species 11-58 form class III was more than half the total volume of all species in the stand, being about 60 m^3/ha and 114 m^3/ha respectively (Table 8.2) Above the 30 cm diameter limit these species represent more than 80% of the total volume. A second treatment to kill trees of non-commercial species above a diameter limit of say 10 or 15 cm, would increase the proportion of commercial species even more. It is not yet known from evidence whether further reduction of non-commercial species would harm the ecological stability of the forest. It may be better to concentrate on thinning the commercial population before considering full eradication of non-commercial tree species.

In Table 8.3 the volumes of all species in Expt 67/9 B are presented in a different way, in order to be compared with data from the 2% Mapane inventory (Boerboom, 1964). Both sets of data were found to be in reasonable agreement.

The effect of tree size on volume production is shown in Table 8.4. The short periods involved, and the wide diameter classes kept, make the question of some trees crossing the class limits in the period unimportant. The more than 10% return on large trees is impressive. This table also shows that production is mainly achieved by the trees above 25 cm dbh. Numbers of these trees are increased by recruitment from lower classes, and as long as this continues, the productivity for commercial timber of this forest will increase in spite of gradually decreasing mean girth increments.

Mean volume production is an important indication of site potential and is needed for calculation of financial results, but is most valid when the stand has attained a reasonable balance. In Expt 67/9 B, this stage had not yet been reached in the first six years studied. When the higher diameter classes have been replenished, average volume increment will be more relevant, and more in agreement with sustained yield.

In Table 8.5, bole volume, periodic annual volume increment, and increment rate in Expt 67/9 B in 16 ha and in Expt 67/2 in two plots of 5 ha are compared. Species group 11-41 form class III was chosen because this was the only form class available in Expt 67/2. Data cover a period of five years in Expt 67/9 B and nine years in Expt 67/2. The standing commercial volume was lower in Expt 67/9 B than in Expt 67/2, but increment rate was far better, especially for trees below 45 cm dbh, and this was presumably because of treatment. The low annual

TABLE 8.3 Expt 67/9B: comparison of bole volume (m^3/ha) of all species before and after refinement with the 2% inventory for Mapane

Lower diameter limit (cm dbh)	Expt 67/9B		Mapane 2% inventory*
	Before refinement 1975	After refinement 1979	
≥65.0	85	6	n.a.
≥45.0	162	23	n.a.
≥35.0	207	45	193
≥25.0	253	66	234
≥5.0	307	114	n.a.
15.0–24.9	36	32	n.a.
5.0–14.9	17	15	n.a.

* Source: Boerboom, 1964.

increment of 1.57 m^3/ha in Expt 67/9 B for diameter classes above 15 cm dbh may be explained by the relatively high mortality in this category of trees (form class III), starting with a high volume of stagnating and defective trees in 1976. Compare this productivity with that of the more selected group species 11-41 form class I, in Table 8.4.

In Expt 67/2, increment was negative for diameter class 25.0-44.9 cm dbh at both locations Sarwa and Goliath, but in Expt 67/9 B increment in this class was very positive. (Volume increment per diameter class is not the same as per tree increment, because mortality causes changes in the population.)

In both Expt 67/2 and Expt 67/9 B, the trees above 45 cm dbh of commercial species were the most productive. This is a good reason not to harvest high quality trees in this class, especially in the lower ranges of the class, but to spare them to

TABLE 8.4 Expt 67/9B: development of bole volume (m^3/ha), periodic annual volume increment (m^3/ha), and periodic annual volume increment rate (% of initial volume), in 1976–82, for commercial species 11–41, form class I

Lower diameter limit (cm dbh)	Bole volume (m^3/ha)			Periodic annual volume increment 1976–82	
	1976	1979	1982	m^3/ha	%
≥45.0	8.9	10.7	14.6	0.7	10.6
≥25.0	20.1	26.4	32.2	2.0	10.1
≥15.0	22.2	28.4	34.0	2.0	8.9
≥5.0	23.1	29.1	34.7	2.0	8.4

TABLE 8.5 Expt 67/9B: comparison of bole volume (m^3/ha), periodic annual volume increment (m^3/ha), and periodic annual volume increment rate (%) for commercial species 11-41, form class III, with Expt 67/2

Diameter limits	Expt 67/9B				Expt 67/2*			
	Bole volume (m^3/ha)		Annual increment		Bole volume (m^3/ha) in 1968		Annual increment rate (%)	
	1976	1981	m^3/ha	%	Sarwa	Goliath	Sarwa	Goliath
≥45.0	13.7	17.5	0.77	+5.7	21	26	+1.1	+3.4
25.0–44.9	21.0	25.1	0.81	+3.8	29	22	-0.3	-0.7
15.0-24.9	4.4	4.4	0.0	-0.3	11	7	-2.6	-1.3
≥15.0	39.1	46.9	1.57	+4.0	60	54	-0.2	+1.2

* See Table 6.14.

promote future productivity of the stand. This can be done only if sufficient standing volume is available in the particular stand to make this possible, without passing the lower volume limit for economic harvesting. In virgin forest there is much more choice in this respect than in stands already impoverished by creaming in previous years.

8.7 Periodic annual increment of girth

Annual girth increment per 5-cm diameter class for the species group 11-41 form class I is presented in Fig. 8.3. The increment for 1976-1977 was lower than for subsequent years, because time was required for the trees to react to treatment given in 1975. The crowns and root systems of trees remaining in the stand evidently grew quite rapidly in reaction to the space provided and to the nutrients set free from the dead organic matter. From 1977, annual girth increment was seldom below 30 mm, that is, roughly one cm diameter growth per year.

In diameter classes above 50 cm dbh, averages are less consistent, because of the few large trees involved. Below 15 cm, no data are presented. The deep depression for trees 15.0-19.9 cm dbh in the period 1981 to 1982 may be temporary, but more probably indicates competition stresses in this class. Increment in this experiment with intermediate treatment compared favourably with those in plots under treatment 20 + 0 and 40 + 0 in Expt 67/9 A. The very dry year 1979-1980 is not discernible in the annual girth increment, possibly because of a relative abundance of water in the soil due to diminished transpiration in this refined stand in which the number of large trees was reduced.

Periodic annual girth increment in two-year periods was calculated to obtain data comparable with those presented for Expt 67/9 A during the first six years. Species group 11-41 form class I was used, instead of the four main commercial species 11, 24-28, 37 and 40, but results did not differ essentially. In Fig. 8.4 data are presented for two diameter classes, 5.0-14.9 and 15.0-29.9 cm dbh, in three consecutive periods of two years, and in Fig. 8.5 girth increment per diameter class is presented. For the smaller trees, increment decreased between 1976 and 1980 whereas for larger trees, above 30 cm dbh, (represented only in Fig. 8.5) increment increased in this period. This same change of pattern was found in comparable treatments in Expt 67/9 A (Chapter 7).

In general, growth of the small trees was stimulated very soon after treatment, and was suppressed again within five to six years. This trend will continue (as was shown in Expt 67/9 A) if the stand is left untreated. A negative selection exerted on the population of these small trees could be expected; those growing well soon leave the lower classes, which then will contain mostly stagnant trees. This negative selection would strengthen the effect of growth retardation by increased competition.

Data presented in Figs 8.4 and 8.5 are considered to be typical for developments during the first years after refinement. A wider selection of trees according to species and quality would give a lower mean annual girth increment in this treated stand of Expt 67/9 B, where secondary commercial species are not numerous. In Expt 67/2, commercial species as a group grew faster than all species of the forest grouped together. This situation is reversed when the stand is destroyed to an extent that secondary species spring up in masses.

An example of increase in volume production with increasing diameter is presented in Table 8.6. The volume increment was calculated from the girth increment in period III (Fig. 8.5) with the aid of the volume tariff (Appendix VII). Table 8.6 shows the superiority in volume production of the large trees, as a tree of, for example, 40 cm dbh produces twice as much as a tree of 25 cm dbh. Moreover, there are no indications of a decrease in production with size of the individual tree in the range of stem diameters available.

If no further treatment is given to the forest in this experiment, the girth increment pattern of commercial species over the years is expected to be similar to that in treatment 20 + 0 of Expt 67/9 A. This will not favour trees of commercial species in the lower diameter classes, because competition will be harsh and recruitment minimal. Volume increment of the large trees will not be reduced very much because of lack of a second treatment, and their increased numbers will compensate partly for the reduced individual growth.

The total basal area data for the 1979 tally of one-hectare plots and half-hectare plots were used to calculate regression of annual girth increment (y) in the period 1978-1979 of commercial species, on total basal area of all species (x), the latter being used as a measure of competition. Girth increment data for the group of the four most abundant commercial species (11, 24-28, 37 and 40, form class I) were used, and two diameter classes: class 2, 15.0-29.9 cm dbh; and class 3, 30.0-44.9 cm dbh. At least five individual trees were required per plot to provide a mean girth increment.

Regression equations in both cases had regression coefficients near to zero, and low coefficients of determination. For stem-diameter class 2, the regression

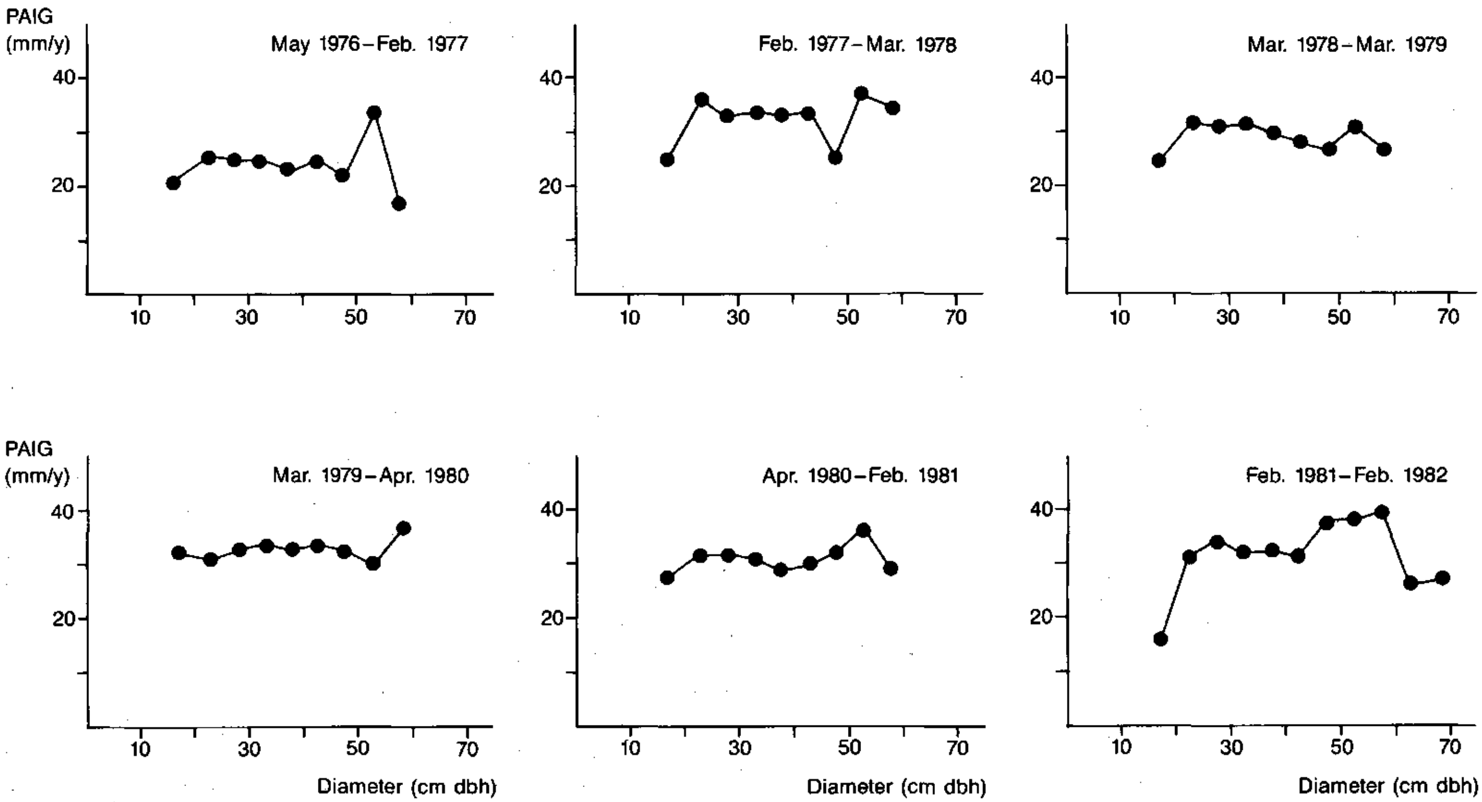

Fig. 8.3 Expt 67/9 B: annual girth increment in mm/y of commercial species 11-41 form class I per diameter in six successive years (1976-1982). Data have been corrected to represent a 12-month average.

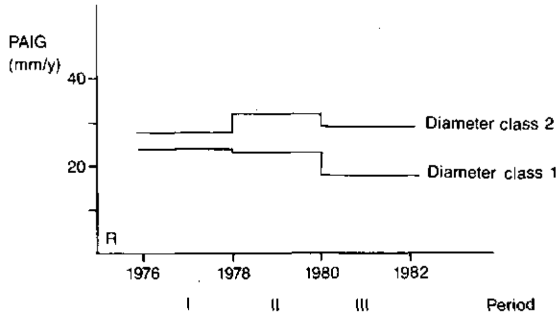

Fig. 8.4 Expt 67/9 B: periodic annual girth increment (PAIG) in mm/y, of commercial species 11-41 form class I in two diameter classes (1, 5.0-14.9 cm dbh; and 2, 15.0-29.9 cm dbh) in three consecutive 2-year periods (I-III). See also Fig. 7.12.

equation was: $y = 0.08\,x + 30.97$, with $R^2 = 0.001$; and for stem-diameter class 3, $y = -0.09\,x + 32.68$, with $R^2 = 0.003$. Basal area ranged from 8.7 m^2/ha to 20.1 m^2/ha. Annual girth increment for trees above 15 cm dbh was mostly higher than 25 mm, with the lowest three of the 29 values used being about 20 mm.

These regression coefficients were unexpectedly low, whereas in Expt 67/9 A and Expt 65/3 reasonably high regression coefficients were obtained. A possible reason for this may be the short period of only four years which had elapsed after initial refinement in Expt 67/9 B before the data were collected. In the other experiments, regression analysis was based on data collected about ten years or more after initial refinement. The refinement releases a lot of nutrients, and it is well possible that competition is not yet affected greatly by total basal area in freshly treated stands.

The size of the sample plots may influence the success of regression studies such as these, but in Expt 67/9 A the plot size of 0.64 ha did produce a reasonably high coefficient of determination. With the very small plot size in Expt 65/3 of 0.07 ha, a high coefficient was obtained, but these plots had only very few large trees.

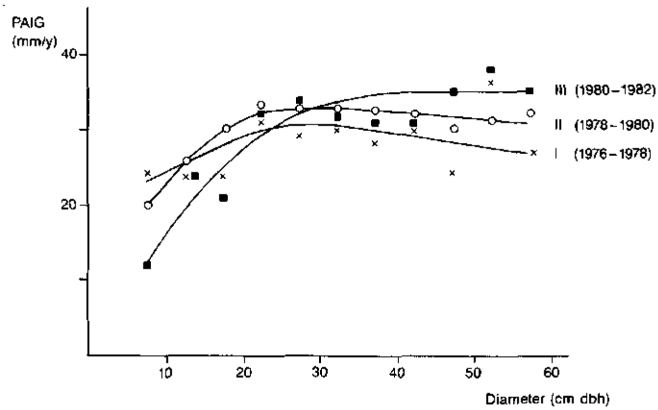

Fig. 8.5 Expt 67/9 B: periodic annual girth increment (PAIG) in mm/y, of commercial species 11-41 form class I per diameter in three consecutive 2-year periods (I-III). See also Fig. 7.13.

TABLE 8.6 Expt 67/9B: annual bole volume increment of individual trees of a certain initial diameter, when growing according to the girth increment curve of period III in Fig. 6.4

Initial stem diameter (cm dbh)	Annual bole volume increment (m^3/tree)
10	0.005
15	0.014
20	0.026
25	0.042
30	0.059
35	0.075
40	0.088
45	0.103
50	0.114
55	0.124

As an example of the variation within diameter classes, girth increment curves for the species *Virola melinonii*, of form class I are given in Fig. 8.6. Data used are from plots under two treatments, treatment 0 in Expt 67/9 A over 3.2 ha, and treatment 20 + ... in Expt 67/9 B over 16 ha. The number of trees per diameter class varied from 4 to 8 in treatment 0, and from 4 to 13 in treatment 20 + ...; all trees were of form class I. In spite of the large standard deviations, the treatments still clearly differ in girth increment. Increment reactions are largest in diameter class 15.0-24.9 cm.

The variation in girth increment of these trees of good stem form can be explained in terms of the variation in growth conditions of individual trees in this forest. Poor growth of certain individuals may be ascribed partly to hidden causes, not indicated in a classification of tree form as applied here, for example rot of the central root system, small size of an otherwise normal crown, individual suffering from leaf insect or leaf blight attack, and temporary exhaustion caused by heavy flowering or seeding. Competition from larger trees nearby, which usually affects the growth of smaller trees considerably, is not difficult to detect and is responsible for most of the poor growth. In treatment 20 + ..., the standard deviation for girth increment in the smallest diameter class was much smaller in period II than in period I, very shortly after release by the refinement, thus indicating recovery of some trees from a suppressed position.

How such curves change over the years has been discussed in Section 7.11, and for individual species by de Graaf and Geerts (1975). The changes brought about by silvicultural treatment can be easily visualized from such girth increment graphs. On the basis of these developments in girth increment, *Virola melinonii* has been

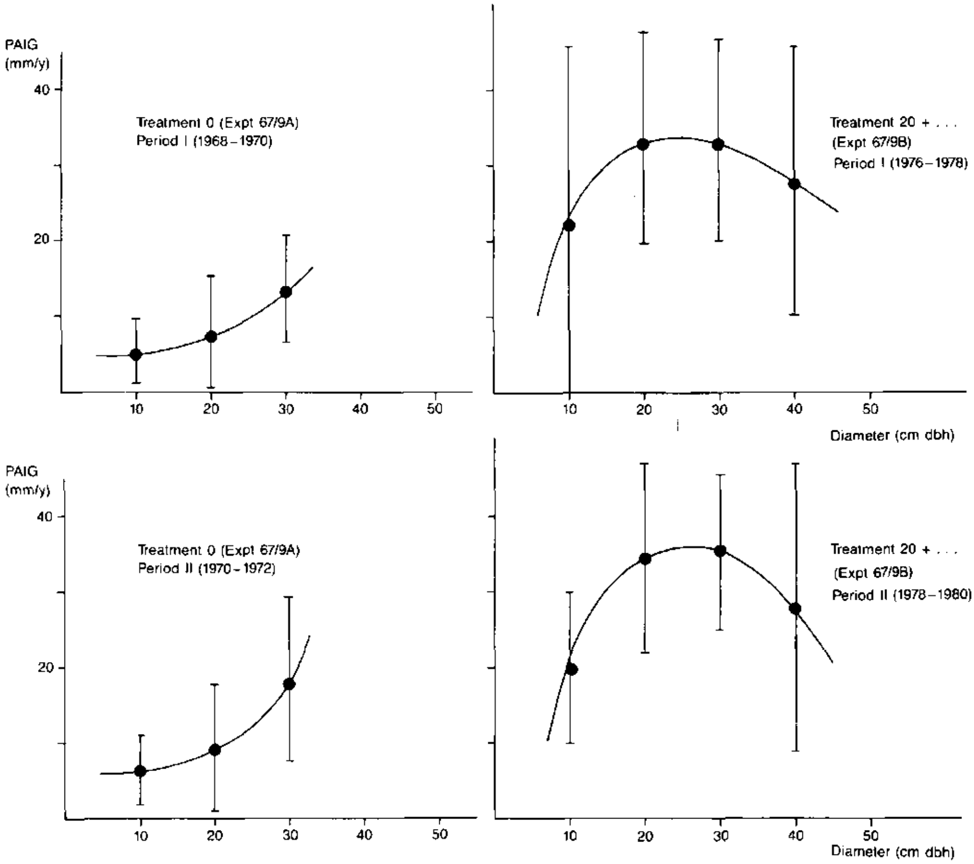

Fig. 8.6 Expt 67/9 B: periodic annual increment of girth (PAIG) in mm/y per diameter in a population of *Virola melinonii* form class I, in two 2-year periods (I and II) after commencement of treatment: treatment 0, no refinement and treatment 20 + ..., refinement with diameter limit of 20 cm, to be followed by a second treatment at a point of time not yet fixed. Standard deviations indicated by verticals in the curve.

categorized by de Graaf and Geerts (1976) as a non-obligatory, light-demanding species, which reacts favourably to silvicultural assistance by refinement and liberation, especially trees of small size. During the early life stages the species seems to be somewhat vulnerable to competition. When shaded in heavy thickets, it often forms a slender stem, too thin to support itself when liberated drastically. Its whorls of horizontal branches are of great assistance in climbing to the light through heavy foliage, and shoot length in the past is easily indicated by whorl distances. *Virola melinonii* clearly displays its architecture, which follows Massart's model (Hallé and Oldeman, 1975).

8.8 Mortality

Data are available on mortality in the population of listed commercial species for the period 1976 to 1982. No information is available on mortality in non-commercial species, but it could be assumed that mortality for these species, apart from deaths due to refinement, was roughly the same as that for commercial species, as indicated in the data from Expt 67/2 (see Section 6.7).

In Table 8.7 the mortality rates are given for species group 11-41 form class I. Data for analogous periods in Expt 67/9 A are given for the two treatments corresponding most closely with the treatment in Expt 67/9 B. The small size of the population sampled in these plots of Expt 67/9 A has led to large variation. As mortality data are considered to be less reliable for samples of less than ten trees per diameter class, in Expt 67/9 B average rates are based on data for the first four diameter classes only. Saplings below the 5 cm dbh limit were sampled inadequately. These probably have a higher than average mortality rate, as had the seedlings and saplings studied by Boerboom (1969), who found a 15% annual mortality rate for small saplings, and about 50% annual mortality for seedlings.

Mean annual mortality rate was low in Expt 67/9 B in period I (1976-1978), when most trees killed by the refinement were still standing dead (see Table 8.7). In Expt 67/9 A, mortality was high in the first period after refinement, and probably was promoted by the drought in that period. In Expt 67/9 B, mortality during period II (1978-1980) was high in diameter class 5.0-14.9 cm dbh. This may have also been the result of drought in 1979-1980 and of deaths due to falling dead timber. The layout with 40 circular plots has the inherent danger of a whole sample plot being destroyed by only one large falling tree, and one plot destroyed means

TABLE 8.7 Expt 67/9B: annual mortality rates per diameter class in three consecutive periods for commercial species 11–41, form class I, for treatment schedule 20 + ... in Expt 67/9B and for treatment schedules 20 + 0 and 40 + 0 in Expt 67/9A

	Treatment code	Diameter class*					Mean for class 1–4
		1	2	3	4	5	
Period I****	20 + ...**	2.4	0.6	1.3	1.3	0	1.4
	20 + 0***	2.8	4.8	4.2	(50)	n.a.	
	40 + 0***	0	2.0	4.2	0	n.a.	
Period II	20 + ...	4.5	1.9	1.0	3.1	5.6	2.6
	20 + 0	1.8	0	0	0	n.a.	
	40 + 0	2.4	0	0	0	n.a.	
Period III	20 + ...	1.6	2.2	3.2	3.3	0	2.6
	20 + 0	5.3	9.4	4.2	0	n.a.	
	40 + 0	1.1	0	4.6	0	n.a.	

* See Table 7.5.
** Expt 67/9B.
*** Expt 67/9A.
**** Period I, 1–3 years after initial refinement (1976–78 in Expt 67/9B, and 1968–70 in Expt 67/9A); Period II, 3–5 years after initial refinement; Period III, 5–7 years after initial refinement.

2.5% mortality in the sample population. During period III, mortality rate in this diameter class returned to average values.

During the six years covered, the average annual mortality rate for trees 5.0-59.9 cm dbh was about 2.2% for species 11-41 form class I. For commercial species 11-58 form class III the annual mortality rate was somewhat higher, about 2,4% (van der Hout, 1983).

Comparison of mortality rates with other silvicultural experiments, even within Suriname, is difficult. In Expt 67/2, mortality was quite erratic for the relatively small populations of commercial species sampled in the two series of plots of five ha (see Chapter 6). For all species, with a population size of about four times that of the commercial population, more reliable average annual mortality rates for stem-diameter classes 25.0-74.9 cm dbh were obtained, being 2.3% for Sarwa and 2.1% for Goliath. Mortality rate under treatment o of Expt 67/9 A for the same species and quality selection as used in Table 8.7 but over a period of 12 years was quite low (1%) compared with the mortality in Expt 67/2 under the same treatment. The scant data in Expt 67/9 A (see Table 7.13) suggest decreasing mortality rate with increasing stem-diameters, but this is not plausible, and moreover does not agree with the fairly even distribution of mortality in Expt 67/2.

Mortality should be studied in quite large populations, larger than necessary for other variables, such as girth increment in reaction to treatment, and recruitment rates from seedlings. The studies need to cover more than a decade. Expt 67/9 B, with 16 ha recorded area, has one of the largest tree populations thus studied in Suriname.

With the average mortality rate in lightly exploited and further untreated forest of Expt 67/2 and in the lightly exploited and afterwards refined forest of Expt 67/9 B both being about 2,2%, it could be concluded that refinement does little damage to the population of commercial species. This is an unexpected conclusion for those that know the ravage done by falling dead timber in refined stands. For smaller individuals than those represented in Table 8.7, that is seedlings and small saplings, the mortality rate probably will be higher, as it is normally also in less disturbed forest. These categories of seedlings and small saplings are easily replenished by natural regeneration if opportunity permits. Replenishing losses of larger saplings takes more time.

Mortality of medium-sized and large trees has a considerable impact on volume production in the stand, as was shown in Expt 67/2. For Expt 67/9 B this impact was confirmed in a study of van der Hout (1983). During the six years studied, the total volume of commercial species above 15 cm dbh which was lost annually by mortality was about 0.5 m^3/ha, that is a quarter of the net volume increment of 2.0 m^3/ha. This is in agreement with a 2% annual volume loss from mortality in a stand containing about 25 m^3/ha volume of commercial species above 15 cm dbh. Harvesting logs from dead trees is almost impossible outside the planned cyclic harvest.

Van der Hout (1983) found that 10% of individual trees was degraded in quality before finally dying. Such effects obscure part of the mortality of the trees of commercial species of form class I. Badly formed trees were found to have a higher mortality rate than well formed trees. The straight and slender stem form of most trees in tropical rain forest testifies to the rigid selection pressure exerted by the environment.

8.9 Aerial and terrestrial photographs and forest profile diagrams

Aerial photographs taken in 1982, seven years after the initial refinement, are presented in Fig. 8.7. Virtually all emergent trees in the plot are of commercial species released from competition for light by the refinement, and most of these have since become highly productive. The aerodynamically rough vegetation structure has been maintained, and the uniform treatment has not led to uniform forest.

The forest profile diagrams show the variation in the vegetation after treatment. The forest profile in Fig. 8.8, drawn in 1982, shows part of subplot 13 containing

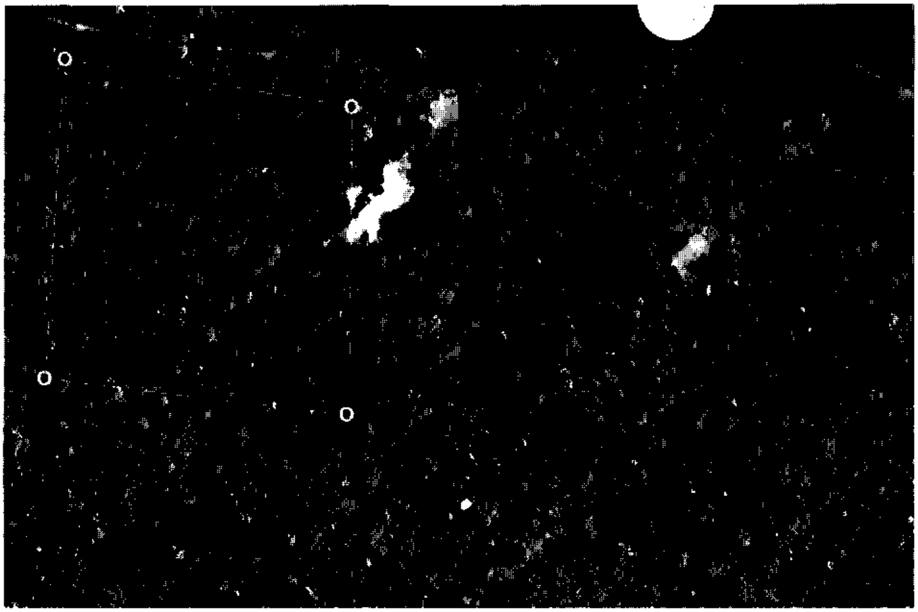

Fig. 8.7 Expt 67/9 B: aerial photograph in 1982, seven years after initial refinement. The 25 ha plot is visible as a square of about 4 × 4 cm in the upper part of the photograph, the left hand photograph of the pair shows the all-weather road north of the plot. Note the irregular structure of the canopy, the few patches of secondary vegetation and the many medium-size and large trees of commercial species left in refinement. A few skeletons of trees killed in 1975 are still visible, but most trees killed at that time fell some years ago. The dry gully running from the north-west to the south-east is more or less discernible, as are the bends of the Mapane river south of the plot. Vegetation in the plot should be compared with that east of the plot, because the forest area south of the Mapane river is quite variable, due to variation in soils and topography. Photo by courtesy of CBL, Suriname.

many commercial species, but only a few medium-sized and no large trees. Two other forest profile diagrams (Figs 8.9 and 8.10) show more medium-size and large individuals, and confirm the impression obtained from the aerial photographs. From Expt 67/9 A it was expected that without further treatment a dense canopy would develop in the 10-20 m height zone within ten years. Such a dense canopy had already developed in some parts of the 25 ha plot in 1982. The photograph of subplot 13 in Fig. 8.11 demonstrates the effects on the undergrowth. Only a few large trees were present before refinement, and basal area in plot 13 had reached 20.1 m^2/ha in 1979, which is very high compared with the average of 13.6 m^2/ha (see also Table 8.9).

Mortality increased slightly after refinement, as already discussed, and the aspect of a fall of an apparently healthy and promising tree of commercial species is shown in Fig. 8.12. Such casualties must be included in estimates of future yield. Not all trees killed in refinement have fallen as yet, but a gap made by such dead timber is shown in Fig. 8.13. Mostly only small trees or saplings are killed directly, but damage can be extensive when liana tangles are hit, thus resulting in groups of bent or broken saplings.

According to the scale of accessibility for treated stands of von Meyenfeldt (1975), given in Table 8.8, Expt 67/9 B could be classified as accessible (score 2) before refinement, with restricted access in some places as a result of the light exploitation. After refinement, the upper storeys became more open for some years, a dense undergrowth developed, and accessibility was reduced (score 3 or 4). By 1979 the situation had improved at places under heavy tree cover, and in 1982 access generally was quite acceptable, (score 2 or 3). In management it is at least six or eight years after a heavy refinement before a labour gang can work easily in the stand, especially if considerable areas have to be covered. The lighter the refinement is, the shorter this period of restricted accessibility.

Accessibility can be judged fairly well from the terrestrial photographs. The 1982 photograph of a part of Expt 67/9 B in Fig.8.11 shows an accessibility score 2. This part of the stand was more open than usual; at that time Expt 67/9 B still showed some variation in accessibility. In the terrestrial photographs of plots of Expt 67/9 A the score of accessibility for treatment 40 + 0 is 1, for treatment 0 is 1 or 2, for 20 + 0 is 2, for 40 + D 8 is 3, and for 20 + D 8 is 2 or 3.

8.10 Variability

To indicate the degree of variation in the stand, data on individual plots are discussed. Firstly, the situation with the circular plots is discussed, then data per ha plot and finally the differences between the 17.7% sample with circular plots and the full enumeration of 16 ha are discussed briefly.

Circular plots. Using the numbers of trees of commercial species in the 40 circular plots, the distribution of the trees was studied (M.A.J. van Montfort, personal communication). The numbers of commercial trees above 5 cm dbh per plot varied

Fig. 8.8 Expt 67/9 B: forest profile diagram of a 20 × 50 m plot located in subplot 13 (see Fig. 8.1), showing only few medium-sized and no large trees, though the number of trees of commercial species present is considerable in subplot 13.

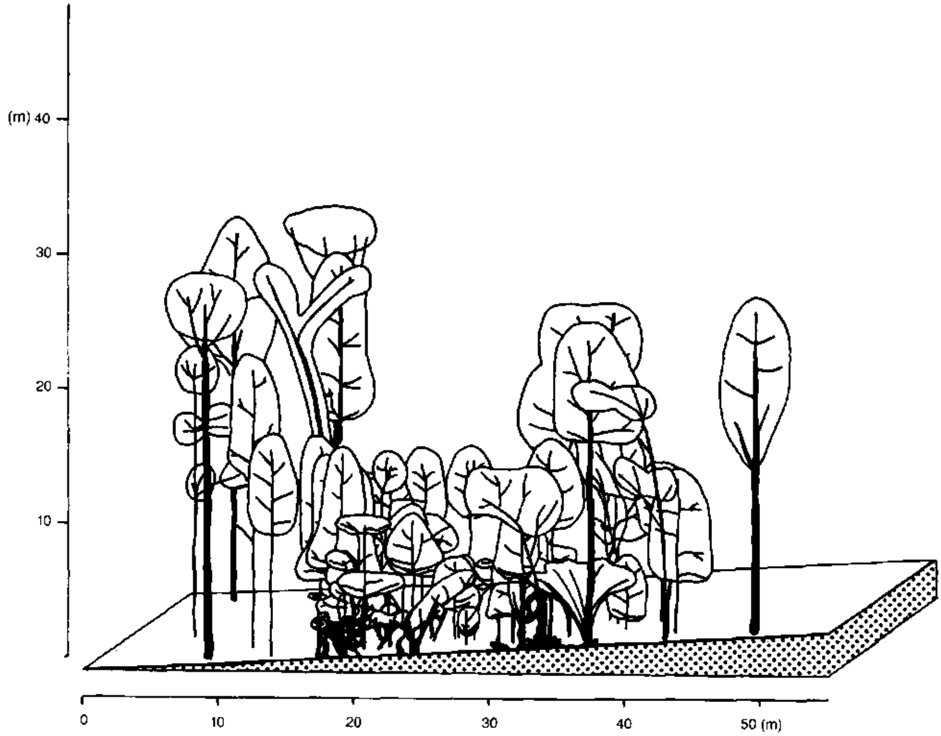

Fig. 8.9 Expt 67/9 B: forest profile diagram of a 20 × 55 m plot, drawn following a method different from the method used in foregoing profile diagrams. The large trees are all of commercial species, as all non-commercial species above 25 cm dbh were killed during refinement. This part of the experimental area was only lightly influenced by the silvicultural treatment. Reproduced with kind permission from Voordouw (1985).

from 4 to 39; the circular plot area was 707 m^2. The Pearson's Chi-square test indicated that distribution over the plots was not random. Analysis of variance applied to these data for 20 pairs of circular plots showed a negative correlation between number of trees per plot within a pair. Differences between such pairs were smaller than would be expected from differences within pairs.

These results indicate considerable differences over short distances in the stand, and demonstrate the small scale of the regeneration processes. The distance between the centres of plots was 50 m, and because the diameter of the plots was 30 m, the closest points of the plots were 20 m apart. Areas of differing regeneration phases may well be of the order of magnitude of the circular plots. Such size is suggested also from the size of the gaps formed by fallen large trees.

One-hectare and half-hectare plots. The experiment has 12 one-ha subplots, and eight half-ha subplots (see Fig. 8.1). Correlation studies were done on total basal area per plot above 5.0 cm dbh, and number of trees of commercial species above the 15.0 cm dbh limit, and also the corresponding basal area of this population (see also Table 8.9). The group selected was species 11-58, and two form classes were

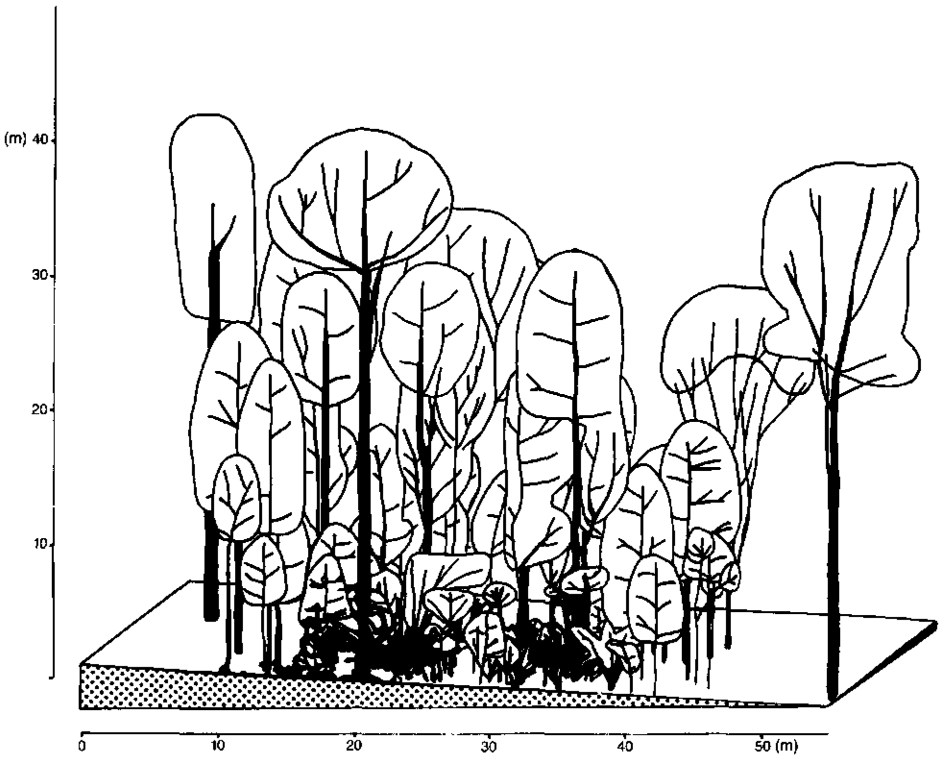

Fig. 8.10 Expt 67/9 B: forest profile diagram of a 20 × 55 m plot drawn with the same method as used in Fig. 8.9. Note the quite open vegetation and the lack of large trees in this plot that was heavily influenced by the refinement seven years ago. Reproduced with kind permission from Voordouw (1985).

used, class I and class III. Correlation between total basal area and number or basal area of commercial species was shown to be low, with coefficients in the four cases between 0.40 to 0.42. At this stage, refinement has had little effect on the number and basal area of commercial species.

Variation between plots was considerable (see Table 8.9). In plot 18, the total basal area was very low (8.7 m^2/ha), probably as a result of the destruction of many smaller trees near the skid roads in this plot of only 0.5 ha. Many larger trees left undamaged by the machines have been killed subsequently by the refinement (see aerial photograph in Fig. 8.7.) Basal area of commercial species of class I was lowest (1.71 m^2/ha) in plot 19 nearby. As total basal area in this plot was high and commercial species of class III were well represented, with a basal area of 3.32 m^2/ha, a large number of damaged trees of commercial species must explain this. Exploitation could have had much to do with this, because there are many skid roads in this area (see Fig. 8.1) but they are not obvious on the aerial photographs.

Highest total basal area and highest number of trees and corresponding basal area for commercial species of both form classes (see Table 8.9) were found in plot no 13. The high total basal area after refinement may be explained by the very few large trees of non-commercial species in this plot before refinement, corresponding

Fig. 8.11 Expt 67/9 B: subplot 13 in 1982, seven years after initial refinement (photo by author). Note fallen logs and trunk of tree killed in 1975, and good accessibility caused by closed canopy.

with an abundance of smaller trees in the same area, many of which are of commercial species. This stand was photographed in 1982 (see Fig. 8.11), and the vegetation structure at that time was as it probably will be in the other plots in about 1987.

TABLE 8.8 Expt 67/9B: scale of accessibility of a forest stand.

Accessibility score		Description	Example of vegetation
1	Well accessible	Walking in a nearly straight course is easy without machete	Virgin forest outside chablis
2	Accessible	Without machete no straight course can be followed	Old secondary forest
3	Less accessible	For walking the machete has to be used regularly	
4	Badly accessible	No progress without machete	Young secondary forest
5	Very badly accessible	Nearly impenetrable without constant use of machete	Liana tangle, Solanum thorn bush

Source: von Meyenfeldt, 1975.

Fig. 8.12 Expt 67/9 B: chablis, caused by the recent fall of a *Vouacapoua americana* tree, some 30 cm in diameter, and lying along a path (photo by author). This is one of the usual 2% annual mortality cases. Such a small gap as shown here is expected not to raise much additional secondary species in the vegetation, but to close mainly by regrowth of branches of trees standing on the margin of the gap, and by promoted growth of seedlings and saplings present already inside the gap. The relatively small trunk of the *Vouacapoua americana* will lie for another half century, as its heartwood is very durable. Such dead stems with sapwood rotted away are preferred by local people for beams in durable constructions, as they are more easy to transport. By contrast the non-durable stem of a *Virola* sp. would be recognizable after falling only for five to ten years, or even less. The clod of earth raised by the root system of the fallen tree will over some decennia be visible only as a small irregularity in the soil level, probably with some washed-out laterite gravel on top. Note the liana alongside the fallen tree. The path (line 100, see Fig. 8.1) between the blackboard and the raised rootsystem causes an unnatural scarcity of seedlings in the foreground. The sapling one metre beyond the blackboard shows regeneration of the main shoot at circa 2 metres height, with the old stump still protruding. This weak spot in the stem, prone to access of rainwater and fungi, can have grave consequences for the future life expectance of the tree. On the small tree some four metres beyond the blackboard the slender and drooping leaves of an epiphyte (*Heteropsis* sp., Araceae) are visible. Its local name is *kamina*; its long roots are collected for strong wickerwork and use as bush rope.

Comparison of stand table of the circular plot sample and of the total experimental area. Stand tables for Expt 67/9 B, constructed from data from the 40 circular plots and from the full enumeration of the 16 ha recording area are presented in Table 8.10. A simple comparison can be made of the differences in results of restricted sampling in 2.83 ha in 40 plots, well distributed over the experimental area, and a full inventory. In spite of the high sampling percentage, the circular plot sample is quite different from the full inventory. The circular plot sample gives a too optimistic picture for diameter class 2 (15.0-29.9 cm), and a too pessimistic picture for diameter class 4 (45.0-59.9 cm). A possible explanation is that the species group studied occurs in groups corresponding with the regeneration pattern. Total basal area estimates (see Table 8.10) are also too high in the circular plots. Apart from these differences, there is progress in the stand tables over the years, as a result of the silvicultural treatment.

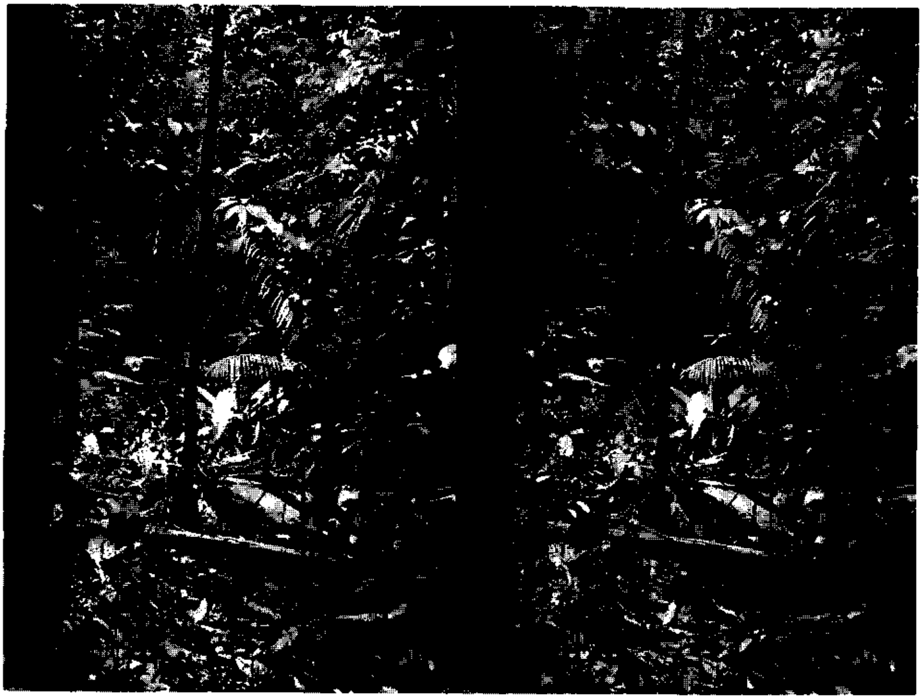

Fig. 8.13 Expt 67/9 B: gap in the undergrowth caused by a recently fallen large piece of timber from a dead tree already overgrown with epiphytes (photo by author). In the foreground some vegetation was removed to have a better view on the fallen timber, from which the shattered pieces are partly visible in the shambles of the crushed vegetation. The large leaves are of an epiphyte, an Aracea. This photograph was taken in the surround, just over the northern border of subplot 1. Such small gaps close again without much secondary vegetation developing. The palms (*Astrocaryum* sp.) visible here will have some highly productive years, until they are overshadowed again. The sapling bent over to the right might produce a thick perpendicular shoot in coming years, to resume its place in the canopy. The bent part of the stem then often dies off and rots away.

8.11 Conclusions

Stem-diameter distribution and rate of girth increment and volume increment per diameter class were still changing in this forest stand; a balance as existed in the original undisturbed forest had not yet been attained. The irregular structure, with many emerging crowns, was similar to that of the original forest, but there were more small trees and the upper storeys were more open. The average annual mortality rate was slightly higher than 2%. Volume increment of commercial species had been stimulated by the refinement to such an extent that the net increment was about 2 m^3/ha for commercial species 11-41 form class I above 15.0 cm dbh. This value is expected to increase further because of the increasing number of highly productive medium-sized trees. Volume production was optimal for these commercial species above 25 cm dbh, with an annual rate of more than 10%, indicating the high return to be expected when trees of about harvestable dimensions are saved from exploitation.

Data for plots under similar treatment schemes in Expt 67/9 A indicated that volume increment would continue at this level for some years to come even if the second refinement were postponed. However, recruitment needed to be stimulated, and a second treatment should be given in time to increase numbers of trees of commercial species in the lowest diameter class, and to stimulate graduation of trees to higher diameter classes. Results of Expt 65/3 have shown such treatment to be successful. Data on volume production and cost in this trial indicate the feasibility of a silvicultural system based on restricted harvesting and stimulation of volume increment and recruitment of commercial species. Increment was sufficient to produce an additional gross standing volume of 40 m^3/ha above felling diameter, in a 20-year cycle, more than enough to provide for a net volume of 20 m^3/ha of selectively felled timber, leaving defect trees and less popular species if necessary. To harvest 20 m^3/ha, about ten trees of 50 cm dbh will have

TABLE 8.9 Expt 67/9B: mean, range and standard deviation in a sample of 20 subplots, for total basal area of all species, and for number and basal area of trees ≥15 cm dbh per ha of commercial species 11-58, form class I and III in 1979

	Total basal area of all species (m^2/ha)	species 11–58, above 15 cm dbh			
		Form class I		Form class III	
		N/ha	Basal area (m^2/ha)	N/ha	Basal area (m^2/ha)
mean	13.6	34.4	3.39	57.4	5.03
range	8.7-20.1	12–76	1.71–5.64	28–100	3.26–7.28
SD	3.3	13.4	0.93	16.8	1.29
%	24	39	27	29	26

TABLE 8.10 Expt 67/9B: development in stem-diameter distributions of commercial species 11–58, form class III, in 17.7% sample with circular plots, and full enumeration of 16 ha, and development of total basal area above 15 cm dbh of the same group of commercial species.

Diameter class*	17.7% circular plot sample			16 ha full enumeration		
	1976	1978	1980	1976	1978	1980
1	94.3	109.9	118.4	n.a.	n.a.	n.a.
2	46.3	409.1	47.4	29.8	27.6	31.9
3	16.3	17.3	21.6	17.4	18.8	19.7
4	2.8	3.9	4.2	5.3	5.7	6.3
5	2.1	2.1	1.8	1.1	1.3	1.5
6	0.4	0.4	0.4	0.3	0.3	0.4
7	0	0	0	0.1	0.1	0
Total >15 cm	67.9	72.8	75.4	54.0	53.8	59.8
Total >5 cm	162.2	182.7	193.8	n.a.	n.a.	n.a.
Total basal area >15 cm dbh (m^2/ha)	5.36	5.93	6.38	4.72	4.96	5.39

* See Table 7.5.

to be taken, and the development of the stem-diameter distribution in this experiment, together with the diameter increment of about one cm annually, indicates that this amount will be available at the end of the cycle, if all trees of species 11-41 form class I of a diameter above the felling limit are accepted.

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APPENDIX I

Rainfall data for Kamp 8 and Goliath.

The two rain gauge stations nearest to the locations of the experiments are Kamp 8 in Mapane, and Goliath in Coesewijne. The distance from Kamp 8 to Expt 65/3, Expt 67/2, Expt 67/9A and B is about 1.5, 6.5 and 7 km respectively, and from Goliath to the site of Expt 67/2 about 2 km.

Daily rainfall data were available for many years, but these have been converted to monthly totals, because increment and mortality of trees, which are influenced most by the rainfall, are given in one or two-year periods. Recording periods for most experiments end in June or July. Dry months have been defined as having a rainfall of less than 100 mm, and very dry months as having a rainfall of less than 60 mm. Severe drought occurred in recording periods 1963-64; 1964-65; 1969-70 and 1979-80. Data for 1975 from the Coebiti station, which is nearest to Goliath, have been included in Table I.2.

TABLE I.1 Total monthly rainfall (mm) at Kamp 8, Mapane.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1960	256.6	n.a.	n.a.	n.a.	n.a.	247.0	297.2	168.9	29.4	148.8	176.7	128.7	n.a.
1961	256.6	n.a.	34.8	n.a.	n.a.	446.2	193.9	168.5	102.5	144.5	194.1	270.0	n.a.
1962	167.7	149.2	116.7	130.9	232.0	258.3	206.0	160.5	52.5	68.2	146.6	140.5	1 829.1
1963	302.7	288.5	154.9	183.1	429.2	270.8	167.6	194.1	73.7	13.7	46.9	113.2	2 238.4
1964	93.9	21.3	74.2	31.8	165.4	208.0	240.8	196.2	43.4	49.8	66.4	260.3	1 451.5
1965	225.9	70.4	83.4	85.7	304.9	209.0	263.6	105.6	97.8	44.3	121.9	134.9	1 747.4
1966	132.1	65.7	205.1	131.2	314.5	375.8	279.9	159.7	88.1	156.3	117.1	144.9	2 170.5
1967	225.9	88.1	110.2	243.7	293.2	323.0	162.5	110.2	137.9	45.3	190.7	115.2	2 045.9
1968	206.2	162.9	209.7	337.3	220.2	204.1	137.2	152.2	106.0	125.8	178.9	161.8	2 202.3
1969	212.4	162.8	139.3	282.4	309.5	233.7	69.4	71.4	28.1	16.5	40.6	166.3	1 723.4
1970	322.3	213.1	208.2	389.0	513.0	350.0	285.0	219.3	80.6	85.2	55.3	202.9	2 823.9
1971	315.4	327.8	278.0	198.3	358.8	298.2	194.0	140.8	65.7	134.2	60.3	43.1	2 414.6
1972	273.2	164.0	163.9	250.7	246.2	223.0	272.0	133.0	118.7	57.4	139.7	125.9	2 167.7
1973	68.9	175.4	93.4	206.1	312.1	370.8	146.8	108.4	n.a.	158.6	174.7	297.9	n.a.
1974	314.8	127.9	232.0	77.3	144.6	236.2	276.1	139.6	178.5	165.3	119.9	n.a.	n.a.
1975	329.1	190.9	170.6	132.0	135.2	312.1	425.2	273.2	182.5	20.0	101.9	134.1	2 586.8
1976	276.6	159.1	221.1	335.5	493.1	221.3	292.1	106.1	64.5	2.6	108.5	306.9	2 587.4
1977	133.4	83.5	151.0	342.0	306.2	264.2	322.9	157.7	198.7	113.7	104.6	168.4	2 346.1
1978	147.3	146.4	80.0	231.7	301.5	271.8	267.1	304.8	145.9	182.6	123.6	n.a.	n.a.
1979	188.1	24.2	287.1	347.4	259.9	359.7	250.2	75.9	98.9	76.4	54.4	191.2	2 213.4
1980	44.6	28.6	227.9	342.9	274.4	345.5	237.4	188.7	80.2	114.3	205.8	155.4	2 256.3
1981	135.1	344.3	168.2	403.4	220.2	333.3	404.5	157.6	104.3	170.0	106.1	146.0	2 693.0

Source: Field records made available by the Meteorological Service of Suriname.
n.a.: not available.

TABLE I.2 Total monthly rainfall (mm) at Goliath, Coesewijne.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1970	n.a.	n.a.	297.3	265.8	434.3	267.0	404.7	233.2	108.3	15.0	114.9	228.9	n.a.
1971	446.5	238.5	160.0	278.4	281.6	362.0	196.6	211.5	20.2	59.1	117.0	78.0	2 449.4
1972	289.1	117.9	243.5	339.1	351.6	279.7	191.7	129.5	173.7	35.2	213.4	89.5	2 453.9
1973	91.0	174.8	145.9	179.4	358.9	373.7	202.4	139.6	211.0	211.5	188.0	201.5	2 477.7
1974	300.9	100.9	117.4	99.4	140.0	243.6	311.4	177.4	245.8	n.a.	171.2	343.5	n.a.
1975	211.5	64.9	106.5	123.0	315.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1976	229.7	211.0	230.1	297.9	355.2	265.1	231.9	79.6	46.8	17.1	120.6	195.7	2 280.7
1977	100.4	93.0	131.4	292.0	247.0	210.6	326.4	293.7	128.0	98.3	113.3	175.4	2 210.4
1978	149.4	138.9	93.0	156.1	310.7	175.6	121.2	155.8	88.6	126.3	138.3	328.4	1 982.8
1979	104.0	33.6	151.7	345.8	174.8	251.1	282.2	144.1	145.9	78.1	83.9	273.0	2 068.2
1980	42.0	24.9	162.0	282.1	348.2	233.9	154.1	87.8	105.3	104.3	213.3	136.3	1 894.2
1981	86.0	222.2	116.4	328.6	338.8	269.1	226.2	88.5	15.3	146.6	79.7	183.8	2 101.2
Additional data for Coebiti:													
1975:	270.1	124.2	107.5	91.8	295.1	314.8	252.8	190.8	104.3	104.6	85.4	142.3	2 083.7

Source: Field records made available by the Meteorological Service of Suriname.
n.a.: not available.

Appendix II

Summary in the English language from Boerboom, J.H.A., 1964. De natuurlijke regeneratie van het Surinaamse mesofytische bos na uitkap. [The natural regeneration of the mesophytic forest of Suriname after exploitation]. Landbouwhogeschool, Wageningen, the Netherlands.

Investigations are reported of the natural regeneration in the Surinam 'drooglandbos' (= highland forest), carried out by the Forest Service of the Department of Development of Surinam. The forest type under consideration forms part of the Tropical Rain Forest (sensu Richards); presumably it is identical to Beard's Evergreen Seasonal Forest.

These investigations, in which the author participated from 1960-1964, were based on Schulz's ecological studies in Northern Surinam. As several experiments are being continued to-day, some parts of the present report are preliminary.

Surinam, on the northern coast of S. America, extends between lat. 2° and 6° N. Mean annual precipitation varies from 2 000-2 400 mm (80-96 in.). There is a marked seasonal distribution in rainfall with two distinct maxima. Temperature averages 27 °C with only slight seasonal variations.

Inland from the Surinam coast the following formations are met: (1) mangrove forest, (2) swamp and marsh forest, (3) savanna and xerophytic forest ('savanna forest'), and (4) mesophytic (highland) forest. The last formation occupies approx. 75% of the country.

The highland forest supplies all the timber for the Paramaribo market, the main species being *basralocus (Dicorynia guianensis), kopie (Goupia glabra),* and *wana (Ocotea rubra).* The supply of other valuable timber species is irregular: *bruinhart (Vouacapoua americana), groenhart (Tabebuia serratifolia), krapa (Carapa* spp.*), rode kabbes (Andira* spp. + *Hymenolobium* spp.*), zwarte kabbes (Diplotropis purpurea), rode lokus (Hymenaea courbaril), slangenhout (Loxopterygium sagotii), rode salie (Tetragastris altissima), pisie (Ocotea* spp. + *Nectandra* spp.*), gronfoeloe (Qualea* spp.*),* and *bolletrie (Manikara bidentata).*

For centuries the working of the forest has been confined to narrow strips along rivers and creeks. The present Forestry Service, created in 1947, carried out forest inventories; subsequently forest access roads have been constructed in the most promising areas. Because of composition of the forest and topography only parts of the northern zone of the highland forest area are suitable for a permanent timber production. Concessions are being granted here on the basis of a management plan.

In terms of volume/area marketable species generally form a small part of the forest. In two reserves with a favourable forest composition trees of 35 cm (14 in.) d.b.h. and over contribute 66.6 and 52.1 m^3/ha (952 and 745 cu.ft./acre) of a total growing stock of 177.9 and 193.0 m^3/ha (2 544 and 2 760 cu.ft./acre) respectively

(2% valuation survey). Even under these conditions the mean yield only amounts to approx. 20 m^3/ha (286 cu.ft./acre), i.e. 10-15% of the total volume estimated in the marketable sizes (over 50 cm = 20 in. d.b.h.).

In the areas under management an increase of the future yield to a multiple of its present value is essential. Therefore silvicultural treatment of the exploited forests has to be undertaken. Artificial regeneration of some light hardwoods *(soemaroeba = Simarouba amara, laagland baboen = Virola surinamensis)* has been successful. The medium and heavy hardwoods concerned, however, presented various difficulties, such as: sufficient seeds are not always available, heavy losses often occur in transplanting and young plants grow relatively slowly. On the other hand, the conditions for natural regeneration are generally favourable. In virgin high forest recruitment of the marketable species is always present, locally even abundant. Most of the species show a positive stand-table, i.e. numbers per size class increase nearly logarithmically towards the lower classes. Exceptions are the strongly light-demanding species *Goupia* and *Simarouba.*

The great variability in density and composition of the existing regeneration necessitates a stock-mapping of advance growth. A sampling technique is proposed. Natural regeneration should be rejected if less than 20% of the 2×2 m^2 (44 sq.ft.) sample plots is occupied with valuable juveniles.

Measurements showed that the growth of seedlings and saplings under virgin forest conditions is extremely slow. On an average the yearly increase in length only amounts to 2 or 3 cm (1 in.). Though many plants perish at an early stage, a number of them survive during a relatively long period, possibly for some decades. Silvicultural treatment aims at stimulating growth and at promoting the chance of survival for the desirables.

The treatment comprises the following operations:

1. Refining of the forest, i.e. the removal of individuals which have no value for the future crop.
2. Liberation of the desirables, i.e. the elimination of harmful and inferior competitors.

Refining follows exploitation within one or two years. It implies the poisoning of (1) all weed trees over 10 cm (4 in.) d.b.h., and (2) all individuals of desirable species expected to be incapable of developing a valuable log at the next exploitation (either unsound or over-mature). Abrupt and drastic canopy-opening induces a vigorous development of climbers and installation of species characteristic of the secondary forest ('kapoeweri'). Though some valuable tree species - *Goupia, Simarouba, Schefflera, Didymopanax* - may install under these conditions, fast-growing weed species - *Cecropia, Inga, Palicourea* - will soon play a dominant role in the dense vegetation springing up.

The application of arboricides on a hormone basis (principally esters of 2,4,5-T) allows of a more or less gradual opening of the canopy, thus restricting the establishment of weeds. A 5% solution of the arboricide in diesel oil is sprayed on the frilled bole basis. The first treatment causes a 85-90% mortality. After about two years trees not yet killed are treated again. Thus a nearly complete elimination of the canopy is reached over a period of several years. The overstorey poisoning stimulates the development of originally suppressed saplings and poles. Mean length growth of seedlings and saplings of most species increases 6-10 fold. Girth increment of poles may be equally pronounced. Even adolescent or mature trees increase growth considerably after opening of the canopy. However, within 2 or 3 years the growth of desirable seedlings and saplings stagnates by crowding and young plants are threatened to smother. Freeing them from harmful competitors at a relatively early stage seems necessary to avoid severe losses.

Liberation of individual plants is not started until the majority of the poisoned trees has fallen down, i.e. approximately three years after the first refining operations. The expensive and unsatisfactory method of tending all regeneration of useful species, used originally, was abandoned in favour of a stripwise liberation. In this method the desirables are liberated in strips approx. 2 m (6 ft.) wide, running in E-W direction. Spacing of the strips depends on the density of existing regeneration. Until now spacing intervals from 10-20 m (33-66 ft.) have been practised. Within these liberation strips all weeds are slashed by cutlass or - if stronger than 3-5 cm (1-2 in.) - poisoned (handsprayer, 2½% arboricide in diesel oil). If no superior desirables are growing nearby, defects should be corrected by pruning. Weeds occurring in the thicket on either side of the strip are treated only if impeding or threatening valuable regeneration in the strip.

Tending of regeneration will soon shift emphasis from clearing the strips to liberating the crowns of desirables from impeding competitors. As the plants grow up this necessitates an increasing penetration into the weed ridges between the strips (tending directed centrifugally). As a result the treated strips become wider. The desirables in the weed ridges become free and can be tended to achieve a complete utilization of the site. Tending will ultimately cover the whole area under regeneration. The frequency of tending operations - initially twice a year - will be reduced considerably after some years.

Total cost - exclusive of overhead - during the first 10 years is estimated at Sf 270,-/ha (refinement Sf 50,-/ha, liberation and tending Sf 220,-/ha). This is 59 US $/acre (refinement 11 US $/acre, liberation and tending 48 US $/acre).

The stand enters into the thinning stage when mutual closure between the desirables is reached. The age at which this occurs depends on initial stocking and growth rate. The naturally regenerated stands of the Forestry Service have not yet reached this stage.

The specific composition of stands may be altered deliberately by thinning, thereby emphasizing one or more species desired in a particular case. Special directions should be drafted for each unit. For this purpose a classification of species is proposed according to silvicultural characteristics and economic value.

Tentative observations indicate that with adequate tending and thinning a rotation of 60 (max. 80) years is required to raise trees of medium and heavy hardwoods of 60-80 cm d.b.h. The possibility is discussed to create a mixed stand of medium hardwoods and fast-growing light hardwoods - *Simarouba, Schefflera,* *Didymopanax* -, the latter to be removed after 30-40 years.

Local name	Volume (m^3/ha)	Botanical name
awaloe pisi	0.30	*Trattinickia burserifolia; T. demerarae; T. rhoifolia*
		Caricaceae
awara oedoe	0.06	*Jacaratia spinosa*
		Caryocaraceae
sawari	1.12	*Caryocar glabrum*
		Celastraceae
kopi	5.94	*Goupia glabra*
sowtmeti oedoe	0.12	*Maytenus myrsinoides*
		Combretaceae
djiendja oedoe	2.71	*Buchenavia capitata*
kalebashout	0.06	*Terminalia amazonia*
bosamandel	0.24	*Terminalia dichotoma; T. lucida*
		Ebenaceae
blakaoema	0.60	*Diospyros guianensis; D. melinonii; D. sp.*
		Elaeocarpaceae
rafroenjanjan	1.48	*Sloanea eichleri; S. grandiflora*
boskoeswe	0.12	*Sloanea sp.*
		Euphorbiaceae
manbébé	0.02	*Alchorneopsis trimera*
fomang	6.64	*Chaetocarpus schomburgkianus*
tabakabron	0.14	*Croton matourensis*
witte foengoe	1.52	*Drypetes variabilis*
hevea	0.02	*Hevea guianensis*
merki oedoe	0.36	*Sapium klotzschianum; S. obtusilobium*
kototiki	0.18	*Mabea sp.*
		Flacourtiaceae
bita oedoe	0.04	*Homalium guianense; H. racemosum*
kaaiman oedoe	0.62	*Laetia procera*
		Guttiferae
laksiri	0.20	*Caraipa densifolia; C. richardiana*
pakoeli (geelhart)	0.28	*Platonia insignis; Rheedia benthamiana; R. macrophylla*
mataki	1.60	*Symphonia globulifera*
bosmangro	0.02	*Tovomita choisyana; T. schomburgkii; T. secunda*
		Humiriaceae
bofroe oedoe	0.14	*Sacoglottis cydonioides; S. guianensis*
		Icacinaceae
jakanta	1.28	*Poraqueiba guianensis; Dendrobangia boliviana*

Local name	Volume (m³/ha)	Botanical name
		Lauraceae
pisi	0.64	*Aniba taubertiana; Endlicheria endlicheriopsis; E. multiflora; E. pyriformis; Nectandra kunthiana; N. pisi; Ocotea neesiana; O. puberula; O. splendens; O. wachenheimii*
kaneel pisi	0.04	*Licaria guianensis*
zwarte pisi	1.52	*Nectandra grandis; Ocotea glomerata*
witte pisi	1.42	*Ocotea globifera; O. petalanthera*
zilver pisi	0.06	*Ocotea guianensis*
wana pisi	3.22	*Ocotea sp.*
wana	0.40	*Ocotea rubra*
kaneelhart	0.02	*Licaria canella; L. cayennensis*
		Lecythidaceae
ingipipa	17.42	*Couratari fagifolia; C. pulchra; C. stellata*
boskalebas	0.04	*Couroupita guianensis*
tité oedoe	7.26	*Eschweilera chartacea; E. poiteaui; E. stellata*
hgl. oemabarklak	2.78	*Eschweilera corrugata*
hgl. manbarklak	7.81	*Eschweilera odora*
kwatapatoe	1.14	*Lecythis davisii*
		Leguminosae-A (Mimosaceae)
tamarin prokoni	0.56	*Enterolobium schomburgkii; Pithecellobium pedicellare*
swietiboontje	2.22	*Inga spp. (about 21 species)*
prokoni	2.62	*Inga alba; I. pezizifera*
agrobigi	0.60	*Parkia nitida*
kwatakama	0.64	*Parkia pendula; P. ulei*
pikinmisiki	8.00	*Piptadenia suaveolens*
bostamarinde	1.90	*Pithecellobium corymbosum; P. racemosum*
sopo oedoe	0.60	*Pithecellobium jupunba*
		Leguminosae-B (Papilionaceae)
rode kabbes	0.58	*Andira coriacea; A. inermis; A. surinamensis*
aroemata	0.02	*Clathrotropis brachypetala*
hoepelhout	0.34	*Copaifera guianensis*
basralokus	4.22	*Dicorynia guianensis*
zwarte kabbes	0.28	*Diplotropis purpurea*
tonka	0.34	*Dipteryx odorata; D. punctata*
walaba	14.32	*Eperua falcata*
makakabbes	0.50	*Hymenolobium flavum*
bosmahoni	0.36	*Martiodendron parviflorum*
hgl. kokriki	0.30	*Ormosia coccinea*
purperhart	0.68	*Peltogyne pubescens; P. venosa*
koenatepi	0.50	*Platymuscium trinitatis; P. ulei*
hgl. bébé	0.04	*Pterocarpus rohrii; P. santalinoides*
rode djedoe	2.42	*Sclerolobium albiflorum*

Local name	Volume (m^3/ha)	Botanical name
savanne djedoe	0.20	*Sclerolobium guianense*
zwarte djedoe	1.64	*Sclerolobium micropetalum*
djadidja	2.62	*Sclerolobium melinonii*
bergibébé	1.98	*Swartzia benthamiana*
gandoe	0.30	*Swartzia tomentosa*
ijzerhart	0.02	*Swartzia prouacensis*
gele kabbes	0.60	*Vatairea guianensis; V. speciosa*
bruinhart	1.33	*Vouacapoua americana*
jongo kabbes	0.55	*Vataireopsis sp.*
		Linaceae
pakira oedoe	0.10	*Hebepetalum humiriifolium*
		Loganiaceae
lika oedoe	0.48	*Antonia ovata*
		Melastomataceae
spikri oedoe	0.56	*Mouriria crassifolia*
		Meliaceae
krapa	4.08	*Carapa guianensis; C. procera*
ceder	0.02	*Cedrela odorata*
doifisiri	0.78	*Guarea guara*
sorosali	0.14	*Trichilia roraimana; T. surinamensis*
		Moraceae
kaw oedoe	0.74	*Bagassa tiliaefolia*
satijnhout	0.04	*Brosimum paraënse*
bospapaja	1.18	*Cecropia palmata; C. surinamensis*
manbospapaja	0.46	*Cecropia sciadophylla*
manletterhout	2.30	*Perebea laurifolia*
letterhout	0.50	*Piratinera guianensis; P. scabridula; P. velutina*
granboesipapaja	0.66	*Pourouma aspera; P. laevis; P. mollis*
takina (takini)	0.02	*Helicostylis sp.*
olie oedoe	0.10	*Trymatococcus amazonicus*
		Myristicaceae
broedoe oedoe	2.00	*Iryanthera sagotiana*
hgl. baboen	3.40	*Virola melinonii; V. sebifera*
		Myrtaceae
rode bosguave	0.06	*Aulomyrcia hostmanniana*
boskers	0.10	*Eugenia coffeifolia; E. patrisii*
		Nyctaginaceae
njamsi oedoe	0.16	*Torrubia olfersiana*
prasara oedoe	0.02	*Torrubia sp.*
		Olacaceae
patakoe wana	0.12	*Chaunochiton kappleri*
alata oedoe	0.20	*Minquartia guianensis*

Local name	Volume (m³/ha)	Botanical name
		Rosaceae
hgl. anaura	1.36	*Couepia caryophylloides; C. versicolor*
kwepi	0.62	*Licania apetala*
rode kwepi	0.20	*Excellodendron barbatum*
santi oedoe	1.70	*Licania ovalifolia*
zwarte foengoe	0.30	*Licania micrantha*
foengoe	0.22	*Parinari campestris*
		Rubiaceae
moeténé (dede oedoe)	0.12	*Capirona surinamensis*
boskoffie	0.02	*Coussarea paniculata*
		Sapindaceae
Zwarte pintolokus	0.22	*Talisia sp.*
		Sapotaceae
batambali	0.02	*Ecclinusa guianensis*
bolletri	0.10	*Manilkara bidentata*
wit riemhout	4.54	*Micropholis guianensis*
zwart riemhout	1.64	*Micropholis guianensis; Pouteria engleri*
pintobolletri	1.74	*Pouteria cladantha; P. robusta*
zwarte pintobolletri	0.10	*Pouteria spp.*
djoebolletri	0.04	*Pouteria spp.*
kwasiba	2.43	*Pouteria spp.*
jan snijder	0.77	*Pouteria guianensis*
kimboto	0.06	*Pouteria ptychandra; P. surinamensis*
apra oedoe	1.54	*Pouteria sagotiana; P. gonggrijpii*
		Simaroubaceae
soemaroeba	0.20	*Simarouba amara*
		Sterculiaceae
okro oedoe	3.68	*Sterculia excelsa; S. pruriens*
		Tiliaceae
kankan oedoe	1.20	*Apeiba echinata*
fokofoko oedoe	0.18	*Apeiba tibourbou*
katoen oedoe	0.54	*Lueheopsis flavescens; L. rugosa*
		Ulmaceae
kwaskwas oedoe	0.10	*Ampelocera edentula*
		Violaceae
taja oedoe	0.02	*Paipairola guianensis*
unknown	0.30	
		Vochysiaceae
hgl. gronfoeloe	2.14	*Qualea albiflora*
gronfoeloe	0.48	*Qualea courulea*
gujavekwari	1.04	*Qualea dinizii*

Local name	Volume (m^3/ha)	Botanical name
wiswiskwari	1.40	*Vochysia guianensis*
wanakwari	0.20	*Vochysia tomentosa*
mawsikwari	0.76	*Vochysia sp.?*
Total	194.42	

APPENDIX IV

Supplementary data for Expt 65/3

TABLE IV.1 Expt 65/3: periodic annual increment of girth (mm/y) of commercial species 11–41, form class I, in the period 1973–77

Treatment code	Diameter class (cm dbh)	
	1 (5.0–14.9)	2 (15.0–29.9)
A 1	34	42
2	27	33
4	33	30
5	17	40
6	14	28
B 1	33	37
2	26	31
4	22	29
5	8	n.a.
6	n.a.	n.a.

n.a.: not available.

TABLE IV.2 Expt 65/3: periodic annual increment of girth (mm/y) of commercial species 11–41, form class I, in the period 1977–79

Treatment code	Diameter class (cm dbh)	
	1 (5.0–14.9)	2 (15.0–29.9)
A 1	11	39
2	9	38
3	15	40
4	11	24
5	9	18
6	8	12
B 1	17	31
2	9	33
3	15	39
4	7	23
5	4	n.a.
6	11	12

APPENDIX V

Supplementary data for Expt 67/2

TABLE V.1. Excerpt from the legend of the Soil Map of Northern Suriname (scale 1:100 000). All the soil mapping units given are in the category 'undulating and rolling low land (10–100 m + NSP) with steepest slopes being 2–16%' (after Dienst Bodemkartering Suriname, 1977)

DEK LANDSCAPE

PLATEAU SOILS

35 *Excessively drained bleached medium and coarse sand*

36 *Well drained medium and coarse sand to sandy clay loam*

37 *(Moderately) well drained sandy loam over sandy clay loam, or sandy clay loam*

38 *Imperfectly drained bleached medium and coarse sand*

SLOPE AND PLATEAU SOILS

39 *Moderately well and imperfectly drained sandy (clay) loam*

40 *Moderately well and imperfectly drained loamy sand to sandy clay; locally somewhat excessively drained (bleached) medium and coarse sand*

VALLEY BOTTOM AND FOOTSLOPE SOILS

41 *Poorly drained medium and coarse sand, sandy loam, often over clay, locally peaty sand*

TIBITI LANDSCAPE

PLATEAU AND HILL-TOP SOILS

42 *Somewhat excessively drained sand*

43 *(Moderately) well and imperfectly drained sandy (clay) loam, often over sandy clay; locally gravelly clay*

PLATEAU AND SLOPE SOILS

44 *Moderately well and imperfectly drained (sandy) clay, locally with gravelly surface*

SLOPE SOILS

45 *Imperfectly drained sandy (clay) loam, mostly over (sandy) clay*

VALLEY BOTTOM AND FOOTSLOPE SOILS

46 *Poorly drained sand, sandy loam to clay*

RAMA LANDSCAPE

HILL-TOP AND PLATEAU SOILS

54 *Well drained mostly gravelly clay*

SLOPE SOILS

55 (Moderately) well drained clay, locally gravelly

VALLEY BOTTOM AND FOOTSLOPE SOILS

56 Poorly drained sand to clay, and imperfectly drained sandy loam over sandy clay loam, locally gravelly and stony

TABLE V.2 Expt 67/2: number of trees and basal area per diameter class of all species, form class III, at Sarwa

Diameter class (cm dbh)	N/ha		Basal area (m^2/ha)	
	1968	1977	1968	1977
5.0– 9.9	775	770	3.41	3.39
10.0– 14.9	150	185	1.85	2.28
15.0– 19.9	123	77	2.95	1.85
20.0– 24.9	60	68	2.39	2.71
25.0– 29.9	35.6	27.4	2.10	1.65
30.0– 34.9	32.6	30.4	2.67	2.51
35.0– 39.9	21.2	20.0	2.34	2.20
40.0– 44.9	17.4	17.2	2.47	2.43
45.0– 49.9	10.8	12.2	1.89	2.19
50.0– 54.9	4.4	6.0	0.94	1.29
55.0– 59.9	4.8	3.8	1.23	0.99
60.0– 64.9	2.6	2.8	0.81	0.84
65.0– 69.9	1.6	2.8	0.56	1.00
70.0– 74.9	0.6	0.8	0.25	0.33
75.0– 79.9	0.2	0.4	0.09	0.18
80.0– 84.9	0.4	0.4	0.20	0.22
85.0– 89.9	0.2	0	0.12	0
90.0– 94.9	0	0	0	0
95.0– 99.9	0	0.2	0	0.14
100.0–104.9	0.2	0	0.16	0
105.0–109.9	0.2	0	0.18	0
>45.0	26.0	29.4	6.45	7.18
>25.0	132.8	124.4	16.03	15.97
>15.0	315.8	269.4	21.37	20.52
>5.0	1 240.8	1 224.4	26.62	26.19

TABLE V.3 Expt 67/2: number of trees and basal area per diameter class of all species, form class III, at Goliath

Diameter class (cm dbh)	N/ha			Basal area (m^2/ha)		
	1968	1977	1982	1968	1977	1982
5.0– 9.9	660	615	n.a.	2.90	2.71	n.a.
10.0– 14.9	210	200	n.a.	2.58	2.46	n.a.
15.0– 19.9	89	69	n.a.	2.14	1.66	n.a.
20.0– 24.9	65	77	n.a.	2.59	3.06	n.a.
25.0– 29.9	41	27.2	n.a.	2.44	1.65	n.a.
30.0– 34.9	33.8	31.8	n.a.	2.78	2.64	n.a.
35.0– 39.9	17.6	25.0	n.a.	1.90	2.70	n.a.
40.0– 44.9	11.4	10.2	n.a.	1.62	1.42	n.a.
45.0– 49.9	8.2	7.6	n.a.	1.44	1.33	n.a.
50.0– 54.9	3.0	7.6	n.a.	0.63	1.60	n.a.
55.0– 59.9	3.6	3.0	n.a.	0.92	0.79	n.a.
60.0– 64.9	3.0	2.2	n.a.	0.93	0.67	n.a.
65.0– 69.9	2.3	2.4	n.a.	0.56	0.86	n.a.
70.0– 74.9	0.6	1.2	n.a.	0.24	0.48	n.a.
75.0– 79.9	0.2	0.2	n.a.	0.09	0.09	n.a.
80.0– 84.9	0.4	0.2	n.a.	0.21	0.11	n.a.
85.0– 89.9	0	0.2	n.a.	0	0.12	n.a.
90.0– 94.9	0	0	n.a.	0	0	n.a.
95.0– 99.3	0	0	n.a.	0	0	n.a.
100.0–104.9	0.2	0	n.a.	0.16	0	n.a.
105.9–109.9	0	0.2	n.a.	0	0.18	n.a.
>45.0	21.5	24.8	21	5.19	6.24	5.2
>25.0	125.3	119.0	133	13.95	14.66	15.0
>15.0	279.3	265.0	287	18.67	19.38	19.8
>5.0	1 149.3	1 080.0	n.a.	24.16	24.54	n.a.

TABLE V.4. Expt 67/2: number of trees and basal area per diameter class of commercial species 11–41, form class III, at Sarwa

Diameter class (cm dbh)	N/ha			Basal area (m²/ha)	
	1968	1977	R*	1968	1977
5.0- 9.9	40	15	n.a.	0.18	0.07
10.0- 14.9	20	20	n.a.	0.25	0.25
15.0- 19.9	22	12	n.a.	0.54	0.31
20.0- 24.9	18	16	18	0.69	0.62
25.0- 29.9	10.8	9.2	10.8	0.64	0.54
30.0- 34.9	8.4	8.2	8.4	0.69	0.68
35.0- 39.9	4.8	5.6	4.8	0.53	0.60
40.0- 44.9	4.6	4.4	4.6	0.67	0.62
45.0- 49.9	2.4	2.6	2.4	0.42	0.46
50.0- 54.9	0.8	1.6	1.0	0.17	0.34
55.0- 59.9	1.2	0.4	2.4	0.32	0.11
60.0- 64.9	1.2	0.8	2.6	0.37	0.24
65.0- 69.9	0.4	1.2	0.6	0.14	0.43
70.0- 74.9	0	0.2	0.4	0	0.08
75.0- 79.9	0.2	0	1.0	0.09	0
80.0- 84.9	0.2	0.2	0.6	0.10	0.11
85.0- 89.9	0	0	0	0	0
90.0- 94.9	0	0	0	0	0
95.0- 99.9	0	0	0	0	0
100.0-104.9	0	0	0	0	0
>45.0	6.4	7.0		1.61	1.78
>25.0	35.0	34.4		4.13	4.22
>15.0	75.0	62.4		5.36	5.15
>5.0	135.0	97.4		5.78	5.46

* Before exploitation, reconstructed data.

TABLE V.5 Expt 67/2: number of trees and basal area per diameter class of commercial species 11–41, form class III, at Goliath

Diameter class (cm dbh)	N/ha			Basal area (m^2/ha)	
	1968	1977	R*	1968	1977
5.0– 9.9	25	15	n.a.	0.11	0.07
10.0– 14.9	0	5	n.a.	0	0.06
15.0– 19.9	15	8	n.a.	0.35	0.18
20.0– 24.9	11	13	11	0.46	0.52
25.0– 29.9	7.8	3.4	7.8	0.47	0.20
30.0– 34.9	5.6	6.0	5.6	0.46	0.51
35.0– 39.9	3.6	4.4	3.8	0.39	0.47
40.0– 44.9	4.0	4.0	4.4	0.56	0.56
45.0– 49.9	3.6	2.4	3.8	0.64	0.43
50.0– 54.9	1.0	4.0	2.0	0.21	0.84
55.0– 59.9	0.8	1.0	3.0	0.21	0.26
60.0– 64.9	0.4	0.8	2.4	0.13	0.24
65.0– 69.9	1.2	0.8	2.0	0.42	0.29
70.0– 74.9	0.2	0.6	0.6	0.08	0.24
75.0– 79.9	0.2	0.2	0.4	0.09	0.09
80.0– 84.9	0.4	0.2	1.0	0.21	0.11
85.0– 89.9	0	0.2	0	0	0.12
90.0– 94.9	0	0	0.2	0	0
95.0– 99.9	0	0	0	0	0
100.0–104.9	0	0	0	0	0
>45.0	7.8	10.2		2.00	2.62
>25.0	28.8	28.0		3.89	4.36
>15.0	54.8	49.0		4.70	5.06
>5.0	79.8	69.0		4.81	5.19

* Before exploitation, reconstructed data.

TABLE V.6. Expt 67/2: bole volume (m^3/ha) per diameter class of commercial species 11–41, form class III, at Sarwa and Goliath

Diameter class (cm dbh)	Sarwa			Goliath		
	1968	1977	Balance	1968	1977	Balance
5.0– 9.9	0.74	0.28	-0.46	0.46	0.28	-0.18
10.0– 14.9	1.46	1.46	0.00	0	0.37	0.37
15.0– 19.9	4.16	2.39	-1.77	2.74	1.43	-1.31
20.0– 24.9	6.42	5.70	-0.72	4.24	4.81	0.57
25.0– 29.9	6.67	5.70	-0.97	4.98	2.15	-2.83
30.0– 34.9	7.79	7.68	-0.11	5.26	5.75	0.49
35.0– 39.9	6.36	7.28	0.92	4.71	5.70	0.99
40.0– 44.9	8.29	7.76	-0.53	6.93	6.95	0.02
45.0– 49.9	5.39	5.88	0.49	8.13	5.43	-2.70
50.0– 54.9	2.12	4.37	2.25	2.74	10.71	7.97
55.0– 59.9	4.05	1.37	-2.68	2.67	3.26	0.59
60.0– 64.9	4.73	3.11	-1.62	1.64	3.10	1.46
65.0– 69.9	1.80	5.47	3.67	5.36	3.73	-1.63
70.0– 74.9	0	1.04	1.04	1.07	3.04	1.97
75.0– 79.9	1.16	0	-1.16	1.16	1.17	0.01
80.0– 84.9	1.30	1.39	0.09	2.71	1.39	-1.32
85.0– 89.9	0	0		0	1.52	1.52
90.0– 94.9	0	0		0	0	
95.0– 99.9	0	0		0	0	
100.0–104.9	0	0		0	0	
>45.0	20.6	22.6	2.1	25.5	33.4	7.9
>25.0	49.7	51.1	1.4	47.4	53.9	6.5
>15.0	60.2	59.1	-1.1	54.3	60.1	5.8
>5.0	62.4	60.9	-1.6	54.8	60.8	6.0

APPENDIX VI

Supplementary data for Expt 67/9A

VI.1 Soil profile description of a soil pit in Expt 67/9A

VI.1.1 Site description

Location: Mapane, Suriname, Experiment 67/9A, centre of plot 8
Described by: J. A. de Fretes and R. L. H. Poels on 30-8-1978
Elevation: approximately 75 m above sea level
Physiographic position of the site: upper part of convex to straight slope
Landform of surrounding country: undulating to rolling
Microtopography: somewhat uneven because of digging by armadillos (fam. *Dasypodidae*)
Slope on which profile is sited: 9%
Vegetation: high dry-land forest; ca 2 m^3/ha timber extracted around 1968; no treatment afterwards; several gaps in canopy
Climate: Tropical rainforest climate (Af) with 2 wet and 2 drier periods: Average precipitation, approximately 2 400 mm/year
Parent material: weathered schist bedrock
Moisture condition: moist throughout
Depth ground water table: not encountered
External drainage: medium
Internal drainage: medium
Drainage class: well to moderately well drained
Presence of surface stones/rock outcrops: no
Evidence of erosion: no
Presence of salt or alkali: no
Human influence: no

VI.1.2. Brief description of the profile

Very deep, well to moderately well drained profile with a brown clay loam to sandy clay topsoil and a bright brown to orange subsoil of clay texture; below 123 cm patchy thin cutans occur and few yellow orange (weathering) mottles.
The subsoil, especially the B12, is rather dense.

VI.1.3. Soil horizon description

A1 0- 7 cm Brown (7,5 YR 4/3) sandy clay loam to sandy clay; moderate fine and medium subangular blocky and fine crumb structure; friable when moist, sticky and plastic when wet; many fine pores; abundant fine, common medium roots; thin litter layer (ca. 1 cm) of leaves and twigs; rootmat slightly developed; leaves and twigs resting directly on the surface (no decomposed litter); no fungi seen; few medium charcoal pieces; gradual smooth boundary.

A3	7– 29 cm	Bright brown (7.5 YR 5/6) clay loam; very few fine faint brown mottles; moderate medium and coarse subangular blocky structure; friable when moist, sticky and plastic when wet; common fine pores; many fine, few medium and large roots; common termite activity; common large dead roots; few medium charcoal pieces; gradual smooth boundary.
B11	29– 51 cm	Dull brown (7.5 YR 5/4) clay; few fine faint brown mottles; weak coarse and medium prismatic and blocky structure; subdivided into fine and medium blocky elements; friable when moist, very sticky and very plastic when wet; common fine and medium, few large pores; common fine and medium, few large roots; few quartz gravels; few round holes (∅ 4 cm) with dark material (probably termite nests); this horizon is somewhat darker than above and below, maybe caused by periodic waterlogging; gradual smooth boundary.
B12	51– 79 cm	Bright brown (7.5 YR 5/8) clay; weak medium and coarse prismatic structure subdivided into fine and medium blocky elements; friable to firm when moist, very sticky and very plastic when wet; common fine and few medium pores; common fine and few medium roots; some termite activity; few quartz gravels, rather dense horizon; diffuse smooth boundary.
B21	79–123 cm	Bright reddish brown (5 YR 5/8) clay; very few fine faint yellow mottles; weak medium and coarse prismatic structure subdivided into fine blocky elements; friable to firm when moist, very sticky and very plastic when wet; common fine and few medium pores; few fine and medium roots; common quartz sand grains; diffuse smooth boundary.
B22	123–180 cm	Orange (5 YR 6/8) clay; few fine and medium yellow-orange (10 YR 7/8) weathering mottles; weak coarse and medium prismatic structure, subdivided into fine blocky and granular elements; friable to firm when moist; very sticky and very plastic when wet; common fine pores; common fine and few medium roots; patchy thin cutans; at 170 cm few quartz gravels; few round holes (∅ 4 cm) filled with dark topsoil materi-

al; in lower part of horizon few to common medium bright brown (2.5 YR 5/8) mottles (weathering).

B3	180–240 cm (boring)	Orange (5 YR 6/8) clay; no mottles; few roots.
C	240–290 cm (boring)	Bright brown (2.5 YR 5/8) clay; no mottles; very few roots.

Classification (USDA): Orthoxic Tropudult or Typic Paleudult

TABLE VI.1 Chemical soil data

Horizon	Depth (cm)	pH		% C	% N	C/N	CEC at pH = 7 (me/100 g)	Exchangeable cations me/100 g soil					Total bases (me/100 g)	CEC at soil pH (me/100 g)	Al sat. at soil pH (%)	P-Bray I (ppm)
		H_2O	KCl					Ca	Mg	K	Na	Al				
A1	0– 7	3.8	3.4	2.03	0.19	10.7	7.92	0.41	0.18	0.14	0.04	1.99	0.77	2.76	72	1.5
A3	7– 29	4.0	3.8	0.91	0.08	11.4	4.09	0.25	0.05	0.04	0.03	1.55	0.37	1.92	81	1.4
B11	29– 51	4.4	3.8	0.61	0.06	10.2	3.52	0.15	0.03	0.05	0.01	1.40	0.24	1.64	85	0.4
B12	51– 79	4.6	3.9	0.37	0.03	12.3	2.63	0.11	0.09	0.01	0.01	0.91	0.22	1.13	81	1.1
B21	79–123	4.6	4.0	0.28	0.02	14.0	2.61	0.08	0.02	0.02	0.01	0.87	0.13	1.00	87	0.4
B22	123–180	4.7	4.0	0.23	0.02	11.5	2.22	0.05	0.00	0.01	0.01	0.66	0.07	0.73	90	0.4
B3	180–240	4.9	4.2	0.23	0.02	11.5	2.22	0.03	0.08	0.01	0.01	0.45	0.13	0.58	78	1.1
C	240–290	5.2	4.3	0.14	0.01	14.0	2.12	0.03	0.03	0.01	0.01	0.41	0.08	0.49	84	0.7

TABLE VI.2 Physical soil data

Horizon	Depth (cm)	Bulk density	Moisture content at pF (vol%)				pF at sampling	Moisture between		Available moisture between pF2 and pF4.2		Penetro meter (kg/m^2)	Organic matter (%)	Particle density	Total porosity (%)	Air at	
			1	2	3.4	4.2		pF1 and pF2 (%)	pF2 and pF4.2 (%)	(mm)	(mm cum.)					pF1 (%)	pF2 (%)
A1	0– 7	1.10	50.2	39.8	16.3	14.8	2.2	10.4	25.0	17.5	17.5	1.0	3.50	2.57	57.2	7.0	17.4
A3	7– 29	1.31	44.4	36.2	22.9	19.8	2.2	8.2	16.4	36.1	53.6	1.5	1.57	2.61	49.8	5.4	13.6
B11	29– 51	1.40	40.9	35.9	26.8	23.7	2.2	5.0	12.2	26.8	80.4	2.0	1.05	2.62	46.6	5.7	10.7
B12	51– 79	1.45	40.2	36.8	29.8	26.2	2.3	3.4	10.6	29.7	110.1	2.5	0.64	2.63	44.9	4.7	8.1
B21	79–123	1.37	45.7	42.9	34.9	30.5	2.3	2.8	12.4	54.6	164.7	2.4	0.48	2.64	48.1	2.4	5.2
B22	123–180	1.37	44.8	42.3	35.0	31.4	2.4	2.5	10.9	62.1	226.8	2.2	0.40	2.64	48.1	3.3	5.8
B3	180–240												0.40	2.64			
C	240–290												0.24	2.64			

TABLE VI.3 Expt 67/9A: number of trees per ha of all species, form class III, under six treatment schedules, in 1980. Averages per treatment

Diameter class (cm dbh)	Treatment code					
	0	40+0	20+0	40+D8	20+D8	V
5.0- 9.9	309	408	423	375	447	318
10.0- 14.9	176	207	244	164	208	196
15.0- 19.9	107	120	120	70	76.6	124
20.0- 24.9	65	84	82	39.1	64.1	81
25.0- 29.9	40.0	49	42.2	12.5	28.1	41.0
30.0- 34.9	30.3	30	18.0	9.4	15.6	28.0
35.0- 39.9	25.3	17	14.8	9.4	4.7	23.0
40.0- 44.9	15.6	10	3.9	4.7	4.7	13.0
45.0- 49.9	26.9	3.1	5.5	12.5	4.7	6.2
50.0- 54.9	8.1	4.7	5.5	6.3	0	5.5
55.0- 59.9	3.1	0.8	0	3.1	0	3.1
60.0- 64.9	2.8	0.8	0	0	0	1.6
65.0- 69.9	2.5	0	0.8	0	0	0.8
70.0- 74.9	1.9	0	0.8	1.6	1.6	2.0
75.0- 79.9	0.94	0	0	0	0	1.2
80.0- 84.9	0.32	0	0	0	0	0.8
85.0- 89.9	0	0	0	0	0	0.8
90.0- 94.9	0	0	0	1.6	0	0
95.0- 99.9	0	0	0	0	0	0.8
100.0-104.9	0.32	0	0	0	0	0.8*

* 0.4 tree from class 110.0–114.9 included.

TABLE VI.4 Expt 67/9A: basal area (m^2/ha) of all species, form class III, under six treatment schedules, in 1980. Averages per treatment

Diameter class (cm dbh)	Treatment code					
	0	40+0	20+0	40+D8	20+D8	V
5.0- 9.9	1.36	1.80	1.87	1.65	1.97	1.41
10.0- 14.9	2.16	2.55	3.00	2.02	2.56	2.40
15.0- 19.9	2.57	2.89	2.89	1.69	1.84	2.98
20.0- 24.9	2.60	3.33	3.27	1.55	2.55	3.20
25.0- 29.9	2.37	2.93	2.51	0.74	1.67	2.41
30.0- 34.9	2.51	2.46	1.50	0.78	1.30	2.30
35.0- 39.9	2.80	1.90	1.64	1.04	0.52	2.55
40.0- 44.9	2.22	1.44	0.56	0.66	0.66	1.83
45.0- 49.9	4.76	0.56	0.97	2.22	0.83	1.11
50.0- 54.9	1.76	1.02	1.19	1.35	0	1.18
55.0- 59.9	0.81	0.21	0	0.81	0	0.81
60.0- 64.9	0.86	0.24	0	0	0	0.48
65.0- 69.9	0.90	0	0.28	0	0	0.28
70.0- 74.9	0.78	0	0.33	0.65	0.56	0.81
75.0- 79.9	0.44	0	0	0	0	0.55
80.0- 84.9	0.17	0	0	0	0	0.42
85.0- 89.9	0	0	0	0	0	0.45
90.0- 94.9	0	0	0	1.05	0	0
95.0- 99.9	0	0	0	0	0	0.58
100.0-104.9	0.26	0	0	0	0	0.71*
total	29.3	21.3	20.0	16.2	14.5	26.5

* 0.4 tree from class 110.0-114.9 included.

TABLE VI.5. Expt 67/9A: bole volume (m³/ha) of all species, form class III, under six treatment schedules, in 1980. Averages per treatment

Diameter class (cm dbh)	Treatment code					
	0	40+0	20+0	40+D8	20+D8	V
5.0- 9.9	5.71	7.56	7.85	6.93	8.27	5.92
10.0- 14.9	12.85	15.17	17.85	12.02	15.23	14.28
15.0- 19.9	19.97	22.46	22.46	13.13	14.30	23.15
20.0- 24.9	24.02	30.77	30.21	14.32	23.56	29.57
25.0- 29.9	24.89	30.77	26.36	7.77	17.54	25.31
30.0- 34.9	28.46	27.90	17.01	8.85	14.74	26.08
35.0- 39.9	33.71	22.88	19.75	12.52	6.26	30.70
40.0- 44.9	27.66	17.94	6.98	8.22	8.22	22.80
45.0- 49.9	60.64	7.13	12.36	28.28	10.57	14.14
50.0- 54.9	22.42	12.99	15.16	17.20	0	15.03
55.0- 59.9	10.32	2.68	0	10.32	0	10.32
60.0- 64.9	10.96	3.06	0	0	0	6.12
65.0- 69.9	11.47	0	3.57	0	0	3.5
70.0- 74.9	9.94	0	4.20	8.28	7.12	10.32
75.0- 79.9	5.61	0	0	0	0	7.01
80.0- 84.9	2.17	0	0	0	0	5.35
85.0- 89.9	0	0	0	0	0	5.73
90.0- 94.9	0	0	0	13.38	0	0
95.0- 99.9	0	0	0	0	0	7.39
100.0-104.9	3.31	0	0	0	0	9.05*
total	314	201	183	161	126	272

* 0.4 tree from class 110.0-114.9 included.

TABLE VI.6 Expt 67/9A: development of numbers of trees (N/ha) per diameter class, of commercial species 11-41, form class I, under six treatment schedules. Averages per treatment

Treatment code	Diameter class*	1968	1974	1980
0	1	61.9	66.3	73.4
	2	17.5	15.9	16.3
	3	7.5	6.9	9.1
	4	2.8	3.7	4.4
40+0	1	61.7	83.7	86.0
	2	20.4	17.2	23.5
	3	11.0	8.6	7.1
	4	0.8	4.7	7.1
20+0	1	43.0	54.7	51.6
	2	16.4	14.1	13.3
	3	9.4	8.6	7.8
	4	0.8	0.8	3.1
40+D8	1	37.5	54.7	53.1
	2	10.9	7.8	14.1
	3	14.1	12.5	9.4
	4	4.7	9.4	15.6
20+D8	1	51.6	43.8	59.4
	2	28.1	34.4	26.6
	3	7.8	7.8	23.4
	4	1.6	0	0
V	1	n.a.	n.a.	n.a.
	2	15.2	14.9	18.0
	3	4.7	5.9	7.8
	4	0.8	0.8	2.0

* Diameter class 1: 5.0–14.9 cm dbh.
2: 15.0–29.9 cm dbh.
3: 30.0–44.9 cm dbh.
4: 45.0–59.9 cm dbh.

TABLE VI.7 Expt 67/9A: development of bole volume (m^3/ha) per diameter class, of commercial species 11–41, form class I, under six treatment schedules. Averages per treatment

Treatment code	Diameter class*	1968	1974	1980
0	1	2.0	2.3	2.6
	2	5.9	5.5	5.7
	3	9.5	8.3	11.7
	4	5.9	8.9	11.9
40+0	1	1.8	2.7	2.8
	2	7.1	5.5	8.1
	3	15.2	10.2	8.6
	4	1.6	10.5	17.4
20+0	1	1.3	1.7	1.7
	2	4.8	5.1	4.8
	3	11.5	12.3	11.1
	4	1.7	1.7	7.5
40+D8	1	0.8	1.3	2.2
	2	3.8	3.2	3.9
	3	20.3	17.7	12.7
	4	10.5	22.3	42.1
20+D8	1	1.9	1.3	2.1
	2	10.4	15.1	9.8
	3	10.3	10.9	26.6
	4	3.5	0	0
V	1	n.a.	n.a.	n.a.
	2	5.1	5.2	6.2
	3	5.7	7.1	10.5
	4	1.8	2.0	4.9

* See Table VI.6.

TABLE VI.8 Expt 67/9A: development of numbers of trees (N/ha) per diameter class, of commercial species 11–41, form class III, under six treatment schedules. Averages per treatment

Treatment code	Diameter class*	1968	1974	1980
0	1	65.0	69.7	76.0
	2	17.5	20.7	16.6
	3	7.5	9.4	10.0
	4	2.8	4.4	4.4
40+0	1	61.8	94.5	93.8
	2	20.3	20.3	25.8
	3	10.9	9.3	7.9
	4	0.8	4.7	7.1
20+0	1	43.7	61.0	58.6
	2	16.4	17.2	14.9
	3	9.4	9.3	7.7
	4	0.8	0.8	3.1
40+D8	1	37.5	64.1	67.2
	2	11.0	7.8	15.7
	3	14.2	12.6	9.4
	4	4.7	9.4	15.7
20+D8	1	51.6	54.7	68.8
	2	28.1	32.9	28.1
	3	7.8	9.4	25.0
	4	1.6	1.6	1.6
V	1	n.a.	n.a.	n.a.
	2	15.2	16.4	18.8
	3	4.7	6.6	8.5
	4	0.8	0.8	2.0

* See Table VI.6.

TABLE VI.9 Expt 67/9A: development of basal area (m^2/ha) above 5.0 cm dbh of commercial species 11–41, form class I, per treatment plot and as an average per treatment

Treatment code	Plot no	Basal area (m^2/ha)							Increment 1968–80	
		1968	1970	1972	1974	1976	1978	1980	Absolute	Annual rate
0	1	2.60	2.63	2.25	2.35	2.48	2.63	2.99	0.33	
	8	1.93	2.04	2.04	2.19	2.34	2.46	2.64	0.71	
	15	3.77	3.85	3.67	3.96	4.22	4.44	4.40	0.63	
	17	1.84	1.85	1.97	2.21	2.38	2.91	3.09	1.25	
	24	1.48	1.46	1.57	1.65	1.70	1.95	2.14	0.66	
	mean	2.32	2.37	2.30	2.47	2.62	2.88	3.05	0.72	1.31
	SD	0.90	0.93	0.80	0.87	0.94	0.94	0.84	0.33	
40+0	3	2.34	2.63	2.47	2.77	2.78	3.04	3.17	0.83	
	7	2.77	2.57	2.78	2.95	3.23	3.57	3.89	1.12	
	mean	2.56	2.60	2.63	2.86	3.01	3.31	3.53	0.98	1.38
20+0	14	2.21	1.89	1.87	2.03	2.21	2.28	2.25	0.04	
	19	1.68	1.97	2.19	2.05	2.47	2.62	2.52	0.84	
	mean	1.95	1.93	2.03	2.04	2.34	2.45	2.39	0.44	1.23
40+D8	23	3.13	3.31	3.55	3.82	4.21	4.63	5.20	2.07	1.66
20+D8	22	2.68	2.79	2.63	2.74	3.24	3.81	3.72	1.04	1.39
V*	4	1.43	1.35	1.25	1.65	1.81	2.22	2.37	0.94	
	6	1.11	1.03	1.15	1.30	1.46	1.73	2.04	0.93	
	12	1.05	1.17	1.27	1.33	1.48	1.65	1.77	0.72	
	25	1.11	1.19	0.82	0.96	1.06	1.40	1.51	0.40	
	mean	1.18	1.19	1.12	1.31	1.45	1.75	1.92	0.75	1.64
	SD	0.17	0.13	0.21	0.28	0.31	0.34	0.37	0.25	

* Diameter lower limit 15.0 cm dbh.

TABLE VI.10 Expt 67/9A: development of basal area (m²/ha) above 5.0 cm dbh of commercial species 11–41, form class III, per treatment plot and as an average per treatment

Treatment code	Plot no	Basal area (m²/ha)							Increment 1968–80	
		1968	1970	1972	1974	1976	1978	1980	Absolute	Annual rate
0	1	2.60	2.63	2.82	2.85	3.07	3.17	3.37	0.77	
	8	1.93	2.04	2.16	2.30	2.46	2.57	2.76	0.83	
	15	3.77	3.85	3.99	4.23	4.47	4.69	4.47	0.70	
	17	1.84	1.85	2.00	2.22	2.40	2.93	3.09	1.25	
	24	1.48	1.47	1.60	1.73	1.89	2.03	2.21	0.73	
	mean	2.32	2.37	2.51	2.67	2.86	3.08	3.18	0.86	1.37
	SD	0.90	0.93	0.94	0.96	0.99	1.00	0.84	0.23	
40+0	3	2.34	2.63	2.93	3.29	3.42	3.51	3.53	1.19	
	7	2.77	2.63	2.97	3.08	3.36	3.69	4.00	1.23	
	mean	2.56	2.63	2.95	3.19	3.39	3.60	3.77	1.21	1.47
20+0	14	2.21	1.89	2.03	2.16	2.37	2.46	2.31	0.10	
	19	1.68	1.98	2.31	2.39	2.64	2.79	2.69	1.01	
	mean	1.95	1.94	2.17	2.28	2.51	2.63	2.50	0.56	1.28
40+D8	23	3.13	3.32	3.58	3.86	4.26	4.74	5.23	2.19	1.70
20+D8	22	2.68	2.79	3.05	3.16	3.69	4.35	4.34	1.66	1.62
V*	4	1.43	1.52	1.42	1.83	1.99	2.40	2.55	1.12	
	6	1.11	1.03	1.15	1.30	1.46	1.73	2.04	0.93	
	12	1.05	1.17	1.32	1.48	1.62	1.80	1.93	0.76	
	25	1.11	1.19	1.13	1.30	1.42	1.52	1.63	0.52	
	mean	1.18	1.23	1.26	1.48	1.62	1.86	2.04	0.83	1.73
	SD	0.17	0.21	0.14	0.25	0.26	0.38	0.38	0.26	

* Diameter lower limit 15.0 cm dbh.

TABLE VI.11 Expt 67/9A: annual mortality rate (%) per diameter class, of commercial species 11, 24–28, 37 and 40, form class I, under six treatment schedules. Averages per treatment

Treatment code	Diameter class*	Period**						Mean	Mean
		I	II	III	IV	V	VI		
0	1	4.6	0.6	1.1	0.5	0.3	1.4	1.4	
	2	2.9	0	0	0	1.0	2.5	1.1	1.7
	3	2.3	0	0	0	0	n.a.	0.4	(class 1–4)
	4	0	0	0	0	0	8.3	1.4	
	5	0	0	50.0	n.a.	n.a.	0	8.3	
40+0	1	0	2.5	1.1	0.5	0.5	1.5	1.0	
	2	2.0	0	0	0	2.2	0	0.7	1.7
	3	7.1	0	4.2	4.6	0	4.6	3.4	(class 1–3)
	4	0	0	0	0	0	0	0	
20+0	1	2.1	2.0	3.3	2.2	2.4	3.3	2.6	
	2	5.0	0	9.4	0	3.1	0	2.9	2.7
	3	5.5	0	6.3	0	0	4.6	2.7	(class 1–3)
	4	50.0	0	0	0	0	8.3	9.7	
40+D8	1	11.1	0	0	0	0	4.0	2.5	
	2	0	0	0	0	0	0	0	1.2
	3	0	0	0	0	0	6.3	1.0	(class 1–3)
	4	0	0	0	0	0	0	0	
20+D8	1	7.8	2.1	0	1.9	3.7	3.8	3.2	
	2	3.1	0	2.9	0	0	0	1.0	2.5
	3	0	10.0	0	0	0	9.1	3.2	(class 1–3)
	4	0	n.a.	n.a.	n.a.	0	50.0	8.3	
V	1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
	2	1.7	3.9	0	1.4	0	1.3	1.4	
	3	4.6	0	0	0	0	2.6	1.2	1.8
	4	0	16.7	0	0	0	0	2.8	(class 2–4)

* See Table 7.5.

** See Table 7.10.

TABLE VI.12 Expt 67/9A: annual mortality rate (%) per diameter class, of commercial species 11, 24–28, 37 and 40, form class III, under six treatment schedules. Averages per treatment

Treatment code	Diameter class*	Period**						Mean	Mean
		I	II	III	IV	V	VI		
0	1	4.6	0.5	1.3	0.7	0.2	1.8	1.5	
	2	2.9	1.0	0	1.0	0.9	2.5	1.4	1.3
	3	2.3	0	2.1	0	0	0	0.7	(class 1–4)
	4	0	0	0	0	0	8.4	1.4	
	5	0	0	50.0	0	0	0	8.3	
40+0	1	0	2.2	1.9	1.8	1.7	2.2	1.6	
	2	1.9	0	0	0	1.8	0	0.6	1.8
	3	7.1	0	3.9	4.2	0	4.2	3.2	(class 1–3)
	4	0	0	0	0	0	0	0	
20+0	1	3.1	2.5	4.8	2.8	2.9	3.9	3.3	
	2	5.0	4.8	7.9	0	2.5	7.9	4.7	3.5
	3	5.6	0	5.6	0	0	4.6	2.6	(class 1–3)
	4	50.0	0	0	0	0	8.3	9.7	
40+D8	1	10.5	0	0	0	2.9	2.8	2.7	
	2	0	0	0	0	0	0	0	1.2
	3	0	0	0	0	0	5.6	0.9	(class 1–3)
	4	0	0	0	0	0	0	0	
20+D8	1	7.8	2.9	5.8	1.4	4.2	4.2	3.9	
	2	3.1	0	5.6	0	0	0	1.0	2.6
	3	0	10.0	0	0	0	8.3	3.1	(class 1–3)
	4	0	0	50.0	0	0	50.0	16.7	
V	1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
	2	1.6	3.5	0	1.3	0	1.2	1.3	
	3	4.6	5.5	0	0	0	2.6	2.1	2.1
	4	0	16.7	0	0	0	0	2.8	(class 2–4)

* See Table 7.5.
** See Table 7.10.

TABLE VI.13 Expt 67/9A: periodic annual increment of girth per diameter class in period 1976–78 for species 11, 24–28, 37 and 40, form class I, and total basal area in 1978 of all species

Plot no	Treatment code	Increment (mm/y)*			Total basal area 1978 (m^2/ha)
		Diameter class**			
		1	2	3	
1	0	6	11	14	27.5
2	20 + A3	19	n.a.	n.a.	13.0
3	40+0	7	18	17	17.6
4	V	n.a.	18	n.a.	21.6
5	20+S3	12	24	n.a.	15.5
6	V	n.a.	19	n.a.	21.5
7	40+0	8	23	n.a.	19.9
8	0	4	11	n.a.	32.4
9	20 + D3	20	36	n.a.	11.7
10	40+D5	23	31	n.a.	8.7
11	20+D5	43	45	n.a.	10.8
12	V	n.a.	25	n.a.	25.4
13	40+D3	21	32	n.a.	12.2
14	20+0	5	n.a.	24	16.3
15	0	3	7	14	27.7
16	20 + S5	28	32	n.a.	14.8
17	0	5	18	10	29.4
18	40+A3	18	37	n.a.	15.2
19	20+0	3	14	n.a.	18.7
20	20+A5	18	31	n.a.	16.6
21	40+A5	17	16	17	20.9
22	20+D8	28	28	33	11.4
23	40+D8	31	n.a.	29	12.3
24	0	4	13	17	26.9
25	V	n.a.	18	n.a.	24.9

* Data are averages of at least five trees per diameter class.

** See Table 7.5.

TABLE VI.14 Expt 67/9A: periodic annual increment of girth per diameter class in period 1978–80 for species 11, 24–28, 37 and 40, form class I, and total basal area in 1980 of all species

Plot no	Treatment code	Increment (mm/y)*			Total basal area 1980 (m^2/ha)
		Diameter class**			
		1	2	3	
1	0	6	11	16	34.9
2	20 + A3	7	17	n.a.	18.5
3	40+0	4	11	22	19.1
4	V	12	17	18	24.1
5	20+S3	3	14	n.a.	21.8
6	V	8	23	n.a.	22.2
7	40+0	5	20	n.a.	23.5
8	0	3	10	n.a.	27.9
9	20 + D3	6	21	n.a.	15.4
10	40+D5	13	31	n.a.	12.7
11	20+D5	28	41	n.a.	14.5
12	V	n.a.	15	33	31.2
13	40+D3	14	22	n.a.	16.0
14	20+0	5	n.a.	17	18.3
15	0	3	10	15	23.1
16	20 + S5	20	31	n.a.	20.5
17	0	4	19	n.a.	29.8
18	40+A3	10	29	n.a.	23.2
19	20+0	3	10	12	21.6
20	20+A5	5	27	n.a.	19.6
21	30+A5	13	20	27	20.9
22	20+D8	20	35	34	14.6
23	40+D8	21	n.a.	32	16.2
24	0	5	17	29	30.9
25	V	n.a.	17	n.a.	28.4

* See Table VI.13.

** See Table 7.5.

APPENDIX VII

Supplementary data for Expt 67/9B

TABLE VII.1 Expt 67/9B: volume tariff* of commercial species

Diameter class (cm dbh)	Diameter of average tree (cm dbh)	Basal area of average tree (m^2)	Bole length (L) of average tree (m)	Volume of average tree over bark (m^3)	$f_{1.30} \times L$
2.0– 4.9	3.5	0.00096	3.5	0.0024	2.45
5.0– 9.9	7.5	0.0044	6.0	0.0185	4.20
10.0–14.9	12.5	0.0123	8.5	0.0732	5.95
15.0–19.9	17.5	0.0240	11.1	0.1865	7.77
20.0–24.0	22.5	0.0398	13.2	0.3678	9.24
25.0–29.9	27.5	0.0594	15.0	0.6237	10.50
30.0–34.9	32.5	0.0829	16.2	0.9401	11.34
35.0–39.9	37.5	0.1104	17.2	1.3292	12.04
40.0–44.9	42.5	0.1418	17.8	1.7668	12.46
45.0–49.9	47.5	0.1772	18.2	2.2575	12.74
50.0–54.9	52.5	0.2165	18.2	2.7582	12.74
55.0–59.9	57.5	0.2597	18.2	3.3086	12.74
60.0–64.9	62.5	0.3068	18.2	3.9086	12.74
65.0–69.9	67.5	0.3578	18.2	4.5584	12.74
70.0–74.9	72.5	0.4128	18.2	5.2591	12.74
75.0–79.9	77.5	0.4717	18.2	6.0095	12.74
80.0–84.9	82.5	0.5436	18.2	6.8108	12.74

* This was derived from bole lengths determined in Expt 67/9B. A form factor at breast height ($f_{1.30}$) of 0.7 was assumed. The volume per diameter class for a certain stand is obtained by multiplying basal area of the diameter class with the factor $f_{1.30} \times L$.

TABLE VII.2. Expt 67/9B: number, basal area and volume of all species, form class III, in 1975, before refinement, and in 1979, four years after refinement

Diameter class (cm dbh)	N/ha		Basal area (m^2/ha)		Bole volume (m^3/ha)	
	1975*	1979**	1975*	1979**	1975*	1979**
5.0- 9.9	429	201	1.89	0.89	7.93	3.74
10.0- 14.9	130	160	1.60	1.96	9.51	11.66
15.0- 19.9	79	89	1.90	2.14	14.73	16.63
20.0- 24.9	58	43	2.31	1.70	21.33	15.71
25.0- 29.9	36	19	2.14	1.11	22.45	11.66
30.0- 34.9	25	10.1	2.07	0.84	23.51	9.53
35.0- 39.9	18	9.7	1.99	1.07	23.92	12.88
40.0- 44.9	12	4.8	1.70	0.69	21.21	8.60
45.0- 49.9	10.6	3.6	1.88	0.64	23.93	8.15
50.0- 54.9	6.6	1.8	1.43	0.38	18.21	4.84
55.0- 59.9	5.4	0.6	1.40	0.15	17.86	1.91
60.0- 64.9	4.5	0.7	1.38	0.21	17.59	2.68
65.0- 69.9	5.7	0.3	2.04	0.12	25.98	1.53
70.0- 74.9	3.6	0.3	1.49	0.14	18.93	1.78
75.0- 79.9	2.6	0.2	1.23	0.08	15.62	1.02
80.0- 84.9	1.6	0	0.86	0	10.89	0
85.0- 89.9	0.6	0	0.36	0	4.60	0
90.0- 94.9	0.3	0.2	0.20	0.11	2.57	1.40
95.0- 99.9	0.3	0	0.23	0	2.85	0
100.0-104.9	0.3	0	0.25	0	3.16	0
Total			28.3	12.2	306.8	113.7

* Data from a 10 ha sample area.
** Data from a 12 ha sample area.

TABLE VII.3 Expt 67/9B: number and bole volume of commercial species 11-41, form class I, in 1976, 1979 and 1982

Diameter class (cm dbh)	N/ha			Bole volume (m^3/ha)		
	1976	1979	1982	1976	1979	1982
5.0– 9.9	15.2	15.6	15.2	0.28	0.29	0.10
10.0– 14.9	8.1	5.7	8.5	0.59	0.42	0.54
15.0– 19.9	4.1	3.6	2.1	0.80	0.68	0.44
20.0– 24.9	3.5	3.6	3.8	1.31	1.29	1.39
25.0– 29.9	3.3	4.8	4.2	2.02	3.05	2.65
30.0– 34.9	2.8	3.3	4.2	2.59	3.08	3.91
35.0– 39.9	2.8	3.8	4.1	3.62	4.96	5.40
40.0– 44.9	1.7	2.6	3.2	2.93	4.61	5.64
45.0– 49.9	1.4	1.5	2.0	3.13	3.38	4.41
50.0– 54.9	0.6	1.1	1.0	1.54	3.12	2.76
55.0– 59.9	0.4	0.5	1.0	1.42	1.64	3.25
60.0– 64.9	0.3	0.3	0.6	0.95	0.96	2.17
65.0– 69.9	0	0.06	0.1	0	0.27	0.58
70.0– 74.9	0.2	0.3	0.1	1.00	1.34	0.32
75.0– 79.7	0.06	0	0.2	0.36	0	1.11
80.0– 84.9	0	0	0	0	0	0
85.0– 89.9	0	0	0	0	0	0
90.0– 94.9	0.06	0	0	0.53	0	0
95.0– 99.9	0	0	0	0	0	0
100.0–104.9	0	0	0	0	0	0
>45.0	3.0	3.8	5.0	8.9	10.7	14.6
>25.0	13.6	18.3	20.7	20.1	26.4	32.2
>15.0	21.2	25.5	26.6	22.2	28.4	34.0
>5.0	44.5	46.8	50.3	23.1	29.1	34.7

TABLE VII.4. Expt 67/9B: number and bole volume of commercial species 11–41, form class III, in 1976 and 1982

Diameter class (cm dbh)	N/ha		Bole volume (m^3/ha)	
	1976	1981	1976	1981
5.0– 9.9	54	57	n.a.	n.a.
10.0– 14.9	18	24	n.a.	n.a.
15.0– 19.9	7.8	6.8	1.52	1.39
20.0– 24.9	7.9	7.9	2.90	2.97
25.0– 29.9	6.6	6.0	4.08	3.75
30.0– 34.9	5.9	6.4	5.57	5.99
35.0– 39.9	4.8	5.8	6.21	7.56
40.0– 44.9	2.9	4.4	5.15	7.75
45.0– 49.9	2.0	2.3	4.57	5.10
50.0– 54.9	0.7	1.3	1.87	3.49
55.0– 59.9	0.7	0.9	2.27	2.83
60.0– 64.9	0.4	0.7	1.71	2.63
65.0– 69.9	0.06	0.1	0.29	0.57
70.0– 74.9	0.3	0.2	1.30	1.01
75.0– 79.9	0.2	0.3	1.12	1.49
80.0– 84.9	0	0.06	0	0.41
85.0– 89.9	0	0	0	0
90.0– 94.9	0.06	0	0.53	0
95.0– 99.9	0	0	0	0
100.0–104.9	0	0	0	0
>45.0	4.4	5.9	13.7	17.5
>25.0	24.6	28.5	34.7	42.6
>15.0	40.3	43.2	39.1	46.9
>5.0	112.5	124.2	n.a.	n.a.