Sustainable development of Scots pine forests

Promotor: Dr.Ir.R.A.A.Oldeman
Hoogleraar in de bosteelt & bosoecologie

Co-promotor: Dr.Ir.H.Koop
Bosecoloog
Instituut voor Bos- en Natuuronderzoek

SUSTAINABLE DEVELOPMENT OF SCOTS PINE FORESTS

J.H.Kuper

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Prospects for forests are prospects for life
To Haijo and Mathilde

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STELLINGEN

1. Hout groeit gratis, dus kan bosexploitatie eenvoudig winst opleveren.

2. Bosinstandhouding kan door bosgebruik bevorderd worden.

3. De tragiek van bosgebruik is, dat het meestal leidt tot bosvernietiging.

4. In tegenstelling tot het gangbare doch onjuiste uitgangspunt is de boseconomie, dat de gedane investering de totale eindopbrengst bepaalt, bepaalt de investering slechts de meeropbrengst boven de houtmassa die het bos ook zonder investering produceert. (Dit proefschrift).

5. Het is onjuist om uit financiële overwegingen te streven naar doelvoorraden, 'normaal' bos, of specifieke diameterverdelingen, want slechts het Faustmann-Pressler-Ohlin theorema bepaalt of een boom uit financiële overwegingen kaprijp is. (Dit proefschrift).

6. De natuur- en produktiefunktie van bos kunnen niet op één en dezelfde plaats integraal gerealiseerd worden, daarom kan duurzame bosontwikkeling slechts door zonering tot stand gebracht worden. (Dit proefschrift).

7. Op bossen die naast marktbare ook niet-marktbare produkten moeten leveren is het marktmechanisme niet toepasbaar. (Dit proefschrift).

8. Het beperken van houtoogst ten behoeve van duurzame bosontwikkeling is te bevorderen door voor het bij duurzame bosontwikkeling geoogste hout zo'n hoge prijs te betalen, dat duurzame ontwikkeling financieel aantrekkelijker wordt dan andere vormen van bosgebruik.

9. Omdat duurzaam geproduceerd hout beschikbaar komt zodra bossen duurzaam worden beheerd, is er geen houtteelttechnische reden om de voorwaarde, dat geïmporteerd hout duurzaam geproduceerd moet zijn, uit te stellen.

10. Evenals vele ontwikkelingslanden die hun bossen zeer snel te gelde maken, verkoopt Nederland zijn minerale rijkdommen en landelijke eigendommen in hoog tempo, en komt dan nog jaarlijks geld tekort.

11. De aanhoudende drang naar economische groei in Nederland wijst óf op een minimaal historisch en geografisch besef, óf op een uiterst ontevreden volksaard.

12. De mooie doeleinden die volgens de Commissie Bosuitbreiding door de aanleg van bos bereikt kunnen worden, zijn goedkoper te realiseren door het doen ontstaan van wildernis.

13. Natuur maakt gebruik van haar mogelijkheden, mensen maken van de hunne nogal eens misbruik.

Stellingen behorend bij het proefschrift van J.H. Kuper:
Sustainable development of Scots pine forests.

Wageningen, 6 april 1994.

Contents

Summary

The objective of this study was to design and test a silvicultural system for Scots pine that meets the conditions set by sustainable forest development, i.e. sustainable provision of timber and conservation of species. The fieldwork done to support the design was conducted in stands of old (60 to 140 years) Scots pine in Het Loo Royal Forest, in the centre of the Netherlands, from 1984 to 1992.

A silvicultural system that combines selection felling with spontaneous regeneration, allows sustainable forest use. If such a silvicultural system is applied in natural forests, by definition composed entirely of indigenous species, and the timber harvesting allows successional processes to continue, then nature conservation can also be optimized.

Most Dutch forests are cultivated. This, coupled with the desire for silvicultural systems that optimize both timber production and nature conservation, means that to achieve sustainable development the existing forests will have to be rehabilitated. Scots pine stands, which are the dominant forests in the Netherlands, offer good opportunities for the successional processes characteristic of natural forests and hence for subsequent sustainable forest development. After thinning Scots pine stands for several decades, beech, oak and birch should generate in these stands. However, if wildlife destroys the deciduous saplings, only Scots pine remains as an indigenous species to regenerate. This species needs specific pioneer conditions for regeneration.

Based on hypothetical models, a silvicultural system was designed to achieve sustainable development of Scots pine forests. The design was tested by formulating a number of questions and then conducting fieldwork and modelling to find answers. The questions posed were: 1. At what diameter should the individual old Scots pine trees be harvested? 2. What can be expected in terms of numbers, quality and height growth of spontaneously regenerated birch, oak and beech under the canopy of old Scots pine? 3. Under what conditions can Scots pine regenerate under old Scots pine? 4. Through what minimal investments can spontaneous regeneration be supplemented in order to generate higher profits? 5. What proportion of the Scots pine stands should receive preliminary management through group felling, and what size of group should be felled? 6. What volume of wood should be left in the forest and how much of the timber produced can be harvested without threatening the conservation of species? 7. What abundance of browsers should be allowed?

In order to find answers to these questions, tree ring research was carried out on Scots pine trees. Volume and value increment were calculated for diameter classes of various yield classes. Further, the height growth of young birch, oak, beech and Scots pine which were growing under the old Scots pine canopy was measured. In order to be able to predict growth of the young Scots pine, the relation between the basal area of the old Scots pine and the percentage of light that reaches the forest floor was examined, under conditions where the basal area was regularly spread over the stand, but also under heterogeneous conditions, and under gaps in the canopy. These investigations included both field measurements and simulations with the FOREYE and SILVI-STAR models (Koop, 1989). These programs were also used to calculate the photosynthetic active radiation in Scots pine stands with birch undergrowth. In addition, the radiation was measured in gaps in the herb and shrub layer in Scots pine stands.

In order to determine the development of the stem of oak saplings over the years, a large number of young oak trees was measured and drawn. This was repeated in three consecutive years.

Originally it was assumed that Scots pine regenerates only on seedbeds composed of mineral soil. A regeneration experiment was started under Scots pine stands with various basal areas. In these stands the soil was treated patchwise with a rotovator or a kuloo. Half of the number of treated areas were then fenced. Although the experiment was seriously disturbed by an unforeseen natural phenomenon, i.e. the storm of January 1990, several conclusions can be drawn.

During the research period, Scots pine regeneration also occurred outside seedbeds of mineral soil. These cases occurred on layers of partly decomposed organic material that had sparse ground cover. These unforeseen cases were also included in the investigations.

Finally, the feasibility of supplementing existing regeneration was investigated, in order to make better use of the available growing space. Oak saplings of various ages were planted among existing regeneration in old Scots pine stands, Scots pine saplings were planted under old Scots pine, and Scots pine seeds of proven provenance were sown on man-made seedbeds.

The results obtained by these experiments are used in the chapter 'Implications for management'.

The value increment was calculated in relation to the financial diameter. This is the stem diameter yielding the highest financial profit. The financial diameter is reached as soon as the current value increment of a tree equals the sum of the interest of the net stumpage value of that tree plus the soil rent of the growing area used. At a fixed interest, financial diameters were determined for various yield classes, at 1. various soil rents, 2. various regeneration costs, and 3. various stumpage prices. In addition, financial diameters were determined for various yield classes, assuming the objective is maximum income generation from timber harvested from the forest.

The number of 'final crop' trees per ha can be derived from the calculated sizes of financial diameters.

The calculated current increment in value and the calculated interest of the net stumpage value of individual trees enable a decision to be made about which tree has to be thinned for maximum profit if there is a choice between trees of different diameters.

The costs of various regeneration methods were compounded over the estimated time until harvest. That gave the minimum net return which has to be realized in order to cover the investment. The conventional way of reafforestation used in clearfelling systems was also analysed in this way.

Finally, the present net value for a number of actual examples and a number of hypothetical situations was calculated. The calculations of present net value also involved situations in which part of the biomass, including old trees, is not harvested.

The questions on accelerating the rehabilitation of cultivated forests regarding proportion and size of group felling, tree species composition, the minimum biomass of wood to be left in the forest, and the abundance of game are dealt with on the basis of a literature study.

The main results and conclusions of the study are:

- At specific stumpage prices financial diameters vary with site index, interest rate, soil rent, regeneration cost and thinning method. The use of financial diameters contributes to the financial results only. It does not contribute to the sustainable flow of timber. It also prevents degradation phases from occurring in the forest. Ecological value is then limited to the treeless, sapling, and young tree phases of the forest.
- The financial diameters of trees are independent of the characteristics of the surrounding stand. So, there is no need to work towards a specific diameter distribution, nor towards a specific standing stock.
- When thinning solely for profit, the biggest tree must be harvested if there is a choice between trees of different diameter.
- Regeneration by deciduous tree species occurs spontaneously in the Scots pine stands. Thus, at Het Loo Royal Forest, deciduous species can be used sustainably if browsing is kept within limits. In places where beech outshades the ground vegetation, the same is true for spontaneous regeneration by Scots pine, oak, birch and beech.

- Scots pine can only be used sustainably if pioneer conditions appear repeatedly.
- Birches create ecological light shafts in which photosynthetic active radiation declines laterally and increases towards the stand canopy.
- Dominant axes of oak saplings situated among other trees, bend towards the vertical over the years.
- Scots pine regenerates well on mineral soil created by soil tillage. It also regenerates on organic topsoil, provided the herb and shrub vegetation is absent or sparse.
- For oak saplings in old Scots pine stands no clear relationship between height growth and Scots pine stand density could be established. Scots pine saplings showed less height growth at the higher stand densities, but the effect was small, statistically significant only for high stand densities of the old stand.
- Enrichment planting of oak, beech and Scots pine enhances sustainable timber production.
- The rates of return from regeneration investments are low, even when management costs are low. At a 3% interest rate, Scots pine plantations show negative present net values at the time of planting. Present net values of observed cases of spontaneous regeneration both on open sites and in old stands were positive, even if a considerable volume of the timber is excluded from harvest. Patchwise soil tillage produces a positive present net value. So does enrichment planting with container-grown Scots pine saplings. The present net value of patchwise soil tillage can be increased by additional sowing. Seed-source planting is the cheapest regeneration technique for oak and beech.
- Big trees can be obtained by postponement of harvest. Zoning into areas with and without harvest guarantees big trees, degradation phases and dead wood.

The overall conclusion is that sustainable forest development is feasible in Scots pine forests in the Netherlands, using a silvicultural system which includes zoning, thinning, selection felling, preliminary fragmentation, spontaneous and semi-spontaneous regeneration and enrichment planting.

Samenvatting

Doel van deze studie was het ontwerpen en toetsen van een bosbeheerssysteem voor grove dennenbos, dat voldoet aan de eisen van duurzame bosontwikkeling, te weten: duurzame voorziening van hout en het behoud van soorten. Het veldwerk werd tussen 1984 en 1992 uitgevoerd in oude grove dennen opstanden (60 tot 140 jaar) in de Koninklijke Houtvesterij Het Loo en Paleispark Het Loo.

Een beheersysteem dat uitkap combineert met spontane verjonging staat duurzaam gebruik toe. Wanneer natuurlijke bossen, die per definitie uitsluitend bestaan uit inheemse soorten, door uitkap zodanig worden benut dat successieprocessen voortgang blijven vinden, kan de natuurfunktie daarin optimaal tot zijn recht blijven komen. Er is dan sprake van duurzame ontwikkeling. Nederland kent geen natuurlijke bossen meer. Bestaand bos moet daarom gerehabiliteerd worden. De aanwezige grove dennenbossen bieden mogelijkheden voor successieprocessen die karakteristiek zijn voor natuurlijke bossen. Na decennia van dunningen, kan daarin verjonging van berk, eik en beuk worden verwacht. Indien de loofhoutverjonging door wild wordt vernietigd, blijft alleen de grove den als inheemse soort in het verjongingsproces over. Deze soort behoeft echter speciale pioniercondities om zich te kunnen verjongen.

Het bosbeheerssysteem dat, op basis van hypothetische modellen, ontworpen werd om duurzame bosontwikkeling op Het Loo tot stand te brengen, werd getoetst door een aantal vragen te formuleren, waarna vervolgens gegevens uit veldwerk, modellering en literatuur werden gebruikt om tot beantwoording van de vragen te komen.

De vragen die dit type beheersysteem opwierpen waren: 1. Bij welke diameter moeten de individuele oude grove dennen worden geoogst? 2. Wat is er te verwachten van aantallen, kwaliteit en lengtegroei van spontane verjonging van berk, eik en beuk onder het kronendak van oude grove den? 3. Onder welke omstandigheden kan grove den zich verjongen onder oude grove den? 4. Met behulp van welke minimale investeringen is spontane verjonging aan te vullen zodat hogere netto opbrengsten kunnen worden verkregen? 5. Welke omvang moet inleidende groepenkap hebben, en hoe groot moeten de groepen zijn? 6. Hoeveel dood hout moet in het bos blijven en hoeveel van de geproduceerde biomassa kan worden geoogst zodat het voortbestaan van soorten niet in het geding komt? 7. Welke wildstand kan worden getolereerd?

Om deze vragen te kunnen beantwoorden werd een jaarringonderzoek verricht aan oude grove dennen. De volumegroei en de waardegroei per diameter-

klasse en per groeiklasse werden bepaald. Vervolgens werd de lengtegroei van jonge berk, eik, beuk en grove den, welke onder oude grove dennen groeien, gemeten. Vooral ten behoeve van de verjongingsverwachtingen voor grove den werd onderzocht welke relatie bestaat tussen de omvang van het grondvlak van de oude grove den en de hoeveelheid doorvallend licht dat de bosbodem bereikt. Dit werd gedaan in situaties waarbij het grondvlak regelmatig over de oppervlakte was verdeeld, maar ook in heterogene situaties en onder gaten in het kronendak. Dit onderzoek vond zowel plaats door meting in het bos als door simulatie met behulp van de programma's FOREYE en SILVI-STAR van Koop (1989). Deze laatste programma's zijn ook gebruikt om de fotosynthese-aktieve straling in gesimuleerde grove dennenbossen met ondergroei van berk te berekenen. Ook werd genoemde straling gemeten in gaten in de kruid- en struiklaag in grove dennenbossen.

Teneinde te kunnen vaststellen hoe de stamkwaliteit van jonge eiken zich over het verloop van jaren ontwikkelt, werd een groot aantal jonge eiken in drie opeenvolgende jaren gemeten en getekend.

Omdat er wordt aangenomen dat grove den zich alleen op een minerale bodem verjongt, werd een experiment opgezet, waarin onder oude grove dennenbossen met diverse volkomenheidsgraden de bodem pleksgewijs werd behandeld met een frees of met de kuloo. Dit terwijl steeds de helft van de plekken werd ingerasterd. Hoewel het experiment door een onvoorziene natuurlijke factor, n.l. de storm van januari 1990, ernstig werd verstoord, waren er toch een aantal conclusies uit te trekken.

Tijdens het onderzoek bleek, in tegenstelling tot wat algemeen wordt verondersteld, dat voorbeelden bestaan waar grove den zich niet op een kiembed van minerale grond had verjongd maar op een strooisellaag met open vegetatie, of zonder enige vegetatie. Deze voorbeelden werden ook bij het onderzoek betrokken.

Als laatste onderzoeksaspect werd uitgezocht of bestaande verjonging kan worden aangevuld zodat een beter gebruik kan worden gemaakt van de produktiemogelijkheden van de grond. Daartoe werden eiken van diverse leeftijden tussen bestaande verjonging onder oude grove dennen geplant. Grove dennen werden onder oud grove dennenbos geplant en selectiezaad van grove den werd bijgezaaid op de kiembedden die door de pleksgewijze bodembewerking waren verkregen.

De verkregen resultaten werden gebruikt als basis voor het hoofdstuk 'Implications for management'.

De waardegroei van oude grove dennen werd verwerkt tot doeldiameters waarbij het hoogste financiële gewin wordt bereikt (financiële diameter). De financiële diameters worden bereikt zodra de lopende waardegroei van een boom gelijk wordt aan de som van de rente van de netto waarde van de staande boom en de grondrente van de ingenomen groeiruimte. De financiële diameters werden uitgewerkt voor diverse groeiklassen, bij diverse grondrentes, en bij diverse niveaus van verjongingskosten en voor drie verschillende prijsniveaus. Afzonderlijk werd uitgewerkt welke financiële diameters voor verschillende groeiklassen gelden indien het bereiken van de maximale inkomstenstroom uit hout de doelstelling is.

Uit de berekende financiële diameters volgt het aantal te selecteren toekomstbomen per ha.

Uit de gevonden lopende waardeproduktie en de berekende rente van de netto staande waarde van individuele bomen werd berekend welke diameters uit financiële overwegingen zouden moeten worden gedund in een opstand met diverse diameters doorelkaar.

De kosten welke verbonden zijn aan de verschillende verjongingsmethoden werden met interest over het verwachte tijdsverloop van de groei doorgerekend. Dit leverde een minimum te realiseren opbrengst voor de investering op. Ook de conventionele methode van herplant na kaalslag werd op deze wijze doorgerekend.

Tot slot werd voor een aantal praktijksituaties en voor een aantal gesimuleerde situaties, de netto contante waarde van de verjonging berekend. Bij het berekenen van de netto contante waarden werd ondermeer in beschouwing genomen dat een deel van de biomassa, met inbegrip van oude bomen, niet te gelde wordt gemaakt.

Op de vragen met betrekking tot omvang en aard van de rehabilitatie maatregelen, de boomsoorten samenstelling, de gewenste hoeveelheid dood hout, en de wilddichtheden werd ingegaan op basis van literatuur gegevens.

De belangrijkste resultaten en conclusies zijn:

- Bij specifieke verkoopprijzen zijn financiële diameters afhankelijk van de groeiplaats, het rentepeil, de grondrente, de verjongingskosten en de dunningsintensiteit. Het gebruik van financiële diameters draagt slechts bij tot de financiële resultaten. Het draagt niet bij tot duurzame voorziening van hout. Het voorkomt tevens dat er vervalfases in het bos optreden. Natuurwaarden blijven dan beperkt tot de waarden van de boomloze fase, de staken fase, en de jonge boomfase van het bos.
- Financiële diameters van bomen zijn onafhankelijk van de eigenschappen van het omringende bos. Er zijn dus geen financiële redenen om een bepaalde diameterverdeling of doelvoorraad na te streven.
- Bij dunning ten behoeve van winstmaximalisatie moet, als er keuze is uit bomen van verschillende diameter, de dikste boom geoogst worden.
- In grove dennenbos treedt spontane verjonging van loofhout op. Op Het Loo kan derhalve, bij beperkte wilddruk, duurzaam gebruik worden gemaakt van loofhout. Op plaatsen waar beuk de bodemvegetatie heeft doen verdwijnen kan dit ook met spontane verjonging van grove den, eik, berk en beuk.
- Grove den kan slechts duurzaam gebruikt worden indien zich regelmatig pionier condities voordoen.
- Berken doen ecologische schachten ontstaan waarin het niveau van de fotosyntese-aktieve straling naar opzij afneemt, en naar boven toeneemt.
- Dominante assen van jonge eiken, groeiend temidden van andere bomen, richten zich in de loop van de jaren op.

- Grove den verjongt goed op minerale bodem welke is ontstaan door bodembewerking. Grove den verjongt ook op een bodemlaag van organisch materiaal als er geen bodemvegetatie aanwezig is, of wanneer de vegetatie open is.
- Bij jonge eiken in oud grove dennenbos kon geen verband worden aangetoond tussen lengte groei van de eik en de omvang van het grondvlak van de grove den. Jonge grove dennen toonden in dat geval een lagere groei bij de grotere grondvlakken. Het effect was echter gering, en slechts significant bij grote grondvlakken van de oude grove den.
- Aanvullende beplanting ('enrichment planting') met eik, beuk en grove den draagt bij aan duurzame produktie van hout.
- De rendementen van verjongingsinvesteringen zijn laag, zelfs bij lage beheerskosten. Bij een rente niveau van 3% tonen conventionele grove dennenbebossingen een negatieve netto contante waarde op het moment van planten. Netto contante waarden van beoordeelde gevallen van spontane verjonging, zowel in open terrein als in oude opstanden, waren positief, zelfs als een substantieel deel van het hout niet geoogst wordt. Pleksgewijze bodembewerking en aanvullende beplanting met container grove dennen tonen ook positieve netto contante waarden. De netto contante waarde van pleksgewijze bodembewerking kan door bijzaaien verhoogd worden. Verjonging door middel van het planten van zaadbronnen ('seed-source planting') is de goedkoopste verjongingsmethode voor eik en beuk.
- Uitstel van oogst voorziet in het ontstaan van dikke bomen. Zonering in gebieden met en zonder houtoogst voorziet in het ontstaan van dikke bomen, degradatie fases en dood hout.

De slotconclusie is dat duurzame bosontwikkeling in grove dennenbossen tot stand kan worden gebracht met een bosbeheerssysteem dat de volgende zaken omvat: zoneren, dunnen, uitkap, inleidende fragmentatie, spontane en semispontane verjonging en aanvullend beplanten.

SUSTAINABLE DEVELOPMENT OF SCOTS PINE FORESTS

PART I INTRODUCTION AND METHODOLOGY

1 Introduction

This study deals with the silvicultural design of managed forests, which develop very much according to nature*, produce timber sustainably and for a profit, have high non-marketable value and display low management risks.

1.1 Objective

The objective of this study was to design and scientifically test a silvicultural system for sustainable use of Scots pine stands that are to be rehabilitated from a 'cultivated system' state to a 'modified system' state, i.e. from a 'cultivated forest' state to a 'modified natural forest' state (IUCN et al., 1991). This silvicultural system should meet the conditions set by sustainable forest development, i.e. sustainable provision of timber and preservation of non-marketable values, in accordance with the definitions given by Poore (1993). These concepts and definitions will be elaborated in the following sections.

If sustainable development, including species conservation, is pursued, target stands* in the silvatic mosaic* must contain all developmental phases of the various successional stages of indigenous forests, including their degradation phases*. Timber from eco-units* in these developmental phases is to be harvested at a rate that does not cause such deviation from natural development that loss of species occurs.

The stands that are currently in a 'cultivated system' state are plantations of even-aged Scots pine (*Pinus sylvestris*) trees, located at Het Loo Royal Forest in the centre of the Netherlands. Timber from those stands is to be harvested sustainably in a way that does not hamper rehabilitation from the 'cultivated forest' state towards a 'modified natural forest' state that consists entirely of indigenous species. The fieldwork done to support the design was conducted from 1984 to 1992.

1.2 Silviculture in the Netherlands today

Large parts of the Veluwe area in the Netherlands are covered with even-aged Scots pine stands* managed and harvested as a crop on the basis of a clearfelling system*, i.e. an agricultural approach. This type of forest management entails

(* see Glossary)

high costs for re-establishment of new stands, which results in a relatively small financial margin between harvest yield and cost. In any case this margin is actually too small to cover the costs of establishing new stands and forest administration in the unproductive interval (Kuper, 1985), not to mention interest on the investment. Moreover, by harvesting stands by clearfelling, the value of the forest for nature conservation and recreation is reduced. The production value, the value for nature and recreation, and the flexibility to re-adjust the goals of this management system are therefore quite mediocre compared to other harvesting and management systems (Kuper, 1986).

The clearfelling system has long been the backbone of forestry tradition in the Netherlands. This was mainly because of the system of afforesting former heathland, which began in the second half of the 19th century. Now that these stands have been established, there is no reason to clearfell them. Especially because ideas on forestry have changed in the Netherlands in recent decades. More emphasis is now placed on the ecological value* of forests. This is apparent not only from government policy documents such as the 'Meerjarenplan Bosbouw' (1986) and the 'Ontwerp Bosbeleidsplan' (Anon., 1993), but also from the elaboration of management objectives of forest estates such as Het Loo Royal Forest (Anon., 1991), where ecology and sustainability have become major issues.

In this study the agricultural approach to forests is abandoned. Instead, forests will be considered as ecological systems, from which commodities are to be drawn to such an extent that sustainability in timber supply and the conservation of species are not threatened.

1.3 Sustainability and its applicability to forestry

Sustainability in timber supply, i.e. the continuous and equable production of timber as considered at the estate level, has been considered to be an essential management objective in forestry over two centuries (Dengler, 1982; Speidel, 1984; Sundberg and Silversides, 1988). Speidel (1984) distinguished various types of sustainability: sustainability in timber sales, in timber growth*, in income generation, in standing timber volume, but also in shelter values and possibilities for recreation. All these forms of sustainability can be achieved at estate level. Under certain conditions they can be achieved even with a clearfelling system. The basis of this sustainability is the productivity of the soil. The soil can be seen as the capital that should be kept in proper condition, and should provide a soil rent* on the basis of the land expectation value*. The stand is only a crop. All trees, even the whole stand, can be harvested. Ecological processes in the stand which span more than one rotation are ignored.

According to the guidelines of the 'Arbeitsgemeinschaft Naturgemäße Waldwirtschaft' ('working group on nature-following forestry'; Wobst, 1954;

Schöpffer, 1983; Hasenkamp, 1990), the soil and stand together form the capital. Thus, under this definition sustainability also applies to the stand itself. The same model holds for the silvicultural systems 'Plenterwald' (Trepp, 1974), 'Naturnahe Waldwirtschaft' (Huber, 1985) and Pro Silva forestry (Kuper, 1992b; Mlinsek, 1993). Soil and stand together provide the forest rent* on the basis of a forest expectation value*. Forest rent here is defined as the net yearly earnings from the *forested* soil, and forest expectation value is the total net income to be expected from a forest system in years to come, without consuming the forest system itself. At an appropriate volume of standing timber, harvest plus mortality should not exceed the current increment. Timber is harvested from the forest in a way and at such a periodicity that the growing area is re-occupied by trees in the shortest possible time. Clearfelling and other methods which destroy ('butchering' rather than 'milking'; Speich, pers. com.) the forest system do not fit in this approach.

By gradually harvesting an even-aged stand*, its basal area* will drop. In order to keep timber production constant, the reduction of basal area must be compensated for by the increase in the basal area of the remaining trees and by the basal area of young trees. If regeneration in the even-aged stand does not take place after selection felling, gradual reduction of basal area will eventually create pioneer conditions and allow pioneer species to regenerate.

Fig. 1. Sustainable timber-producing forest. Palace Park 14, 1986.

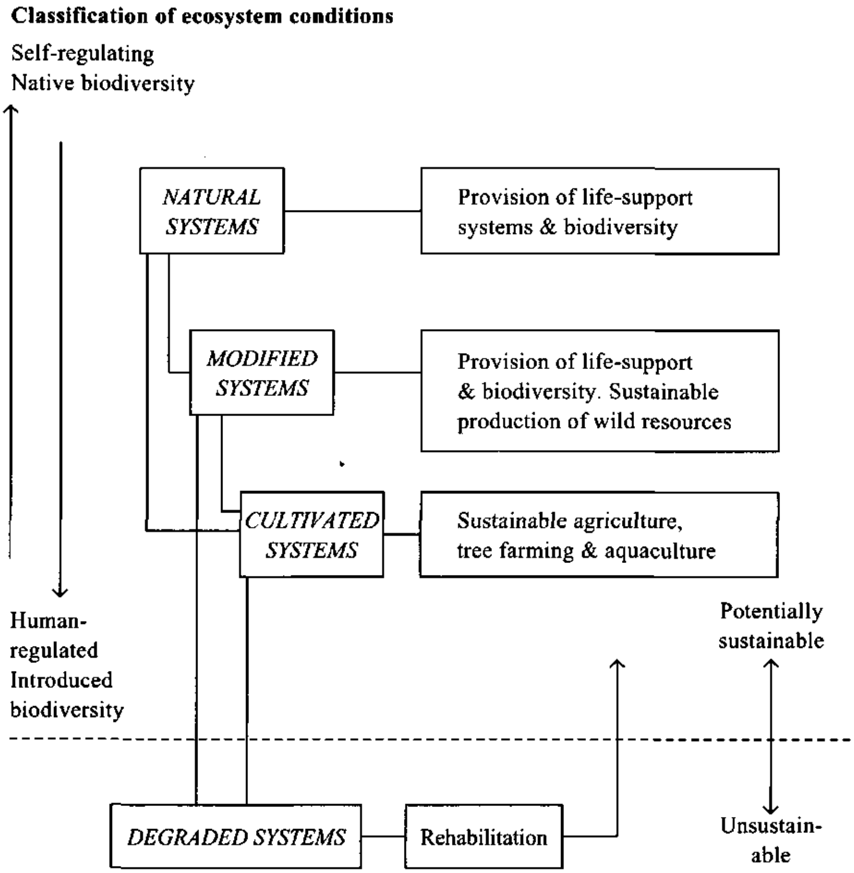
If the various successional stages develop spontaneously out of the original even-aged stands, the harvest of timber will continue through selection felling and will thus provide a sustainable timber-producing system (fig. 1). This system possesses functional and financial relations that differ greatly from the traditional clearfelling system. Ecological value increases (Janse and Kessler, 1981; Van Vuure, 1985; Opdam and Schotman, 1986; Schepers and De Zee, 1991) and so does recreational value (Van den Berg and Coeterier, 1980; Heytze and Herbert, 1991).

The World Commission on Environment and Development (WCED; 1987), has an approach to sustainability in which development is integrated. They state that (p.43): 'Sustainable development* is development that meets the needs of the present without compromising the ability of future generations to meet their own needs', and: (p.46) 'Development tends to simplify ecosystems and to reduce their diversity of species. The loss of plant and animal species can greatly limit the options of future generations; so sustainable development requires the conservation of plant and animal species', and (p.46): 'In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations'.

IUCN et al.(1991) produced several statements on sustainability (p.10): 'Sustainable use is applicable only to renewable resources: it means using them at rates within their capacity for renewal', and: 'Sustainable development is used in this strategy to mean: improving the quality of human life while living within the carrying capacity of supporting ecosystems'. This is consistent with the WCED's definition but explicitly recognizes that qualitative development can be maintained, whereas quantitative growth in the scale of the economy is constrained by the capacity of the ecosystems.

A classification of ecosystem conditions, inspired by IUCN et al. (1991), is given in box 1.

Box 1. Classification of ecosystem conditions. (Inspired by IUCN et al., 1991, their fig. 1).



Natural* systems.

Ecosystems where since 250 years human impact (a) has been no greater than that of any other native species, and (b) has not affected the ecosystem's structure*.

Climate change is excluded from the definition, because human-caused climate change is likely to affect all natural ecosystems as defined here.

Modified systems.

Ecosystems where human impact is greater than that of any other species, but whose structural components* are not cultivated. Most of the planet is now modified, including land and sea areas usually considered 'natural'. For example, spontaneously regenerating forest used for timber production; spontaneously regenerating rangeland used for livestock production.

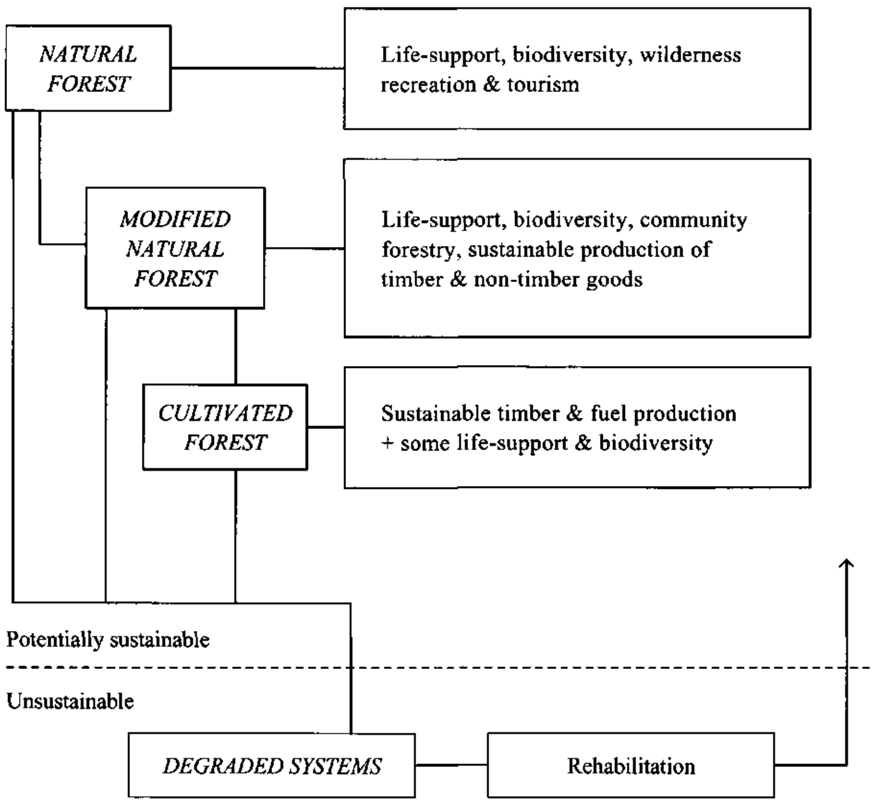
Cultivated systems.

Ecosystems where human impact is greater than that of any other species, and most of whose structural components are cultivated: e.g. farmland; sown pasture; plantations; aquaculture ponds.

Because of the importance of forest lands, IUCN et al. (1991) produced a special chapter on forestry. In that chapter an adaptation of the above classification of ecosystem conditions is given. It resulted in the 'Main conditions of forest lands', which is given in modified form in box 2.

Box 2. Main conditions of forest lands. (Inspired by IUCN et al. 1991, their fig. 5).

Main conditions of forest lands



Natural forest. Forest where trees have never been cut down or have not been felled for the past 250 years. Also known as primary or old growth forest.
Modified natural forest. Forest where trees have been felled during the past 250 years, by logging or by shifting cultivation, and that retain an indigenous tree or shrub cover. New tree growth may entirely be derived from spontaneous regeneration* or supplemented by enrichment planting* (Mergen and Vincent, 1987; Poore and Sayer, 1987; Wyatt-Smith, 1987; Poore et al., 1989).
Cultivated forest. Forest in which all or most (51% or more of the woody biomass) trees have been planted or sown by people.

Several authors (Poore and Sayer, 1987; Wyatt-Smith, 1987; Anon., 1990b) have also included conservation* of indigenous* plant and animal species and the use of non-timber products in sustainable use. Howe (1979) stated that avoidance of irreversibilities in all renewable resource systems is a prerequisite for a responsible natural resource policy. He considered it likely that continued extinction of plant and animal species will lead to less resilient, less varied, and less interesting environments.

Poore (1993) defined sustainable forest development as (p.2): 'consistent, deliberate, and sustained, yet flexible, action to maintain in a balanced manner the goods and services of the forest and to use these to increase the contribution of the forest to social well-being'.

Sustainable forest development depends on sustainable forest management. At the Ministerial Conference on the Protection of Forests in Europe, held in Helsinki in 1993, sustainable forest management was defined as: 'the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems' (*ex* Poore, 1993, p.2).

In order to apply sustainable forest development a special form of forest management is required, which integrates silviculture and conservation. The main criteria that distinguish sustainable development are (Stortenbeker et al., 1983; Kuper, 1992b; Maini, 1993):
- use of the forest may not cause loss of species;
- use of the forest may not cause loss of production potential.

The criteria can be met by keeping timber extraction at a low level throughout the area, or by restricting timber extraction to zones reserved as buffer zones, after a sufficiently large area has been designated strictly for species conservation. These two possible approaches are called in this study the 'low-level model' and the 'zoning model'. In the low-level model, the volume of timber extraction is restricted to allow the development of the aggradation*, biostatic* and degradation* phases* of all successional stages* possible in the indigenous forests (Kuper, 1992b). In the zoning model, where timber extraction is restricted to harvest zones, the level and methods of timber extraction allow stable soil fertility. Within these restrictions, timber is harvested when it generates the highest financial profits. This includes interest from the earnings of harvested trees.

If timber extraction is one of the objectives, compromises have to be made as to the naturalness* of the forest. The naturalness of the forest is determined by the degree of interference by man. Compromises are recognized on five issues (Kuper, 1992b):
1. extraction of biomass from the system,
2. limitation of tree sizes,

3. addition of anthropogenic dynamics to the natural dynamics of the system,
4. manipulation of the tree species composition*, and
5. manipulation of the distribution and abundance of game.

The compromise on extraction of biomass is clear: the more extraction, the less natural the system will be. This also concerns the limitation of tree sizes and the manipulation of tree species composition: the more limitation and manipulation, the less natural the system. Although it is not clear what the 'natural distribution and abundance' of game in the forests of the Netherlands would be, it is almost certainly different from an evenly distrubuted low abundance that allows deciduous tree species to regenerate spontaneously in such a way that they produce straight stems. Here too it holds that the more distribution and abundance are manipulated, the less natural the system is.

The compromise on dynamics is complex. Timber extraction creates zero events*, which by themselves have equivalents in natural dynamics (Westhoff, 1976). However, in nature the frequency differs (Koop, 1981b), and the biomass remains in the forest. Koop (1981a, 1981b, 1986) has stated that in forests in north-western Germany, the occurrence of zero events, as a result of natural dynamics, decreases exponentially as the sizes of the gaps created increase. He has also indicated (Koop, 1986) that the small-scale zero events have the lowest impact on the forest ecosystem*, as judged by the criterion of micro-climate. Londo (1991) confirmed this for nature conservation aspects.

Natural dynamics, such as the mortality of standing trees and windthrow, cause trees to die. Selection felling can partly replace natural thinning* caused by natural mortality of standing trees (Kuiper, 1988; Kuper, 1992a). That is why selection felling has an impact on the development of the stand similar to natural thinning. The impact is less than by group felling or clearfelling. Group felling and clearfelling have natural equivalents too. However, natural processes at that scale, such as group windthrow, are likely to occur anyway. Those processes are not replaced by group felling. The frequency of that kind of dynamics is increased by the felling activities, and so is its impact on the development of the stands involved. Increase in dynamics causes an increase in early successional stages (Koop, 1992).

If the method of harvesting imitates the natural dynamics by practising selection felling, the stand will remain as natural as is possible in combination with timber harvest. Nevertheless, selection felling will affect the structure and therewith the development of the forest.

1.4 Selection felling and regeneration

Most of the available literature on selection felling and spontaneous regeneration in selection felling systems deals with shade-tolerant species such as beech

(*Fagus sylvatica*), Norway spruce (*Picea abies*) and silver fir (*Abies alba*) (Biolley, 1919; Ammon, 1951; Schütz, 1981; Dengler, 1982; Favre, 1982; Leibundgut, 1984), of which the latter 2 species are not indigenous in the Netherlands. Few publications are available about light-demanding indigenous species such as Scots pine (Wiedemann, 1925; Wohlfarth, 1939; Weck, 1940 and 1947; Kräuter, 1966; Junack, 1970; Lang, 1977; Trepp, 1981). In these publications oaks play no significant role. Ebeling and Hanstein (1989), Steiger (1989), Seefelder (1991) and Fischer (1993) reported on young oak in Scots pine stands.

Under a selection felling system, the composition of tree species and tree numbers change because of harvest, forest development and succession. The site conditions, zero events and human interference affect these changes. According to Fanta (1982), the species composition of spontaneously regenerated trees in Scots pine stands depends on the age of the old Scots pine, the state of soil development, the type of soil parent material, the herb and shrub vegetation, the percentage of cover of the mature stand, the influence of wild animals, the presence of seed sources and the occurrence of seed years.

Based on present knowledge, Fanta (1982) and Hanstein (1986) indicated ways in which this vegetational succession may proceed on humus podzols (de Bakker, 1979; very dry humus podzol soils according to Bannink et al., 1973) and brown podzolic soils (de Bakker, 1979; humus-iron podzols according to Bannink et al., 1973) in the Netherlands and Lower Saxony. Humus podzols form the substratum of the Betulo-Quercetum roboris, as well of part of the Fago-Quercetum petraeae. Brown podzolic soils at Het Loo Royal Forest form the substratum of the Fago-Quercetum petraeae (Van der Werf, 1991). These soil types dominate in Het Loo Royal Forest.

Nearly all even-aged Scots pine stands at some time show spontaneous regeneration, mostly by various tree species (Sissingh, 1976). But when a closed vegetation of bracken (*Pteridium aquilinum*) covers the soil, spontaneous regeneration is absent (Fanta, 1982). In Scots pine stands at Het Loo Royal Forest and Het Loo Palace Park (fig. 2) spontaneous tree regeneration has been recorded of pedunculate oak (*Quercus robur*), sessile oak (*Quercus petraea*), beech (*Fagus sylvatica*), European birch (*Betula verrucosa*), rowan (*Sorbus aucuparia*), alder buckthorn (*Frangula alnus*), Scots pine (*Pinus sylvestris*), Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), Norway spruce (*Picea abies*), red oak (*Quercus rubra*) and American black cherry (*Prunus serotina*) (De Boer et al., 1985; Clercx et al., 1986; Vester, 1987; Al and Montizaan, 1987). In stands where the abundance of browsers does not exert a dominant influence, regeneration of birch and pedunculate oak occurs most frequently, followed by beech and red oak. The regeneration of Douglas-fir has been increasing because many planted Douglas-fir stands have reached sexual maturity in recent decades. Regeneration of sessile oak occurs less often, because of the relative scarcity of seed sources and seed years, whereas regeneration of Scots pine is

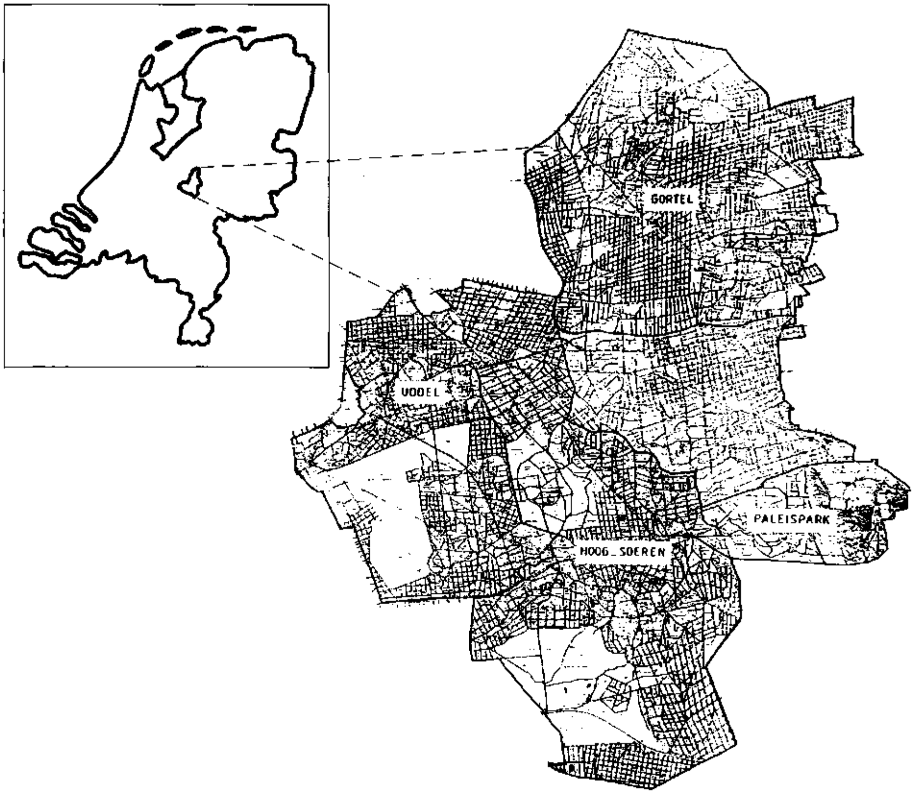


Fig. 2. Location of Het Loo Royal Forest and Het Loo Palace Park, the Netherlands.

rare. Fanta (1982) mentioned pubescent birch (*Betula pubescens*) regenerating in addition to the species mentioned above.

Examples of stadia of a successional sequence of indigenous forests in the 'cultivated forest' state are found at several localities in the Netherlands, Germany, Scotland and Belgium. The examples at Het Loo Royal Forest of regeneration of oak, birch and beech under Scots pine, are Palace Park 13 and 14, Uddel 44, Gortel 52 and 80 and Soeren 15. Ebeling and Hanstein (1988), Steiger (1989) and Fischer (1993) mentioned regeneration of indigenous oak under Scots pine in Germany. In Gartow (Olberg, 1957; Junack, 1970; fig. 3), Bärenthoren (Weck, 1947; Krutzsch, 1951; Kräuter, 1966), and Eberswalde (Grossmann, 1966), all of which are in Germany, examples are found of Scots pine stands in which Scots pine has regenerated spontaneously – always in stands from which the leaf litter used to be removed. The moment the litter collection was stopped, a suitable seedbed for Scots pine was available. Stands that have developed in this way contain only 2 age classes. These examples show little or no admixture of deciduous species in the oldest, first, generation of Scots pine. Neither is there much admixture with deciduous tree species in the second generation. This lack

Fig. 3. Regeneration of Scots pine underneath an old Scots pine stand. Gartow, 1984.

of admixture with other tree species is mainly caused by a lack of seed sources. Since the cessation of litter collection by farmers, there has been an increase in soil vegetation cover, particularly by wood small-reed (*Calamagrostis epigejos*) (pers. observation, 1986). This grass interferes with a spontaneous regeneration of a third generation of Scots pine (Wiedemann, 1925). If a suitable seedbed is created once more, as was done in Bärenthoren by ploughing, the next generation of Scots pine establishes.

In Eberswalde, which has a number of sessile oak seed sources, and a soil more fertile than in Gartow and Bärenthoren, sessile oak has regenerated in a stand consisting of first and second generation Scots pine (fig. 4). Weck (1940) mentioned more examples of uneven-aged Scots pine stands with admixture of some oak and birch. These uneven-aged stands originated from what Weck called 'Plünderwald'; plundered forest.

McNeill (1955) and Lust (1987) published cases of spontaneous regeneration in Scots pine stands with ground vegetation, in Scotland and Belgium respectively. Both authors recorded examples of regeneration of various deciduous species. Scots pine seedlings did not survive after germination. Mees (1981) also described regeneration of deciduous tree species under Scots pine in Belgium. Peterken and Stace (1987) reported on a Scots pine stand at Loch Rannoch in Scotland under which Scots pine regenerated. These authors considered this Scots pine forest to be a 'disturbance climax*' because Scots pine regenerates following events such as windthrow, fire, and disease.

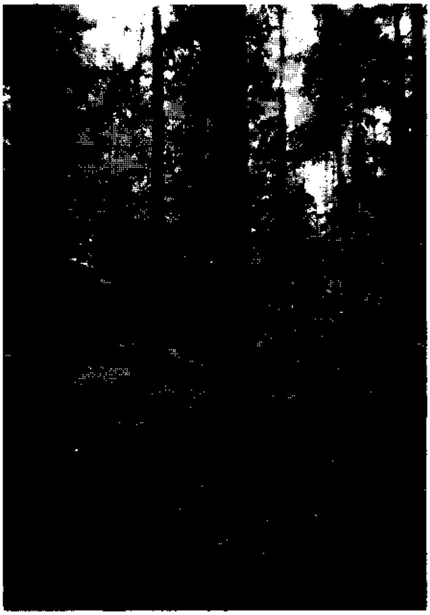


Fig. 4. Deciduous species established under two, mixed, generations of Scots pine. Eberswalde, 1986.

The following preliminary conclusions can be drawn from the cases presented above:

- Scots pine stands can, by spontaneous processes, develop to mixed beech/oak/birch/Scots pine stands;
- Regeneration by light-demanding species, Scots pine included, is possible under Scots pine;
- If Scots pine regeneration is absent, the limiting factor is not necessarily light shortage, but possibly the condition of soil or vegetation: so a suitable seedbed should be prepared.

If only indigenous tree species belonging to the Betulo-Quercetum roboris or the Fago-Quercetum petraeae are considered, the following species emerge by spontaneous regeneration processes in stands composed of those species on humus podzols and brown podzolic soils at Het Loo:

- in beech stands: beech and, to a lesser extent, birch
- in birch stands: beech, oak and Scots pine (see box 3)
- in sessile oak stands: beech, sessile oak and, to a lesser extent, birch
- in pedunculate oak stands: beech, pedunculate oak and, to a lesser extent, birch
- in Scots pine stands: beech, birch and oak
- exceptionally, Scots pine regenerates in Scots pine stands and on open areas in beech stands.

Box 3. Scots pine as an indigenous species in the Netherlands.

Several authors contend that Scots pine is indigenous in the Netherlands (Zonneveld, 1965; Wolterson, 1973; Van der Woude, 1983). Polak (1959) found pollen of *Pinus sp.* throughout the periods of Boreal, Atlanticum and Subboreal in the peat of the Uddelermeer, a small lake in Het Loo Royal Forest. Only in the Boreal was *Pinus sp.* an important component of the forest.

Although Westhoff and Den Held (1975) mentioned Scots pine as a species of the Betulo-Quercetum roboris, and Van der Werf (1991) has reported the spontaneous occurrence of Scots pine under poor pioneer conditions in degraded Betulo-Quercetum roboris, the species is more at home in the Cladonio-Pinetum sylvestris, the Leucobryo-Pinetum and the Empetro-Pinetum (Van der Werf, 1991) than in the Betulo-Quercetum roboris or Fago-Quercetum petraeae.

Scots pine provides good conditions for potential Betulo-Quercetum roboris or Fago-Quercetum petraeae to develop (Van der Werf, 1991). In this study Scots pine is regarded as an indigenous species, without closely defining the geographical and ecological extent of the area in which it is indigenous.

1.5 Hypothetical development of Scots pine stands

In addition to the factors mentioned above, development of regeneration also depends on the tree species composition of regenerating compartments at the time of establishment, the difference in growth rate and shade tolerance of the regenerating species and mutual competition* between these species. Ultimately, shade-tolerant species will become dominant (Sissingh, 1977; Bormann and Likens, 1979). Table 1 shows a hypothetical regeneration sequence if beech, birch and oak regenerate in a Scots pine stand.

The stands which develop according to the regeneration sequence of table 1 fit the conditions of target stands because they fit in successional stages of indigenous forest.

Lust (1987) mentioned a similar regeneration and successional process towards red oak dominance through regeneration in Scots pine stands in Belgium.

Table 1. Hypothetical development sequence of a cultivated Scots pine forest to a modified natural beech forest via a mixture of oak, birch and beech (assumed average felling ages: birch 75, Scots pine 100, beech 120, oak 150 years).

Starting point: Scots pine stand age 75 or more			
Regeneration at year 0 (fig. 5)	oak	birch	beech
Stand composition after ca. 75 years	oak	birch	beech
Regeneration after ca. 75 years		beech	
Stand composition after ca. 150 years		oak	beech
Regeneration after ca. 150 years		beech	
Stand composition develops towards		beech	

Fig. 5. Scots pine with regeneration of oak, birch and beech, Gortel 79a, 1993 (cf. table 1).

Similar regeneration can be expected if other shade-tolerant species are present, such as Douglas-fir. Table 2 shows a hypothetical regeneration sequence of oak/birch/Douglas-fir in a Scots pine stand, in the absence of beech.

The stands which develop according to the regeneration sequence of table 2 are different from the target stands. Because Douglas-fir is an exotic species these stands do not fit in successional stages of indigenous forest.

Commercial indigenous tree species of the Betulo-Quercetum roboris and Fago-Quercetum petraeae in the Veluwe area of the Netherlands which are available to regenerate in selection-felled Scots pine stands are: beech, sessile oak, pedunculate oak, birch and Scots pine. Beech, as shade-tolerant species, will dominate these forests in the Fago-Quercetum petraeae, where it overgrows the other species (Van der Werf, 1991). It is still not clear what role beech plays

Table 2. Hypothetical development sequence of a cultivated Scots pine forest to a cultivated Douglas-fir forest via a mixture of oak, birch and Douglas-fir (assumed average felling ages: birch 75, Scots pine 100, Douglas-fir 75, oak 150 years)

Starting point: Scots pine stand age 75 or more			
Regeneration at year 0 (fig. 6)	oak	birch	Douglas
Stand composition after ca. 75 years	oak	birch	Douglas
Regeneration after ca. 75 years		Douglas	
Stand composition develops towards		Douglas	

Fig. 6. Scots pine with regeneration of Douglas-fir, birch and oak, Gortel 78, 1993 (cf. table 2).

in the Betulo-Quercetum (Van der Werf, 1991). Dominance of beech leads to a successional stage with reduced numbers of other species (Peters, 1992), and to one single species as the timber crop.

If beech, and other shade-tolerant tree species, are absent, the hypothetical regeneration sequence in the Scots pine stand is assumed to be as given in table 3.

However, the mixed Scots pine/oak/birch stand in Duddel (Het Loo Palace Park 13), does not show regeneration of Scots pine (Tjebbes, 1989). Only deciduous

Table 3. Hypothetical development sequence of a cultivated Scots pine forest to a modified natural forest composed of oak, birch and Scots pine (assumed average felling ages: birch 75, Scots pine 100 and oak 150 years).

Starting point: Scots pine stand age 75 or more			
Regeneration at year 0 (fig. 7)	oak		birch
Stand composition after ca. 75 years	oak		birch
Regeneration after ca. 75 years	oak		Scots pine
Stand composition after ca. 150 years	oak		Scots pine
Regeneration after ca. 150 years	birch		oak
Stand composition develops towards	oak	birch	Scots pine

Fig. 7. Scots pine with regeneration of oak and birch, Gortel 80a, 1993 (cf. table 3).

Fig. 8. Regeneration of deciduous species under a mixed stand of Scots pine, birch and oak. Duddel, Palace Park 13, 1993.

species appear (fig. 8). The existing cover of bilberry (*Vaccinium myrtillus*) is expected to prevent Scots pine regeneration (Olberg, 1957). The prognosis is, therefore, for Scots pine to gradually disappear from this mixed stand.

As can be observed in Scots pine stands in Het Loo Royal Forest, shrubs* such as bilberry become abundant due to successional processes. Where bilberry occurs, Scots pine will no longer be able to regenerate (Olberg 1957).

Through selection felling, again in absence of beech, stands that consist of mixtures of sessile oak, pedunculate oak and birch will develop. Oak will dominate (Savill, 1991). This situation is presented in table 4.

Table 4. Hypothetical development sequence of a cultivated Scots pine forest to a modified natural oak forest via a mixture of oak and birch (assumed average felling ages: birch 75, Scots pine 100 and oak 150 years).

Starting point: Scots pine stand aged 75 or more		
Regeneration at year 0 (fig. 9)	oak	birch
Stand composition after ca. 75 years	oak	birch
Regeneration after ca. 75 years	oak	
Stand composition after ca. 150 years	oak	
Regeneration after ca. 150 years	oak	birch
Stand composition develops towards	oak birch	(predominantly oak)

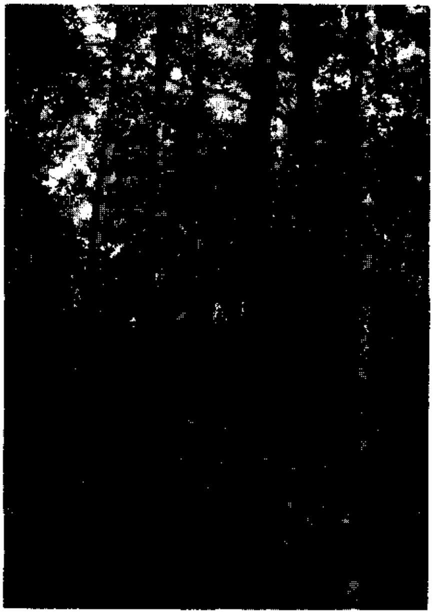


Fig. 9. Scots pine with regeneration of oak and birch. Gortel 80a, 1993 (cf. table 4).

The timber which provides financial revenue, according to table 4, is at first exclusively Scots pine. Later in the development process birch and oak will gradually become available. This is a favourable transformation in terms of forest utilization (de Lange, 1987; Meerjarenplan Bosbouw, 1986).

Regeneration of deciduous tree species will not always take place spontaneously. This can be because of the impact of browsers, which have a preference for deciduous tree species (Wiedemann, 1925; Van de Veen, 1979; Fanta, 1982; Hol and Schalk, 1986; Hespeler, 1989).

In the absence of deciduous species, Scots pine sometimes regenerates in Scots pine stands. Several examples exist at Het Loo (Palace Park 19c, Uddel 141, and Gortel 8 and 19, fig. 10). In these situations the litter layer or herb and shrub cover appeared to be sparse or absent.

The ground vegetation can temporarily be removed by soil tillage to allow various tree species to regenerate, such as Scots pine, which is less favoured by browsers than deciduous tree species. The latter can be observed in stands Palace Park 13 and Soeren 46g. Given the management objectives stated earlier, Scots pine is also an acceptable tree species. According to Wiedemann (1948), Houtzagers (1954) and Wolterson (1973) Scots pine is a pioneer species* which is shade-intolerant. To regenerate, Scots pine saplings require more light than generally available in a closed Scots pine stand. Therefore the crown cover of such

Fig. 10. Scots pine regenerated under Scots pine. Gortel 181, 1993.

a Scots pine stand has to be reduced (McLaughlin, 1978). Gradual reduction is brought about by harvesting. So is reduction of the basal area. The relation between crown area of Scots pine and basal area of stems has been reported by Ilvessalo (1950) and Erteld (1979).

Table 5 gives a hypothetical development sequence of a Scots pine stand with oak, birch and Scots pine regenerating under it.

Table 5. Hypothetical development sequence of a cultivated Scots pine forest to a modified natural oak forest via a mixture of oak, birch and Scots pine (assumed average felling ages: birch 75, Scots pine 100 and oak 150 years).

Starting point: Scots pine stand age 75 or more			
Regeneration at year 0 (fig. 11)	oak	birch	Scots pine
Stand composition after ca. 75 years	oak	birch	Scots pine
Regeneration after ca. 75 years		oak	birch
Stand composition after ca. 150 years		oak	birch
Stand composition develops towards	oak	birch	(predominantly oak)

Fig. 11. Scots pine with regeneration of oak, birch and Scots pine. Gortel 52, 1989 (cf. table 5).

1.6 General

This study is a *design study*. Although the system analysis used would have enabled extensive use to be made of mathematical operations (cf. Koop, 1989, and Leersnijder, 1992), this was considered to be marginally relevant for design purposes. The following quotation from Goewie (1993, p.13, translated from Dutch) supports this :'The objective of designing is not aimed at interpretation of reality, but at developing reality towards a desired goal'. Van den Kroonenberg (*ex* Goewie, 1993, p.15, translated from Dutch) has a similar view: 'The designer's starting point is his final goal, that which he wants to achieve with his design. Therefore it is the designer's duty to determine the functions of what he designs, in order to achieve those goals'.

Warning: This design study cannot be extrapolated to other areas without risks. Among others, moisture balances were not defined, stress factors such as acid deposition were not measured, and the rhizosphere was not analysed. Locally, these scientific aspects may justifiably be circumvented by using empirical data, which leave the above systems and processes in the design as 'black boxes'. However, this would reduce the universal applicability of the design.

Most of the field research was carried out in stands in Het Loo Royal Forest and Het Loo Palace Park. Additional field research was carried out in Petrea and Imbosch, both also in the Veluwe area, and in Amerongseberg in the province of Utrecht. All stands are on Pleistocene sandy material in almost flat country. The altitude is between 20 and 80 m above sea level. Mean annual temperature is 9 °C. Mean temperature in July is 17 °C. Mean annual rainfall at the nearest meteorological station, Deelen, is 800 mm. Mean annual rainfall minus evaporation from a water body is 300 mm (Anon., 1988c).

2 Design and questions

2.1 Design of the silvicultural system

Bearing in mind the objectives stated earlier (section 1.1), a silvicultural system offering a sustainable flow of timber, preservation of non-marketable values and rehabilitation of the current Scots pine stands to a 'modified natural' state was designed.

The basic elements of the design are: 1. sustainable timber exploitation through selection felling and spontaneous regeneration by indigenous trees, and 2. conservation of species through occurrence of all developmental phases and successional stages of the natural forest mosaic.

If spontaneous regeneration does not occur, semi-spontaneous* regeneration can be initiated through fencing or soil tillage. If the regeneration does not contain sufficient trees of marketable value in future, artificial regeneration* can be applied with restraint, through enrichment planting* or sowing.

Noting the above tables of hypothetical development (nos 1 to 5), the following treatments of Scots pine stands are proposed as the *silvicultural system design*:

- The current even-aged Scots pine stand is harvested by gradual thinning. Optimal use is made of value increment* by selecting 'final crop' trees at an early phase. Since the harvest will take place over a long period it is not appropriate to use the term 'final crop' trees. The 100 to 200 trees per ha of best quality which are kept in a favourable social position in the stand, and are expected to be kept in the stand until they reach the largest desired diameter, the financial diameter*, are referred to in this study as 'future trees*'.

  Trees that have reached the financial diameter are harvested. Data from Beninde (1938b), Wiedemann (1949), and Franz (1983) show that current growth of Scots pine trees increases after an increment felling*. This means that the financial diameter increases once trees become 'solitary'. The examples in literature in which small numbers of individual Scots pine trees are left after shelter felling (Baader, 1942; Mrazek, 1966; Schölzke, 1970; Jaeger, 1974) do not represent the necessary reduction of basal area required for regeneration. The former approach is mainly directed to the regeneration process as such and to a limited extent to volume increase in a small number of old trees. The target stands in this study aim at sustainability in both material and non-marketable values; therefore as much of the old stand as possible is maintained during the regeneration process. Kräuter (1967) compared 2 examples in Bärenthoren and Dobritz, both in Germany, with 2 densities of remaining shelter trees*. The Bärenthoren example is comparable to the approach to the target stands in this study. The Dobritz example is rather a uniform shelterwood regeneration system, i.e. the reduction of basal area is greater.

- Species diversity is linked to the occurrence and spatial arrangement of the various developmental phases and successional stages which exist in natural forests. To avoid the prolonged absence of different developmental phases, which is characteristic of even-aged stands, preliminary fragmentation* is carried out, by felling groups of various sizes.
- When the available light increases due to the harvest, beech, oak and birch will establish under Scots pine. Beech could have done so the earliest, in darker conditions than oak and birch can tolerate. If regeneration by beech, oak and birch is abundant, regeneration by Scots pine will no longer be possible, because of the slow growth rate of Scots pine and the reduced light availability. This was observed in stand Gortel 77g. In that scenario Scots pine will no longer be necessary.
- If beech is absent, and Scots pine fails to regenerate, the following situations may occur:
  1. the regeneration compartments consist entirely of oak;
  2. the regeneration compartments consist entirely of birch;
  3. the regeneration compartments consist of a mixture of oak and birch.

  When regeneration compartments consist only of oak, the number of spontaneously established* oaks generally is not high enough to ensure the desired straight stem form and stem height. These sparse oaks generally produce undesirable stem forms, due to the formation of spreading crowns, as recorded in Het Loo Royal Forest. Tree form can be improved by increasing the number of oaks per hectare, but this requires a considerable investment. When regeneration consists entirely of birch, a reduction of value increment has to be assumed because of the low value of birch timber. This is undesirable. However, birch stands observed in Het Loo Royal Forest constitute an appropriate environment for future regeneration of oak and Scots pine. Examples are Gortel 77f and 80a (fig. 12). Production values may be increased by enrichment planting with limited numbers of oak during the process of birch regeneration under Scots pine.

  It is, however, not known whether the half-shade in Scots pine stands, in which birch regeneration takes place, is also suitable for oak, not only to establish and survive among the birch trees, but also to produce stem forms of good quality. Therefore planting experiments have to be carried out in Scots pine stands with a reduced basal area, where spontaneous regeneration by birch occurs. The stem qualities of oak need additional research.

  In mixtures of oak and birch, birches are generally much more numerous than oaks. Vester (1987) pointed out that young oaks in mixture with birch, in a mature Scots pine stand at Het Loo, have straight stems. This is possibly the result of the birch crowns filling the space and thereby forcing the oaks to grow upwards in a kind of 'ecological shaft', i.e. a narrow vertical shaft

Fig. 12. Oak and Scots pine under birch. Gortel 80a, 1991.

of specific radiation characteristics (cf. 'ecological chimney'; Oldeman, 1974).

- The oak trees which are expected to reach the maximum felling age are financially the most interesting. According to Möller (1933), this limits the number to 80 oaks per ha at the age of 150 years for oaks of the third yield class; i.e. management is successful if there are ultimately 80 healthy and well-shaped oaks among a majority of birches. Generally, 80 oak saplings* will not produce 80 oaks of adequate quality after 150 years (Smeulders and Van Wageningen, 1988). In order to obtain enough trees for selection and losses, the existing population of oak saplings could be enlarged by extra sowing or enrichment planting.
- The harvest of mature oaks will allow oak, and, to a lesser extent, birch, to regenerate – as can be seen in Palace Park 13. Several authors (Houtzagers, 1954; Krahl-Urban, 1959) have indicated that sessile oak can tolerate more shade than pedunculate oak, therefore it is probable that sessile oak will be more appropriate to this system than pedunculate oak. However, Longman and Coutts (*in* Morris and Perring, 1974) have stated that both species can still display high rates of photosynthesis at reduced daylight levels. Also, observations in Het Loo Royal Forest show that both species can maintain themselves in such a silvicultural system. If beech occurred, this species would be able to regenerate at any time.
- When oak does not establishes spontaneously in sufficient numbers, or if the oak does not possess the required genetic crop qualities, the oak population

could be supplemented by sowing or planting. Only a limited number of saplings has to be added. The saplings must be carefully selected for their growth qualities. Addition of pedunculate as well as sessile oak is recommended. Addition of oaks by sowing has the disadvantage of vulnerability to browsing. This problem can be solved by planting saplings that are too tall for game to browse. Planting, however, includes the risk of mortality that accompanies the process of the sapling becoming established at the planting spot.

- If browsers prevent broadleaved species surviving, they create one of the conditions for successful Scots pine regeneration. Regeneration of Scots pine can be initiated after ongoing thinning (or the preliminary fragmentation) has resulted in a decrease of basal area (Beninde, 1938a; Baumgartner, 1955; Gatherum et al., 1963; Klein, 1964; Erteld, 1986).
- Once the available light is sufficient for the regeneration of Scots pine, a suitable seedbed must be provided for its seeds (Zentgraf, 1940; Wiedemann, 1948; Wittich, 1955; Olberg, 1957; Rottmann, 1966; Brechtel, 1969; Seitz, 1979; Fanta, 1982; Erteld, 1986). Therefore soil tillage should be carried out. Full soil tillage is expensive and destroys a major part of the ecosystem. A patchwise treatment suffices, because only a limited number of trees is allowed to grow to 'financial diameters'. Patchwise soil tillage has equivalents in nature in the form of uprooting of trees (Koop, 1989), and through rooting by wild boar.

  In Scots pine stands in which the basal area is greatly reduced, the soil is treated patchwise. Originally, a traditional forestry machine, the kulla (Schütz and Van Tol, 1981) was used, which removes the sod from a patch of approximately 60 x 70 cm. Experiments at Het Loo Royal Forest with the kulla were not very successful, since most Scots pine seedlings* in the kulla patches did not survive the first year. Some of the sods which were removed, remained partly attached to the untouched sod. Foraging wild boars lifted these sods and rolled them back on the seedbed, and seedlings were destroyed. In the seedbeds which were not covered by the sod, most seedlings died, and showed signs of needle cast (*Lophodermium seditiosum*). Needle cast thrives on Scots pine needles under moist and cool conditions (Göhre, 1954; Bolland, 1957; Squillace et al., 1975; Butin, 1983; Kriek, 1983; De Kam, 1985), for example in small patches amidst bilberry shrubs (Hardeveld, 1988). Therefore larger and more open patches had to be tried as seedbeds. Since the patches made by kulla and also by the Nya Kulla (Holodynski, 1982) were expected to be too small, a new sod-stripping machine was developed by staff at Het Loo Royal Forest, called the kuloo* (Kuper, 1989). Later, other machines for preparing seedbeds were also tried out (subsection 3.2.2).
- The genetic qualities of Scots pine trees are sometimes said to be poor (Jansen and Broekhuizen, 1952; Fanta, 1983; Kriek, 1983), although they can be better than a phenotypical* judgement indicates (Wiersma, 1985; Prins and Kuper, 1989). If the inherited tree qualities of the old Scots pine stand are judged to be too far from those which are required, regeneration can be supplemented by sowing selected Scots pine seeds.

- In practice, conditions of reduced basal area, fragmentation of the canopy* and chablis* frequently occur spontaneously by windthrow: conditions are provided which create regeneration units, eco-units* (Oldeman, 1990). These may even be large enough and sufficiently well illuminated for pioneer species such as Scots pine.
- The regenerated trees grow in the half-shade of the old stand. Half-shade occurs in contrast to full shade, the latter prevailing when no reduction of basal area has occurred.

  Only from Germany and Switzerland are examples available of the growth of suppressed Scots pine trees in half-shade (Wiedemann, 1925 and 1948; Weck, 1938, 1940 and 1947; Hunziker, 1956; Jünemann, 1986) and of their timber quality (Düesberg, 1893; Olberg and Kühn, 1930; Beninde, 1938c; Olberg, 1943; Voegeli, 1961).

  No satisfactory data on spontaneous regeneration of Scots pine are available for the Netherlands (Weidema, 1961; Hol and Schalk, 1986; Elgersma, 1980). Again, little information exists on regeneration of oak in Scots pine stands (Ebeling, 1985; Ebeling and Hanstein, 1988; Fischer, 1993).
- Young beech, oak and Scots pine trees in the stand can be selected as future trees and are liberated when the Scots pine is harvested.
- Beech, birch, second generation Scots pine trees and, finally, oaks are gradually harvested by thinning.

  Patches where beeches have been harvested, and where herbs* and shrubs have been shaded out can provide seedbeds for pioneer species such as Scots pine and birch.
- For nature conservation purposes, portions of the tree compartments of all species are left to degrade naturally (Barkman, 1983; Komdeur and Vestjens, 1983; Koop, 1983; Mabelis, 1983; Van der Werf, 1983).

A number of uncertainties in the above silvicultural design needed further research. This research is described in the next chapters.

2.2 Questions that required answers

In order to make sustainable use of forests in the Veluwe that are to be rehabilitated from even-aged Scots pine stands via a mixture of oak, birch, beech and Scots pine, to modified natural forests consisting of mixed oak/birch/beech stands, a number of uncertainties in the proposed silvicultural design needed further research. These uncertainties can be grouped under the following headings:

1. volume and value increment in Scots pine trees, and time of harvest;
2. regeneration of indigenous oak;
3. regeneration of Scots pine;
4. height growth of young trees under Scots pine;
5. rehabilitation measures to enhance ecological value.

In order to solve the uncertainties, answers were sought for the questions formulated below. The answers and a description of how they were obtained can be found in the chapters, sections or subsections referred to in brackets after each question.

2.2.1 Volume and value increment in old Scots pine trees

Trees should be harvested at the moment they contribute optimally to the financial objectives. Therefore it is necessary to know:

1. At what diameter size should trees be selected for thinning? (This question is elaborated in subsections 3.3.1, 3.4.1, 3.4.2, chapter 4 and section 9.5).
2. At what diameter size should trees be harvested? (Subsections 3.3.1, 3.4.1, 3.4.2, chapter 4, sections 9.1 and 9.2).

2.2.2 Regeneration of indigenous oak

The presence of competitors for light, water and minerals influences the growth of oak under a Scots pine canopy. The basal area* of the Scots pine stand is a parameter for stand density* and hence for competition* from the old stand. It must be known:

3. What is the relation between the height growth of oak saplings and the basal area of the Scots pine stand in which the young oak trees have established? (Subsections 3.2.3, 3.3.5 and section 7.1).

Since the oak must produce valuable boles of timber for the market, regeneration must not only take place successfully, but the trees must also produce straight stems. In a conventional oak plantation the stem form of the oak is influenced by the density of the surrounding planted trees. In an uneven-aged stand*, both the old trees and surrounding young trees influence the stem form of the oak.
This raises the question:

4. How does a canopy cover of old and small trees affect the pattern of the percentage of photosynthetic active radiation (PAR) penetrating through the forest canopy in Scots pine stands with and without small trees in the undergrowth? (Subsections 3.4.3.3, 3.4.3.4 and 5.2.3).

Young oak trees seldom have straight stems. It is not clear whether or not stems straighten out over the years. To understand this it is necessary to know:

5. Do stems of oak saplings become straighter over the years? (Subsection 3.3.2 and section 5.2).

The sooner oak regeneration starts under Scots pine, the shorter the interval between the harvest of the last Scots pine and the harvest of the oak trees. It is not known at what age of the Scots pine oak regeneration under the Scots pine will be successful. The question involved is:

6. At what age of the Scots pine can oak regeneration establish successfully? (Subsection 3.2.1 and section 5.1).

Establishment by sowing or planting can succeed in open-field conditions. It is not known whether this is also true for oak planted under old Scots pine. Therefore the following question is of interest:

7. Can planted oak saplings establish successfully in Scots pine stands with reduced basal area? (Subsection 3.2.3 and section 5.3).

2.2.3 Regeneration of Scots pine

It is rare for Scots pine to regenerate spontaneously in places other than in patches of mineral soil. This leads to the following question:

8. Among what cover of herbs and shrubs is regeneration by Scots pine possible? (Subsection 3.2.2 and section 6.1).

A seedbed for Scots pine can be created by removing the cover of herbs and shrubs from the soil. The question involved is:

9. Do Scots pine seedlings establish on man-made seedbeds and if so, is there a relation between numbers of established seedlings and soil type, soil tillage, stand density, browsing intensity and seedbed size? (Subsections 3.2.2, 3.2.5, 3.2.7, sections 6.2 and 6.4).

Herbs and shrubs will re-establish on the seedbed, ultimately preventing further Scots pine regeneration. This leads to the following question:

10. What species of herbs, shrubs and deciduous trees establish on patches of scarified soil under Scots pine, and what percentage of cover do they reach over the years, in relation to stand density on different soil types, soil tillage and browsing intensities? (Subsections 3.2.7, 3.3.6 and section 6.2).

Together with the establishment of herbs and shrubs, the numbers of Scots pine seedlings that germinate and survive are of interest in order to ascertain the prospects for regeneration in the first and subsequent years. This leads to the following question:

11. What is the survival of Scots pine seedlings over a certain series of years, related to stand density on different soil types, soil tillage, browsing intensity and sowing treatments? (Subsection 3.3.4 and section 6.3).

Once the cover percentage of herbs and shrubs, and the numbers of established Scots pine seedlings have been recorded, it is of interest to search for relations between those data. This leads to the following question:

12. What is the relation between the cover percentage of established herbs and shrubs, and the numbers of established Scots pine seedlings? (Subsection 3.3.6 and section 6.2).

Once the seedlings have become established on the sowing bed, and grown to saplings, it is essential to gather information on their growth rate. This leads to the following question:

13. What is the growth rate of Scots pine saplings related to stand density on different soil types, soil tillage, browsing intensity and sowing treatments? (Subsections 3.2.4, 3.3.5 and 7.4.1).

Plant growth depends on the availability of PAR. Therefore it is necessary to know how much PAR penetrates the stand canopy to reach the seedbeds. The questions are:

14. What is the relation between the percentage of PAR reaching the forest floor and the basal area of the stand? (Subsections 3.2.4, 3.3.3.1, 3.4.3.1, 6.4.1 and 6.4.2).
15. What is the relation between the percentage of PAR reaching the forest floor under various gap sizes in the stand canopy (subsections 3.3.3.2, 3.4.3.2, 6.4.3 and 6.4.4), and the relation with gap sizes in the ground vegetation? (Subsection 6.4.5).
16. What is the relation between height growth of Scots pine saplings and the percentage of PAR reaching the forest floor at different soil types, soil tillage, browsing intensity and sowing treatments? (Subsections 3.3.3.1, 3.3.5 and 7.4.3).

Scots pine does not regenerate easily on the forest floor in the Veluwe area. If regeneration is successful, it is not clear whether the suitability for regeneration is caused by the lack of vegetation or the lack of organic topsoil, or both, or other factors. In forests, patches occur where herbs and shrubs and the organic topsoil have been removed, for instance by wild boar. Also situations occur where only the herbs and shrubs fail, but the organic topsoil remains, for instance under beech trees. Where browsers have clipped the herbs and shrubs a third situation occurs: the organic topsoil and root system of the herbs and shrubs are both available. Such a situation can arise under heavy browsing pressure. This leads to the questions:

17. Is regeneration by Scots pine possible on patches of soil with layers of organic topsoil without herbs and shrubs? (Subsections 3.3.7 and 6.5.1).
18. Is regeneration by Scots pine possible on patches of soil where the organic topsoil remains but where the herbs and shrubs have been clipped? (Subsections 3.3.7 and 6.5.1).

The genetic qualities of trees in newly regenerated compartments could be improved by bringing selected material, either seeds or saplings, into the compartment. The questions are:

19. Can planted Scots pine saplings establish successfully under old Scots pine? (Subsections 3.2.3 and 6.5.2).
20. Is there a relation between the survival rate of planted trees and the basal area of the old stand? (Subsections 3.2.3, 3.2.4 and 6.5.2).

If planting is successful, it is of interest to investigate the growth in relation to growing conditions. The question involved is:

21. What is the relation between the height growth of planted Scots pine saplings under older Scots pine trees and the basal area of the latter? (Subsections 3.2.4, 3.3.5 and 7.4.4).

Similar questions arise on the sowing of Scots pine:

22. Does additional sowing with selected seeds of Scots pine under old Scots pine trees produce an increase in numbers of seedlings? (Subsection 3.2.6 and section 6.2).
23. Is there a difference in height growth between saplings on seedbeds with selected seeds added and seedbeds without selected seeds being added, and if so, is this related to stand density on different soil types, soil tillage and browsing intensity? (Subsections 3.2.6, 3.3.5 and 7.4.1).

2.2.4 Height growth of young trees under Scots pine

To optimize the financial aspect of the objectives, the net value production must be improved. To be able to choose the proper moment to fell old Scots pine trees to meet such objectives, it is necessary to know the expected height growth of young oak, birch, beech and young Scots pine, growing under a canopy of old Scots pine. This leads to the following question:

24. What is the height growth of young oak, birch, beech and Scots pine trees growing under a canopy of old Scots pine? (Subsection 3.3.8 and sections 7.1 to 7.4).

2.2.5 Rehabilitation measures to enhance ecological value

To accelerate the rehabilitation of even-aged stands, natural fragmentation* and the development of small eco-units are imitated and initiated through group felling. The questions involved are:

25. How much of the stand, with what group sizes, and at what age, should be group felled? (Chapter 8).
26. In what way should browsers be managed to create conditions for restoration of small eco-units? (Chapter 8).

To provide opportunities for species conservation equal to those in natural forests, indigenous tree species of all sizes should be available and dead wood should be left in situ to decay. This means that only part of the timber produced can be harvested. The questions are:

27. How much dead wood must remain in the forest for species conservation purposes, and how much timber can be harvested? (Chapter 8).
28. What sizes of trees should be present in the forest? (Chapter 8).
29. What tree species should be present, at what abundance? (Chapter 8).

3 Materials and methods

Before the materials and methods for this study could be chosen, the patterns and processes involved in the designed silvicultural system had to be defined. The objects chosen for the study were even-aged Scots pine stands, artificial eco-units*. They included compartments of trees of 60 to 140 years old, which are the components determining the pattern (architecture*) of each stand. An eco-unit is a unit of vegetation which started its development at the same moment and on the same surface (Oldeman, 1983, *ex* 1990). A compartment is a set of abiotic and/or biotic subsystems or components in a living system, that is delimited as a recognizable, functional ensemble (Oldeman, 1990). A component is an organism, or an abiotic system of the same order, considered as an individual subsystem in a forest ecosystem. (Oldeman *in*: Oldeman et al., 1990). This hierarchy 'eco-unit/compartment/component' can be conveniently chosen to avoid both oversimplification and overcomplication of the analysis of the forest, while at the same time remaining close to the nature of the forest.

The *structural* compartments of Scots pine stands, i.e. the tree compartments, are subjected to the *process* of thinning. This results in a process of growth increment of each component in the compartment, but also in a *process* of regeneration. Gradually, stands with 2 age classes develop in which a compartment of old Scots pine coexisting with compartments of young trees determines a new *pattern*. The components of the old tree compartment show increased growth, whereas the components of the young tree compartment show suppressed growth.

Ongoing thinning causes gaps in the stand. The gaps created in the compartment of old trees form the *pattern* for young eco-units to grow up. It is in these gaps that the regeneration *process* takes place, which results in a silvatic mosaic* with a *pattern* determined by the remnants of the old compartment and the compartments of regenerating eco-units. The components in both the old tree and young tree compartments grow, but these growth processes differ in rate and distribution. In particular, diameter growth predominates over extension growth in the old compartment.

The research described in this study covered several *processes*: *growth* of the components in the old and young tree compartments, *regeneration* of young tree compartments, and *interaction** between the old and young compartments of trees.

3.1. General approach

A silvatic system consisting of indigenous species and based on selection felling was designed in accordance with the objectives mentioned in chapter 1, starting from even-aged Scots pine stands. Selection felling comprises thinning, the gradual harvest of trees that have reached the financial diameter, and continuous regeneration.

This chapter deals with the methods and materials used to investigate: 1. value increment in Scots pines, 2. oak regeneration, 3. Scots pine regeneration, 4. height growth in young trees, and 5. enhancement of ecological value. The materials and methods appropriate for investigating these issues were chosen. Supporting issues described in this chapter are: planting of oak and Scots pine, reduction of basal area, soil scarification, sowing of Scots pine, fencing, measuring stem form, light and topsoil thickness.

The research was empirical, except for that done on the enhancement of ecological value. This topic was investigated via literature study.

3.2 Selection of materials and methods

3.2.1 Old Scots pine stands with spontaneous regeneration

The growth in old Scots pine trees and saplings growing under them was studied in selected Scots pine stands with spontaneous regeneration in Het Loo Palace Park and Het Loo Royal Forest. The oldest trees in the regeneration were approximately 40 years old and were Scots pine, beech, sessile oak, pedunculate oak and birch.

The soil of the selected stands was mapped at a scale of 1:2500 (Kleijer et al., 1988; Mekkink, 1989). See appendix 2 for data on maps and stand localities. At the moment of their selection the characteristics of the stands were as given in table 6.

3.2.2 Old Scots pine stands selected for semi-spontaneous regeneration

In order to study conditions for regeneration of Scots pine in old Scots pine stands in the absence of regeneration of deciduous tree species, the basal area of old stands was reduced. Ideally this should have been done at the moment that the current net value increment of a tree equalled the sum of the net interest of the value of that tree plus the soil rent of the growing area* used (Kuper, 1992a; cf. sections 9.1, 9.2). At the start of the regeneration experiments, the characteristics of these trees were not yet known, because this was one of the outputs of the study. Stands with homogeneous stem distribution are rarely old.

Table 6. Scots pine stands with spontaneous regeneration.

stand number	soil type#	stand age in 1990, in years	approx. age regeneration in years	regenerated species
Pal.Park 141	H/Y	133-137	25-40	Scots pine, sessile oak, pedunculate oak, beech, birch
Pal.Park 19c	H	76	10-15	Scots pine, birch
Uddel 26a	H	87	30-35	Scots pine
Uddel 52n	H	77	30-35	Scots pine, pedunculate oak, birch, beech
Uddel 131f	H	85	10-15	Scots pine
Uddel 141a	H	76	10-15	Scots pine
Gortel 8d	H	80	30-35	Scots pine
Gortel 19b	H	79	5-35	Scots pine
Gortel 52b	Y	82	5-15	Scots pine, pedunculate oak, beech, birch
Gortel 77g	H	65	1-5	Scots pine, pedunculate oak, beech, birch
Gortel 80a	H/Y	81	25-35	Scots pine, pedunculate oak, birch, beech
Gortel 92h	H	64	5-10	Scots pine
Gortel 94c	H/Y	81	25-35	pedunculate oak, birch, beech

# Soil type H = humus podzol
Y = brown podzolic soil
H/Y = mosaic of both soil types

The available age group of Scots pine stands with more or less homogeneous stands and lacking regeneration, was 60 to 80 years old. Stands for regeneration experiments were selected from this group.

Selection started with 4 stands in 1984, in which Scots pine saplings were planted after a reduction of basal area of the stands. Three of those stands were on humus podzols, 1 was on partly humus podzol and partly brown podzolic soil.

In 1987 4 more stands were selected for a regeneration experiment. One of these stands was on humus podzols, 1 on brown podzolic soils, and 2 on partly humus podzol and partly brown podzolic soil (Kleijer et al., 1988; Mekkink, 1989). Two of those stands were situated in an area with only roe deer (*Capreolus capreolus*), the other 2 stands were in an area with red deer (*Cervus elephas*), fallow deer (*Dama dama*), roe deer and wild boar (*Sus scrofa*). The regeneration experiment is described below. Data on soil maps and stand localities are given in appendix 2. All stands are situated in Het Loo Royal Forest and Het Loo Palace Park, both located on the Veluwe, west of Apeldoorn, the Netherlands. The characteristics of the selected stands at the moment of their selection are given in table 7.

The ground vegetation* in the 4 experimental stands of 1987 was composed mainly of bilberry (*Vaccinium myrtillus*), cowberry (*Vaccinium vitis-idaea*), grasses and mosses. The composition is given in table 8.

The dominant moss species were *Pseudoscleropodium purum* and *Pleurozium schreberi*. Other moss species found were *Hypnum jutlandicum* and *Dicranum*

Table 7. Scots pine stands selected for reduction of basal area for regeneration experiments.

stand number	soil type#	basal area in m^2	stand density index##	dominant height in m	stand age in years	year of germination
Pal.Park 19d	H/Y	23.9	0.98	19.2	65	1922
Pal.Park 20f	H	25.5	1.00	20.2	62	1923
Uddel 2a	H	21.3	0.81	22.5	79	1908
Uddel 140b	H/Y	23.7	0.88	22.8	71	1914
Soeren 107b	H/Y	23.7	0.92	20.1	73	1914
Gortel 77g E	H	26.9	1.08	19.5	60	1925
Gortel 77g W	H	26.4	1.07	19.8	60	1925
Gortel 84a	Y	16.8	0.67	21.6	78	1909
Gortel 133f	H	25.7	1.00	20.2	98	1886
Gortel 133h	H	25.7	1.00	20.2	93	1891

# Soil type H = humus podzol
Y = brown podzolic soil
H/Y = mosaic of both soil types
Stand density index based on Grandjean and Stoffels (1955).

Table 8. Composition of ground vegetation in the 4 experimental Scots pine stands of 1987, given as ground cover percentages.

stand no.	bilberry	cowberry	grass	moss and bare	others
Pal.Park 19d	32%	12%	8%	92%	
Uddel 2a	44	22	*	100	
Soeren 107b	30	1	33	66	* *Rubus sp.* * bracken * heath bedstraw
Gortel 84a	72	1	19	80	* rowan * *Rubus sp.* * pill sedge * heath bedstraw

* Less than 1% cover.

scoparium. The dominant grass species were wavy hair grass (*Deschampsia flexuosa*) and purple moor grass (*Molinia caerulea*). Common bent (*Agrostis capillaris*) and sheep's fescue (*Festuca ovina*) were occasionally found.

1987 Regeneration experiment

In order to determine whether the various regenerating trees, including Scots pine, can survive under Scots pine, the characteristics of the compartment of old Scots pine need to be known. Therefore in 1987 an experiment was designed and started in 4 old Scots pine stands on 2 soil types, in which a reduction of basal areas was carried out at 4 intensities by felling trees. In the 4 felling treatments, 3 soil tillage treatments were applied in order to find the optimal seedbed.

The impact of browsers on seedling establishment and growth is thought to be considerable (Dzieciolowski, 1970a and 1970b; Van de Veen, 1979; Mayer, 1981; Gossow, 1987). To study it, half of the number of prepared seedbeds were fenced. Figure 13 shows the outline of the experiment in 1 of the 4 stands.

The 4 stands (Palace Park 19d, Uddel 2a, Soeren 107b and Gortel 84a) belong to the first generation Scots pine plantations on former heathland. The following variables occur:
2 soil types among 4 stands, in each stand there are:
4 categories of basal area,
3 soil tillage treatments,
2 fencing treatments and
2 sowing treatments.

The 4 stands were 2 ha each. Reductions of basal area were carried out at 4 intensities over a plot of 0.5 ha each. Basal areas after reduction are given in table 11. The plots of 0.5 ha were 100 m long and 50 m wide, 4 in a row, 200 m long, 100 m wide. The felling treatments were allocated at random over

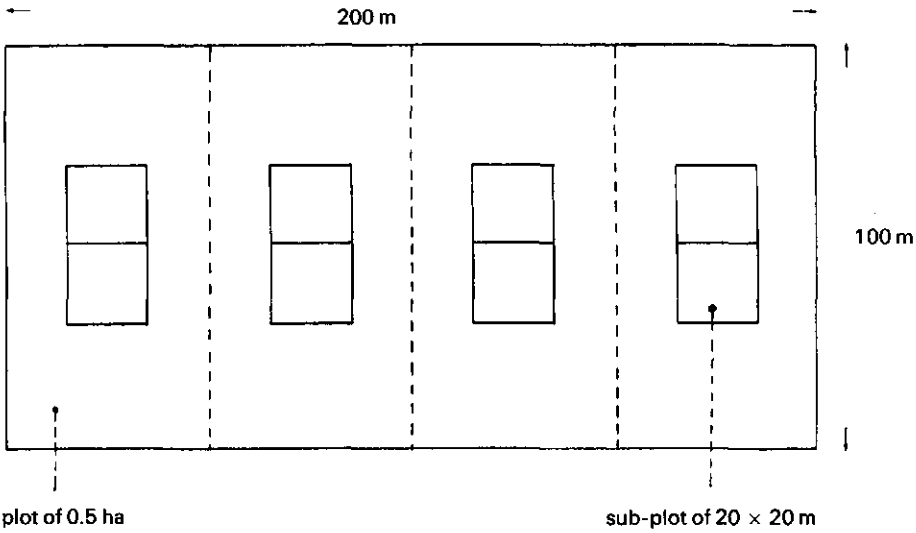


Fig. 13. Outline of the 1987 regeneration experiment.

the 4 plots. In the middle of each plot, 2 sub-plots were laid in which the different soil tillage treatments were carried out. The treated area was surrounded by a buffer zone of at least 20 m wide, which Koop (1987) considered to be wide enough to reduce influences from the sides to negligible proportions. The soil tillage was done with a kuloo (Kuper, 1989; fig. 14), or with a mulching machine plus rotovator* (figs. 15 and 16). The treatments were carried out in sets of 3 rows: 1 row with kuloo treatment, 1 row rotovator treatment after the vegetation had been clipped by the mulching machine, 1 row remained untreated.

The sequence of the treatments was determined at random. Every sub-plot had 3 sets of treatment rows. These were laid out lengthwise in a rectangular area of 20 x 40 m. Half of the sub-plot 5, 20 x 20 m, was fenced. The fenced one was chosen at random.

In all the treated and untreated rows, both within and outside the fence, 2 permanent quadrats* of 0.5 x 1.0 m were marked. The location of the permanent quadrats within the rows was chosen at random. In order to avoid a different impact by browsing than could be expected at a soil tillage in an area larger than 800 m^2, outside the 20 x 40 m plot the soil of the stand was treated patchwise by kuloo, resulting in approximately 600 patches evenly distributed per ha.

To ascertain the feasibility of improving the genetic qualities of the future stand, seeds of the Scots pine provenance Voorsterbos 02 were sown on half of the permanent quadrats in every sub-plot.

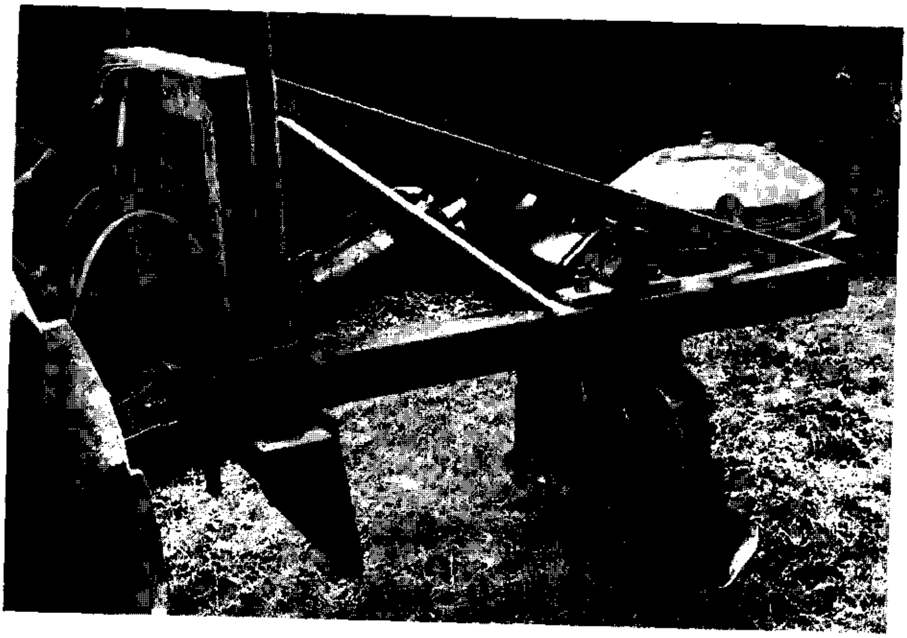


Fig. 14. The kuloo.

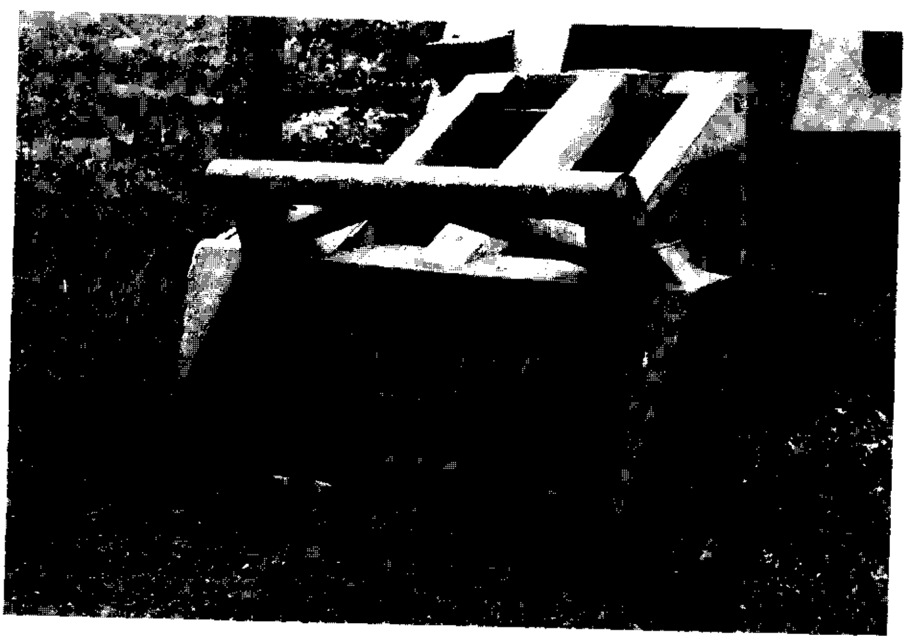


Fig. 15. The mulching machine.

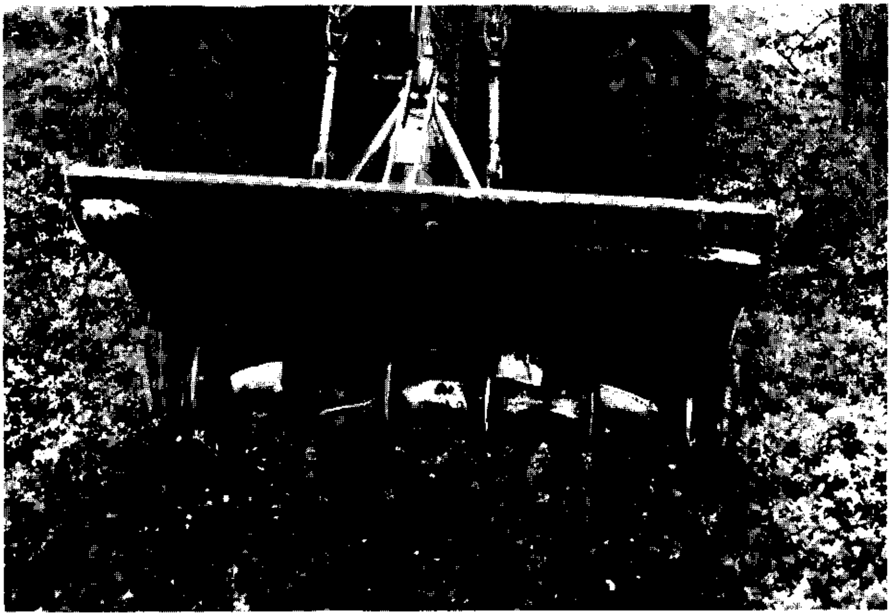


Fig. 16. The rotovator.

The results of these experiments are given in sections 6.1, 6.2, 6.3 and 7.4.

3.2.3 Planting of oak and Scots pine

Planting in Scots pine stands without existing regeneration

In any stand the number of trees which individually produce enough timber to generate income is quite low. In an agricultural silvicultural system (cf. Spedding et al., 1981) a stand should never have more than the number of trees required to occupy the growing area. However, higher numbers of trees than those indicated, forces trees to grow taller. In selection felling systems, however, it is the current old stand which, through half-shade, provides the conditions for continued extension growth and proper stem forms of the regenerating trees (Wobst, 1970). In those circumstances, the number of young trees can be kept low. However, the number of available young trees which have established spontaneously can be too low to reach the financial targets. Therefore the establishment success of Scots pine saplings as well as of pedunculate oak and sessile oak saplings planted in old Scots pine stands with various basal areas, was studied. In the Scots pine stands selected for reduction of basal area, oak and Scots pine saplings were planted. The characteristics of the latter stands are given in tables 7 and 9.

Table 9. Characteristics of Scots pine stands in which oak and Scots pine saplings were planted.

stand no.	stand age in years	basal area, m^2/ha				age of planted saplings, years
Pal. Park 19d	65	19.7	16.9	11.3	9.6	1 y oak
Pal.Park 20f	62	21.2	17.8	15.3	13.9	3 y Sc.p.
Uddel 2a	79	20.0	18.8	13.9	9.6	1 y oak, 2 y Sc.p.
Uddel 140b	71	23.7	20.1	15.8	14.6	2 y oak, 3 y Sc.p.
Soeren 107b	73	20.8	17.2	12.5	9.6	1 y oak
Gortel 77g E	60	26.9	21.2	22.4 (19.7)#	19.8 (16.7)#	2 y oak 3 y Sc.p.
Gortel 77g W	60	21.5	26.4	23.9 (22.6)#	17.6 (19.4)#	2 y oak, 3 y Sc.p.
Gortel 84a	78	18.2	16.7	13.3	9.8	1 y oak

Figures in brackets indicate the basal area after a second reduction.

One-year-old oak saplings

In 1987, 10 1-year-old pedunculate and sessile oaks were planted in each fenced sub-plot of the 4 experimental stands of 1987. Altogether 160 pedunculate oaks of provenance NL-3 and 160 sessile oaks of provenance D-818-08 were planted.

Two-year-old oak saplings

In 1986, 50 2-year-old pedunculate oaks were planted in each sub-plot in Gortel 77gE and W, and in Uddel 140b 48 2-year-old pedunculate oaks were planted in each sub-plot. Altogether 592 pedunculate oaks of provenance NL-3 were planted.

Four-year-old oak saplings

In 1989, 200 4-year-old pedunculate and sessile oak saplings each, were planted in Soeren 90c and d, both fenced 72-year-old Scots pine stands with low stand density index on brown podzolic soil. The pedunculate oak was of provenance NL-3, the sessile oak of D-818-08. At the same time 100 pedunculate and sessile oaks each, of the same age and provenance, were planted in Soeren 75b, 76a and 85a. These were fenced stands of mixed beech/oak with low stand density index on brown podzolic soil of respectively 190, 233 and 190 years of age.

Two-year-old Scots pine saplings

In 1988, 25 2-year-old Scots pine saplings were planted in each of the fenced 4 sub-plots in experimental stand Uddel 2a. Altogether 100 saplings of the provenance 'Grubbenvorst' were planted. The 2-year-old saplings were planted one year after the reduction of basal area.

Three-year-old Scots pine saplings

In 1984, 3-year-old Scots pine saplings were planted in a 5 × 5 m grid in Palace Park 20f and Gortel 77gE and W, immediately after the reduction of basal area. Altogether 1248 Scots pine saplings, equally divided over 3 provenances: 'Junne', 'Scherpenberg' and 'Grubbenvorst' were planted.

Planting in Scots pine stands with existing regeneration

Scots pine stands might not provide the half-shade conditions needed for the development of good quality stem forms of young oak. Scots pine stands that are filled up with young birch might provide those conditions. Therefore, to test the efficacy of planting saplings, Scots pine stands in which birch regeneration was already present were selected. The birch regeneration was spontaneous. Storms had fragmented the canopy of the Scots pine, providing conditions for birch to regenerate. Oak also established spontaneously in those stands, but mostly in insufficient numbers to be economically viable (Clercx et al., 1986). The saplings planted were 4 years old and were too tall for roe deer to browse.

Between 1989 and 1992 altogether 8170 4-year-old pedunculate and sessile oaks were planted in Scots pine stands with undergrowth of birch. The 4-year-old pedunculate oak was of provenance NL-3, the sessile oak of D-818-08. Scots pine stands in which oak were planted are listed in table 10.

In order to be able to measure the extent of fray damage caused by roe deer in relation to the abundance of spontaneous saplings, 4-year-old saplings were also planted in 2 stands without undergrowth of birch.

Table 10. Scots pine stands with and without undergrowth of birch, in which 4-year-old oak saplings were planted.

stand no.	stand age at year of oak planting, year	height of birch, m	basal area, m^2 1991/1992
Pal.Park 4n	44	–	29.8
Uddel 1a, 2a	82	–	14.9
Uddel 147a	72	0-5	14.2
Soeren 13f#	36	12	15.0
Soeren 14c,g	83	0-10	14.3
Soeren 15d,f	75	0-5	21.1
Soeren 16b	83	0-10	27.7
Soeren 17a	74	0-5	27.6
Gortel 52b,c	82	3-10	13.3
Gortel 65a	64	1-15	24.2
Gortel 65b	61	1-15	24.2
Gortel 77g	65	0-2	22.1
Gortel 141t	63	1-5	16.9

Stand Soeren 13f is a birch stand, without Scots pine trees.

The results are given in sections 5.3 and 6.5.

3.2.4 Reduction of basal area by harvest and by storm

As explained by Schütz and Van Tol (1981) neither the basal area nor the stand density index* by themselves produce precise data on the amount of PAR that can penetrate the canopy and reach the ground. The reduction of basal area and stand density index, however, is still a parameter of the change in PAR interception by the canopy, although it does not take into account the architectural homogeneity or heterogeneity of the crown canopy.

In early 1987, at the start of the experiments described in subsection 3.2.2, a reduction of basal area was carried out in Pal.Park 19d, Uddel 2a, Soeren 107b and Gortel 84a by felling a number of trees calculated with reference to the yield tables* of Grandjean and Stoffels (1955). The reduction was evenly spread over the 0.5 ha plots investigated. The reduction was carried out to reduce the stand density index to 0.75, 0.60, 0.45 and 0.30 respectively. The basal areas actually produced are given in table 11.

In the night of January 25th 1990 a severe storm ravaged the forests of the Netherlands. This caused a considerable change of the basal area in some of the experimental stands of 1987. This second reduction of basal area had an unquantifiable impact on the regeneration process because it destroyed the former homogeneity of the experimental reduction. In the other experimental stands the basal area was reduced in 1984. These stands did not suffer from the storm in 1990. Table 11 shows the basal area reduction after felling, and after the storm.

Table 11. Basal area after felling and storm.

stand no.	various basal areas after reduction, in m^2/ha			
Pal.Park 19d	19.7(15.4)#	16.9(15.7)#	11.3(8.0)#	9.6(5.1)#
Pal.Park 20f	21.2	17.8	15.3	13.9
Uddel 2a	20.0(17.6)#	18.8(12.8)#	13.9(12.0)#	9.6(6.1)#
Uddel 140b	23.7	20.1	15.8	14.6
Soeren 107b	20.8(19.4)#	17.2(15.1)#	12.5(10.3)#	9.6(6.0)#
Gortel 77g E	26.9	21.2	22.4	19.8
Gortel 77g W	21.5	26.4	23.9	17.6
Gortel 84a	18.2(17.2)#	16.7(15.4)#	13.2(11.9)#	9.8(8.2)#
Gortel 133f	14.4			
Gortel 133h	14.4			

Figures in brackets indicate the basal area after the storm of 25-1-1990.

3.2.5 Scarification of the soil

In the Scots pine stands at Het Loo, most soils are covered by ground vegetation consisting mainly of bilberry, cowberry and wavy hair grass. In order to denude the mineral soil it was necessary to treat the soil plus that vegetation. In 1987 treatments were carried out in the 4 experimental stands of 1987. These treatments included: 1. removal of the sod and organic topsoil*, 2. mixing the sod with the mineral soil, and 3. no treatment.

Using the kuloo (fig. 14) the sod was removed and seedbeds approximately 120 cm wide and 150 cm long were made. The mulching machine clipped the herbs and shrubs, the rotovator mixed them with the organic topsoil and mineral soil.

To study the regeneration by Scots pine on soils which still have a layer of organic matter, a mulching machine was used to clip herbs and shrubs in 1990 in Gortel 6r, 7b and 8c. These first generation Scots pine stands on humus podzols, 84, 78 and 79 years old respectively, were opened up by the storm of January 25th 1990.

Regenerated Scots pine was also observed on vegetation-free soils, covered by a layer of needles in various stages of decomposition from shade-tolerant coniferous trees. Such successful Scots pine regeneration occurred after the clear-felling of Douglas-fir (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Western hemlock (*Tsuga heterophylla*) and grand fir (*Abies grandis*). In order to investigate whether this successful Scots pine regeneration on bare organic soil would also be successful in spots where beech had forced the disappearance of the herbs and shrubs, beeches were cut in the mixed Scots pine/oak/birch/beech stand in Palace Park 14.

For economic and ecological reasons treatments of vegetation, sod and soil were carried out on limited parts of the stand area. Table 12 shows the seedbed sizes prepared.

Table 12. Seedbed sizes prepared by various machines.

machine type	approx. patch width	approx. patch length
Kulla#	50– 70 cm##	50– 90 cm
Kuloo	100–150 cm##	120–300 cm
Rotovator	120–140 cm	length of the stand area
Mulching machine	120 cm	length of the stand area

\# Because kulla treatment was not successful in an earlier experiment, the kulla was not used in this experiment.

\## In these cases the patch width was sometimes wider than the width of the machine. The coherence of the sod resulted in a variable patch width, the minimum width being determined by the machine width.

3.2.6 *Sowing of Scots pine*

The feasibility of sowing and establishing of seeds of selected provenances underneath old Scots pine stands was investigated. In the 4 regeneration experimental stands of 1987 seeds of a selected provenance of Scots pine were sown on patches of treated soil, and on untreated spots. This was done at different stand densities of the old stand (subsection 3.2.2).

The stands in which Scots pine was sown are listed in table 13.

Fifty seeds were sown in each permanent quadrat of 1 m x 0.5 m. The seeds on the treated seedbeds were covered with a layer of mineral soil less than 5 mm thick, to protect them from birds.

Table 13. Scots pine stands in which selected Scots pine seeds were sown.

stand no.	provenance of Scots pine seed
Pal. Park 19d	Voorsterbos 02
Uddel 2a	Voorsterbos 02
Soeren 107b	Voorsterbos 02
Gortel 84a	Voorsterbos 02

Another sowing experiment was carried out in Gortel 84a in 1989, where Scots pine seeds of provenance Voorsterbos 02 were sown on mineral soil, on clipped vegetation of herbs and shrubs, and in untreated vegetation of herbs and shrubs. The seeds were not covered with mineral soil. To investigate the survival rate on those 3 seedbed types, this experiment was monitored every 2 weeks during the growing season and at longer intervals after the growing season. The results are given in subsections 6.2.1. and 6.5.1.

3.2.7 *Browsing and fencing*

In order to investigate the impact of different intensities of browsing on regeneration, half of the number of regeneration sub-plots in the 4 regeneration experimental stands of 1987 were fenced with 1.75 m high fences. These fences kept out red deer, fallow deer, roe deer and wild boar and also made it possible to plant oak saplings, in order to study their establishment and growth. The estimated abundance of game per 100 ha in spring 1991 was as given in table 14.

The results are given in section 6.2.

Table 14. Estimated abundance of game per 100 ha in spring 1991.

	roe deer	red deer	fallow deer	wild boar
Pal.Park 19d	12-14	0	0	0
Uddel 2a	12-14	0	0	0
Soeren 107b	2-4	3-5	2-4	6-8
Gortel 84a	4-8	2-4	2-4	8-10

3.3 Measurements and counts

3.3.1 Volume increment in old trees

Scots pine stands assumed to be sufficiently mature to produce data on growth for management purposes were selected. Stands which already showed regeneration were therefore chosen. Tree rings were extracted from 286 Scots pine trees. Of these, 213 were, in randomly chosen plots of 700 m^2, proportionally spread over the various diameter classes as occurring over the basal area (cf. Kramer and Akça, 1982) in 16 Scots pine stands with regeneration of oak, beech, birch or Scots pine in the stand (Palace Park 141, Uddel 2a, 26a, 131f, 140b, 141a, Gortel 8d, 19b, 52b, 77g, 80a, 84a, 92h, 94c, 133f and Soeren 107b). Another 73 trees were solitary Scots pines which showed spontaneous regeneration of Scots pine under their crown (Palace Park 141, 19b, Uddel 26a, 52n, Gortel 8d, 19b, 92h and 133f). All stands were used for timber production. Numbers of selected trees per stand are given in appendix 3. Two of the 18 stands were growing on brown podzolic soils, 5 partly on brown podzolic soils and partly on humus podzols, the other 9 only on humus podzols (see tables 6 and 7).

Every tree ring was, with the total of earlier rings as the basis, considered as an individual case. There were 5,923 cases in the randomly chosen trees, and 3,685 cases in the solitary trees.

The volume increment of individual trees was determined by taking 2 tree ring samples with a Pressler borer out of the bole at breast height, straight to the core of the tree. The tree ring samples were taken at the longest and shortest radius of the bole (cf. Prodan, 1951). To calculate the volume increment per year, the width of the tree rings and height of the tree was used. The height of the trees was measured in the field with a topcon dendrometer. The age of the trees was either taken from the planting records, or counted from the number of tree rings. The change in tree height over the years was obtained with the Chapman and Richards formula (Faber, 1987; subsection 3.4.1). Tree rings were measured with the Sistema Misura Incrementi Legnosi 3 Tipo (SMIL) of the LEGA company of Firenze, Italy. The results are given in section 4.1.

3.3.2 Stem form development in oak

Sufficient straightness of the stem of oak is generally reached in even-aged stands that start with a high number of individuals. In old Scots pine stands, oak is spontaneously sown by jays (*Garrulus glandarius*; Bossema, 1979; Ebeling, 1985), in variable numbers of course. The growing conditions of these oaks differ from those of oaks growing in an even-aged stand. Therefore the stem development also has a different causality. Instead of oak trees influencing each other, the old Scots pine and other occurring tree species such as birch and rowan, have an impact on the way the young oak develops its stem. It was investigated whether the quality of stems of oak saplings, growing among the regeneration of various tree species in Scots pine stands, improves over the years. To do this, the length and positioning of stems and first order branches of 89 young oaks in Gortel 77g (subsections 3.2.3 and 3.2.4) were measured and drawn in 1990. The instruments used were a plumb line, a spirit level and a long ruler. Gortel 77g was chosen because it was fenced, so roe deer could not affect the oak saplings. After 1 and 2 growing seasons the same trees were remeasured and redrawn. Of the 89 oaks 16 were planted and 73 appeared spontaneously after the stand was fenced. After fencing a large number of saplings of birch, Scots pine and oak appeared; on average, 21,530 per ha. The heights of the drawn oak saplings varied from 25 to 200 cm. The results are given in section 5.2.

3.3.3 Amount of diffuse light

3.3.3.1 Basal area and amount of diffuse light

Brechtel (1962) showed from literature and field studies that under shelter of Scots pine the percentage of diffuse light reaching the forest floor is an appropriate parameter for precipitation, soil moisture, and air and soil temperature. However, this parameter is not practical. Crown cover area and basal area are more convenient parameters which could be used to indicate the amount of photosynthetic active radiation (PAR) reaching the forest floor that is available to regenerating tree species. The crown cover percentage can, with some difficulty, be measured by crown projection assessment in the field, or from aerial photographs. The basal area is easier to measure and to be used as a management tool. and therefore in this study the use of basal area as a parameter for PAR reaching the forest floor was investigated.

The basal area may be irregularly distributed in the stand, making it difficult to interpret the basal area in terms of availability of PAR at any particular spot on the ground. Direct measurement of PAR can give that information. To eliminate the effects of the pattern of shade and full sunlight, only indirect PAR was measured. This must be done on overcast days, i.e. at a low level of irradiance, which also minimizes the inaccuracy of the equipment used (Van Bruggen, 1986). PAR was measured with 2 light gauges, one of which was held in the open field and the other one at the ground level in the stand. With 2 of those gauges, as described by Van der Hage (1984), in combination with a portable field computer for the calculation and storage of the irradiance* values, series of measurements were made in Scots pine stands. The diffuse irradiance of the photosynthetic active radiation was measured, in the wavelength interval 400–700 nm (Schurer, 1989).

The mean PAR percentage reaching the forest floor is defined as: the irradiance measured at a certain horizontal level, expressed as the percentage of the irradiance at a horizontal level above the tree canopy. The PAR was measured directly above the seedbeds of the 4 experimental stands of 1987, described in subsection 3.2.2. It was also measured at ground level in 3 Scots pine stands, Soeren 31d, 97a and 98b, with various basal areas. The basal area was measured in a circular area of 700 m^2 around the spot of PAR measurement. The 3 selected stands were respectively 76, 103 and 85 years old and were growing on humus podzols. The latter stands were selected because: 1. they were thought to contain trees with the financial diameter, 2. they showed an irregular distribution of the basal area in the stand, and 3. they were located near an open field, necessary for reference measurements. The results are given in subsection 6.4.2.

3.3.3.2 Gaps in the canopy and amount of diffuse light

Gaps in the canopy also create conditions suitable for initiation of regeneration. Gaps can be caused by storm or by group felling. For measuring PAR at various gap sizes, larger gaps were created in the stand canopy than the gaps which were the result of thinning. PAR measurements were carried out in Scots pine stands by starting the measurement when the stand was still untouched. Then a small group of trees was felled, and the PAR at ground level (just above the herbs and shrubs) was measured. The group of trees felled was then enlarged, and diffuse PAR was remeasured. This was continued until PAR levels were reached at which Scots pine seedlings were able to survive, according to the levels measured around available Scots pine saplings elsewhere.

Two such groups were felled in Soeren 36 (a Scots pine stand 40 years old), 3 groups were felled in Gortel 50f (a Scots pine stand 62 years old), and 2 groups were felled in Gortel 134a (a Scots pine stand 67 years old). These stands were growing on humus podzol soils. They were selected because they still showed a homogenous distribution of basal area, and were located near an open field, needed for reference measurements. The results are given in subsection 6.4.4.

3.3.3.3 Gaps in the herb and shrub vegetation, and amount of diffuse light

The above PAR measurements were carried out in the absence of herbs and shrubs or just above such vegetation. If herbs and shrubs are present, they reduce the irradiance on the ground. They must be removed, not only to expose the mineral soil, but also to increase the irradiance; this is necessary for pioneer tree species to survive after germinating. In order to determine how large the area of vegetation treatment must be in relation to the height of the herbs and shrubs, it is necessary to investigate the amount of PAR at different opening sizes of the herb and shrub cover. In bilberry of different heights, gaps were clipped and PAR at the ground was measured. The openings were enlarged until the amount of PAR ceased to increase significantly.

The stand selected for this experiment was Gortel 84a, with basal area 11.9 m^2, because Scots pine regeneration was successful on the scarified patches in that stand. The results are given in subsection 6.4.5.

3.3.4 Seedling and sapling* establishment*

Regeneration is not yet successful at the stage when seeds germinate and seedlings flourish using non-renewable resources from the cotyledons. It can be considered successful once the saplings survive the competition from other vegetation, including existing trees. Saplings that have overgrown the herbs and shrubs have, from that moment on, improved their competitive position considerably. Thereafter, the main competitors for PAR are the trees of the same or older cohorts. Competition for water and minerals from all vegetation, including the old trees, continues.

If regenerated saplings under old stands have been able to survive, they have done so even though the basal area and crown cover of the old stand increased in the years following the moment of establishment. With a new thinning, the basal area and crown cover are reduced again. For this reason, regeneration can be said to have succeeded if the saplings survive the interval between two thinnings.

In Het Loo Royal Forest thinning takes place approximately every 5 years. Thinning ultimately leads to reduction of the crown cover to the level at which regeneration is successful. In the 4 regeneration experimental stands of 1987 such a thinning was carried out by the severe storm which took place on January 25th 1990, 3 years after the experimental reduction of basal area. This thinning by storm had the characteristics of a strong reduction of basal area, but was not uniform.

Over a period of 5 years from germination until the end of the experiment the establishment and survival of all seedlings in the permanent quadrats (subsection 3.2.2) were recorded. Data were generated on survival rates in all combinations of treatments that were available in the experiment.

Planted saplings of the various ages mentioned in subsection 3.2.3 have to recover from being planted. Not all survive. The Scots pine saplings and all oak saplings of 1 and 2 years old were examined 1, 3 or 6 years after planting. A sample of the 4-year-old oak saplings was examined for survival after 1, 2 and 3 years. The results are given in sections 5.3, 6.2 and 6.3.

3.3.5 Sapling growth

Once regeneration success has been ascertained, timber production analysis requires data on growth under various conditions. Height growth is relevant in this respect. Only a limited number of all the regenerated individuals will be part of the future stand. Only the growth of those individuals is important.

The tallest Scots pine sapling in each permanent quadrat in the 4 regeneration experimental stands of 1987 was measured. The height growth of these saplings was measured, starting from germination until autumn 1991. Height was measured with a ruler.

In Gortel 77g (subsection 3.3.2) 6 transects* were laid out, each 200 m long and 1 m wide, and in each the tallest sapling per m^2 of every occurring tree species was labelled and measured. This measuring was done in 4 consecutive years. Height growth was measured in the following numbers of saplings: 165 pedunculate oaks, 371 birches and 325 Scots pines. At the location where the saplings grew, the basal area of the Scots pine stand was measured with a Bitterlich Wedge Prism with counting factor 2.

The height growth of the planted Scots pine saplings and the 1 and 2-year-old oak saplings was also measured.

The results are given in sections 7.1 to 7.4.

3.3.6 Re-establishment of herbs and shrubs on man-made seedbeds

At the patches where soil and sod treatments were carried out, vegetation re-established spontaneously. According to Erteld (1986) the re-establishment of herbs and shrubs has an impact on the establishment success of young trees. Therefore the development of herbs and shrubs was recorded from the moment the soil and sod treatment took place.

The herbs and shrubs in the permanent quadrats in the Scots pine stands were monitored for 5 years by visual estimation of the ground cover percentage of each plant species in cover percent classes of 5%. The results are given in subsection 6.2.4.

3.3.7 Thickness of the organic topsoil

Contrary to expectations, Scots pine was found to have regenerated in sites other than those on mineral soil. Where Scots pine was found to be established on soils which still had an organic topsoil, the thickness of that topsoil under the Scots pine saplings was measured. The organic topsoil was defined as the layer from the top of the dead organic matter to the top of the mineral soil. The layer was measured with a ruler. These data gave the thickness of organic topsoil on which regeneration by Scots pine is still possible.

Organic layers were measured under Scots pine saplings in Palace Park 13, 14 and 19, Uddel 52, 131, 141 and 156, Gortel 19b, 35, 77g, 78, 84a and 92. Except in Palace Park 14 and Gortel 84a all Scots pine regeneration was on humus podzols. Palace Park 14 has a mixture of humus podzols and brown podzolic soils. Gortel 84a has a brown podzolic soil.

Examples also occurred where Scots pine stands were blown down in 1972 and 1973, and where Scots pine had regenerated in spite of the presence of an organic layer. These stands were outside Het Loo. They were: Amerongseberg 7b, Imbosch 3w, 13h, 23a, 24p, Petrea 12c, 12d and 12e. Except for Amerongseberg these stands were on humus podzols, and located on the Veluwe. Amerongseberg was on brown podzolic soil, and located in the province of Utrecht. These stands were selected because they were the few examples where no reafforestation took place after the trees had been removed.

Another category of examples where Scots pine regenerated on organic layers was created by clearing stands of exotic shade-tolerant trees. The stands were Palace Park 14a, 14b, 14c, 14d and 19d, and Soeren 46g. Here, the tree species removed were respectively Douglas-fir, black pine (*Pinus nigra*), Western hemlock, sitka spruce, Douglas-fir and red oak.

The results are given in subsection 6.5.1.

3.3.8 Height growth of young trees

Increment of commercial value in young trees, which have no marketable value as yet, is hypothetical. These hypothetical values contribute to the level of the soil rent. The hypothetical value increment of young trees is determined by the part of the life of a tree that is to be covered in a specific year. For instance, a suppressed tree that grows half the height of a non-suppressed tree, produces half the hypothetical value increment of the non-suppressed tree, assuming that: 1. the tree sizes will be equal at the moment of harvesting, and 2. height-diameter ratios will not differ between suppressed and non-suppressed trees*. The height growth of young Scots pine, oak, birch and beech trees was determined by counting the tree rings at every 50 cm of their height.

In Palace Park 14l and Gortel 80a, Scots pine stands with regeneration of beech, oak, birch and Scots pine (table 6), 31 oaks which were dominant among the regenerated trees were selected. These oaks were cut, after which a cross-section slice of the stem was taken at every 50 cm. At the moment of felling the basal area of the old Scots pine in Palace Park 14l was 13.8 m^2 and in Gortel 80a 11.5 m^2. The wood slices were used to count the age of the tree at that particular height with a dendrochronograph.

In Gortel 80a 33 birches which were dominant among the regenerated trees were selected. At the moment of felling the basal area of the old Scots pine was 11.5 m^2.

In Palace Park 14i 10 beeches which were dominant among the regenerated trees were selected. At the moment of felling the basal area of the old Scots pine was 28.8 m^2.

From Palace Park 14 and 19, Uddel 26 and 52 and Gortel 8, 19, 92 and 133, all of which are Scots pine stands on humus podzols with a second generation Scots pine, the height growth of 258 Scots pine saplings taller than 1.3 m was analysed. Each sapling was growing under the crown of an old Scots pine.

The results are given in sections 7.1 to 7.4.

3.4 Calculations

3.4.1 Volume increment in old trees

The volume increment was calculated from the tree rings taken for measuring diameter increment (subsection 3.3.1). The tree rings were measured with the SMIL (subsection 3.3.1). The average of the tree ring width from the longest and shortest radial at breast height produced the average diameter for previous years (Hildebrandt, 1967).

The diameter at breast height (dbh) was measured with a diameter tape (π-tape). The measured diameter includes bark. The measurements of tree rings without bark were converted to sizes including bark by using the tree ring width divided by the sum of tree ring widths as an index in the following equation:

$$dbh_{t-1} = dbh_t - (ring_t / \Sigma \text{ rings 1 to t}) * dbh_t \quad (1)$$

The tree height was measured. The change in tree height over the years was obtained with the Chapman and Richards formula (Faber, 1987):

$$h = S * \{1 - Exp(-a_7 * T)\} \wedge a_8 \quad (2)$$

in which h is height, S is site index*, T is age, and a_7 and a_8 are empirical constants. For Scots pine in the Netherlands $a_7 = 0.0248$ and $a_8 = 1.0475$ (Faber, 1990). The value of S was calculated for each tree.

Volume was calculated using Dik's (1984) formula:

$$v = dbh \wedge a_1 * h \wedge a_2 * e \wedge a_3 \quad (3)$$

For Scots pine in the Netherlands $a_1 = 1.82075$, $a_2 = 1.07427$, $a_3 = -2.88085$ (Dik, 1984).

Volume increment, related to dbh, was calculated with the equation:

$$i_v = v_{dbh(t+1)} - v_{dbh(t)} \quad (4)$$

in which t stands for subsequent development moments with steps of 1 year. The results are given in section 4.1.

3.4.2 Value increment in old trees

Multiplying the volume increment by the stumpage prices gives the value increment. Stumpage prices, for marketable timber without bark, were taken from the Meerjarenplan Bosbouw ('Multi-year Forestry Plan'; 1986). Because the stands are exploited in the presence of undergrowth of young trees, the estimated extra cost of felling and hauling in such circumstances was subtracted from the stumpage prices. The extra costs of felling and hauling were estimated at an arbitrary 25% of the felling and hauling costs that were given per diameter class in the SBB working time standards table (Anon., 1990a). From the calculated stumpage prices another Dfl 25 per m^3 were deducted for overhead costs of the harvest. These costs include marking, sale, measuring, administrative expenses and road maintenance. Although the marking costs per m^3 are dependent on tree diameters, and the sale and administration costs per m^3 are dependent on the volume of the sale, for practical reasons a fixed level of overheads was chosen here. It was based on the average overheads incurred by the Hoog Soeren Forestry, which is part of Het Loo Royal Forest, over the years 1986-1990, to harvest 10,000 m^3 timber from 2,200 ha forest: Dfl 110 per ha or Dfl 24.20 per m^3. As a result, stumpage sale price differs from net stumpage price. The latter was used in the calculations in this study. The various prices are given in tables 15a and b. When calculating current increment in value the net volume has to be used instead of standing volume with tree top and bark. To represent the loss of tree tops and bark, the calculation of value increment was reduced by 25% (Hajer et al., 1990). The net stumpage prices were multiplied by the net volumes:

$$\text{value} = v * (1-0.25) * \text{net stumpage price} \quad (5)$$

Table 15a. Stumpage prices in Dfl per m^3 for Scots pine without bark. Equity in 1993: 1 US$ = 1.80 Dfl = 0.8 ECU.

dbh# cm	(MJPB)##	price 1###	price 2####	price 3#####
10	(10)	–	–	–
12	(30)	1.80	–	–
14	(40)	19.50	–	–
16	(50)	35.75	10.75	–
20	(60)	48.70	23.72	10.00
24	(75)	65.50	40.50	25.00
37	(100)	92.88	67.88	45.00
>37	(125)	120.00	95.00	60.00

\# dbh = diameter at breast height under the bark.
\## MJPB = the stumpage price from the Meerjarenplan Bosbouw (1986) in Dfl.
\### price 1 = price MJPB minus 25% of the conventional felling and hauling costs per m^3.
\#### price 2 = price 1 minus Dfl 25 overhead costs per m^3.
\##### price 3 = the approximate average sales price in 1989 at Het Loo Royal Forest minus Dfl 25 overhead costs per m^3.

Table 15b. Stumpage prices in Dfl per m^3 for oak and other deciduous trees, without bark.

	oak	oak	other deciduous trees	
dbh# cm	price 1##	price 2###	price 1##	price 2###
12	–	–	–	–
14	5	–	5	–
16	16	–	16	–
18	28	3	28	3
22	40	15	40	15
26	52	27	47	22
38	93	68	58	33
45	145	120	75	50
50	195	170	90	65

\# dbh = diameter at breast height under the bark.
\## price 1 = price MJPB (Meerjarenplan Bosbouw, 1986) in Dfl minus 25% of the conventional felling and hauling costs per m^3.
\### price 2 = price 1 minus Dfl 25 overhead costs per m^3.

3.4.3 Light in simulated stands

3.4.3.1 Light in simulated stands, calculated with FOREYE, in relation to the basal area

Photosynthetic active radiation (PAR) is essential for plant growth. Insight into the amount of PAR reaching the forest floor is thus essential in order to know whether regeneration of trees is possible or not. Koop (1987, 1989) and Bijlsma (1990) developed computer programs that can calculate the probable PAR availability at any point within the virtual forest patch considered. A brief description of the programs used is given in box 4.

Radiation values above the stand canopy were calculated with FORFLUX for the period May to September, at latitude 52° 19′ North, based on data from the Royal Dutch Meteorological Institute (KNMI, 1986). Five radiation fractions were calculated: direct sunlight radiation (SUND), diffuse radiation at cloudless moments (DFCL), diffuse radiation at overcast moments (DFOV), total diffuse radiation (DFTOT) and the total of direct and diffuse radiation (TOTAL).

The results are given in sections 4.2 and 4.3.

The radiation per fraction is:
SUND = PAR from direct sunlight 11.9563 MJ/m^2.day.
DFCL = Diffuse PAR at cloudless moment 2.4883 MJ/m^2.day
DFOV = Diffuse PAR at overcast moment 2.9393 MJ/m^2.day
DFTOT = Total diffuse PAR 5.4276 MJ/m^2.day
TOTAL = Total PAR 17.3838 MJ/m^2.day.

The diffuse radiation at a 1 by 1 m grid was calculated as a percentage of the radiation above the tree canopy at that specific site.

A hypothetical 60-year-old Scots pine stand, yield class II (Grandjean and Stoffels, 1955) was simulated according to the SILVI-STAR format. A regular triangular treebase distribution was assumed. The PAR at the forest floor was calculated after various simulated reductions of basal area. Measurements of Scots pine crowns, needed to fit the model to reality, were obtained from trees with diameters between 21 and 25 cm in the stands Gortel 77 and 84. These trees have heights similar to those in the simulated stand. An average inner crown cover was estimated from trees in the real stands. The results are given in subsection 6.4.1.

Box 4. SILVI-STAR, FOREYE and FORFLUX.

SILVI-STAR describes the complex reality of a heterogeneously structured forest and is derived from existing techniques of forest monitoring such as remote sensing, profile analysis, tree mapping and ground photography (Koop, 1989).

For each tree in a research plot, the following restricted numbers of spatial coordinates are measured: the tree base, 4 extreme peripheral points of the crown projection and the heights of the first living branch, the base of the crown, the periphery height and the height of the top of the tree. These coordinates describe a three-dimensional tree model, made up of quarters of ellipses between these coordinates. Tree attributes include species, stem diameter and crown cover.

FOREYE calculates the angles of the sky covered by trees for a specific viewpoint by making use of measured crown and stem positions of trees. FOREYE computes hemispherical crown cover for fixed points at any place, in simulated forest models as well as in existing stands, over a matrix of 360 azimuthal degrees by 90 zenithal degrees.

FORFLUX calculates the radiation, making use of monthly data on hourly values of sunshine duration distributed in percentages (averaged over the period 1956-1980) from the KNMI Royal Dutch Meteorological Institute in De Bilt, the Netherlands.

For more details on these programs, see Koop (1989).

3.4.3.2 Light in simulated stands, calculated with FOREYE, in relation to gap sizes in the canopy

Harvesting timber may boost available PAR at ground level either by ongoing thinning, or by enlarging canopy gaps, or again by combining those two.

In a simulated 60-year-old Scots pine stand of yield class II (Grandjean and Stoffels, 1955) gaps were simulated at various stand density indices. The simulated gap sizes were up to 1.63 times the height of the trees. Gap sizes were measured from the edges of the crowns of the surrounding old trees. For the various simulated gaps the amount of PAR on the forest floor was calculated with the FOREYE program. The results are given in subsection 6.4.3.

3.4.3.3 Vertical light profiles in simulated Scots pine stands without undergrowth of birch

The pattern of PAR availability from the forest floor upwards is important for the stem development in young trees, especially oak. Therefore the PAR profile in a vertical plane was calculated. With the FOREYE program, the PAR availability as percentage of the PAR availability above the canopy, was calculated in a simulated 75-year-old Scots pine stand, with stand density index of 0.5. A 0.5 stand density index is a site characteristic in which young oaks can certainly grow, as shown in stands Gortel 52 and 80. The results are given in subsection 5.2.3.

3.4.3.4 Vertical light profiles in simulated Scots pine stands with undergrowth of birch

In Scots pine stands with an existing undergrowth of young deciduous trees, especially birch, additional regeneration by oak is of special importance (section 2.1). Because of the prolific reiteration and inherent sympodial extension growth of indigenous oak (subsection 3.3.2) the pattern of PAR availability from the forest floor up to the stand canopy is of specific importance to the stem shape development of oak. Vertical PAR profiles were calculated with FOREYE in simulated 75-year-old Scots pine stands of yield class II (Grandjean and Stoffels, 1955) that had undergone a simulated reduction of basal area to reach a stand density index of 0.5 (220 trees per ha). It was assumed that birch existed. There were 440 9 m tall birch trees per ha in the stand. Data on birch were obtained from stands Gortel 52 and 80, which show a structure similar to the simulated stand. A second calculation was carried out with 12 m tall birch. The data on these birches were obtained from the RIN Forest Ecological Information System (Koop, 1987) from stands similar to the one simulated. The results are given in subsection 5.2.3.

PART II RESULTS, DISCUSSION AND CONCLUSIONS

4 Volume and value increment in old Scots pine

4.1 Volume increment in Scots pine trees in even-aged stands

The tree rings taken from the 213 randomly sampled Scots pine trees (subsection 3.3.1) were used to determine volume increment. In the cross-section of a tree, each tree ring was considered a new case. The cases were used for a descriptive, not an explanatory model. Altogether there were 5,923 cases in the randomly sampled Scots pine trees.

At a specific thinning regime, tree ring growth is expected to be dependent on the diameter at breast height (dbh) and the site index (S). The following equation was formulated to carry out the regression of current increment in volume (i_v):

$$i_v = dbh \wedge c_1 * S \wedge c_2 * e \wedge c_3 \quad (1)$$

in which the site index S was calculated with the Chapman and Richards formula (subsection 3.4.1), c_1, c_2 and c_3 are empirical constants. The SPSS program was used to calculate the regression of:

$$\ln i_v = c_1 \ln(dbh) + c_2 \ln(S) + c_3 \quad (2).$$

Figure 17a shows 10% of all observed cases in a scatter diagram. The cases shown were obtained from the database by systematically plotting every tenth

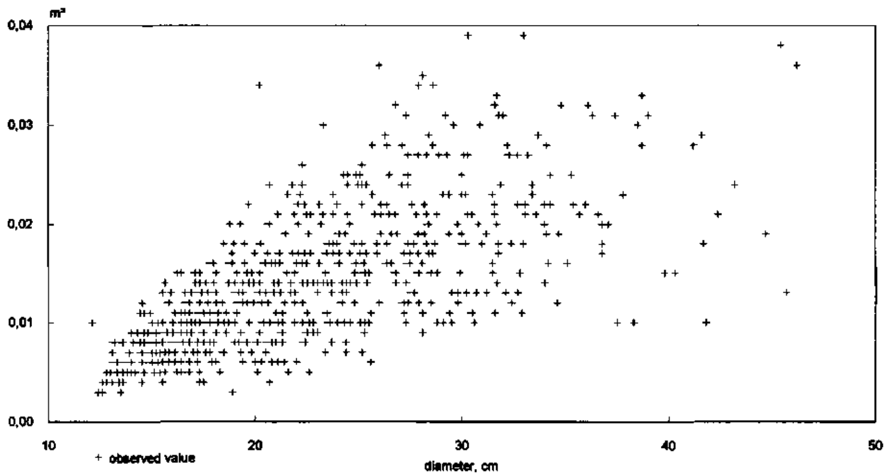


Fig. 17a. Scatter diagram of 10% of all the volume increment data observed.

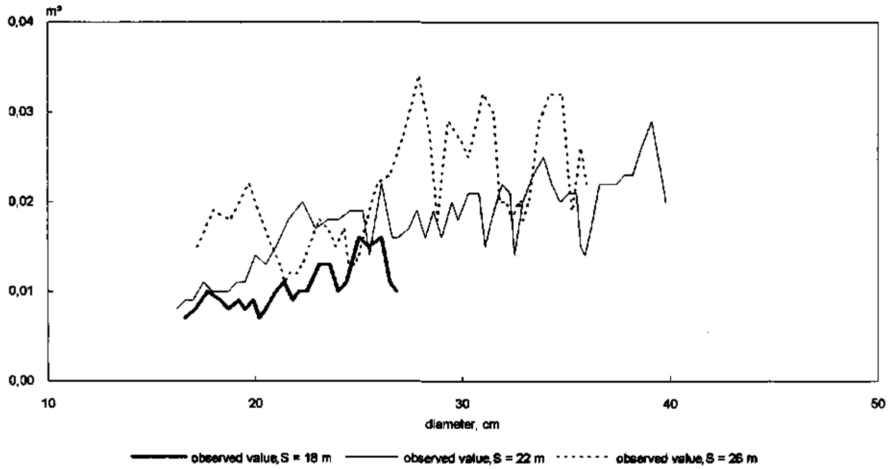


Fig. 17b. Examples of observed volume increment plotted against diameter development of 3 randomly chosen trees.

case. In figure 17b examples of volume increment of 3 randomly chosen trees, one from each occurring site class, are plotted against the diameter development of those trees.

The empirical constants and R^2 found for the 213 trees sampled from the Scots pine stands are as follows:

c_1	c_2	c_3	R^2
1.2	1.7	–13.6	0.70

In figure 18 the fitted current increment in volume per tree per year is plotted against the diameter at breast height for 3 chosen site indices, measured over the bark.

Discussion and conclusions

Figure 18 shows an increasing volume increment per tree as diameters increase. However, the value of R^2 of the fit is low. The diameter growth of trees depends on the available growing space (Leersnijder, 1992). Hence, growth rate depends on the thinning intensity.

According to Fritts (1976) successive tree rings can show poor growth through climatic causes of one particular year. Although each tree ring is independent of the previous tree rings as such, it reflects the autecology of the whole tree in one year of a series. This occurs independently of tree age.

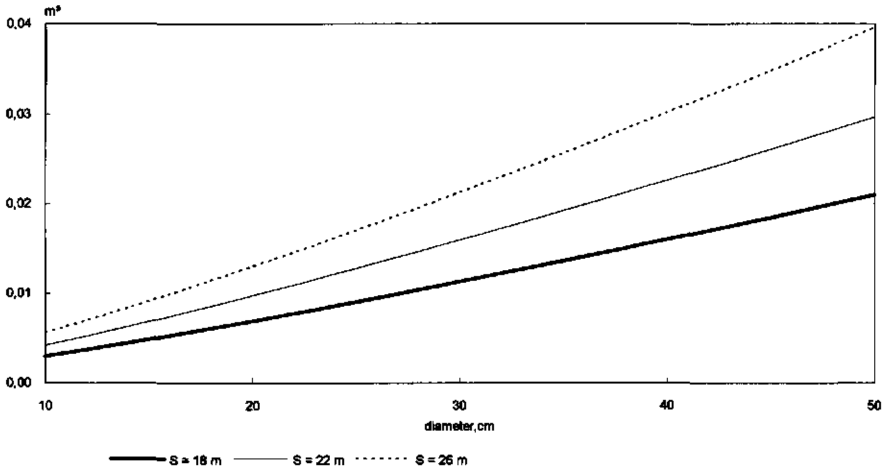


Fig. 18. Fitted current increment in volume per tree per year versus diameter at breast height, for 3 chosen site indices.

Lück and Pump (1992) also showed high volume increment in 150-year-old Scots pines in northern Germany, particularly if the old trees have much growing space.

4.2 Value increment in Scots pine trees in even-aged stands

The value increment in the 213 randomly chosen Scots pine trees reported in this section is only valid for the net stumpage prices given in subsection 3.4.2, and for the specific management history of the stands these trees were drawn from. When diameters fell between fixed stumpage price steps, the stumpage prices were interpolated. At different prices the value increment changes.

Value increment depends on volume increment at the various diameters. The hypothesis was that at a specific management history and stumpage price, value increment is dependent on diameter at breast height and site index. The following equation was formulated to carry out the regression of value increment (i_{val}):

$$i_{val} = dbh \wedge c_4 * S \wedge c_5 * e \wedge c_6 \qquad (3)$$

The empirical constants and R^2 which were calculated with the SPSS program for 3 price levels are given in table 16.

In figures 19 a and b the fitted current increment in value in Dfl per tree per year versus diameter at breast height measured over the bark is given for 3 chosen site indices at 2 stumpage price levels (subsection 3.4.2).

Table 16. Regression results on current increment in value in Scots pine trees at 3 price levels.

price level	c_4	c_5	c_6	R^2
1	2.0	1.7	−11.8	0.77
2	2.4	1.7	−13.5	0.73
3	1.6	1.8	−11.5	0.54

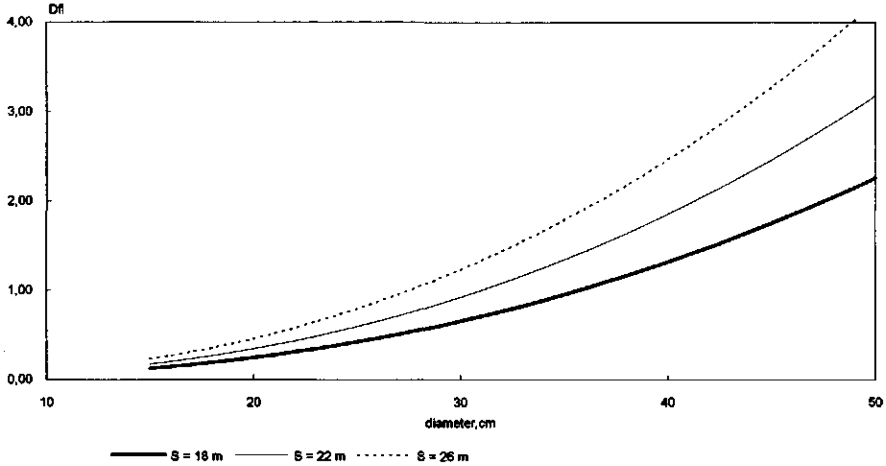


Fig. 19a. Fitted current increment in value per tree per year versus diameter at breast height for 3 chosen site indices at price level 2.

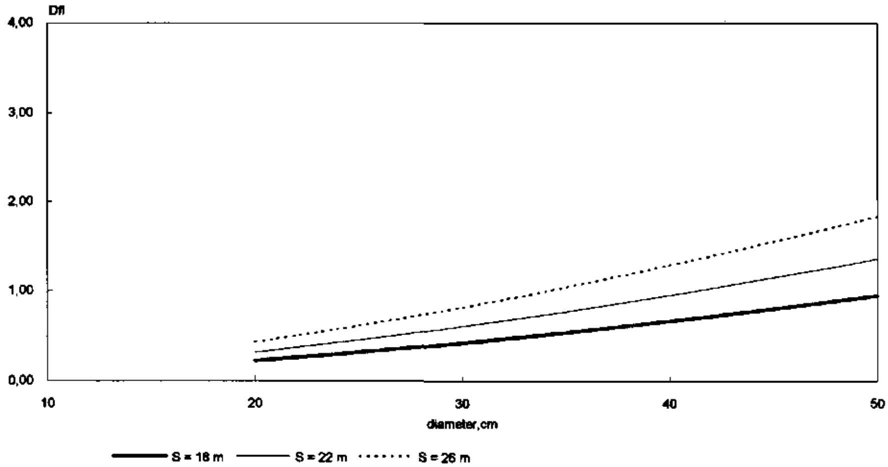


Fig. 19b. Fitted current increment in value per tree per year versus diameter at breast height for 3 chosen site indices at price level 3.

To ascertain the accuracy of the fit of the current increment in value given in figure 19a a fit was determined for the current increment in value of the individual trees at price level 2. Only trees that had at least 10 year rings with real value were examined. The average values of c_4 (determined from equation 3) and their standard deviations and errors are given in table 17.

Table 17. Average values of c_4 (from equation 3), their standard deviations for individual trees, and the standard errors of the mean, at various site classes at price level 2.

site class:	16 to 20 m	20 to 24 m	24 to 28 m
average c_4:	2.6	2.6	2.5
standard deviation:	1.0	1.2	1.1
standard error of mean:	0.33	0.14	0.14
number of trees:	9	69	59

One-sided t-tests were used to investigate whether the average c_4 is statistically significantly higher than 1. At the various site classes this is the case at price level 2 ($p < 0.001$). It was also investigated whether the data of c_4 were statistically significantly higher than 2. This was found to be the case for site classes 20 to 24 m and 24 to 28 m ($p < 0.001$). For site class 16 to 20 m, c_4 is not statistically significantly higher than 2 ($p = 0.36$).

Discussion and conclusion

As with volume increment, figures 19a and b show that value increment increases with increasing diameters. The constant c_4 is greater than 1. When c_4 is greater than 2 (at price level 2) the value increment also increases per square metre basal area as diameters increase.

Risks of mortality and decay were not incorporated in the calculations.

4.3 Percentage value increment in Scots pine trees in even-aged stands

The percentage value increment of the 213 randomly chosen Scots pine trees is only valid for the used net stumpage prices given in subsection 3.4.2 at the particular management history of the stands these trees were drawn from.

The percentage value increment was calculated from the equation:

$$ir_{val} = i_{val}(t) / val(t-1) \qquad (4)$$

in which ir_{val} is the percentage value increment, $i_{val}(t)$ is the current increment in value at year t, and val(t–1) is the stumpage value at year t–1. The hypothesis was that percentage value increment is dependent on diameter at breast height and site index. Therefore a regression analysis was done on the calculated data, using the equation:

$$Ir_{val} = dbh \wedge c_7 * S \wedge c_8 * e \wedge c_9 \qquad (5)$$

Table 18. Regression results on percentage value increment in Scots pine trees at 3 price levels.

price level	c_7	c_8	c_9	R^2
1	–1.7	1.0	4.1	0.64
2	–1.9	1.0	4.8	0.62
3	–2.4	1.0	6.3	0.60

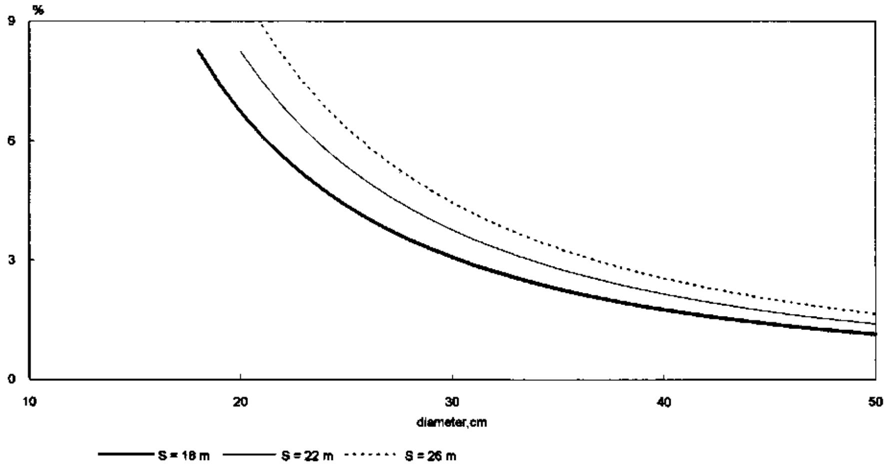


Fig. 20a. Fitted percentage value increment per tree and year versus diameter at breast height, for 3 chosen site indices at price level 2.

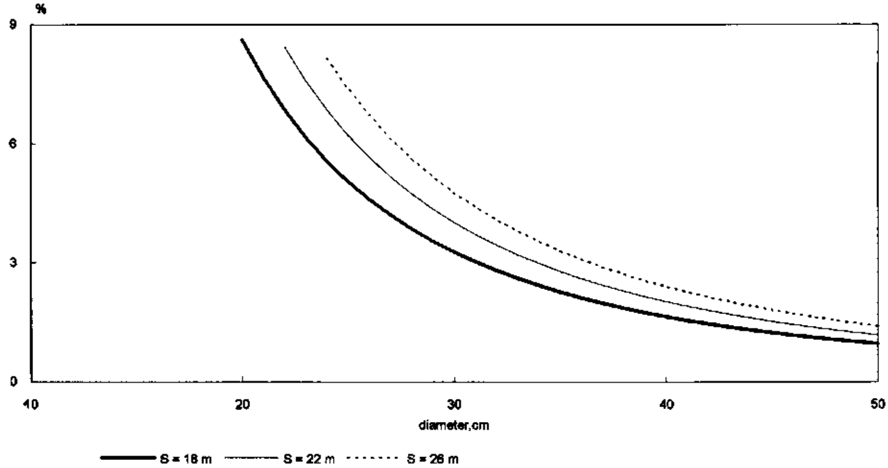


Fig. 20b. Fitted percentage value increment per tree and year versus diameter at breast height, for 3 chosen site indices at price level 3.

The constants and R^2 which were calculated with the SPSS program for 3 price levels are given in table 18.

In figures 20 a and b the fitted percentages value increment per tree and year versus the diameter at breast height, measured over the bark, are given for 3 chosen site indices at 2 price levels.

Discussion and conclusions

Figures 20 a and b show that the percentage value increment decreases with increasing diameters. At the same diameters the percentage value increment decreases at decreasing site indices. This leads to different financial diameters at different site indices. However, values of R^2 are low. At the various price levels at the same site index, there are also differences between the curves of percentage value increment. Considering the substantial differences among the price levels, the small differences between the diameters where the curves cross the 3% interest level is striking. However, this is not so remarkable if one realizes that the increment percent would be independent of the price level if timber assortments had the same price, independent of diameter. This is explained further in section 9.1.

A decreasing percentage value increment at increasing diameters was also described by Moog and Karberg (1992).

5 Oak regeneration in Scots pine stands

5.1 Occurrence of oak saplings at different ages of the old Scots pine stands

Saplings of pedunculate and sessile oak appear spontaneously in Scots pine stands of various ages. Seeds are often brought in by jays (Bossema, 1979). In Palace Park 14 oak appeared when the Scots pine was 93 to 96 years old, after the stand canopy had been opened by a storm, which coincided with a sharp decline in numbers of red deer (Al and Montizaan, 1987). In Gortel 80, oak appeared much earlier, when the Scots pine stand was 46 to 50 years old (Vester, 1987). Three years before this establishment the stand density index was 0.7 (Grandjean en Stoffels, 1955). Twenty years after the oak had established there were still 447 Scots pine trees of 65 years per ha, resulting in a stand density index of 0.7. In Palace Park 4n, oak aged 3 to 5 years was present in 44-year-old Scots pine with a stand density index of the old stand of 1.18. In Gortel 77, oak appeared when the Scots pine stand was 60 to 65 years old, immediately after the stand had been fenced, under conditions of high stand density indices (table 7, subsection 3.2.2).

Discussion and conclusions

Research into the history of the stands revealed that in Gortel 80 and Palace Park 14 the oak saplings appeared shortly after the red deer were moved from the area. Because roe deer remained in both areas, browsing did not stop completely. In Gortel 77 oak appeared immediately after the stand was fenced.

Rackham (*in*: Savill, 1991) also related the absence of oak regeneration to abundant browsing animals. Schmidt (1991) and Jauch (1991) mentioned the need to fence, to achieve regeneration of deciduous tree species in coniferous stands. Fischer (1993) reported 15- to 25-year-old sessile oak established under 60-year-old Scots pine in Osterholz-Scharmbeck, Germany.

From the above it can be concluded that indigenous oak can establish in Scots pine stands as early as 40 to 50 years after the germination of the Scots pine, even when these stands have stand density indices of 0.7 and higher, but only if browsing pressure has been limited or temporarily excluded. This means that oak saplings can be brought into young Scots pine stands as a seed source as early as that. Beech for that purpose can be brought in even earlier. The introduction of oak and beech as seed sources is elaborated in section 5.3 and subsection 9.7.4.

5.2 Stem form of young oak trees

5.2.1 Stem form of young oak trees in old Scots pine stands

The stem form of young indigenous oak was examined by Smeulders and Van Wageningen (1988) in Palace Park 14. They recorded 232 oaks on 7.6 ha. Of these, 30 (13%) had a straight bole and 155 (67%) had a rather straight bole. Here 'rather straight' means: with slight curves, which are less than the stem thickness from the central axis of the stem. The mentioned authors counted total number of trees in the undergrowth, accompanying the oaks, in 34 plots of 700 m^2 and found on average 779 young trees per ha in this undergrowth (Smeulders and Van Wageningen, 1988).

In Gortel 80, 49 oaks per ha on 3.5 ha were examined. Of these oaks 12 (24%) had straight or rather straight boles at least 6 m long. Nineteen oaks (39%) per ha had straight or rather straight boles of at least 4 m long. The total number of trees in the undergrowth was counted in 17 plots of 700 m^2, and amounted to an average of 834 young trees per ha.

Discussion and conclusions

For use as saw logs, boles must be straight over at least 2.4 m (Smeulders and Van Wageningen, 1988). Straight boles of 4 and even 6 m are more valuable. In the stands investigated there were not many tall trees per ha with straight or rather straight boles. However, several oaks had those specific qualities; their percentage varied considerably over the area, possibly in relation to the abundance of the young trees (Houtzagers, 1954; Krahl-Urban, 1959). In that respect it must be noted that densities of young trees, particularly birch, in Palace Park 14 were very uneven (Clercx et al., 1986) and low compared to stands that suffered no or little pressure from browsers (section 5.3). On the other hand, poor stem form may be genetically determined (Oosterbaan, 1979; Schoenfeld, 1979). However, because the parents of the young oaks are unknown, this could not be ascertained in the stand investigated.

The data show that some of the spontaneously regenerated indigenous oaks posses straight stems, but that a high percentage of the trees do not. It was not clear to what extent the percentage of straight trees was determined by the abundance of neighbouring trees, and to what extent by genetic qualities. In 5.2.2 the gradual improvement of oak stems growing in high densities of young trees is investigated.

5.2.2 Stem form development

Straightening of stems

Of 89 pedunculate oak saplings, which were measured and drawn in 3 consecutive years, the following stem form development was recorded:

- 72 oak saplings (81%) showed the stem straightening towards the vertical. Of these, 28 saplings not only had old Scots pines above them, but also neighbouring saplings of birch, oak or rowan within a distance of 150 cm from their base.
- 3 (3%) oak saplings showed no measurable change of their stem with regard to verticality.
- 6 (7%) oak saplings first showed straightening of their stem, but the opposite effect in the second year. Four of these 6 had neighbouring saplings within 150 cm. Three of the 6 had forked stems, both axes of which were estimated to be of equal dominance and hence were called co-dominant axes.
- 8 (9%) oak saplings showed movement away from the vertical. Three of them had forked stems. In 2 of the 8, the sapling was impeded by a closely neighbouring birch sapling.

If the successive yearly shoots, which together built up the dominant axes, were reviewed per year, the following results became available from 168 observed shoots:

- 145 (86%) shoots showed an improvement in quality. They were more vertical after the growing season than before that season. The shoots were bayonet-shaped, because they had bent at their base.
- 20 (12%) shoots showed a deterioration in stem quality. They became less vertical than before.
- 3 (2%) shoots showed no measurable change in stem quality.

In addition to the 145 improving shoots, 69 co-dominant shoots were measured. Co-dominant shoots are second best in dominance. Of these 69 co-dominant shoots 56 (81%) showed less improvement than the dominant shoot, or showed deterioration. Two (3%) shoots improved more than the dominant shoot. Eleven shoots (16%) showed no measurable difference in improvement compared to the dominant shoot. Of the latter group, 6 formed forked stems with both shoots co-dominant, in the other 5 cases the dominant shoot remained dominant.

Of the 89 saplings, 35 were located within 150 cm of a birch or oak sapling of equal height or taller. In order to see whether the change of shoots was affected by the neighbouring sapling, these 35 saplings were reviewed. Among the 35 saplings, 72 shoots were observed. Of these, 64 improved, and 8 deteriorated in stem quality. Of the 64 improvements, 33 did so by bending towards the neighbouring sapling, and 31 did so by bending away from the neighbouring sapling. Eight shoots deteriorated, 4 of which by bending towards the neighbouring sapling and 4 by bending away.

The development of the oak saplings at scale 1:27 is shown in figure 21.

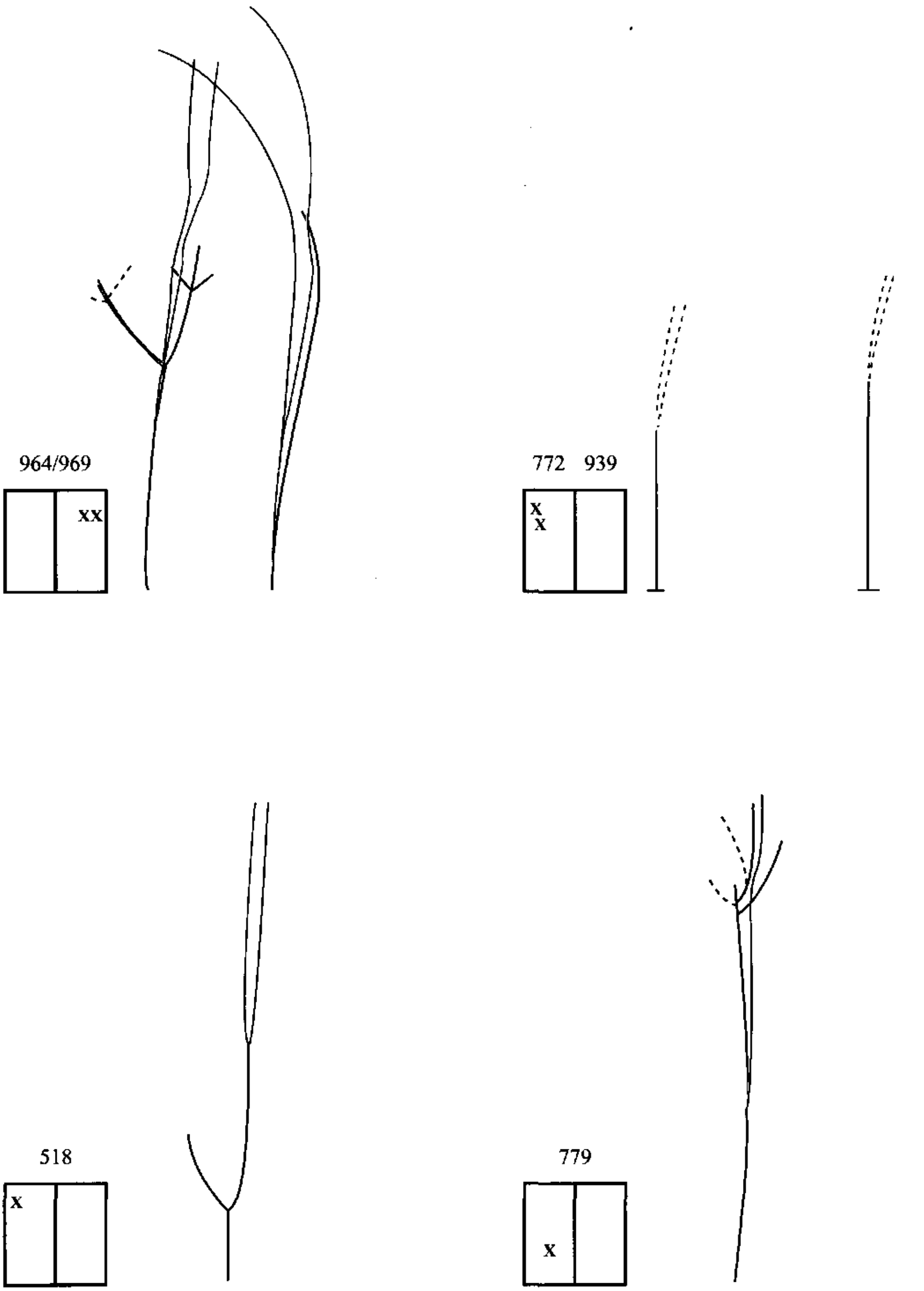


Fig. 21. Pedunculate oak saplings, drawn at scale 1:27 in 3 consecutive years. Solid lines are axes in the plane of the drawing. Broken lines are axes which jut out forward or backward from the plane of the drawing. Black lines represent the stem form in 1990, blue lines in 1991, and red lines in 1992.

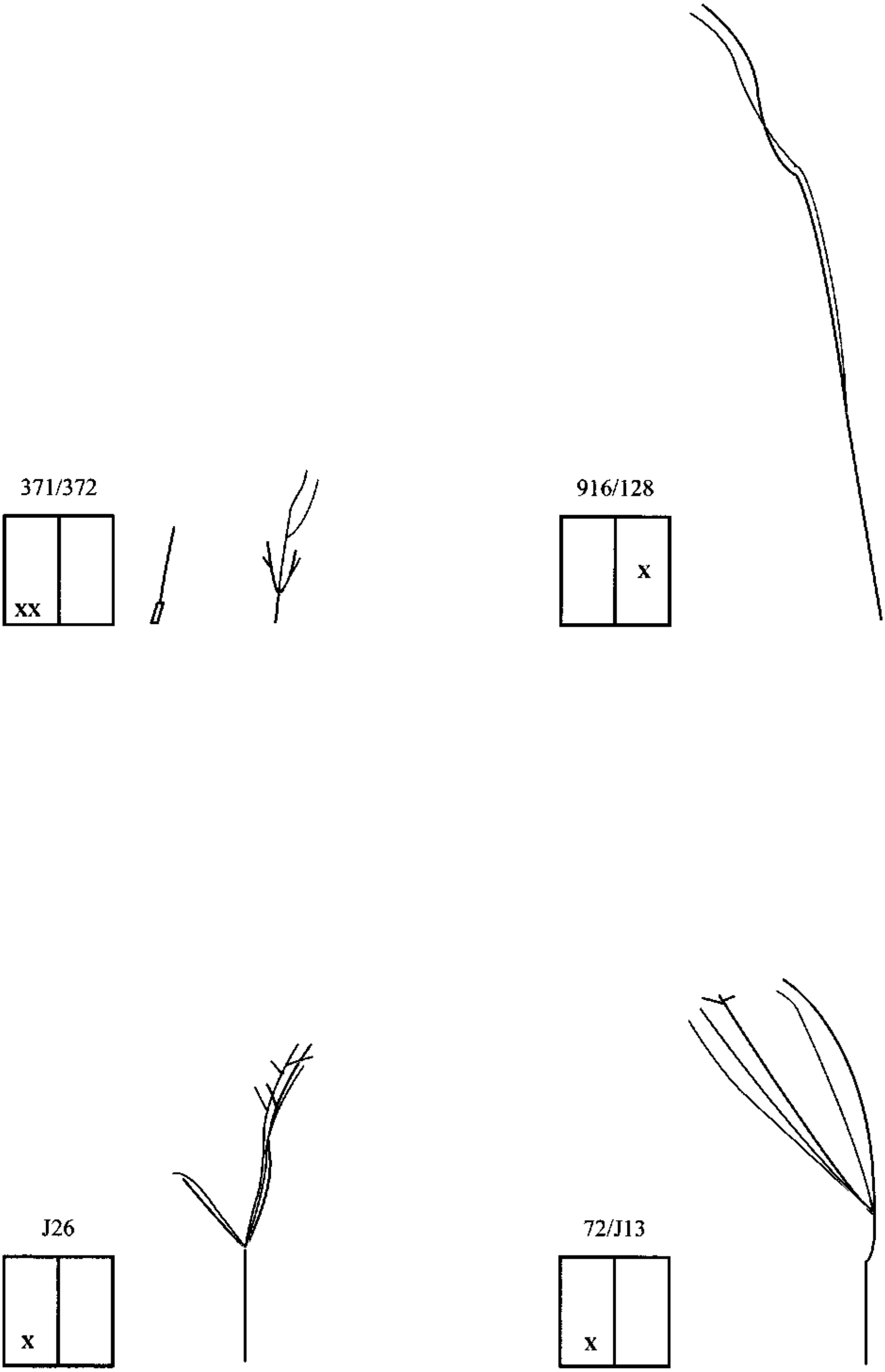
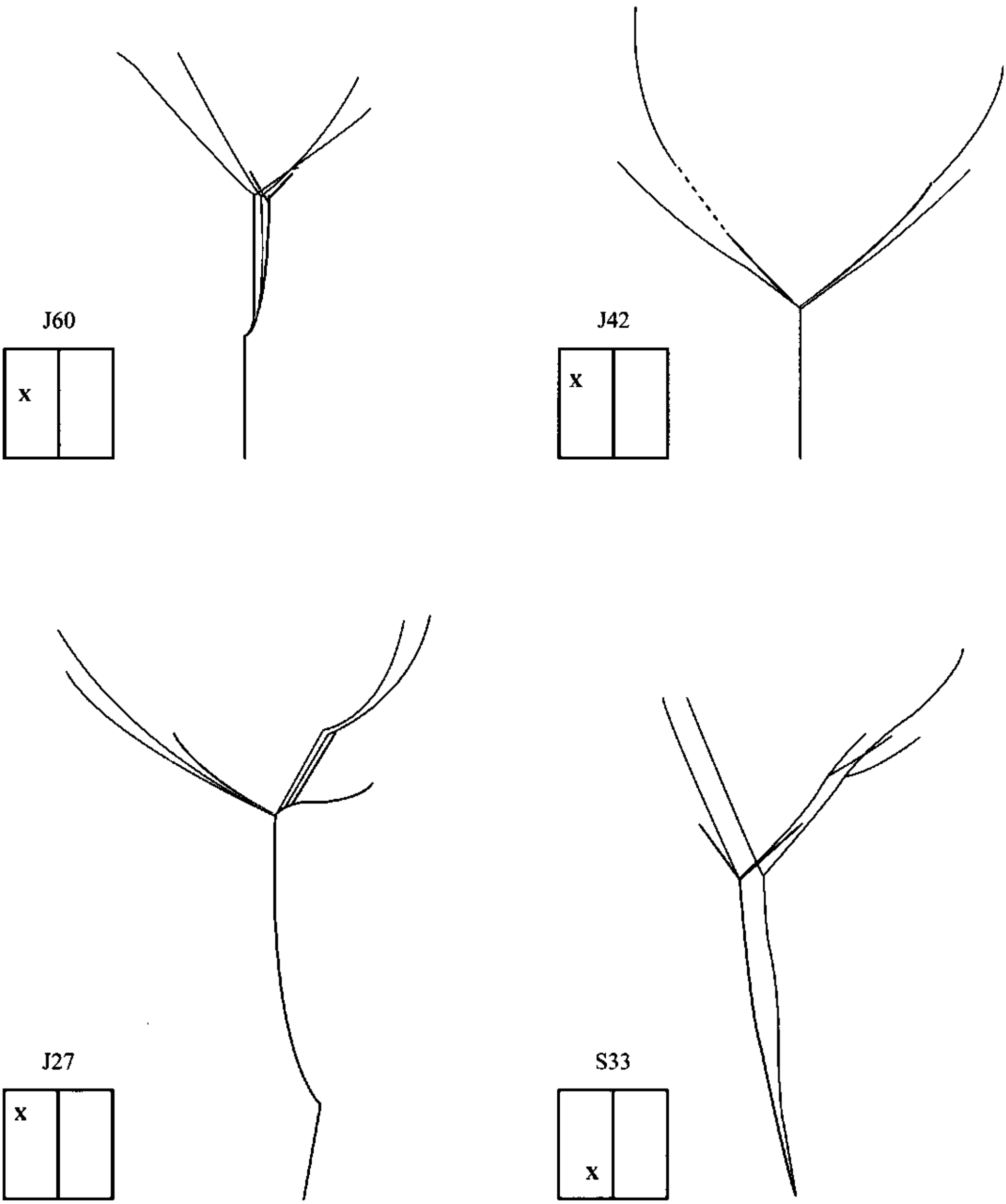


Fig. 21. (continued)



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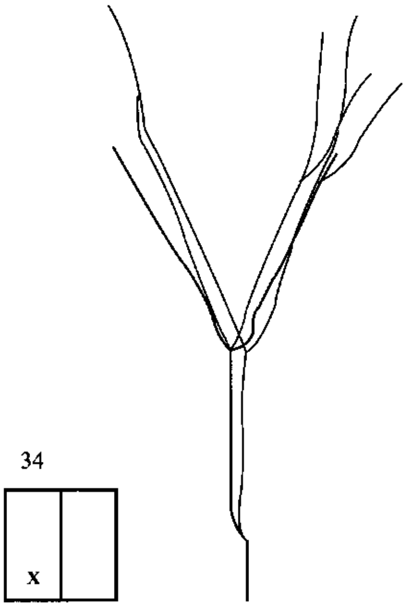

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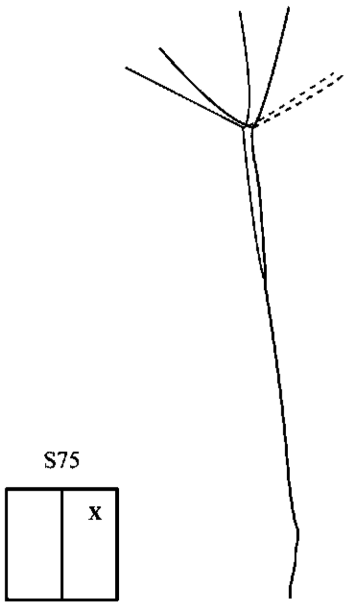

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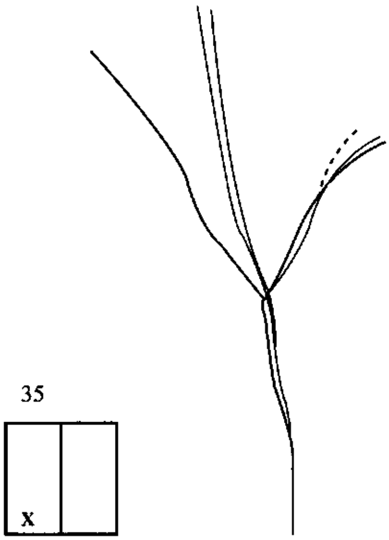

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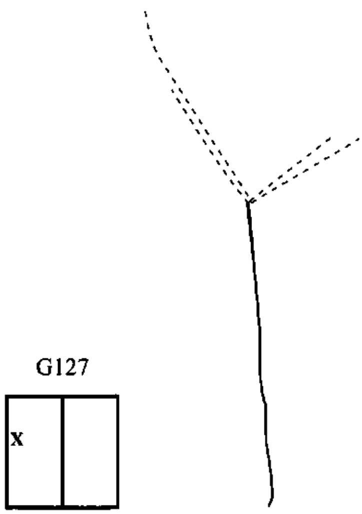

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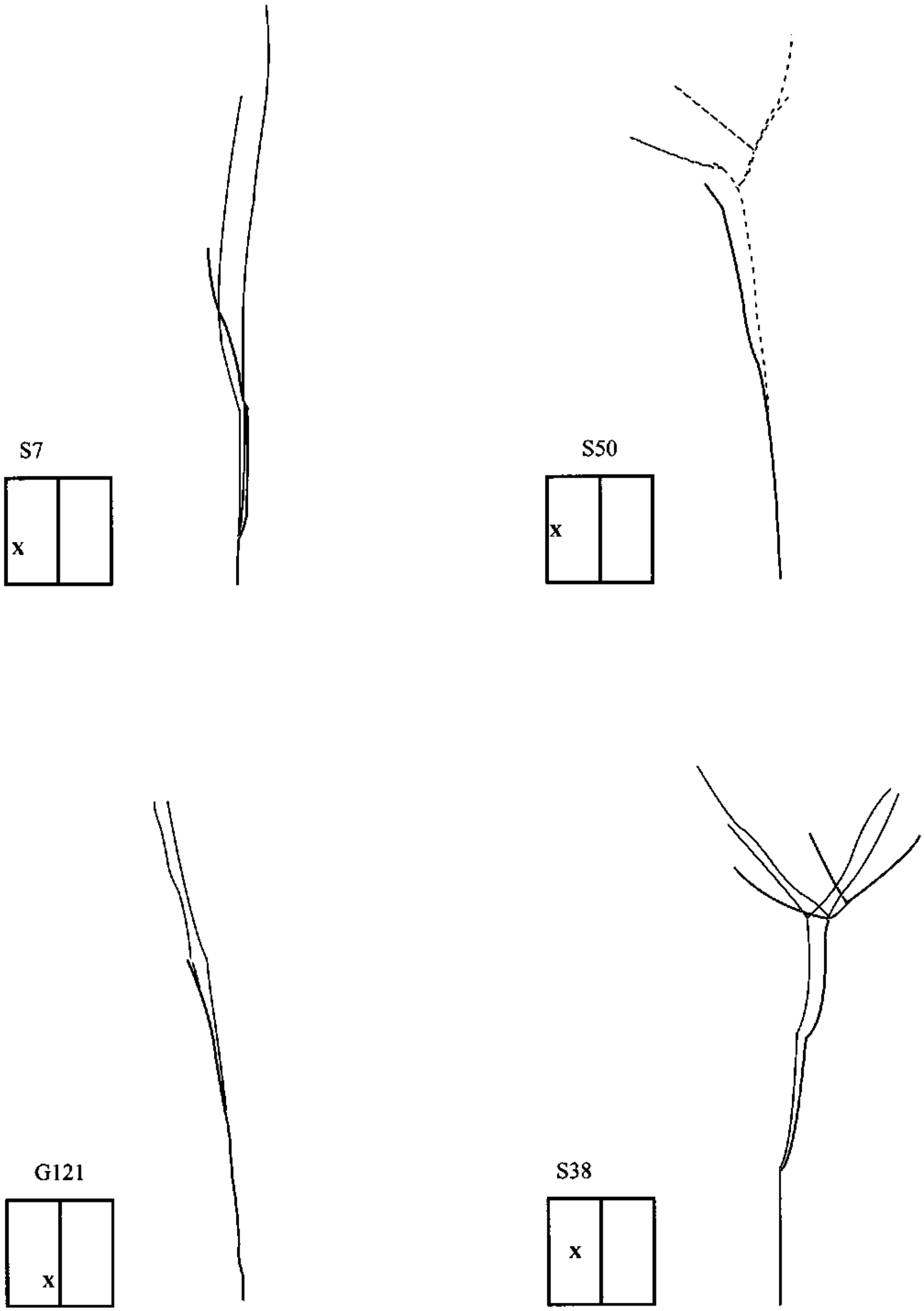

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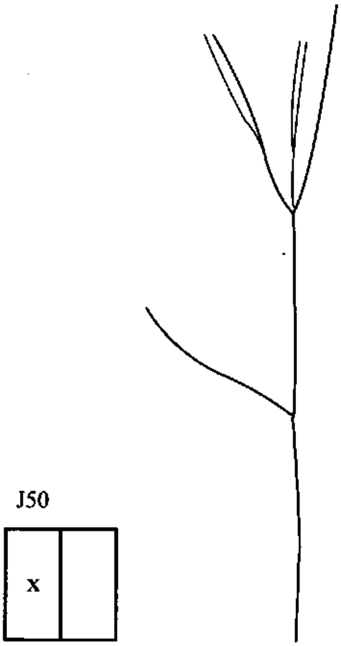

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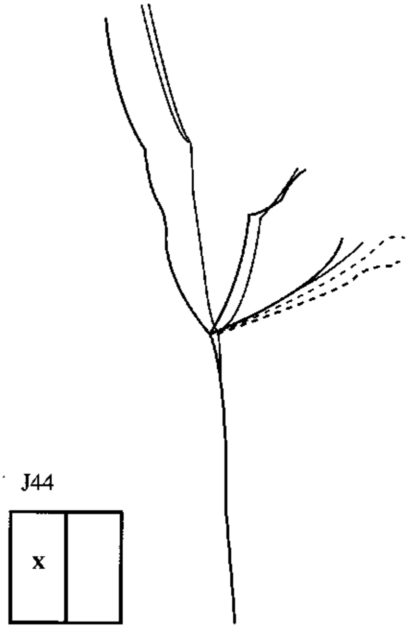

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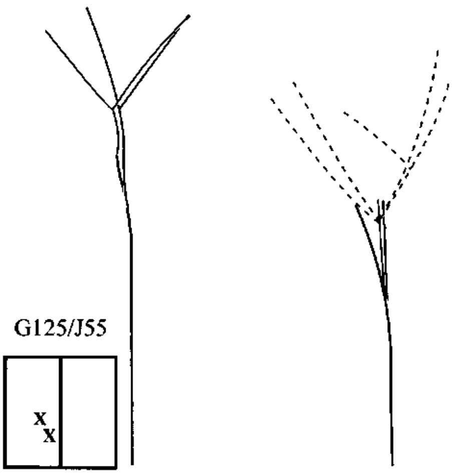

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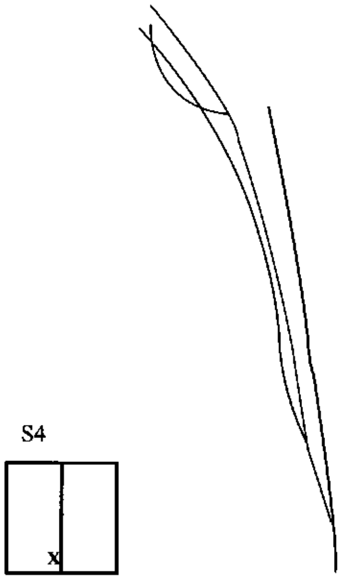

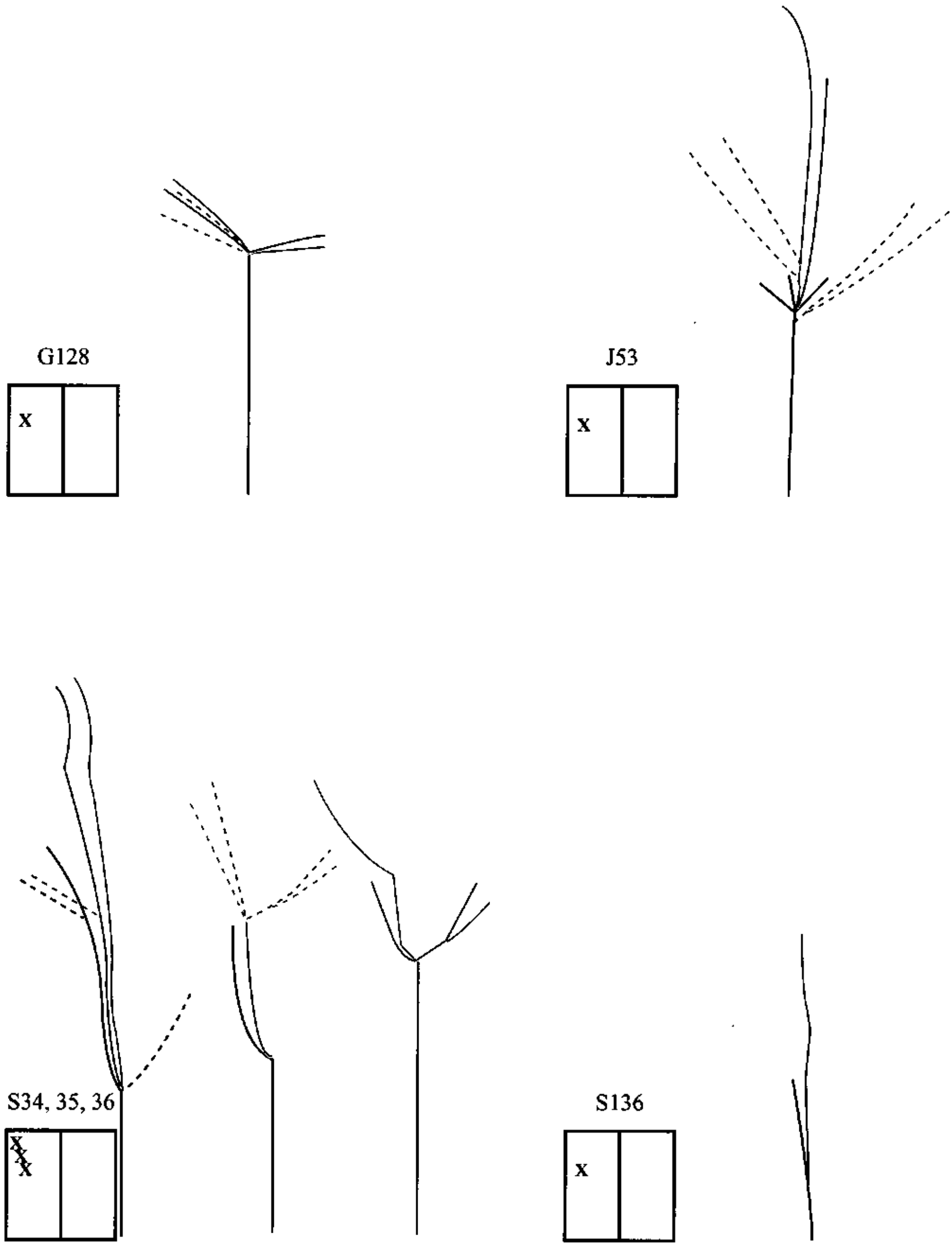

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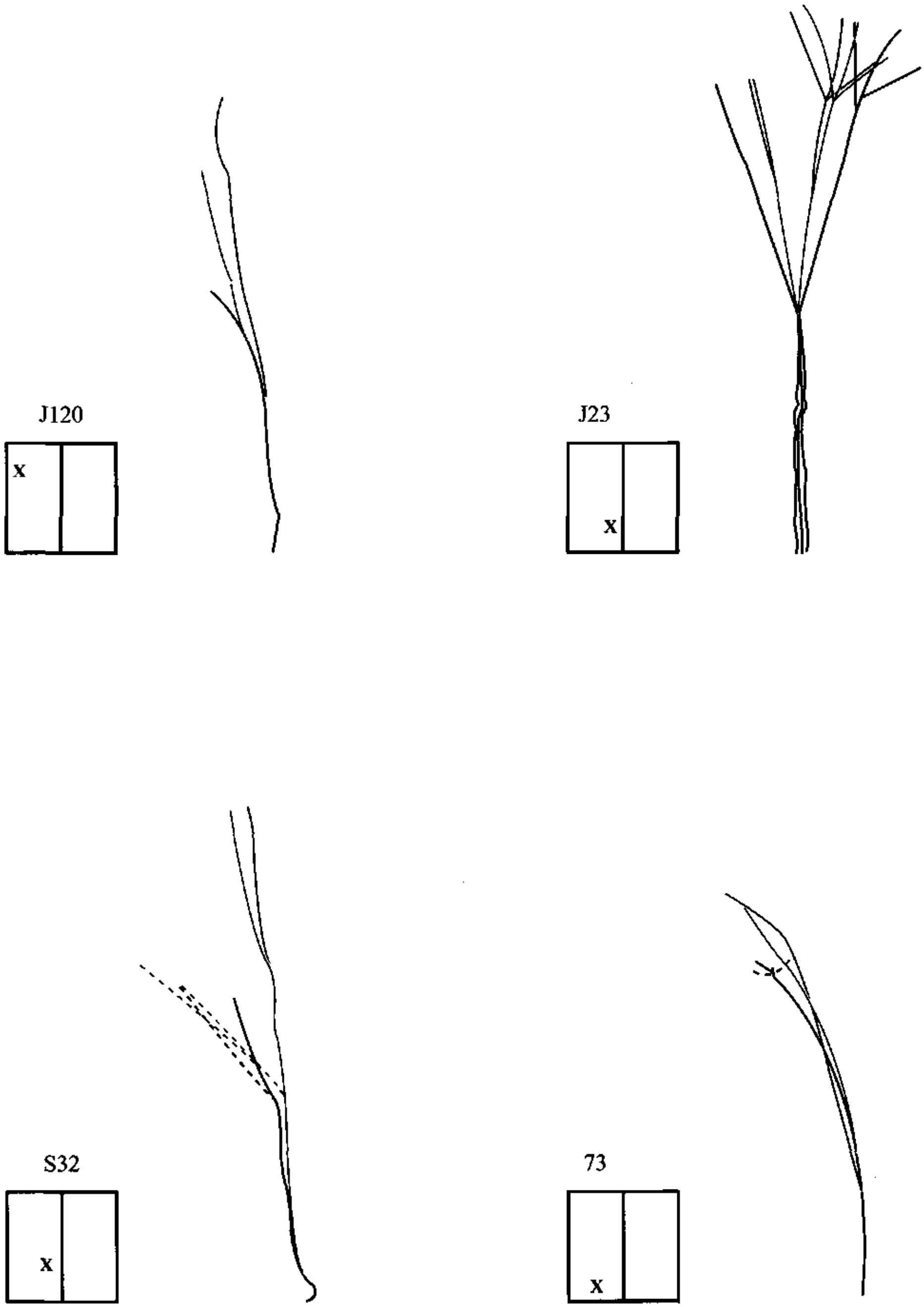

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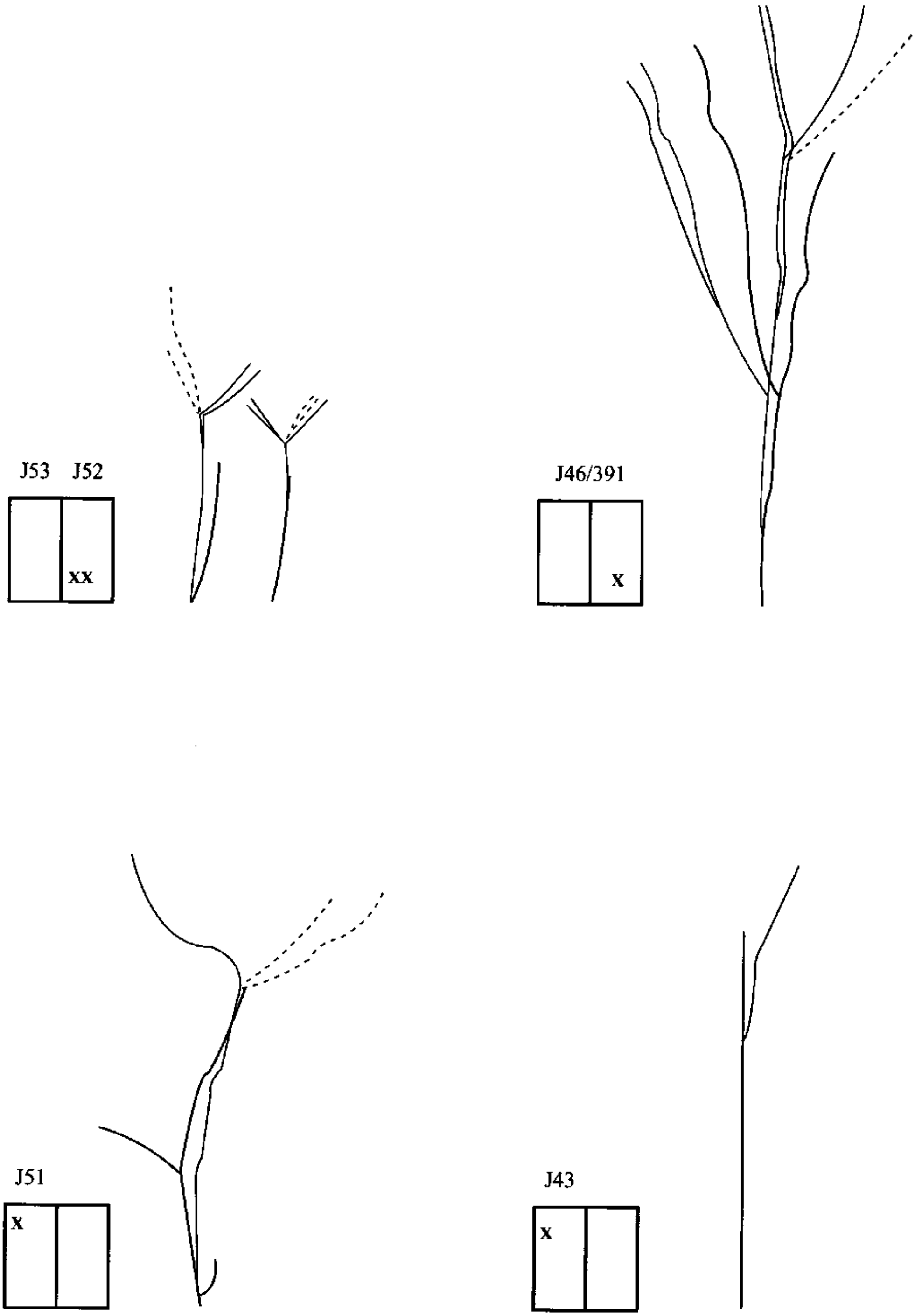

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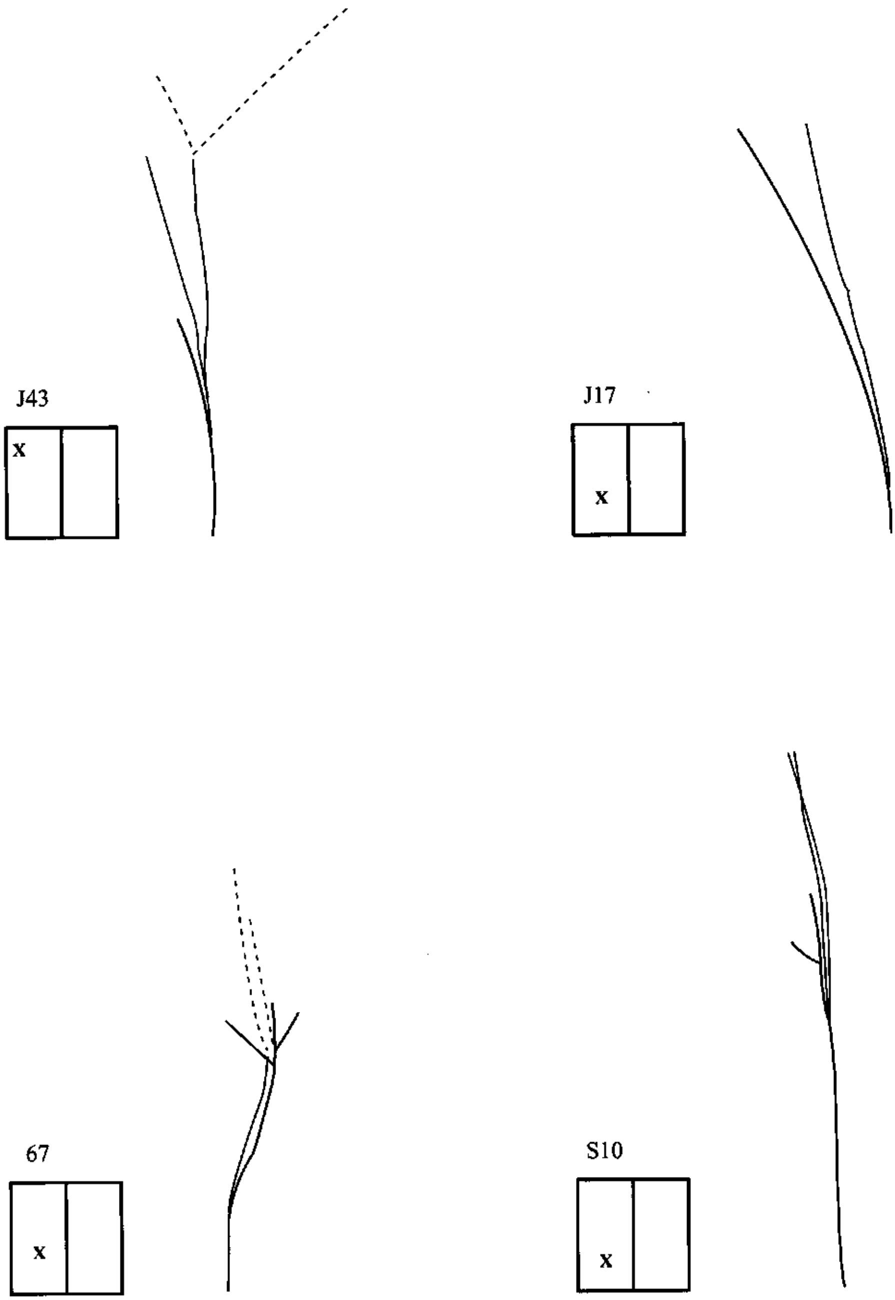

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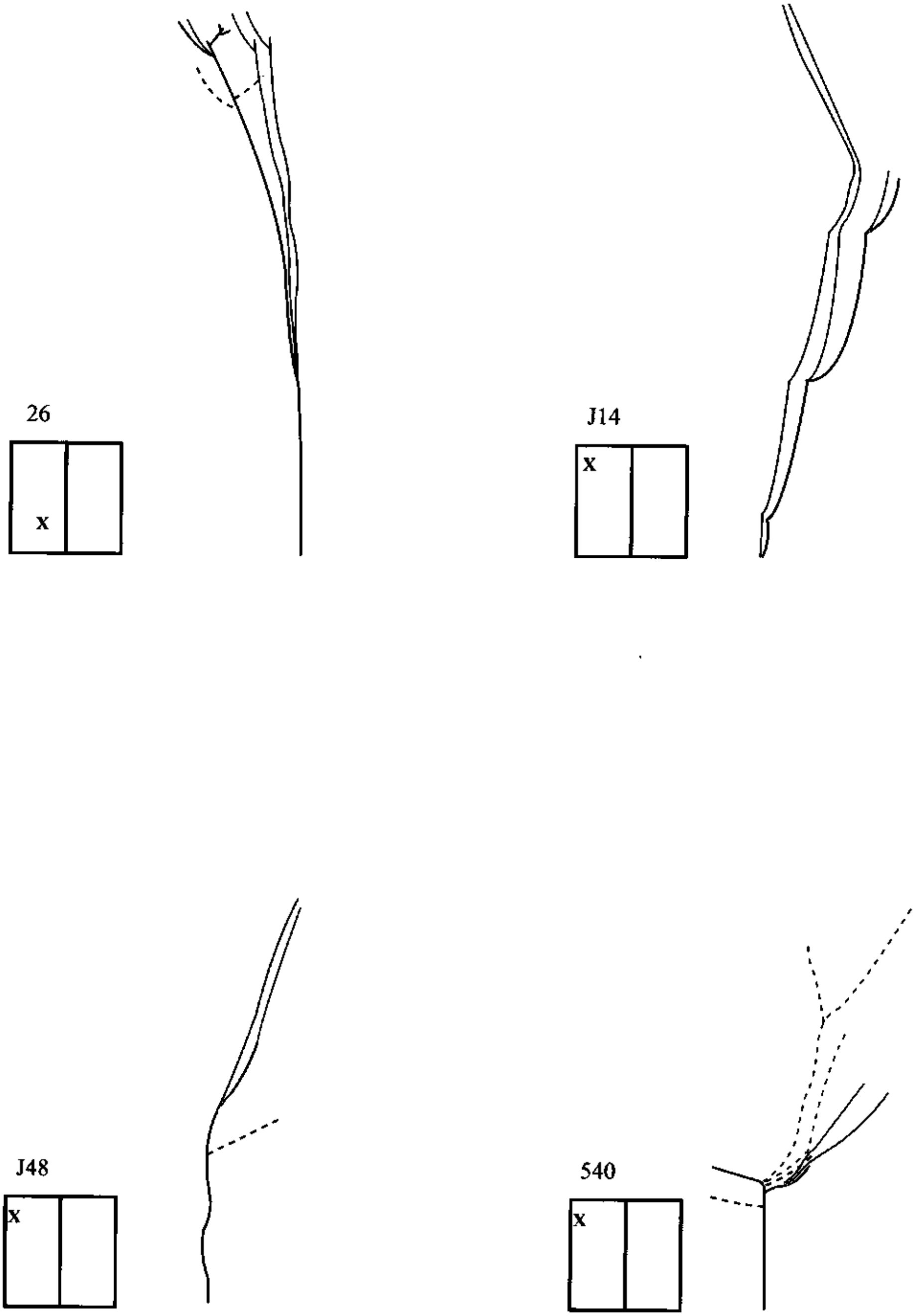

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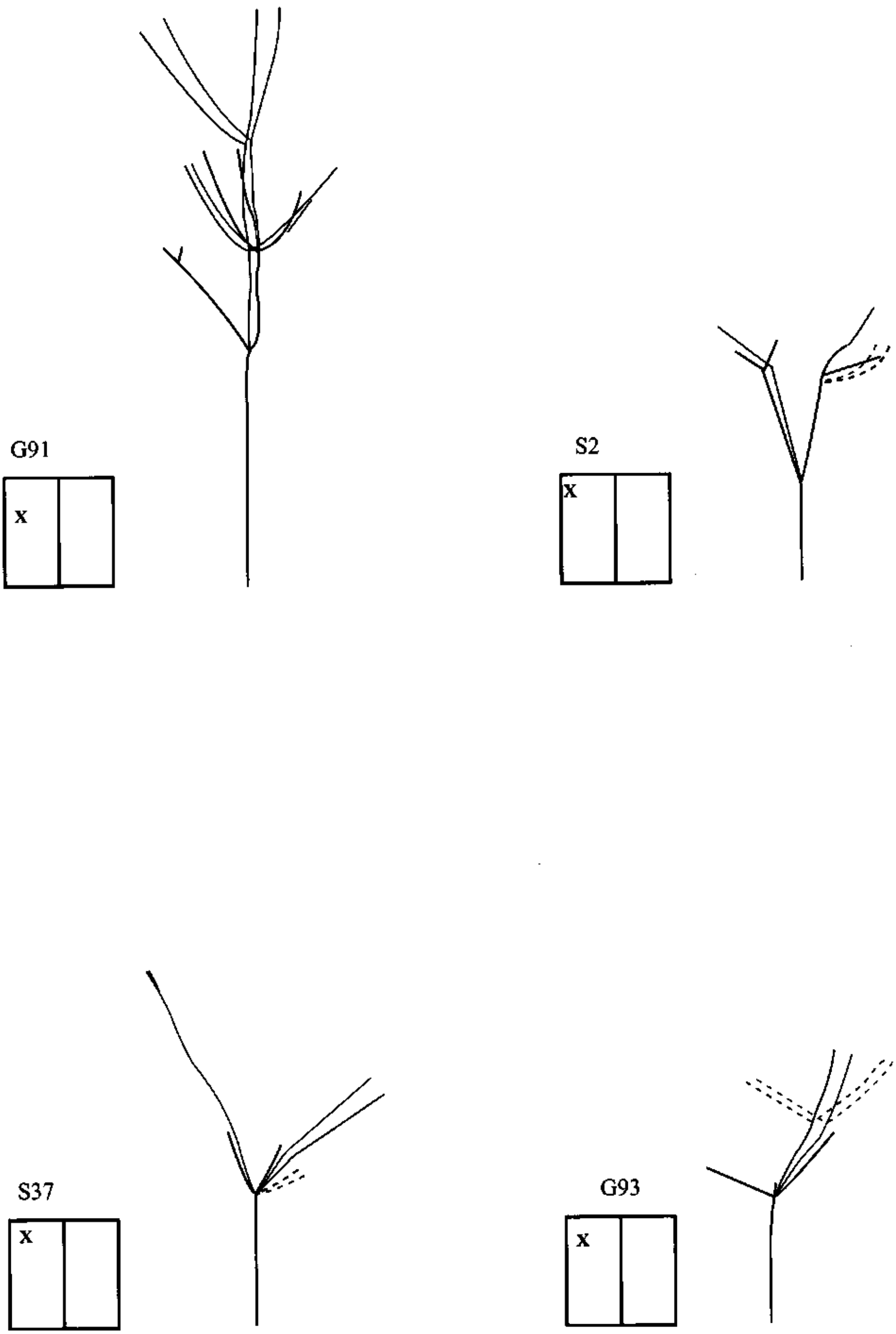

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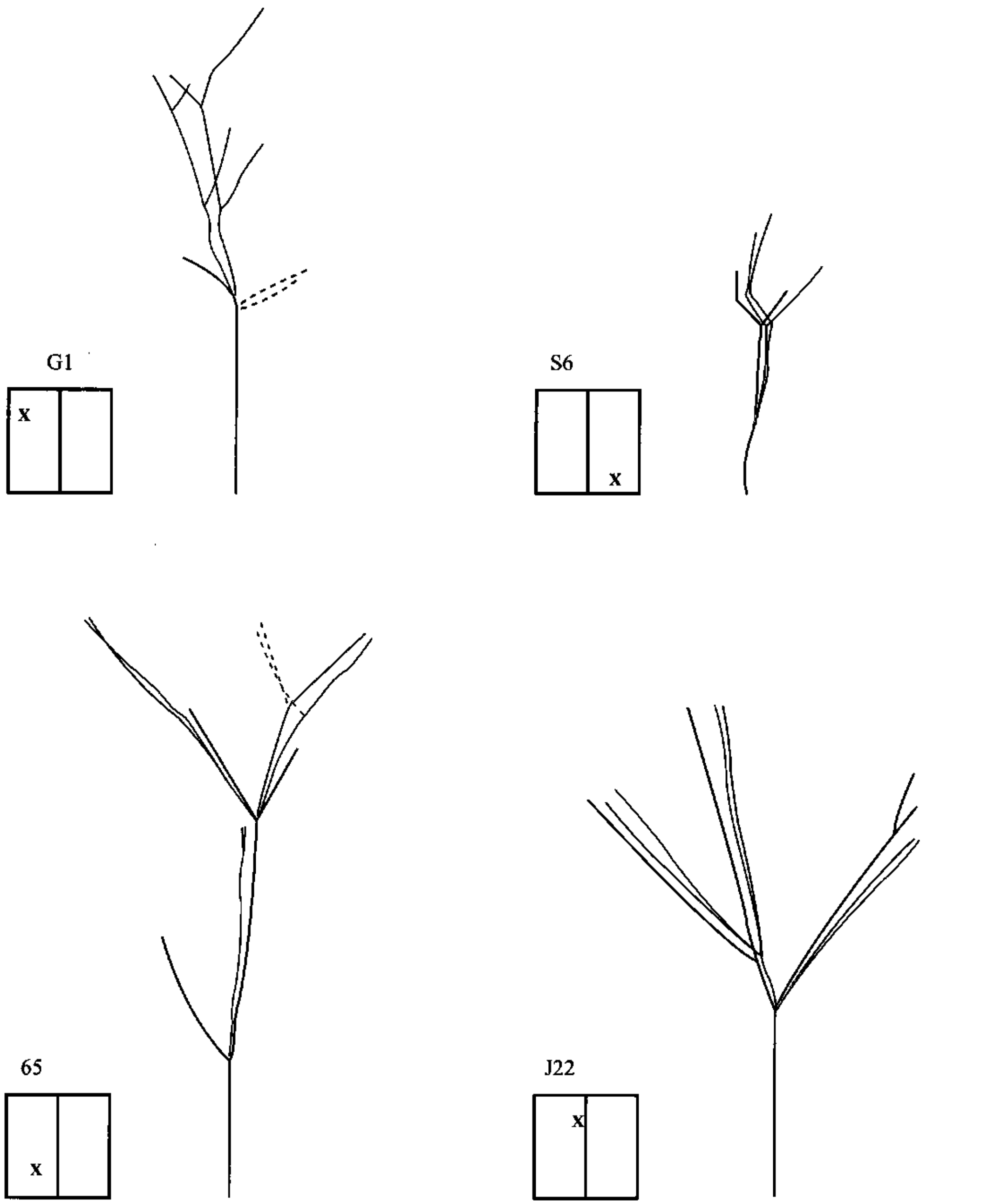

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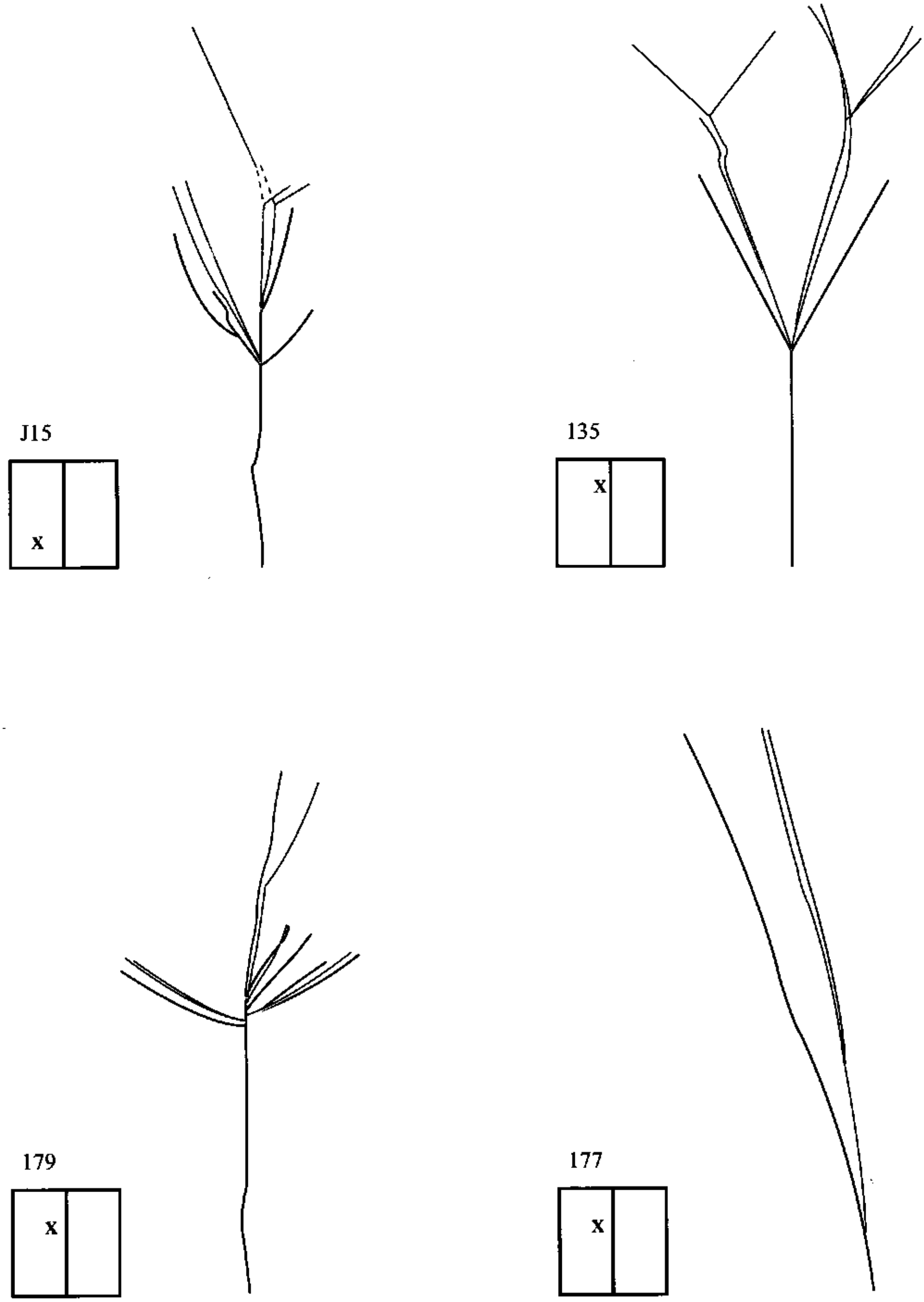

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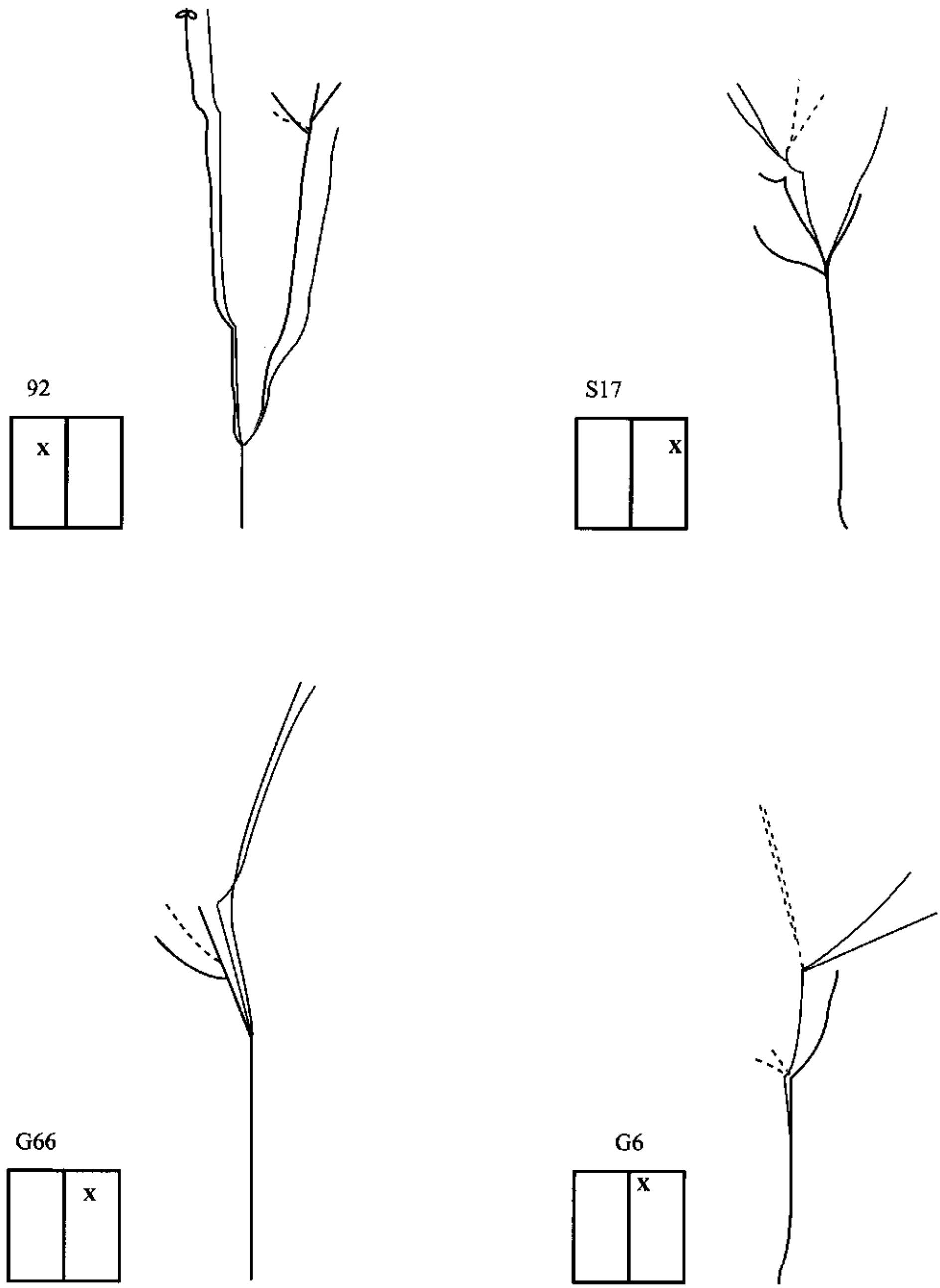

Fig. 21. (continued)

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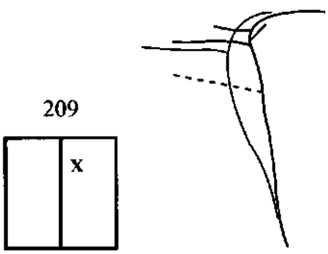
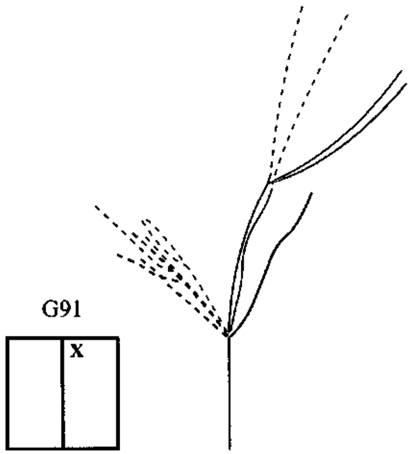


G91



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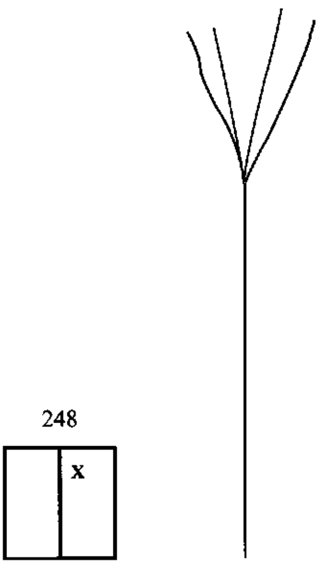

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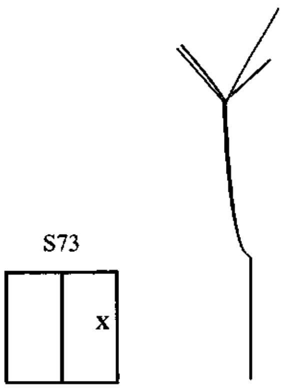

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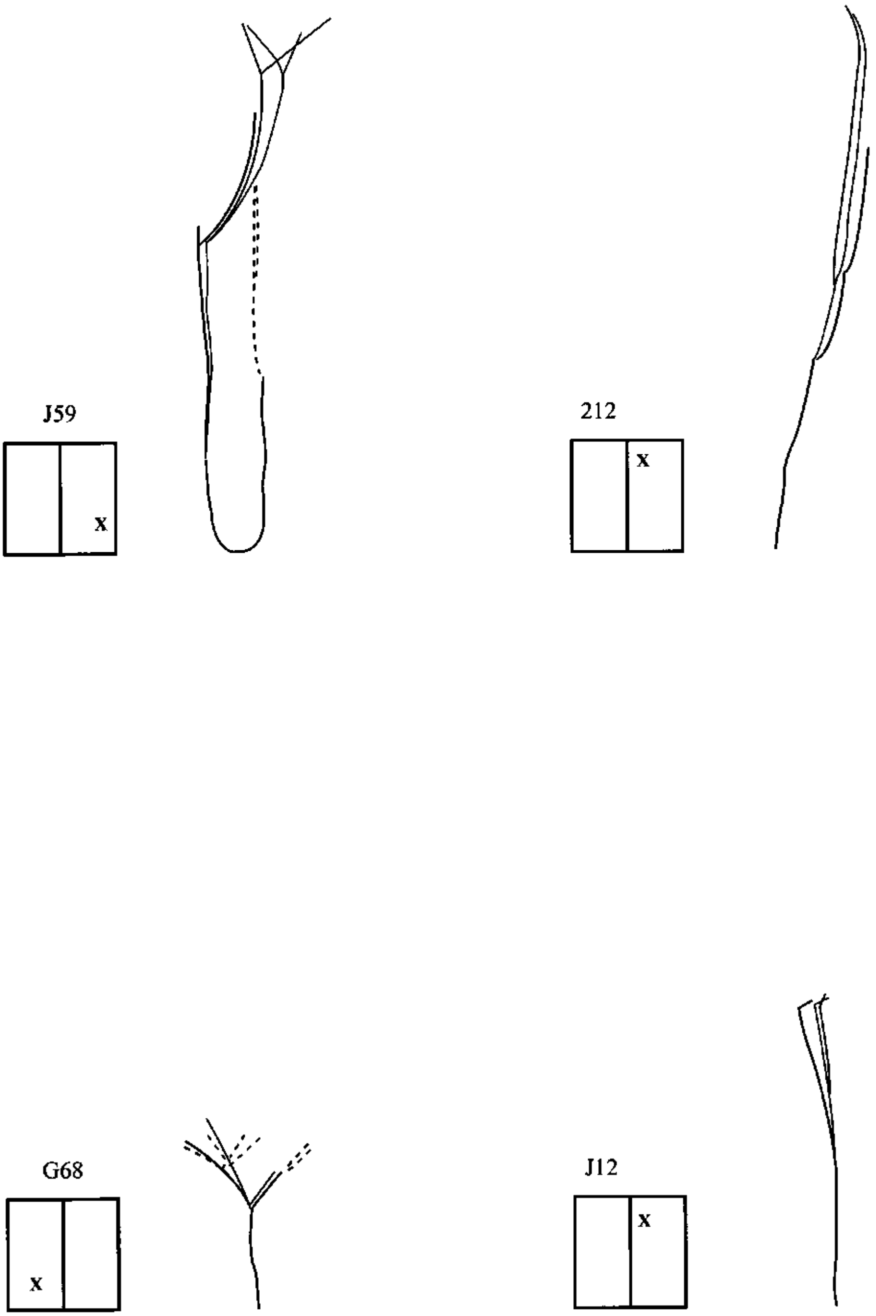

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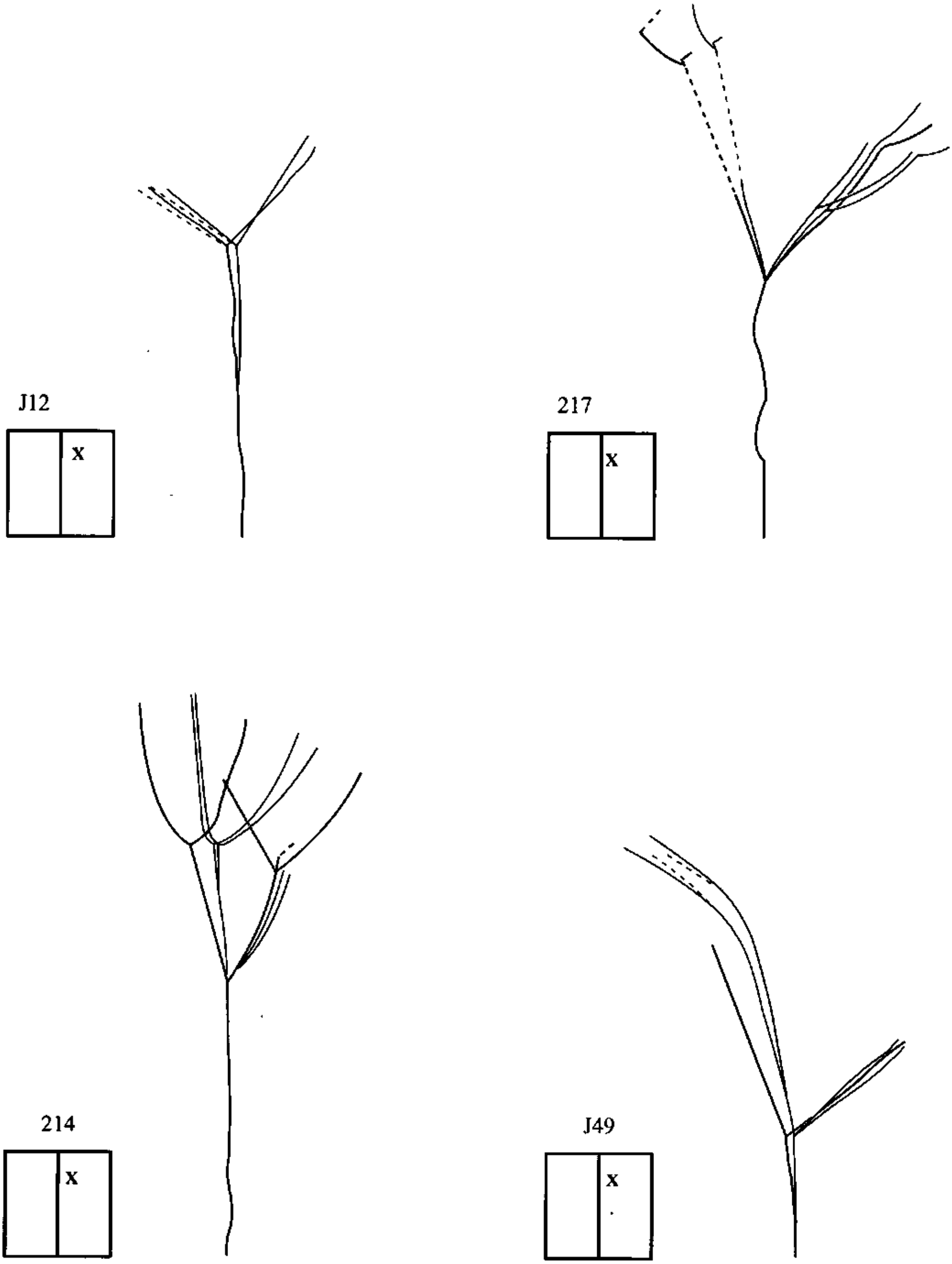

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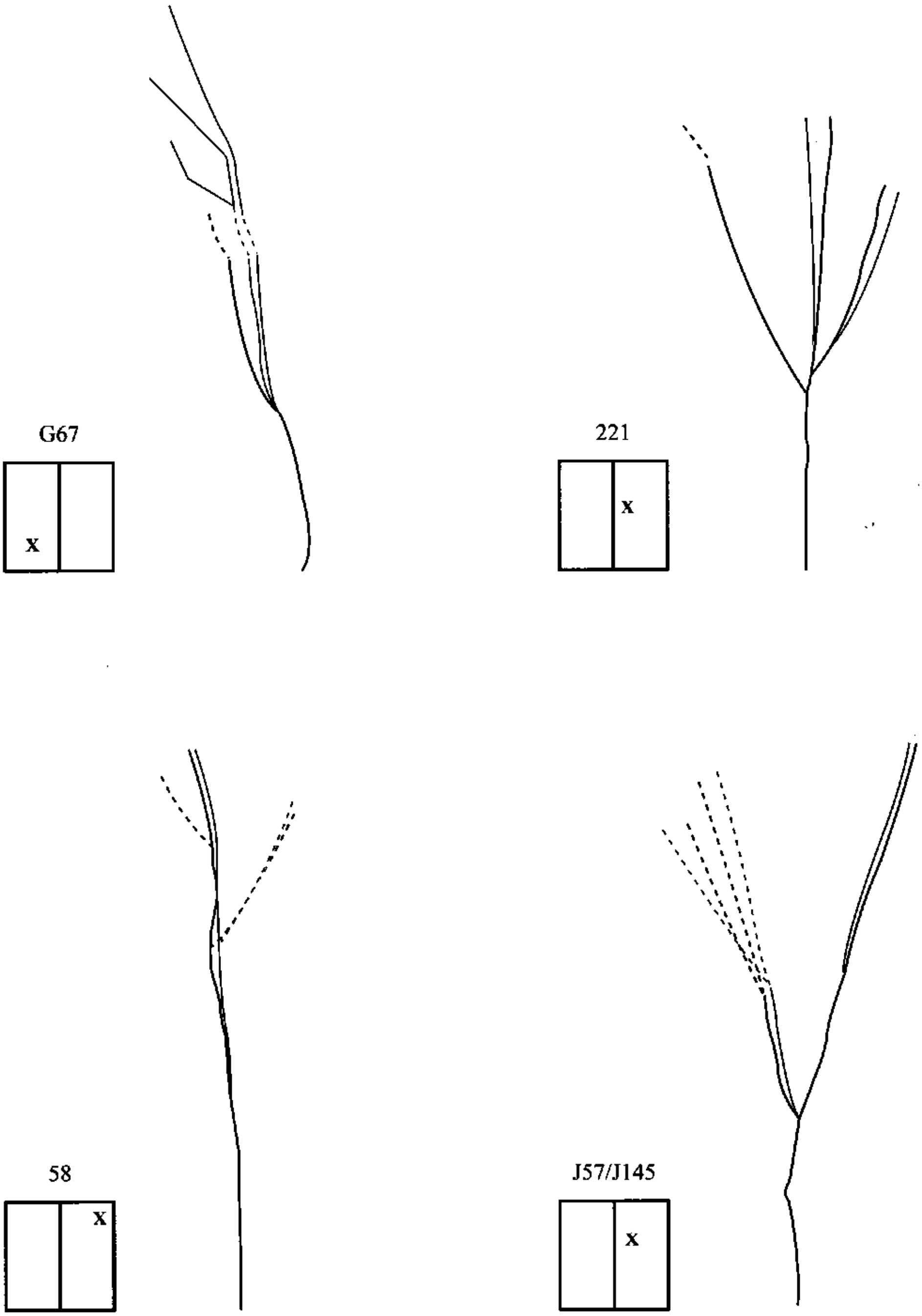

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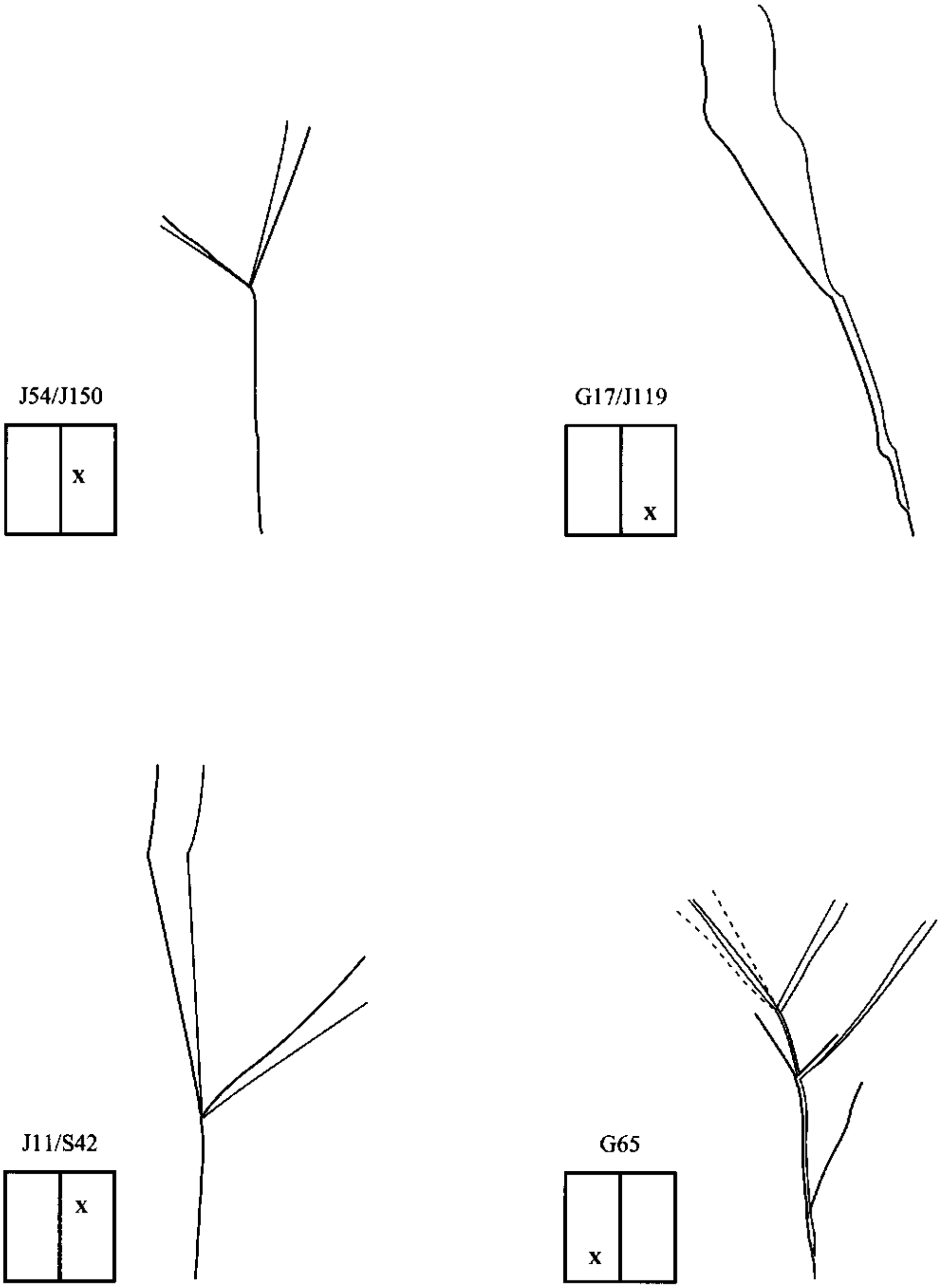

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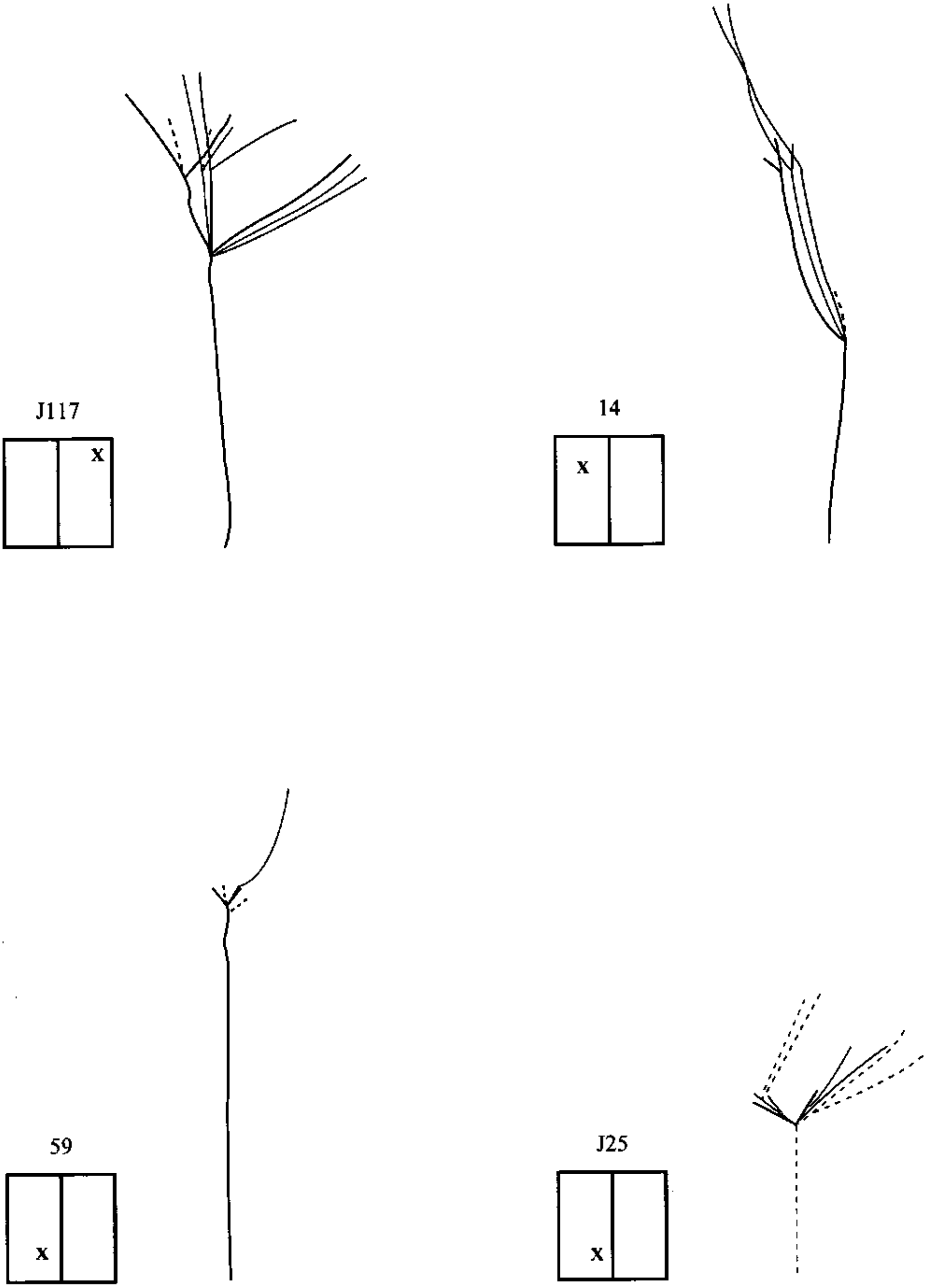

Fig. 21. (continued)

Discussion and conclusions

There is a difference in architecture between oak, birch, beech and Scots pine. Therefore different growing conditions are required to make them grow straight. Oak and Scots pine grow according to the Rauh model (Hallé et al., 1978). The architecture of Rauh's model is determined by a monopodial trunk which grows rhythmically, and so develops tiers of branches, the branches themselves morphogenetically identical with the trunk. The model produces a rather unspecialized shoot system which is inherently very adaptable because all meristems are equivalent and rhythmic. The tree may grow precisely according to the model throughout its life-cycle. However, if the trunk meristem is destroyed, it is readily replaced, usually by the uppermost lateral meristem, or if the damage is more extensive, by the uppermost branch which rapidly substitutes as a leader (Hallé et al., 1978). If damage occurs when the trees are still small, this can cause poor stem forms.

There is a difference between oak and pine in this respect. This is presumably caused by the heliotropism* of oak and the apical dominance in pine (Koop, 1991). Therefore it is important to ascertain the growing conditions in which oak produces straight stem forms.

Birch grows according to Roux's model (Hallé et al., 1978). The architecture of Roux's model is determined by a monopodial orthotropic trunk meristem, which shows continuous growth; branches are plagiotropic and inserted continuously (Hallé et al., 1978). The current market prospects for birch are mainly limited to firewood, and for this the shape of the stem is unimportant. Therefore, the market prospects for birch will change in future: high stem densities will mean that more straight stems will be available. This, together with an increased volume of birch timber, will create new market opportunities.

Beech grows according to Troll's model (Hallé et al., 1978; Peters, 1992). In that model all axes are plagiotropic, the architecture being built by their continual superposition; main-line axes contribute part trunk, part branch, the proximal part becoming erect, most often secondarily after leaf fall. The distal part of each axis is then a branch with or without determinate growth, bearing lateral axis which often do not form a basal erect portion (Hallé et al., 1978). If beech grows solitarily, or is surrounded by shade-intolerant tree species, the plagiotropy of Troll's model makes beech grow in wide crowns. In such conditions, the beech produces timber of firewood quality only.

From the measured data it can be concluded that most dominant axes in oak saplings bend to vertical over the years. Verweij (1989) reported that forks in oak sapling stems could change towards either a dominant stem, or a branch. He suggested that this might be caused by multi-branching in 1 of the 2 axes of the fork, causing the other to have more chance of becoming dominant, or by 1 of the 2 axes bending away. The above data corroborate the latter hypothesis. Houtzagers (1954) and Krahl-Urban (1959) mentioned the phenomenon of straightening of oak saplings, but did not explain the process.

Although oak grows according to Rauh's model it also shows some of the characteristics of Koriba's model, in which one of several originally equal axes becomes dominant, forming part of the stem, the other axes becoming branches (Hallé et al., 1978). In oak the axes are originally also equal. The axis that happens to be in the most favourable position (often the highest) improves its position by becoming more vertical, leaving co-dominant axes behind. Co-dominant axes improve their position less. Occasionally none of the axes becomes dominant, thus none of them achieves a more favourable position. Then forks are formed. If light is abundant, co-dominant axes continue to strengthen their position. This is the case when oaks do not suffer competition for light from neighbouring trees. It also happens when light comes from all directions as is the case under even-aged Scots pine stands without an undergrowth of young trees (subsection 5.2.3). In that case the dominant axis (top shoot) cannot intercept the light reaching the co-dominant axis (side branch). This can be seen in the drawings of oak under Scots pine made by Verweij (1989). Young oak saplings between competing neighbours suffer most competition for light when they are small. This explains why Feith (1990) recorded few forks below 5 m from the ground in young oaks in Scots pine stand Gortel 80.

The above data allow the conclusion that dominant axes in oak saplings become more vertical over the years. Stems which were originally slanting or curved, can, through the movement of their constituent axes, become straight and vertical. If more than one top shoot develops, generally only one shoot becomes dominant, and improves its dominance over the years at the cost of other shoots. The other shoots become side branches, plagiotropic by apposition, only because they have not had the chance to become orthotropic. Once the competition for light results in a leader and losers, co-dominant axes are liable to remain co-dominant.

During the first 6 years of the life of the measured oaks, neighbouring birches were not noted to have a negative impact on the shape of the oak sapling, even when there were birches less than 150 cm from that sapling. On the contrary, birches seem likely to enhance the difference between light availability at the top of dominant axes and at the top of co-dominant axes. This gave dominant axes a better chance to straighten up than co-dominant axes.

Buis (1985) mentioned an anonymous author from 1850, who wrote about the advantage of mixed plantations of oak with birch, because the faster growing birches gave protection to the oaks, and 'stretched the oaks'.

Oaks grown in between birches

In Gortel 80, 39% of the pedunculate oaks showed straight to rather straight stems (subsection 5.2.1). The number of regenerated trees of various species of approximately the same age as the oak compartment was, on average, 834 per ha in 1986, 766 of which were birches, 49 oaks and 19 beeches.

In 1991, at the age of 28 to 35 years a number of the straight oaks were still surrounded by birches. The height growth over several years of 10 of those oaks, together with the surrounding birches, was analysed. The distances of the birches from the oaks are given in appendix 5.

In figure 22 a line is drawn through the average height growth data for each age, for both oak and birch. Figure 22 illustrates the competition between oaks and birches by their average height growth.

Discussion and conclusions

From figure 22 it can be concluded that oaks on these soils can withstand the competition from birches of the same age. During the years of competition the dominant top shoots of the oak were liable to show 'straightening of stems' (subsection 5.2.1), and form straight boles. These years cover the period in which the most important marketable part of the bole of the oaks was formed.

5.2.3 Light in simulated Scots pine stands with and without undergrowth of birch

In order to ascertain whether the occurrence of trees in the undergrowth in Scots pine stands affects light conditions and hence stem development of regenerating oak saplings, the percentages of TOTAL PAR were calculated under

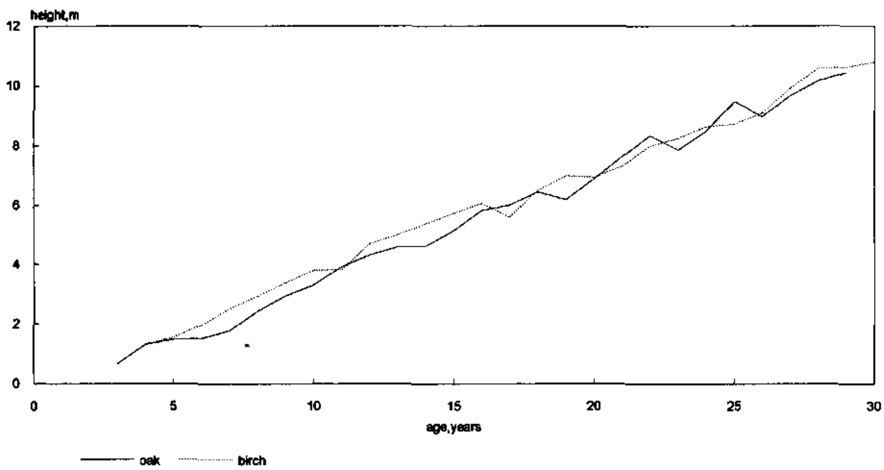

Fig. 22. Average height growth of oaks and birches measured in Gortel 80.

3 scenarios with FOREYE, for a simulated 75-year-old stand of yield class II (Grandjean and Stoffels, 1955) and stand density index 0.5. In the first scenario there was no undergrowth of birch in the Scots pine stand. In the second scenario there were 440 birch trees 9 m tall in the stand. The birches were evenly spread over the stand. In the third scenario 440 birch trees 12 m tall were simulated in the stand. The results of the calculations are given in figures 23 a to c.

Discussion and conclusions

Figures 23 a to c show that the percentage of TOTAL PAR increases irregularly from the forest floor towards the top of the canopy. The pattern of the amount of PAR was similar to that described by Terborgh (1985). From the forest floor up to a certain height there is a zone with small differences in PAR percentage. In the simulated stand this height is approximately 10 m. Almost all of the increase of PAR occurs higher up. However, there is a difference in the rate of PAR increase in the lowest 10 m between the stands without and with undergrowth of birch. In the stand without birch undergrowth the PAR percentage increased from 48% at the forest floor to approximately 55% at half the stand height. In the stand with birches 9 m tall, the PAR percentage increased from 36% at the forest floor to approximately 55% at half the stand height. In the stand with birches 12 m tall, the PAR percentage increased from 31% at the forest floor to approximately 55% half the stand height. The low values at the base of one of the old trees, as shown in figure 23c were not used to calculate this figure.

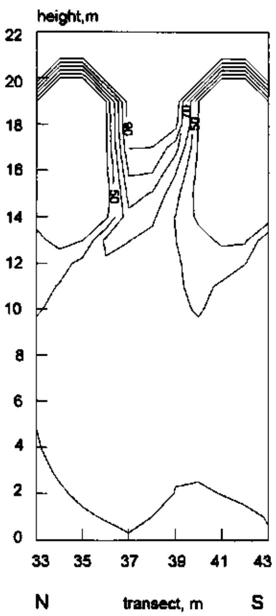

Fig. 23a. Percentages of TOTAL PAR at various heights above the forest floor in a simulated 75-year-old Scots pine stand, yield class II, stand density index 0.5, without undergrowth of birch. (TOTAL PAR = the total of direct and diffuse photosynthetic active radiation).

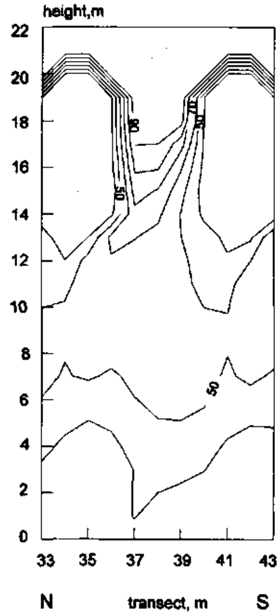

Fig. 23b. Percentages of TOTAL PAR at various heights above the forest floor in a simulated 75-year-old Scots pine stand, yield class II, stand density 0.5, with 9m-tall birch undergrowth.

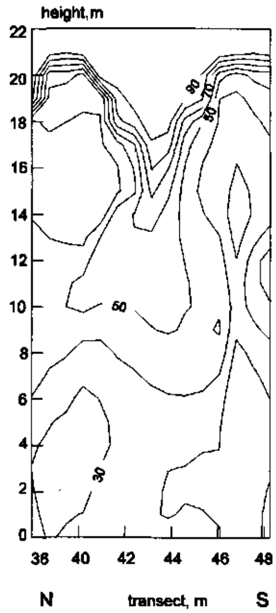

Fig. 23c. TOTAL amount of PAR at various heights above the forest floor in a simulated 75-year-old Scots pine stand, yield class II, stand density index 0.5, with 12m-tall birch undergrowth.

The above data allow the conclusion that PAR gradients in Scots pine stands are indeed steeper if undergrowth of trees is present. The trees in this undergrowth create ecological shafts. The light shaft is characterized by the differences in PAR gradients: the vertical PAR gradient runs upwards to lighter conditions, while the horizontal gradient runs to darker conditions.

If oak saplings tend to grow towards the light, then ecological light shafts contribute to the growth of straight stems. Also, ecological light shafts make it hard for co-dominant axes to become dominant: leaders improve their position faster than axes which lag behind.

5.3 Establishment success of oaks planted in old Scots pine stands

Planting of 1-year-old oak saplings

The planted pedunculate oak saplings described in subsection 3.2.3 were on average 32.7 cm long, the sessile oak saplings 31.4 cm. Survival rates after 1 and 3 years are given in tables 19 and 20.

Discussion and conclusion

In all experimental stands of 1987 the survival of sessile oak saplings was low after 1 and 3 growing seasons. Survival in pedunculate oak saplings was much higher than in sessile oak saplings.

Table 19. Survival rates in 1-year-old pedunculate oak saplings after 1 and 3 growing seasons.

stand no.	number planted	survival rates first year %	survival rates after 3 years %
Pal.Park 19d	40	100%	97%
Uddel 2a	40	100	95
Soeren 107b	40	90	85
Gortel 84a	40	95	82

Table 20. Survival rates in 1-year-old sessile oak saplings after 1 and 3 growing seasons.

stand no.	number planted	survival rates first year %	survival rates after 3 years %
Pal.Park 19d	40	45%	30%
Uddel 2a	40	52	35
Soeren 107b	40	57	38
Gortel 84a	40	67	58

Planting of 2-year-old oak saplings

The average height of the planted 2-year-old pedunculate oak saplings was 62.4 cm. The stands in which the saplings were planted were fenced against deer. The stands had undergone a reduction of basal area as shown in table 9. Survival rates of the oaks are given in table 21.

Table 21. Survival rates in 2-year-old pedunculate oak saplings after 1 and 6 growing seasons.

stand no.	s.d.i.[#]	number planted	survival first year %	survival 6 years %
Uddel 140b	0.58	48	96%	88%
	0.63	48	96	88
	0.77	48	98	88
	0.88	48	98	94
Gortel 77gE	0.79	50	80	64
	0.85	50	92	90
	0.89	50	82	80
	1.08	50	96	68
Gortel 77gW	0.71	50	91	72
	0.86	50	90	90
	0.95	50	88	72
	1.06	50	90	78

[#] s.d.i. = stand density index, based on Grandjean and Stoffels (1955).

Discussion and conclusions

It can be concluded that 80 to 98% 2-year-old oak saplings planted in Scots pine stands survived the first year, and 64 to 94% survived the first 6 years. No conclusions could be drawn about differences of survival among the various plots with different stand density indices.

The oak saplings were planted in spring, which gave the tree's hair roots little time to develop before the leaves started to grow.

Four-year-old oak saplings

Four-year-old pedunculate oak and sessile oak saplings were planted on brown podzolic soils in open mixed stands of oak and beech, and also in an open Scots pine stand. The survival rates of the 2 oak species were recorded after 3 seasons (tables 22 and 23).

Another batch of 4-year-old saplings of pedunculate and sessile oak was planted in various Scots pine stands, partly on humus podzols and partly on brown podzolic soils (Gortel 52b/c and 65a). In most of these stands young

Table 22. Survival rates in 4-year-old pedunculate oak saplings in 3 open mixed oak/beech stands, and in 1 open Scots pine stand (Soeren 90cd), after 3 seasons.

stand no.	s.d.i.	number observed	survival rates after 3 years[#]
Soeren 75b	0.48	13	69%
Soeren 76a	0.45	22	91%
Soeren 85a	0.45	28	86%
Soeren 90cd	0.53	143	73%

[#] Individual saplings with dead tops which re-sprouted below 120 cm, were considered dead, because roe deer are certain to eat these unprotected sprouts.

Table 23. Survival rates in 4-year-old sessile oak saplings in 3 open mixed oak/beech stands, and in 1 open Scots pine stand (Soeren 90cd), after 3 seasons.

stand no.	s.d.i.	number observed	survival rates after 3 years
Soeren 75b	0.48	16	75%
Soeren 76a	0.45	24	88%
Soeren 85a	0.45	38	89%
Soeren 90cd	0.53	176	64%

birches were present (table 25). After 1 and 2 growing seasons survival of a sample of the saplings was checked. The species of the dead saplings could not be identified. The results are given in table 24. Damage caused by roe deer through fraying was also measured (table 25).

Discussion and conclusions

The 4-year-old saplings were planted without protection against browsers. The extent to which they were affected by browsers depended on the abundance of browsers and the abundance of small trees in the existing undergrowth (see table 25). The saplings in stands with no small trees in the undergrowth suffered most from fray damage by roe deer. Of the 2 other stands with low survival in the oak saplings one, Soeren 16b, was on a very poor and dry soil with crowberry (*Empetrum nigrum*). According to Van der Werf (1991) the potential natural vegetation here was Empetrum-Pinetum, which is unsuitable for oak. In this stand the impact of roe deer was negligible. In the other stand with low survival in the oak saplings (Uddel 147c) there were besides roe deer also red deer and fallow deer affecting the oak saplings.

In the remaining stands, with an undergrowth of more than 1000 saplings of various tree species per ha, and without browsers able to reach above 120 cm, the survival rate after 2 seasons was 65% or higher. In these stands fray damage was negligible. Stand Uddel 147c was an exception. Fray damage there

Table 24. Survival rates in 4-year-old oak saplings after 1 and 2 growing seasons.

stand no.	s.d.i.	basal area#, m^2/ha	number observed	survival first year	survival after 2 years
Pal.Park 4n	1.18	29.8	49	65%	22%
Uddel 1a/2a	0.57	14.9	122	72%	46%
Uddel 147c	0.56	14.2	152	51%	38%
Soeren 13f##	–	–	144	80%	70%
Soeren 14gnm	0.56	14.3	131	87%	78%
Soeren 15f1	0.84	21.1	162	88%	65%
Soeren 16b	1.11	27.7	14	93%	33%
Gortel 52bc	0.53	13.3	104	88%	88%
Gortel 65ab	0.93	24.2	150	89%	88%
Gortel 77g	0.88	22.1	85	98%	96%
Gortel 141t	0.65	16.9	112	98%	78%

These stands were generally very heterogeneous, the average basal area gives only a general indication of the density of the stands at the time of planting.

Soeren 13f is a birch stand.

Table 25. Fray damage by roe deer on oak saplings, given as percentage of the number of saplings observed.

stand no.	undergrowth abundance, trees/ha	roe deer abundance, N/100ha	≤ 10%# fray damage	10-50% fray damage	> 50% fray damage
Pal.Park 4n	0	12-14	49%	12%	39%
Uddel 1a/2a	0	12-14	40%	14%	46%
Uddel 147c##	2810	10-12	86%	3%	11%
Soeren 13f	2130	8-10	100%	0%	0%
Soeren 14gnm	1700	8-10	97%	2%	1%
Soeren 15f1	1120	8-10	98%	1%	1%
Soeren 16b	1070	8-10	100%	0%	0%
Gortel 52bc	2070	7-9	99%	0%	1%
Gortel 65ab	2180	7-9	99%	0%	1%
Gortel 77g###	21530	0	100%	0%	0%
Gortel 141t	5600	5-7	95%	0%	5%

Fray damage as part of the bark circumference which was removed.

Uddel 147a was not only affected by roe deer, but also by 5-6 red deer per 100 ha and 2-3 fallow deer per 100 ha (pers. com. Van de Pol, 1991).

Gortel 77g was fenced.

was greater than in the other stands with small trees in the undergrowth. It is not clear whether this was due to a greater abundance of roe deer or to greater roe deer activity, caused by the abundant wild boar in that area.

6 Scots pine regeneration in Scots pine stands

6.1 Regeneration among existing herbs and shrubs

In the experimental Scots pine stands of 1987 (Palace Park 19d, Uddel 2a, Soeren 107b and Gortel 84a) regeneration of Scots pine was studied in 192 permanent quadrats without either soil or vegetation treatment. The ground vegetation consisted of mixtures of mainly bilberry, cowberry, wavy hair grass and mosses. Bilberry was the most dominant shrub. In October of the first growing season a few Scots pine seedlings were observed in only 11 out of the 192 permanent quadrats. By the end of the second growing season they had all disappeared. During the following years, no seedlings managed to establish and survive at any of these untreated permanent quadrats.

Discussion and conclusions

It can be concluded that Scots pine is unlikely to regenerate in a mixed herb and shrub vegetation of bilberry, cowberry and wavy hair grass. A similar result was obtained from a sowing experiment in Gortel 84a in 1989 (Van Ingen, 1990) where 150 Scots pine seeds were sown in each of 18 untreated permanent quadrats of 0.25 m^2, with a mixed vegetation of bilberry, cowberry and wavy hair grass. After 6 months, 9 permanent quadrats showed a total of 27 seedlings. Six months later, 16 seedlings remained, spread over 5 permanent quadrats. After the second growing season only 3 seedlings remained on only 1 quadrat. These 3 seedlings were located on a spot where mosses and heath bedstraw (*Galium saxatile*) grew, and some cowberry was present. There was no bilberry growing near the seedlings.

Both experiments showed that it is difficult for Scots pine to regenerate on a forest floor covered by the herbs and shrubs mentioned, but also that a few seedlings survive the first growing season in such a situation. If these seedlings happened to be growing in a spot where the herbs and shrubs were low or open, they had a better chance of survival than among high or dense ground vegetation. This could be the reason for the survival of the few surviving seedlings in open Scots pine stands, as observed e.g. in Palace Park 13 and 19, Uddel 52 and 131 (subsection 6.5.1). In subsection 6.5.1 the influence of the thickness of organic topsoil layers and the height of the ground vegetation on the establishment success and survival of seedlings is reported on.

Wittich (1955) reported that successful Scots pine regeneration depends on availability of sufficient water. Scots pine has little chance of surviving among grasses and bilberry which compete for water. Heather (*Calluna vulgaris*) uses much less water than grasses or bilberry, and so allows Scots pine regeneration.

Olberg (1957) confirmed the difficulty of regeneration by Scots pine among existing ground vegetation in Gartow, Germany. Among bilberry, he found regeneration was only successful in small gaps in the bilberry cover. There was no regeneration among purple moor-grass (*Molinia caerulea*), but there was among sparse cover of wavy hair grass on poor soil. Pine regeneration was also successful among moss vegetation. On dry soils the regeneration was independent of the moss species. Olberg suggested that moss prevents the soil from drying up, hence favouring Scots pine seedlings.

Wittich (1955) stated that Scots pine saplings that root in mosses have a higher chance of survival than those rooting in dead organic matter. He also expected mosses to reduce the evaporation of the organic topsoil, so providing better chances for Scots pine seedlings.

In Scotland Henman (1961) found various factors associated with successful regeneration including: soil with low ground vegetation cover, ground vegetation of heather, sparse grass or rarely bilberry or purple moor-grass. Also in Scotland, McVean (1963) reported that Scots pine failed to regenerate in soils with felted and deep feather-moss mats under thick bilberry swards in closed canopy stands, and in dense *Sphagnum spp.* mats under heather and bilberry in open stands. From Switzerland, Koch (1968) mentioned the absence of Scots pine saplings in grass, and the occurrence of these saplings in patches of mosses.

Malcolm (1976) reported the failure of Scots pine regeneration among grasses in Scotland. Regeneration was successful if all heather, grass and *Vaccinium sp.* was removed. He did not state the grass species.

Vanselow (1931), Lehto (1953), McNeill (1955), Yli-Vakkuri (1961), Leibundgut (1964), Mees (1981) and Lust (1987) also showed that it is difficult for Scots pine to establish and survive on soils with ground vegetation.

6.2 Regeneration of trees, herbs and shrubs on man-made seedbeds

6.2.1 Regeneration of Scots pine on man-made seedbeds in the first year

Seedbeds were prepared using the kuloo and the rotovator in the Scots pine stands Palace Park 19d, Uddel 2a, Soeren 107b and Gortel 84a. These seedbeds were made after 4 reductions of basal area had been carried out in each of the stands (see subsection 3.2.2). Half of the number of seedbeds were fenced. On half of the fenced and unfenced seedbeds an additional 50 Scots pine seeds were sown, supplementing the number of seeds which reached the seedbeds spontaneously from the remaining old trees. This resulted in series of seedbeds with combinations of 4 different treatments: soil tillage, reduction of basal area, fencing and sowing. Each combination of treatments was repeated 3 times. During 5 years the establishment and survival of the seedlings and saplings were recorded. The numbers of established seedlings are given in table 28; for criteria of establishment see subsection 3.3.4.

Table 28. Accumulated number of established Scots pine seedlings in the first year, for 3 permanent quadrats of 0.5 m^2, at 4 basal areas, with various soil/sowing/fencing treatments.

Pal.Park 19d

	Large basal area											Small basal area
	Dark			Medium D			Medium L			Light		
kuloo/sown/fenced	10	12	9	8	21	27	3	18	6	19	20	14
kuloo/sown/unfenced	9	26	18	10	27	7	20	11	17	13	11	10
kuloo/not sown/fenced	1	3	3	0	1	2	0	1	0	5	4	7
kuloo/not sown/unfenced	5	5	0	0	3	4	6	0	3	4	0	0
rotov/sown/fenced	2	9	10	8	6	7	3	0	3	6	11	5
rotov/sown/unfenced	6	3	12	2	1	22	5	0	4	7	2	2
rotov/not sown/fenced	7	4	6	4	4	2	5	0	2	2	12	0
rotov/not sown/unfenced	1	13	1	6	2	3	1	0	2	1	1	1

Uddel 2a

	Large basal area											Small basal area
	Dark			Medium D			Medium L			Light		
kuloo/sown/fenced	12	1	14	2	16	18	9	10	12	2	12	9
kuloo/sown/unfenced	7	0	2	15	26	8	1	16	8	16	9	2
kuloo/not sown/fenced	0	0	1	11	4	1	1	0	0	0	6	1
kuloo/not sown/unfenced	0	5	0	0	3	3	2	1	3	4	0	2
rotov/sown/fenced	12	13	1	17	4	13	7	14	7	3	7	7
rotov/sown/unfenced	3	0	1	4	9	6	7	6	8	7	8	5
rotov/not sown/fenced	0	4	0	5	1	0	2	0	1	1	1	0
rotov/not sown/unfenced	2	0	0	2	1	0	0	1	0	2	0	0

Soeren 107b

	Large basal area											Small basal area
	Dark			Medium D			Medium L			Light		
kuloo/sown/fenced	10	20	6	9	12	16	11	18	17	19	6	11
kuloo/sown/unfenced	13	15	8	8	15	16	16	8	7	5	13	15
kuloo/not sown/fenced	1	1	0	0	4	4	2	1	0	0	0	1
kuloo/not sown/unfenced	2	0	0	5	0	0	3	1	3	2	2	1
rotov/sown/fenced	0	5	5	4	6	2	11	7	9	14	6	10
rotov/sown/unfenced	3	10	3	11	10	7	4	4	3	0	0	3
rotov/not sown/fenced	2	1	2	0	3	0	0	0	1	1	0	0
rotov/not sown/unfenced	0	1	4	3	1	3	0	0	0	1	1	3

Gortel 84a

	Large basal area											Small basal area
	Dark			Medium D			Medium L			Light		
kuloo/sown/fenced	13	15	17	17	7	14	13	8	12	17	14	7
kuloo/sown/unfenced	14	10	4	5	0	10	4	13	18	8	8	7
kuloo/not sown/fenced	5	4	2	1	2	6	5	1	4	2	2	2
kuloo/not sown/unfenced	6	4	1	0	2	8	0	0	3	4	1	0
rotov/sown/fenced	13	11	19	14	6	9	9	7	9	4	11	11
rotov/sown/unfenced	10	7	20	9	6	10	14	6	11	2	11	2
rotov/not sown/fenced	3	3	7	8	1	11	9	8	3	2	1	1
rotov/not sown/unfenced	5	10	9	3	1	5	4	4	2	3	1	5

The design of the regeneration experiment was described in subsection 3.2.2. The 4 treatment factors were allocated randomly to units of different size:

- stand density (4 densities) to 40 x 20 m plots,
- fencing (yes/no) to 20 x 20 m sub-plots,
- soil tillage (kuloo/rotovator/untreated) to rows within a lengthwise division of each plot into 3 sets of 3 rows, and
- sowing (yes/no) to 0.5 x 1.0 m permanent quadrats within each half-row.

Each level of the experimental design is called a stratum in statistical analysis.

The basic data consist of the numbers of Scots pine seedlings per 3 permanent quadrats in the first year. Untreated rows did not contain any seedlings. The data can be found in table 28.

The numbers of seedlings in the first year were analysed by analysis of variance (ANOVA) on ranks. In simple cases tests based on such a procedure are equivalent to nonparametric tests, e.g. in randomized block experiments the analysis of variance on intra-block ranks gives test results equivalent to those from the Friedman test (Conover and Iman, 1981). However, for complex nesting and crossing structures like those in this experiment no standard nonparametric tests are available, whereas the rank transformation approach can easily be extended.

Statistical analysis was performed using the Genstat statistical package (Anon., 1987). The structure of experimental units and treatments was specified in Genstat as:

- BLOCK stand/plot/(sub-plot*(setrows/rows))/pq;
- TREAT density*fence*soiltreat*sowing.

The stars in the latter formula indicate that treatment interactions are also to be fitted. Interactions are estimated in the highest stratum with units that have homogeneous values for all their components, e.g. the interaction between fencing and soil treatment is estimated in the half-row stratum. The counts in all 384 permanent quadrats were replaced by their rank number, irrespective of their treatment. Conover and Iman (1981) call this a RT-1 rank transformation and claim it compares favourably in terms of robustness and power with intra-block ranking in the case of randomized block designs. Equal counts were replaced by midranks, i.e. the mean of the rank numbers of all units with equal counts.

The ANOVA table from the rank analysis is shown in appendix 6.2.1. From the p-values in appendix 6.2.1 it is clear that soil treatment and sowing as well as their interaction are the most significant factors. The data of mean ranks for these factors are given in table 29.

Table 29 shows higher ranks (and therefore higher counts) after sowing, but more so after soil tillage with the kuloo than with the rotovator. When the differences between these means are compared against the standard error of differences (s.e.d.; 10.6 for means in the same row, 11.5 otherwise), it is found that

Table 29. Mean ranks for soil tillage and sowing treatment.

	sowing	no sowing
kuloo	296.9	116.6
rotovator	231.8	124.6

the soil tillage difference is statistically significant after sowing, but not in the case without sowing.

A weak indication of statistical significance (p-values between 0.05 and 0.10) is found for the fencing treatment and its interaction with sowing (appendix 6.2.1). The mean ranks corresponding to this interaction are given in table 30.

Table 30. Mean ranks for fencing and sowing treatments.

	sowing	no sowing
fenced	279.7	123.3
unfenced	249.1	117.9

Considering the s.e.d. for this table (10.6 for means in the same row, 11.8 otherwise), fencing leads to higher counts after sowing, with no indication of a similar effect in permanent quadrats without sowing.

No statistically significant effects due to stand density were detected (appendix 6.2.1).

Discussion and conclusions

Only a small portion of the available seeds germinated and established on the seedbeds. Loss of seeds can be caused by predation by various insects, birds and mammal species. The seed-eating birds, mentioned by Turcek (1961), which are most common at Het Loo, are chaffinch (*Fringilla coelebs*), brambling (*F. montifringilla*) and great tit (*Parus major*). Common mammals at Het Loo, which eat Scots pine seeds (Turcek, 1967) are wood mouse (*Apodemus sylvaticus*) and bank vole (*Clethrionomys glareolus*). The latter 2 species eat both seeds and seedlings.

Yli-Vakkuri (1961) reported damage by seedling eaters in Finland especially among seedlings growing on mineral soils. From Scotland, McVean (1963) mentioned rodents, birds and slugs as causes for loss of germinating seeds, with chaffinches clipping the tops off seedlings as long as the cotyledons were still enclosed in the seed coat. The same causes of seedling mortality were given by Lehto (1956) for Finland. He also noted that only 1 to 16% of the seeds germinated. Leibundgut (1964) reported a germination percentage of 30% for Scots pine on soils without ground vegetation in Switzerland. Rohmeder (1972) mentioned several insect species which damage the seeds of Scots pine.

Wittich (1955) stated that seedbeds, whether spontaneous or man-made, should guarantee a sufficient water supply to the seedling and a sufficient lack of competition by herbs and shrubs. On soils which have such water supply, and on which natural ground vegetation had developed, he did not find such combined conditions. He concluded that such conditions only occur after disruptive activities such as litter collection. The man-made seedbeds on the soil types available in the experiment described above, fit the combined conditions mentioned by Wittich. From Switzerland, Hunziker (1956) mentioned the effect of thin layers of organic matter or sparse ground vegetation in reducing the drying up of the soil. This produced improved conditions for the establishment of Scots pine seedlings. The absence of such soil protection may be the cause of a reduced number of seedlings on the kuloo treated seedbeds in this experiment.

From Gartow, Germany, Olberg (1957) reported successful regeneration of Scots pine in 'small' gaps in 60-year-old Scots pine stands, with a stand density index (s.d.i.) of 0.7 (probably based on Schwappach, 1908), and on dry patches at s.d.i. 0.5 to 0.6. In mosses with some wavy hair grass, regeneration appeared at s.d.i. 0.7 to 0.8, and in heather/lichens at s.d.i. 0.7. Olberg found no relation between the basal area of the Scots pine and the number of seedlings present under the Scots pine. Neither did Seitz (1979) from Bavaria. In Finland Yli-Vakkuri (1961) recorded more seedlings established on scarified soil than on untreated soil.

From the statistical analyses of the number of Scots pine seedlings in the regeneration experiment it can be concluded that the number of seedlings was primarily determined by the factor 'sowing'. On average, sowing increased the number of seedlings fivefold. Without sowing, no influence of density, soil treatment or fencing was found. With sowing there were differences between the two soil treatments, with the kuloo giving most regeneration. A positive effect of fencing was also found after sowing only. No density effect was found.

6.2.2 Regeneration of Scots pine on man-made seedbeds, over several consecutive years

The seedbeds mentioned in 6.2.1 showed new Scots pine seedlings in consecutive years. These seedlings were counted in 5 autumns, starting in the first year. Appendix 6.2.2 gives data on seedlings established in 1987, 1989 and 1990. The data are averages over 6 permanent quadrats of equal treatment from the experimental stands of 1987 (subsection 6.2.1). The averages of 1987 only concern the 3 permanent quadrats without additional sowing. The averages of 1988 are not given, since only low numbers established, due to low seedfall numbers.

Table 31. Seedfall on seed traps in 2 experimental stands per year and per m^2.

stand no.	s.d.i. in 1987	seeds 1987	seeds 1988	seeds 1989	seeds 1990	seeds 1991
Pal.Park 19d	0.38	32	7	82	24	9
	0.38	18	5	57	13	7
	0.44	29	7	147	56	24
	0.44	12	10	228	54	27
	0.69	85	5	124	114	28
	0.69	94	11	69	118	41
	0.81	55	3	85	52	16
	0.81	79	4	37	67	25
Uddel 2a	0.76	17	13	97	51	3
	0.76	20	11	50	53	4
total average:		44/m^2	8/m^2	98/m^2	60/m^2	18/m^2

Discussion and conclusions

During the experiment, Scots pine seeds were caught on seed traps with a surface area of 4 m^2 which were placed in 2 of the experimental stands of 1987. The number of seeds caught during the experiment are given in table 31.

Seedfall is variable from year to year. In Gartow, Germany, Olberg (1957), recorded average seedfalls of respectively 65, 195, 19 and 514 per m^2 between 1953 and 1956. These seeds had a germination success of 56% to 83%; the highest success was in the year with the highest seedfall. His numbers of seedfall resulted in the following numbers of new seedlings on mineral soil in autumn, from 1953 to 1955: 3.4, 62.3 and 5.1 per m^2. Rohmeder (1972) stated that in Germany Scots pine produced a high yield of seeds every 10 years, but on the other hand in 8 out of every 10 years it produced more than 10% of the number of seeds of a 'Vollernte' ('abundant seed production').

Dimbleby (1953) and Seitz (1979) stated from respectively England and Bavaria that differences in seedfall do not cause the absence of Scots pine regeneration in any one year. Borset (1976) reported from Sweden a yearly, but variable, production of Scots pine seeds.

Average seedfall at Het Loo in the years 1987 to 1991 varied from 8 to 98 per m^2 on the seed traps. The establishment of seedlings in the first year was elaborated in 6.2.1. In 1989 and 1990, higher seedfalls were recorded than in 1987. The seedlings that established in 1989 and 1990 on the permanent quadrats with the same treatment, were counted. The averages of groups of 6 permanent quadrats with equal treatment were compared with the average numbers of established seedlings in 1987. There were 16 groups of each 6 permanent quadrats treated with the kuloo, at 4 stand densities in 1989 and 1990, and at 2 fencing treatments. There were also 16 such groups of 6 permanent quadrats treated

Table 32. Number of averages of established seedlings out of 16 groups in 1989 and 1990, which are equal to, or higher than the average of established seedlings in 1987.

	kuloo treatment		rotovator treatment	
	1989	1990	1989	1990
Pal.Park 19d	2	5	1	0
Uddel 2a	1	1	0	1
Soeren 107d	7	6	2	3
Gortel 84a	4	5	0	0

with the rotovator. In table 32 the number of averages in 1989 and 1990 which are equal or higher than the average in 1987 are given.

Compared to the kuloo-treated permanent quadrats, the rotovator-treated permanent quadrats showed a decrease in establishment success after 3 and 4 years. A possible cause for this effect is given in subsection 6.2.4 . In the areas treated by kuloo a reduction in numbers of established seedlings was less pronounced.

In England, Dimbleby (1953) found that most seedlings establish within 3 to 5 years after 'soil tillage' by fire. He found hardly any relation between the differences in numbers of seeds in the various years and the numbers of established seedlings. Due to an increasing cover of ground vegetation, establishment rates decreased after 5 years.

6.2.3 Regeneration of deciduous trees on man-made seedbeds

At the end of the 5-year regeneration experiment, the number of seedlings and saplings of deciduous tree species in the permanent quadrats of 0.5 m^2 were counted. The results are given in table 33.

Discussion and conclusions

Table 33 shows little difference between the numbers of deciduous saplings

Table 33. Number of survivors among spontaneously established deciduous trees on the seedbeds of the permanent quadrats, after 5 growing seasons.

	within fence	outside fence
Pal.Park 19d	11 birches on 8 beds	8 birches on 7 beds
	4 oaks on 2 beds	1 oak on 1 bed
Uddel 2a	6 birches on 5 beds	5 birches on 4 beds
Soeren 107b	5 birches on 5 beds	3 birches on 3 beds
Gortel 84a	34 birches on 21 beds	32 birches on 17 beds
	1 oak on 1 bed	2 oaks on 2 beds

established on the seedbeds inside or outside the fence. On the other hand, it appeared (subsection 7.1.4), that the growth of deciduous tree saplings within the fence was much stronger than outside. Fanta (1982), Van Vuure (1985) and Hespeler (1989) also described reduced growth of unprotected deciduous tree saplings.

From the above data it appears that at the herbivorous pressure as occurring in the experiment, fencing causes a limited increase in the number of established saplings.

6.2.4 Regeneration of herbs and shrubs on man-made seedbeds

At the end of the 5 consecutive growing seasons, the cover percentages of all plant species in the permanent quadrats in Palace Park 19d, Uddel 2a, Soeren 107b and Gortel 84a were assessed by eye.

Each of the 4 experimental stands of 1987 had 96 seedbeds with a permanent quadrat. Of these 96 permanent quadrats, groups of 6 had the same soil tillage, fencing treatment and basal area. Hence over the 4 experimental stands there were 4 times 16 (64) such groups of 6 permanent quadrats with the same soil tillage, stand density, plus fencing treatment. The average cover percentages of the 6 seedbeds with this equal treatment were calculated for grasses (mainly wavy hair grass, to a limited extent purple moor-grass and occasionally common bent and sheep's fescue), heather and bilberry. Full results are given in appendix 6.2.4. The average cover percentages of grasses, heather and bilberry in Gortel 84a are given in figures 24 to 26. The basal areas of the Scots pine at the start of the experiment are given.

The ground vegetation cover in the various experimental stands, as it was before scarification, is given in table 8 (subsection 3.2.2).

Discussion and conclusions

In the study area grasses, heather, bilberry and, to a certain extent, cowberry, will cover substantial parts of the man-made seedbeds. Heather was not part of the ground vegetation before the experiment started (see table 8). Heather seeds from before the afforestation, i.c. some 80 years ago, must still have been available in the mineral soil.

Over the 5 years of observation, the average cover of grasses, heather and bilberry showed regular increases on the seedbeds in all experimental stands. However, 13 out of 64 averages for heather showed a decrease in cover after an initial increase.

Grasses

In Palace Park 19d average grass cover never exceeded 3%. Because of this sparse cover, no conclusions could be drawn on differences between soil tillage,

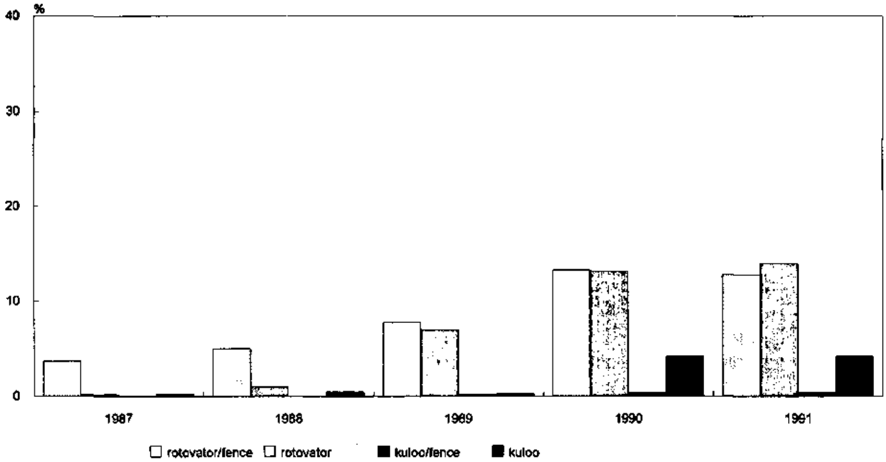

Fig. 24a. Average percentage grass cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 9.8 m^2.

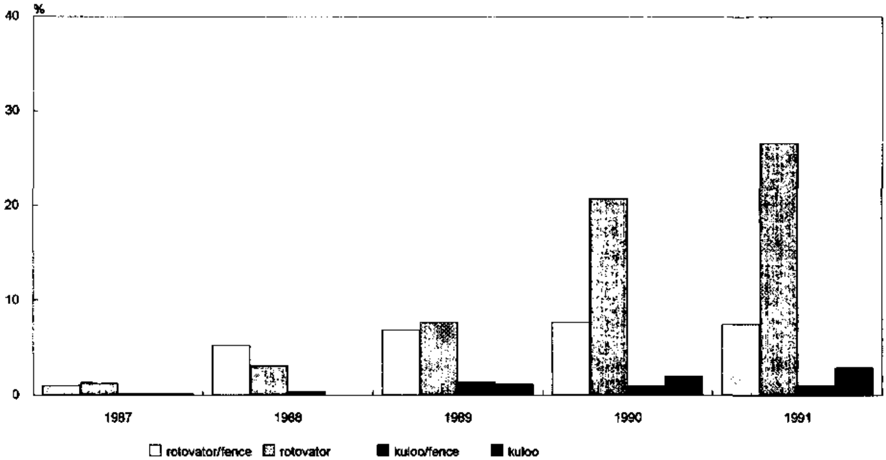

Fig. 24b. Average percentage grass cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 13.2 m^2.

fencing and stand densities. In Uddel 2a average grass cover went up to 66%, in Soeren 107b to 54%, and in Gortel 84a to 36%. The grass cover at 2 different soil tillage treatments was investigated in the permanent quadrats in those 3 experimental stands with the same fencing treatment and basal areas. The averages from the 2 different soil tillage treatments form one data pair. In those 3 experimental stands 19 of the 24 pairs of averages with the same treatment showed more grass cover in rotovator-treated seedbeds than in kuloo-treated

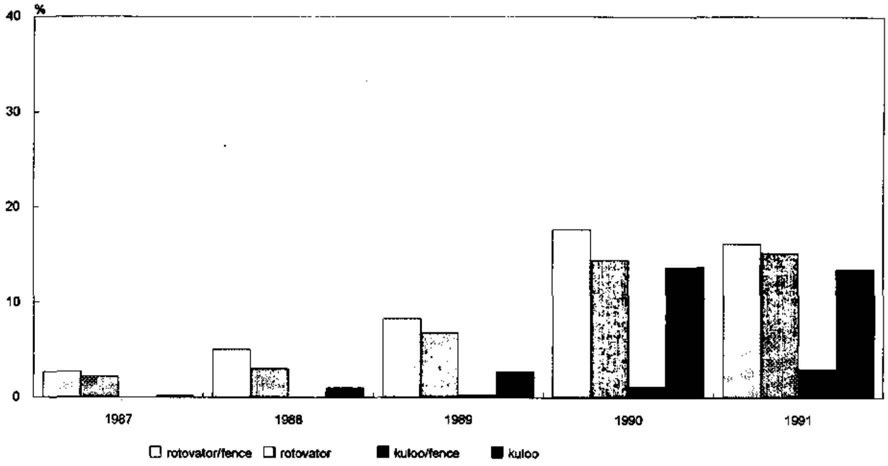

Fig. 24c. Average percentage grass cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 16.7 m^2.

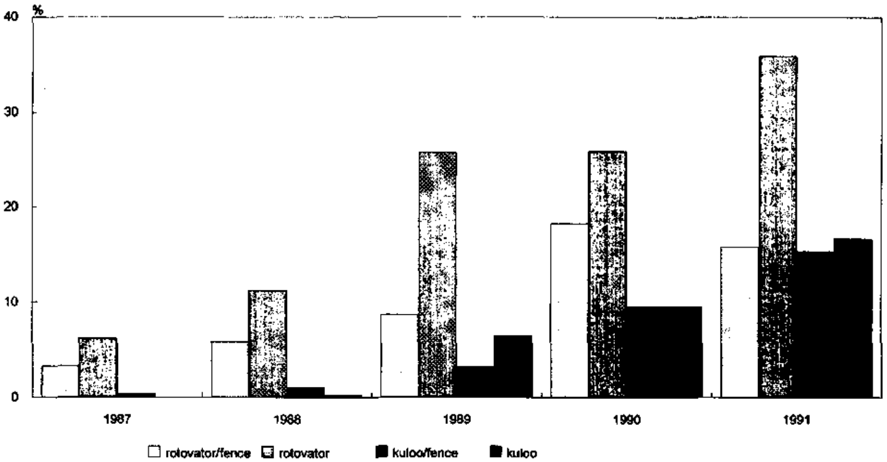

Fig. 24d. Average percentage grass cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 18.2 m^2.

beds. Three pairs showed a greater grass cover in the kuloo treatment, and 2 pairs of average cover were less than 1%, which is too low to draw any conclusion. The rotovator mixes the organic topsoil with the mineral soil. This may cause nitrogen mobilization. Grasses benefit from this (Anon., 1988a). The kuloo causes the opposite: the organic topsoil is removed from the seedbed, resulting in loss of organic matter and hence of nitrogen (Anon., 1988a). This is a probable explanation for the greater grass cover on the rotovator-treated areas.

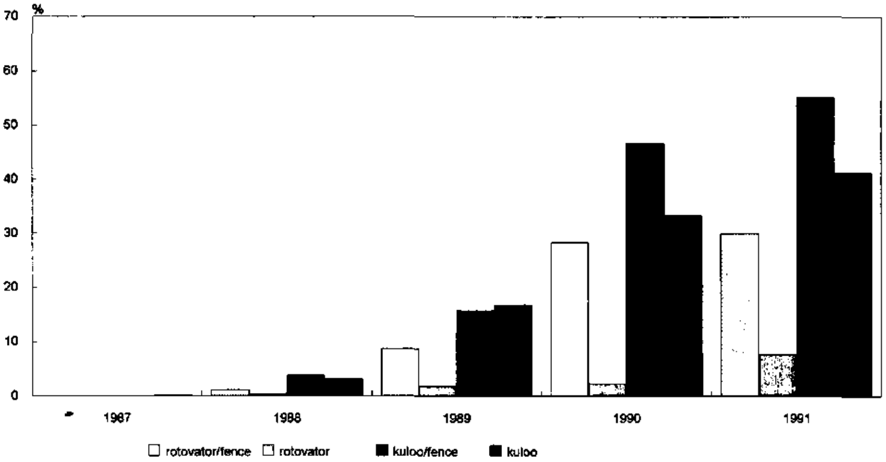

Fig. 25a. Average percentage heather cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 9.8 m^2.

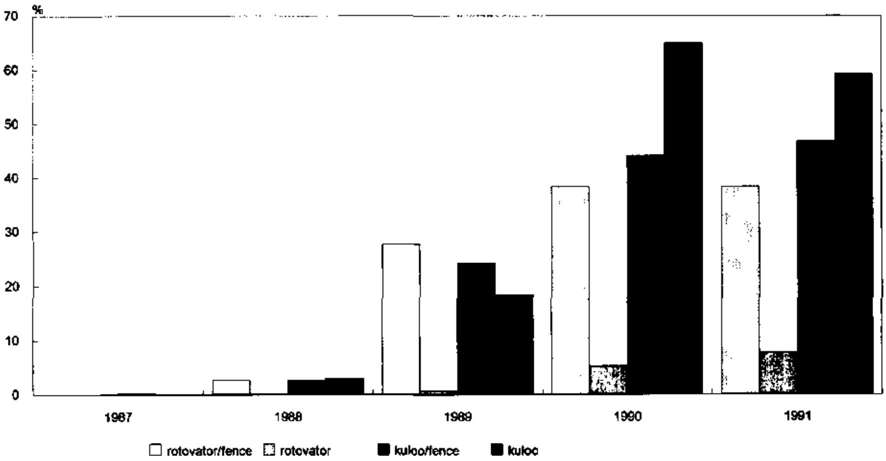

Fig. 25b. Average percentage heather cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 13.2 m^2.

On rotovator-treated soils in Isenburg, Germany, Brechtel (1969) reported that the grass sward recovered after one year.

When differences between the pairs of averages with the same soil tillage and basal area were investigated to ascertain the effect of fencing, it was found that 9 of the 24 pairs had a greater average grass cover in the fenced areas. Fencing did not increase the grass cover.

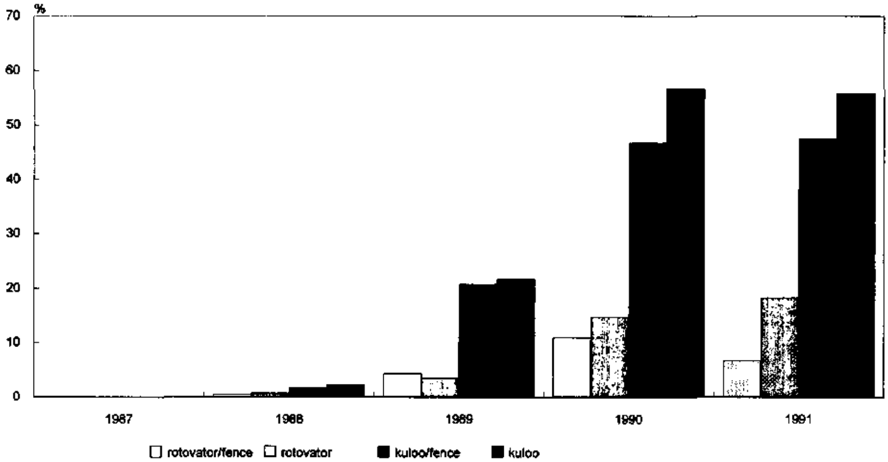

Fig. 25c. Average percentage heather cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 16.7 m^2.

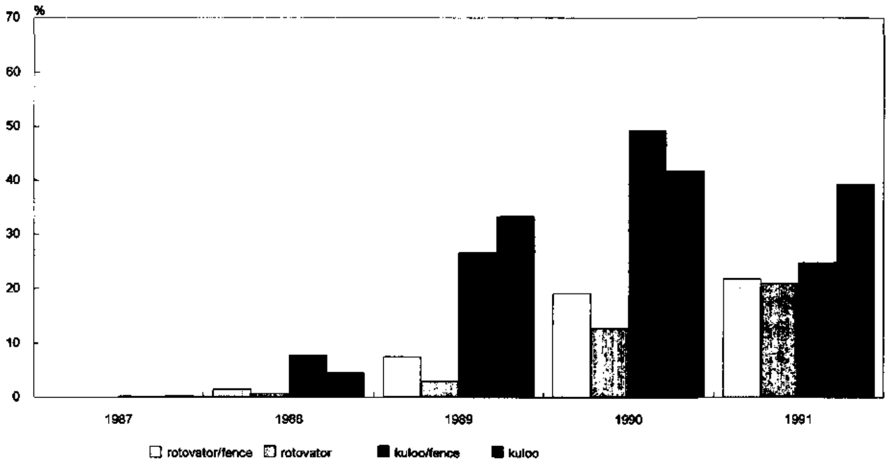

Fig. 25d. Average percentage heather cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 18.2 m^2.

Stand density (basal area) did not show any significant effect on average grass cover at the same soil and fencing treatment.

Heather

In the 4 stands, in 29 of the 32 pairs the average heather cover was greater on the kuloo-treated areas than on the rotovator-treated areas. Heather may have benefited from the low nitrogen availability in the kuloo-treated seedbeds.

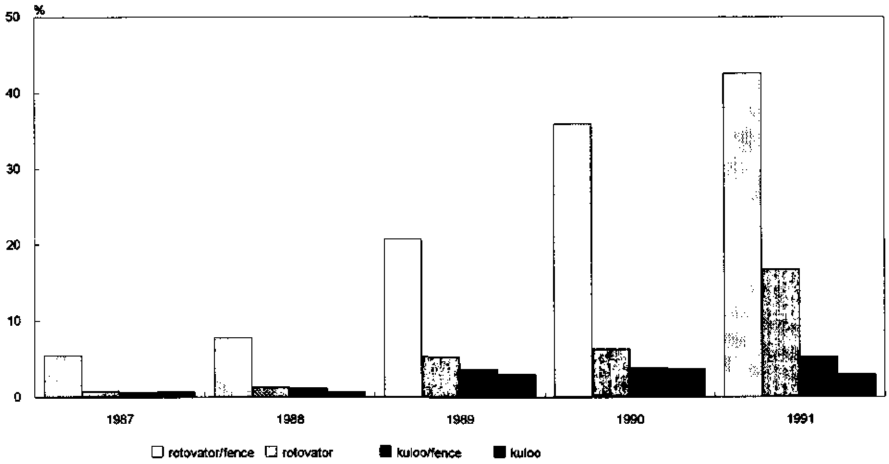

Fig. 26a. Average percentage bilberry cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 9.8 m^2.

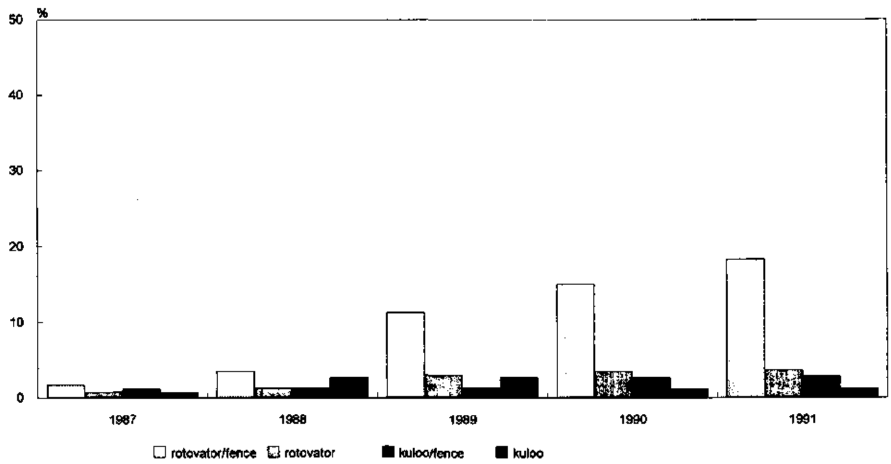

Fig. 26b. Average percentage bilberry cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 13.2 m^2.

Similarly, 24 of the 32 pairs of the fenced/unfenced areas had a greater heather cover in the fenced areas as compared to the unfenced areas.

Stand density showed no structural relationship with average heather cover.

Bilberry

In the case of bilberry cover 8 of the 32 pairs had a greater cover on the kuloo-

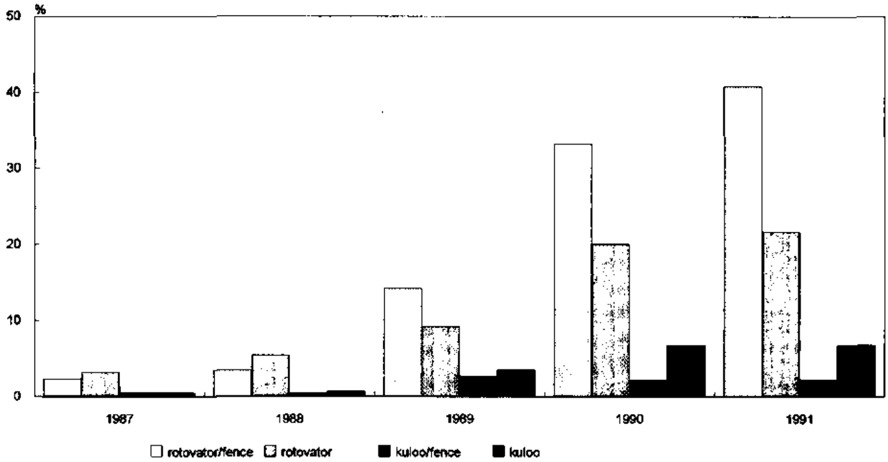

Fig. 26c. Average percentage bilberry cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 16.7 m^2.

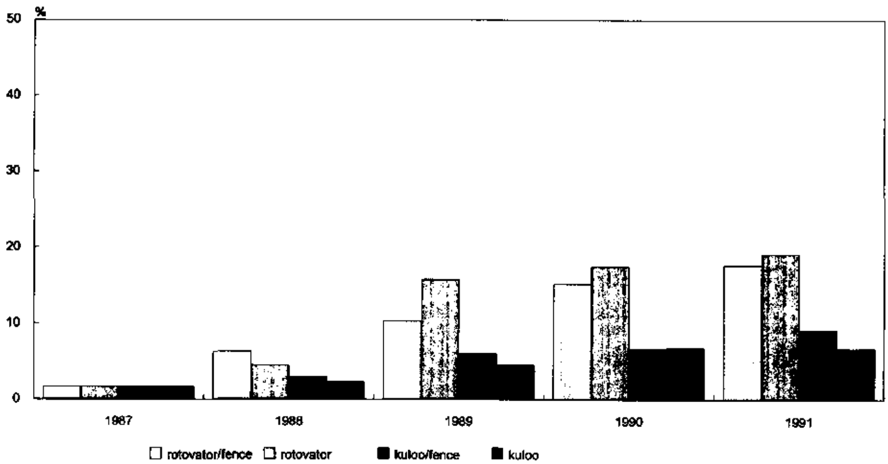

Fig. 26d. Average percentage bilberry cover of groups of 6 seedbeds with the same treatment in Gortel 84a, over 5 growing seasons, basal area 18.2 m^2.

treated areas than on the rotovator-treated areas. The other 24 pairs had less bilberry cover than on the rotovator-treated areas.

Twenty-one out of the 32 pairs in the fencing/unfencing experiments showed a greater average bilberry cover in the fenced areas.

Stand density treatment showed no structural relationship with average bilberry cover.

Cowberry

Cowberry showed variable average cover percentages after 5 seasons. Where cowberry occurred it gradually increased over the years. In Gortel 84a cowberry occurred in 15 of the 16 cover averages. All averages of cowberry cover were less than 9% of the area, except for 1 (which was 33%). In Soeren 107b none of the 12 cover averages which contained cowberry reached 7%. In Uddel 2a, 10 averages were below 10%, 5 were between 10% and 22%, and 1 average was 46%. In Palace Park 19d 9 averages were less than 8%, 6 averages were between 8% and 31%, 1 average was 43%.

Other species

Bramble (*Rubus sp.*) and pill sedge (*Carex pilulifera*) never covered much of the seedbeds. Sheep's sorrel (*Rumex acetosella*) and heath bedstraw (*Galium saxatile*) did not cover much of the seedbeds after 5 growing seasons. Heath bedstraw covered appreciable parts of some of the seedbeds (in 8 of the 64 averages, more than 10% and up to 30%) in the years between the soil tillage and the end of the 5-year experiment, but only on the brown podzolic soils. Sheep's sorrel showed a similar effect, but at smaller coverage: only 1 of the 64 averages was higher than 10%.

In Gortel 84a, bramble occurred in 7 averages, 3 in fenced areas and 4 in unfenced areas. Two of the 16 bramble average covers were higher than 1%, being 12 and 13%. Sheep's sorrel occurred in only 1 of the 16 averages, being 15%. Heath bedstraw occurred in 15 of the 16 averages, all cover percentages were less than 3%. Pill sedge occurred in 11 of the 16 averages, all of them less than 4%. After 1 year bramble did not show an increase in average cover, with the exceptions of the 2 large coverages mentioned above, which both occurred in fenced areas. After a number of years of increase, sheep's sorrel and heath bedstraw showed a decrease in cover. Pill sedge showed a small increase in cover over the 5 years.

In Soeren 107b, bramble occurred in only 4 of the 16 averages, 3 in fenced areas and 1 in an unfenced area, all values being 3% or less. Sheep's sorrel occurred in only 3 of the 16 averages, never exceeding 2%. Heath bedstraw showed up in 15 of the 16 averages, all less than 3%. The values for heath bedstraw had been higher in the previous years, the maxima were 12%, 25% and 28%. Pill sedge occurred in 12 of the 16 averages, all values were less than 7%.

In Uddel 2a, no bramble, heath bedstraw or pill sedge were recorded. Sheep's sorrel showed up in only 1 of the 16 averages, and was 2%.

In Palace Park 19d no bramble, sheep's sorrel or heath bedstraw were recorded. Pill sedge occurred in 9 of the 16 averages, all values less than 6%.

Mosses

Mosses were recorded in the last year only. At that time the average covers of the various moss species ranged from 1% to 37% in Gortel 84a, from 1% to 52% in Soeren 107b, from 11% to 50% in Uddel 2a, and from 8% to 53% in Palace Park 19d. The moss species recorded were: *Polytrichum formosum, Pleurozium schreberi, Campylopus pyriformis, C. flexuosis, Dicranella heteromalla, Hypnum jutlandicum* and *Dicranum scoparium.*

Hunziker (1956), Olberg (1957) and Seitz (1979) all reported that mosses were no obstacle to regeneration by Scots pine. They did not record differences in regeneration for the different moss species.

In Gartow, Germany, Olberg (1957) recorded the establishment of herbs and shrubs during 3 years on patches where the organic topsoil had been removed, leaving ½ to 1 cm of organic material on the mineral soil. The soils had formerly been covered by heath. After afforestation with Scots pine, litter was collected by farmers. On patches where purple moor-grass was present before treatment, purple moor-grass and pill sedge re-established quickly. Where the groundwater level was shallow, the grass cover reached over 50% in 3 years, on dry soils this was at most 5%. On dry patches where wavy hair grass was growing, Olberg noted re-establishment by wavy hair grass, heather, sheep's sorrel and mosses. Patches originally covered by mosses and debris, showed no recolonization except by mosses. On untreated patches, Olberg did not observe any change in ground vegetation cover over the 3 years.

Wagenknecht (1939) investigated the recovery of ground vegetation on poor sandy soils on the Hackenhausen estate, Germany, several years after litter collection had stopped. The ground vegetation was recorded in Scots pine stands of yield class III and IV (Schwappach, 1908), with stand density indices of 0.7 to 1.0. On those soils only heather and mosses reached ground cover of over 5%. Wagenknecht noted that heather established within 2 years, together with the mosses *Hypnum cupressiforme* and *Dicranum scoparium.* After the heather had expanded, *Hypnum schreberi* established below the heather on the better soils, on the poorer soils *Dicranum undulatum* came in. After 15-20 years heather reached its greatest expansion and retreated again through die-back and overgrowth by *Hypnum schreberi.* Wagenknecht described the habit of young heather plants, which were short and dense, and the deteriorating heather plants, which were long and straggling.

In some of the permanent quadrats in the experimental stands of 1987, similar patterns of expansion and growth habit in heather were already visible within 5 years. This might be due to the richer conditions in minerals and water in the experimental stands, and/or to the current atmospheric deposition of nitrogen.

Wagenknecht (1939) recorded that 50% of the soil was covered after 5 years, and after 10 years no bare patches were left. Ultimately, heather covered less than 25%, while *H. schreberi* expanded up to 75%. The long-term sequence was:

heather-*H. schreberi*-bilberry. Wittich (1955) noted the long period needed for bilberry to re-establish. He believed that pedological change brought about by decades of litter removal caused this long period.

It can be concluded that herbs, shrubs and mosses appear immediately after the moment of treatment, little in the first year, steadily increasing in the following years. Grasses and bilberry increased more quickly on rotovator-treated beds than on kuloo beds. This was probably why numbers of established Scots pine seedlings on rotovator-treated seedbeds fell after 3 to 4 years after treatment. No grass established on the poorest soil of Palace Park 19d. Heather increased quicker on the kuloo beds. On some of the seedbeds heather cover decreased again, after some years of increase. No other general differences could be noted among various treatments. Cowberry increased in cover, but slowly. Bramble occurred rarely on these soils. Sheep's sorrel, heath bedstraw and pill sedge never covered a substantial part of the seedbeds after 5 years, although sheep's sorrel and heath bedstraw covered up to 15% and 30% respectively in the years between the start and the end of the experiment. Bramble, sheep's sorrel and heath bedstraw did not colonize the poor soils of Palace Park 19d.

6.3 Survival of seedlings on seedbeds

The fate of the seedlings on the seedbeds described in 6.2.1 was recorded over a period of 5 years. In the experimental stands of 1987 there were sets of 3 permanent quadrats that received the same combination of treatments (soil tillage/fencing/sowing). The average survival rates of seedlings of these sets of permanent quadrats were recorded (table 34; see table 28 for the total number of seedlings per permanent quadrat).

Survival after 5 years was analysed by analysis of variance on the empirical logit transform of the numbers surviving. If y out of n seedlings survive, the empirical logit transform z is given by:

$$z = \ln\{(y+\tfrac{1}{2})/(n-y+\tfrac{1}{2})\} \qquad \text{(Cox, 1970).}$$

In this analysis the weight of evidence is chosen to be equal for all permanent quadrats, ignoring the differences in numbers of seedlings.

The ANOVA table from the analysis of survival is given in appendix 6.3. Soil treatment and density are the most significant factors ($p=0.001$ and $p=0.02$ respectively). The means from the ANOVA transformed to survival percentages are as follows:

soil treatment:	kuloo	rotovator		
	50%	30%		
density:	high	medium high	medium low	low
	31%	32%	50%	46%.

Table 34. Survival percentages of Scots pine seedlings after 5 years in sets of 3 permanent quadrats with the same treatment.

Palace Park 19d				
treatment:	Large basal area	------------------	------------------	Small basal area
kuloo/sown/fenced	35%	48%	78%	62%
kuloo/sown/unfenced	43	23	83	56
kuloo/not sown/fenced	29	67	0	63
kuloo/not sown/unfenced	70	43	56	0
rotov/sown/fenced	10	43	67	32
rotov/sown/unfenced	14	4	56	91
rotov/not sown/fenced	29	10	43	0
rotov/not sown/unfenced	27	18	67	33
Uddel 2a				
treatment:	Large basal area	------------------	------------------	Small basal area
kuloo/sown/fenced	59%	58%	87%	91%
kuloo/sown/unfenced	44	69	92	81
kuloo/not sown/fenced	100	81	100	86
kuloo/not sown/unfenced	80	33	83	83
rotov/sown/fenced	12	15	39	18
rotov/sown/unfenced	25	32	29	35
rotov/not sown/fenced	0	33	33	50
rotov/not sown/unfenced	0	100	0	50
Soeren 107b				
treatment:	Large basal area	------------------	------------------	Small basal area
kuloo/sown/fenced	11%	19%	22%	39%
kuloo/sown/unfenced	22	5	39	15
kuloo/not sown/fenced	50	13	0	100
kuloo/not sown/unfenced	0	0	43	40
rotov/sown/fenced	30	25	7	57
rotov/sown/unfenced	13	0	18	0
rotov/not sown/fenced	40	33	0	100
rotov/not sown/unfenced	0	0	–	0
Gortel 84a				
treatment:	Large basal area	------------------	------------------	Small basal area
kuloo/sown/fenced	51%	61%	64%	71%
kuloo/sown/unfenced	11	73	46	61
kuloo/not sown/fenced	73	56	70	67
kuloo/not sown/unfenced	45	10	67	40
rotov/sown/fenced	44	55	72	38
rotov/sown/unfenced	14	16	45	7
rotov/not sown/fenced	23	55	55	75
rotov/not sown/unfenced	21	44	30	33

In the case of density the significant increase in survival occurs between the 2 middle classes, with hardly any difference between the 2 highest densities or between the 2 lowest densities.

There is a slight indication ($p = 0.13$) of a possible effect of fencing on survival, from 35% for unfenced to 44% for fenced. No statistically significant effect of sowing on survival was found (38% with sowing 41% without sowing). None of the interactions was found to be statistically significant.

Discussion and conclusions

Survival of Scots pine seedlings in the experiment was mainly dependent on soil treatment and stand density. Soil treatment using the kuloo instead of the rotovator increased the average survival from 30% to 50 %. At high and moderately high densities the average survival was slightly more than 30%, whereas more open stands had an average survival of almost 50%. The effect of fencing on survival was indicative (from 35% to 44%), though not statistically significant. No effect of sowing on survival was found.

Wittich (1955) showed that on dry sandy soils in Germany, with less rainfall than in the Netherlands, the dependence of survival on water supply was apparent. If sufficiently supplied with water, Scots pine seedlings survived higher stand densities of Scots pine shelter.

In Gartow, Germany, Olberg (1957) recorded survival rates of 18% and 12% on mineral soil and scarified soil in open Scots pine stands after one year, and 8% and 3% after the second year. For seedlings which appeared during the second year after treatment the survival rates after 1 year were 10% and 4% respectively. Nowhere was survival high, except on the poorest soils, where only lichens grew. However, because these soils were very dry, seedling establishment on them during the first year was relatively poor. Olberg suggested needle cast (*Lophodermium seditiosum*) to be the main cause of seedling mortality. He reported that the younger the saplings were, the more they suffered from needle cast. On bare mineral soil the seedlings suffered less from needle cast than on soils with some ground vegetation. Olberg concluded that Scots pine regeneration can only be successful when the production of seeds and years without needle cast are accompanied by the availability of a seedbed free from herbs and shrubs. Browsing by wild ungulates was of no importance, nor was trampling by game, although the latter was noticed.

From Scotland, McVean (1963) reported browsing by wild ungulates as a major reason for regeneration failure .

Vanselow (*in*: Olberg, 1957) mentioned mortality rates of 89% from Uetze, Germany, in Scots pine seedlings after the first year on dry sandy soils from which the litter layer had been removed and where there was no shelter of old trees.

In Scotland the causes of mortality were rodents, roe deer, red deer and waterlogging, but especially the gradual weakening of the plants by faulty mineral nutrition, inadequate illumination and competition from other plants for available nutrients (McVean, 1963).

Taher and Cooke (1975) found that in Scots pine seedlings grown in natural soil under a range of light intensities there was greater mortality, caused by damping-off by soil-borne fungi at lower light intensities than at higher light intensities. Mortality was as high as 90%.

6.4 Light in Scots pine stands

6.4.1 Light in simulated Scots pine stands in relation to basal area

In order to find a relation between basal area and penetration of PAR through the canopy, the percentage of PAR penetration was simulated with the FOR-EYE program (Koop, 1987 and 1989; Bijlsma, 1990). A 60-year-old Scots pine stand, of yield class II (Grandjean and Stoffels, 1955) was simulated. Average tree height was 18.8 m, the average tree crown diameter 3.83 m, there were 620 trees per ha, the basal area at stand density index 1.0 was 25.75 m^2 per ha. The basal area was reduced by lowering the number of trees. Data are given in table 35.

At 50 randomly chosen spots on the forest floor the PAR percentage was calculated for the various PAR fractions as given in table 36.

The *average* percentages of TOTAL and DFOV PAR on the forest floor for such a stand are plotted versus the basal area in figure 27.

Discussion and conclusions

From figure 27 it can be concluded that the percentage of TOTAL PAR as well as DFOV PAR on the forest floor decrease at increasing basal areas. The percentage of TOTAL PAR is always a little higher than the percentage of

Table 35. Characteristics of simulated stands used for calculation of PAR.

number of trees/ha	s.d.i.#	g##, m^2
620	1.0	25.75
527	0.85	21.88
434	0.7	18.02
310	0.5	12.87
186	0.3	7.72

\# s.d.i. = stand density index.
\#\# g = basal area.

Table 36. Average PAR on the forest floor, relative to PAR above the canopy, for a simulated 60-year-old Scots pine stand of yield class II.

g, m^2	SUND %	DFCL %	DFOV %	DFTOT %	TOTAL %
25.75	26.64	24.24	21.19	22.59	25.38
21.88	34.17	31.34	28.26	29.67	32.77
18.02	41.34	37.70	34.53	35.99	39.67
12.87	53.24	48.78	45.65	47.09	51.32
7.72	67.49	61.06	58.01	59.41	64.97

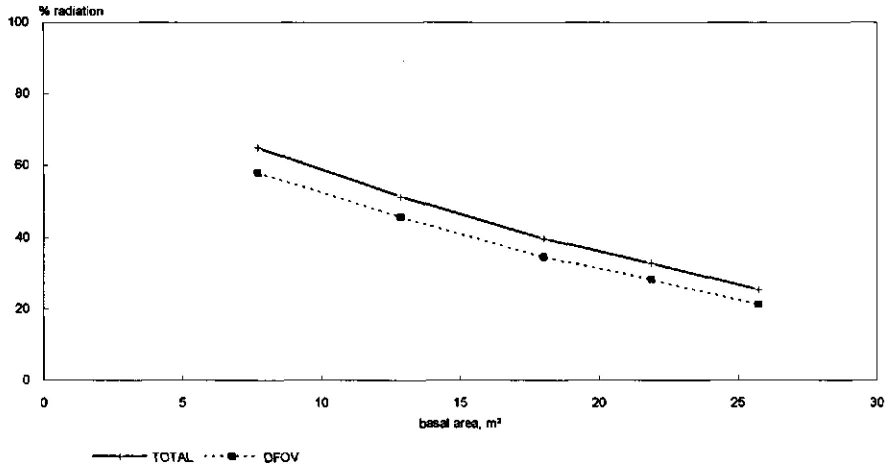

Fig. 27. Average relative TOTAL PAR and DFOV PAR versus basal area of a simulated Scots pine stand of 60 years and yield class II.

DFOV PAR. The difference between TOTAL PAR and DFOV PAR changes from 4% at a basal area of 25 m^2 to 7% at a basal area of 8 m^2. Therefore, in practice the percentage of DFOV PAR can serve as a parameter for the percentage of TOTAL PAR.

Brechtel (1962) produced a linear relation between the percentage of PAR and the basal area, and between the percentage of PAR and the crown cover. This does not correspond with figure 27, but regression curves through a scatter of measured data could indeed give the illusion of a linear regression (figure 29).

6.4.2 Light measurements in the field at various times of the day and at various basal areas

Light measurements at various times of the day

On the permanent quadrats of the regeneration experiment, the percentage of diffuse PAR was measured on overcast days (DFOV). In order to find out whether it is correct to measure at all times of the day, in 2 plots (compartments) of Gortel 84a measurements were carried out at fixed points in 7 periods, spread over one full day. Within each period, all permanent quadrats of one plot were measured first (within 8 to 25 minutes), followed (on average 16 to 22 minutes later) by all permanent quadrats of the other plot (within 10 to 16 minutes). Therefore, the differences between plots were in fact confounded with certain time differences, but this would not lead to serious distortions if it was assumed that DFOV PAR changes only gradually over the day. The means of the measurement periods, per plot, and for both plots combined are given in appendix 6.4.2. Stand density was different for the two experimental plots: the basal area of one plot was 11.9 m^2, that of the other was 15.4 m^2.

The average relative DFOV PAR at basal area 11.9 m^2 and 15.4 m^2, spread over the day are given in table 37. Full data are given in appendix 6.4.2.

Discussion and conclusions

Statistical analysis was done by means of analysis of variance on the DFOV PAR values followed by t-tests to find pairwise differences between times of the day. Although the DFOV PAR values were fractions, and therefore necessarily restricted to the interval 0 to 1, the actual range of data values was limited and remained far from the extreme scale points (0.25 to 0.67), making a data transformation unnecessary. The questions to be answered were: 1. are there differences in DFOV PAR between various times of the day?, and 2. if so, are these differences specific for each plot?

Pairwise differences were tested by ordinary t-tests with pairwise confidence level of 5%. A higher than 5% probability of any spurious significance for the complete series of pairwise comparisons was thus accepted. Both the main effect of period, and the interaction of period with plot were statistically significant. This meant that there were differences between certain times of the day, but that these differences were not always equal for both plots.

The pairwise tests showed that in one plot the periods around noon (intervals 3 and 4) had a statistically significantly elevated radiation. In the other plot the same pattern could be noted (although not statistically significant for interval 3), moreover there was a large and statistically significant dip in radiation in the period around 14.00 to 15.00 h (intervals 5 and 6) without any equivalent in the first plot.

Full data from the ANOVA and t-tests are given in appendix 6.4.2. Although differences in the data were small, there were statistically significant differences. This means that it is risky to compare data which have been measured at different times of the day. Standard overcast sky might not have been reached in all measurements.

Table 37. Average relative DFOV PAR in 2 Scots pine compartments with different basal areas, measured at regular intervals spread over the day.

g\interval	1	2	3	4	5	6	7
11.9 m^2	0.48	0.47	0.49	0.50	0.47	0.47	0.46
15.4 m^2	0.40	0.41	0.42	0.43	0.37	0.38	0.41

It is important to realize that all conclusions may be specific for the actual day of measurement.

Light measurements at various basal areas in the field

In Soeren 31d, 97a and 98b the DFOV PAR percentage was measured at different spots on the forest floor. It was assumed that the basal area is the parameter explaining the variable of relative DFOV PAR exclusively. The hypothesis was that the model is described by the equation:

$$\text{DFOV\%} = c_1 * g + c_2 \qquad (1)$$

in which g = basal area in m^2, c_1 and c_2 are empirical constants. Linear regression was carried out with that equation. The results are given in table 38 and figure 28.

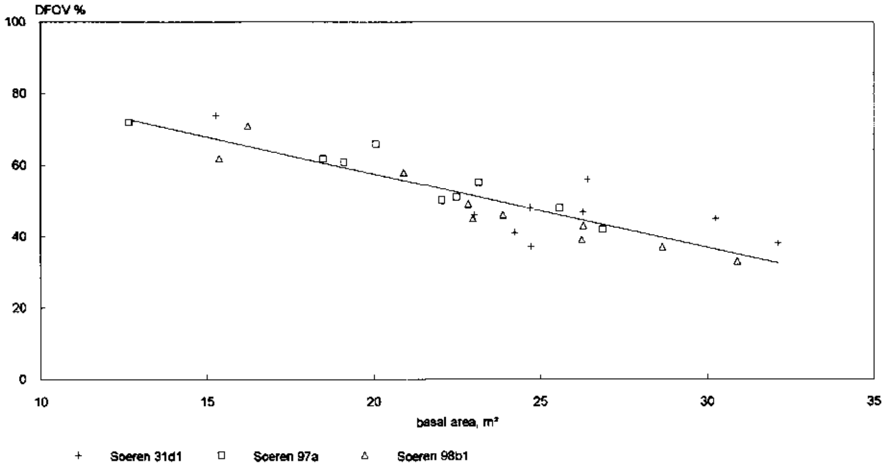

Fig. 28. Measured relative DFOV PAR versus basal area in Soeren 31d, 97a and 98b. (DFOV PAR = diffuse photosynthetic active radiation on overcast moments).

Table 38. Regression data on basal area versus relative DFOV PAR in Scots pine stands Soeren 31d, 97a and 98b.

stand no.	c_1	c_2	R^2
Soeren 31d	-1.76	92.31	0.54
Soeren 97a	-2.11	100.97	0.86
Soeren 98b	-2.30	102.11	0.91
All three	-2.08	99.09	0.77

In the 4 experimental stands of 1987 relative DFOV PAR was measured on the forest floor in the permanent quadrats. At the same spot the basal area was measured with a Bitterlich Wedge Prism with counting factor 2 (De Vries and

Stoffels, 1967). Regression lines were calculated in the same way as described above. Results are given in table 39. Scatter diagrams are given in figures 29 a to d.

Table 39. Regression data on basal area versus relative DFOV PAR for the permanent quadrats in the experimental Scots pine stands.

stand no.	c_1	c_2	R^2
Pal.Park 19d	–2.49	93.29	0.73
Uddel 2a	–1.79	93.66	0.69
Soeren 107b	–1.57	85.06	0.83
Gortel 84a	–1.55	80.52	0.50

Discussion and conclusions

Compared to the relative DFOV PAR curve in a simulated stand, in figure 27, the values measured in the field were higher over the whole range of basal areas. This might partly be caused by FOREYE calculations giving the average DFOV over the period from May to September, whereas the field measurements were obtained on one day in June. Also, the stands in the field had a different yield class than the simulated stand. Another factor contributing to the discrepancy might be that some direct PAR (which showed a higher penetration percentage than DFOV PAR) might have been measured. The data measured in gaps in stands (subsections 6.4.3 and 6.4.4) also showed higher relative DFOV PAR in the field measurements than in gaps in simulated stands.

The general conclusion may be drawn that there is a clear relation between basal area and mean DFOV PAR penetration.

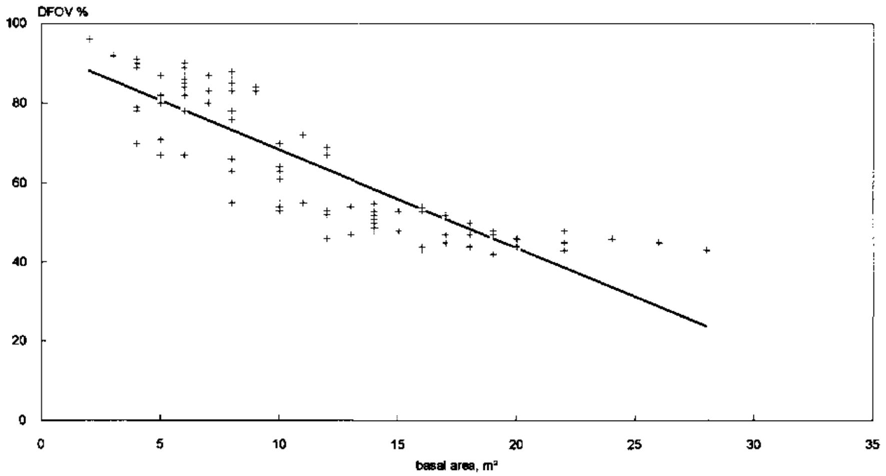

Fig. 29a. Measured relative DFOV PAR versus basal area in Palace Park 19d.

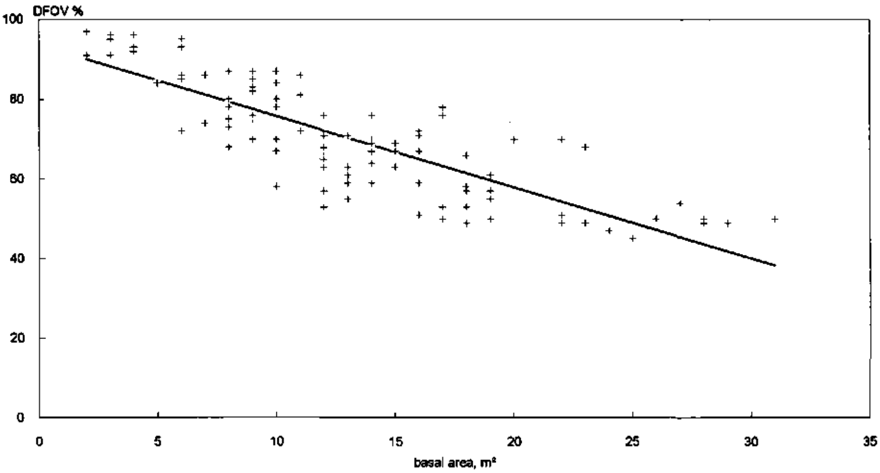

Fig. 29b. Measured relative DFOV PAR versus basal area in Uddel 2a.

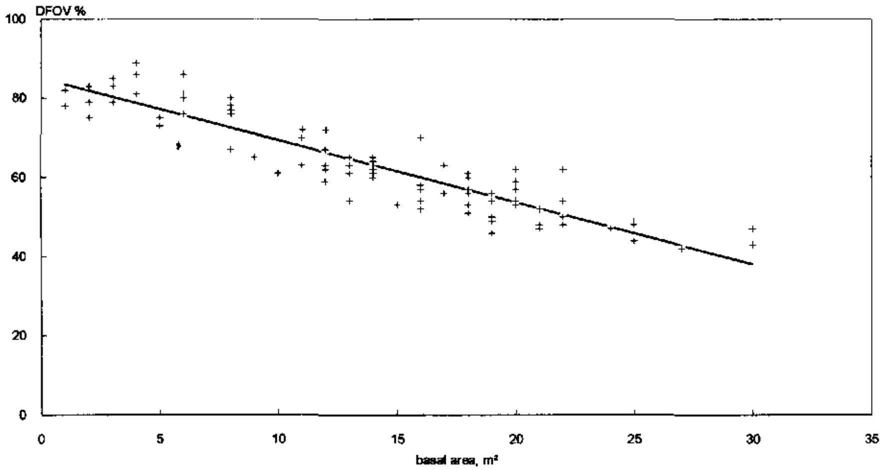

Fig. 29c. Measured relative DFOV PAR versus basal area in Soeren 107b.

6.4.3 Amount of light in simulated Scots pine stands in relation to gap sizes in the canopy

A 60-year-old Scots pine stand, yield class II (Grandjean and Stoffels, 1955), with gaps, was simulated. The PAR percentage in the simulated gaps was calculated with the FOREYE program. The gap size was made variable, as was the stand density index. The trees were arranged in a pattern of triangles. The circular gaps consisted of groups of 1, 7, 19 and 37 removed trees. This resulted in 1, 3, 5 and 7 trees removed across the gaps. The characteristics of the stands

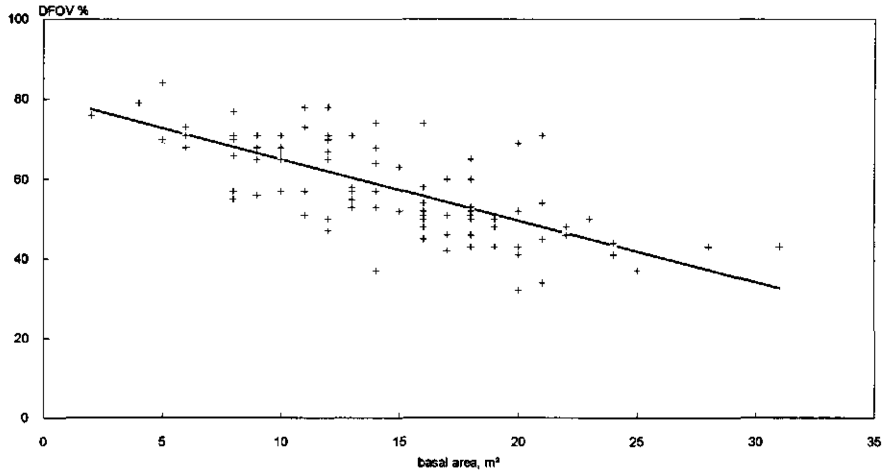

Fig. 29d. Measured relative DFOV PAR versus basal area in Gortel 84a.

for the calculated situations are given in table 40. The 3 highest PAR rates in a 1 × 1 m grid in each gap, for TOTAL PAR, and the 3 measurements in the middle of the gap for DFOV PAR, are given in appendix 6.4.3.

Table 40. Characteristics of gaps and surroundings in simulated 60-year-old Scots pine stands.

gap no.	number of trees in the stand/ha	stand density index	number of trees removed in the gap	distance crown to crown in the gap, m	distance form crown to crown in th#	ill. fig.
1	620	1.0	0	0.49	0.03	
2	620	1.0	1	4.81	0.26	fig.30a
3	620	1.0	7	13.45	0.72	fig.30b
4	620	1.0	19	22.09	1.18	fig.31a
5	620	1.0	37	30.73	1.63	
6	527	0.85	0	0.85	0.05	
7	527	0.85	1	5.53	0.29	
8	527	0.85	7	14.89	0.79	
9	527	0.85	19	24.25	1.29	fig.31b
10	434	0.70	0	1.33	0.07	
11	434	0.70	1	6.49	0.35	
12	434	0.70	7	16.81	0.89	
13	434	0.70	19	27.13	1.44	fig.31c
14	310	0.50	0	2.28	0.12	
15	310	0.50	7	20.61	1.10	
16	310	0.50	19	32.83	1.75	fig.31d
17	186	0.30	0	4.04	0.21	

th = tree height*, the dominant height of the trees surrounding the chablis.

The pattern of relative TOTAL PAR in gaps of various sizes is given in figures 30 a to c. The pattern of relative DFOV PAR is given in figures 31 a to d.

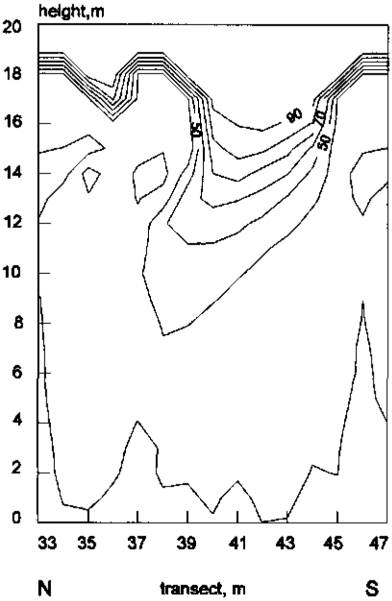

Fig. 30a. Pattern of relative TOTAL PAR in a simulated 60-year-old Scots pine stand with gap type 2 of table 40, one tree felled, s.d.i. 1.0.

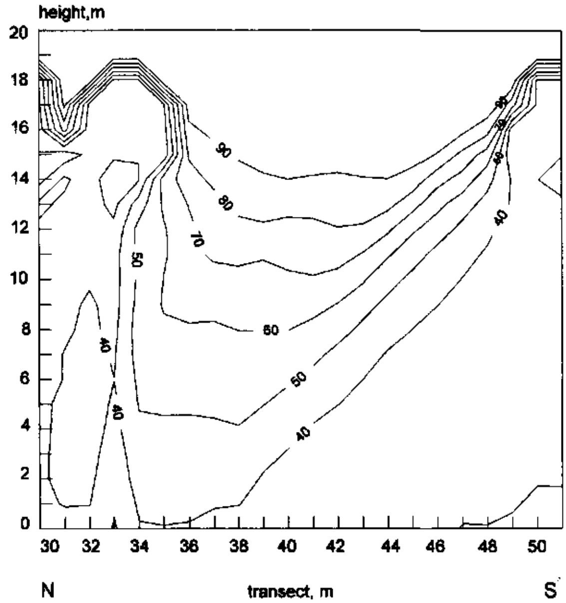

Fig. 30b. Pattern of relative TOTAL PAR in a simulated 60-year-old Scots pine stand with gap type 3, 7 trees felled, s.d.i. 1.0.

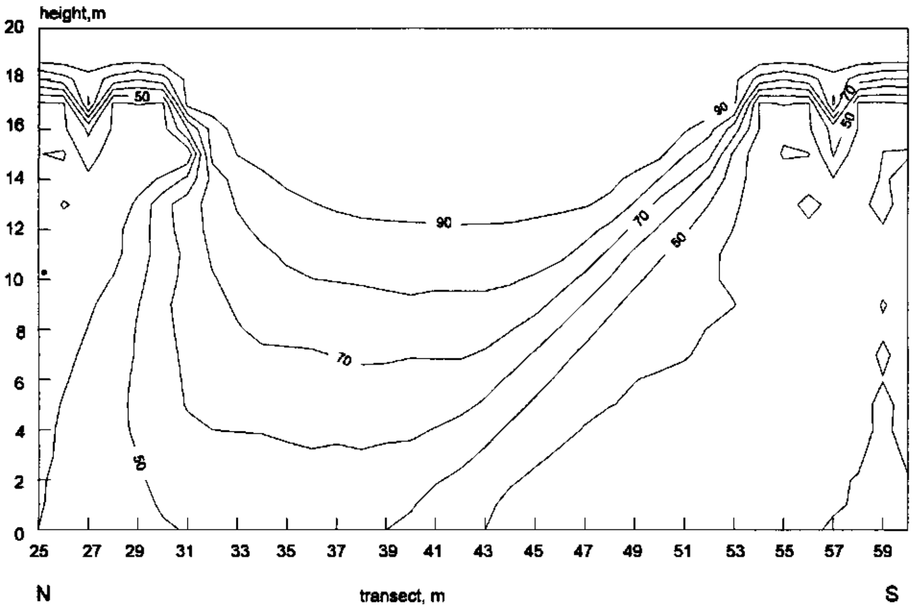

Fig. 30c. Pattern of relative TOTAL PAR in a simulated 60-year-old Scots pine stand with gap type 4, 19 trees felled, s.d.i. 1.0.

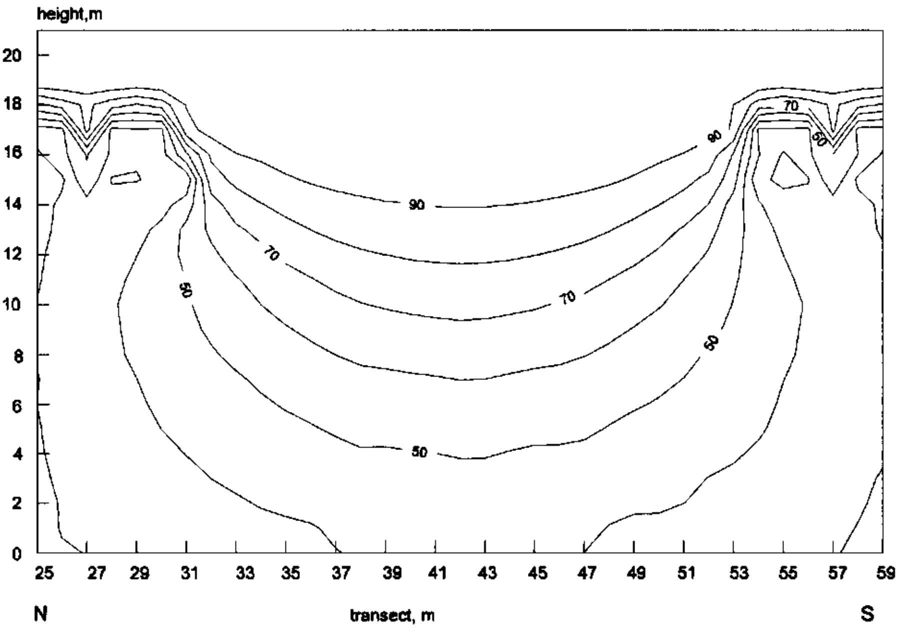

Fig. 31a. Pattern of relative DFOV PAR in a simulated 60-year-old Scots pine stand with gap type 4 of table 40, 19 trees felled, s.d.i. 1.0.

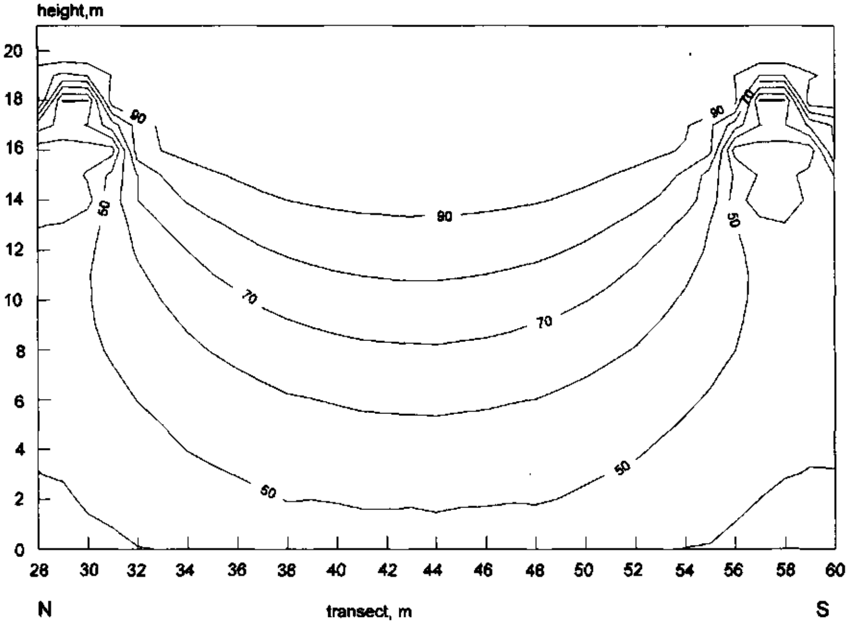

Fig. 31b. Pattern of relative DFOV PAR in a simulated 60-year-old Scots pine stand with gap type 9, 19 trees felled, s.d.i 0.85.

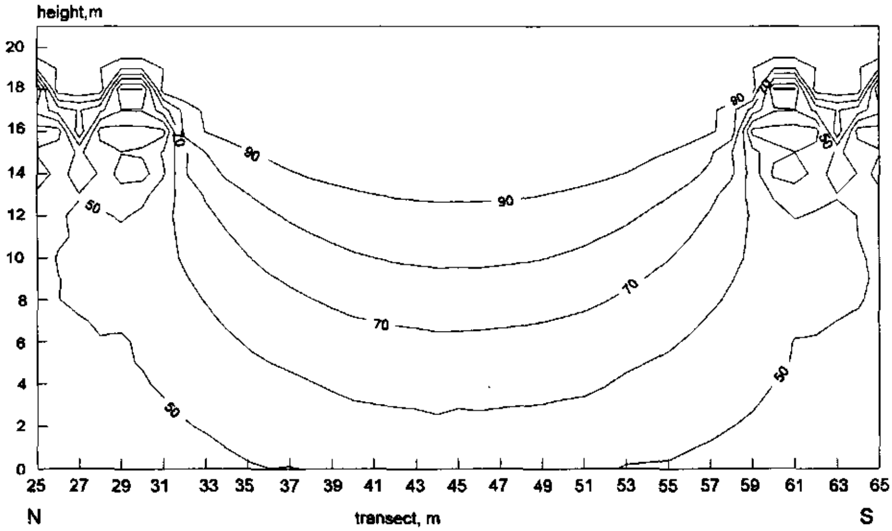

Fig. 31c. Pattern of relative DFOV PAR in a simulated 60-year-old Scots pine stand with gap type 13, 19 trees felled, s.d.i. 0.70.

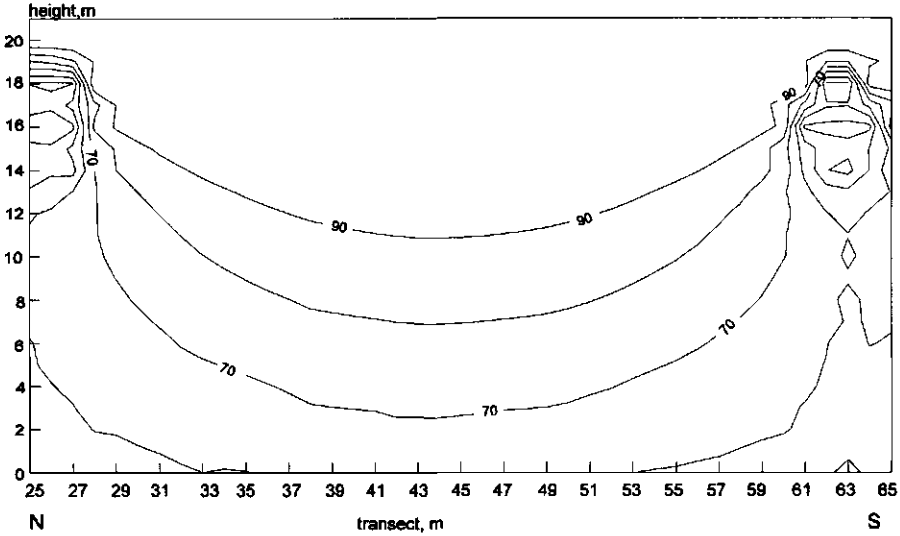

Fig. 31d. Pattern of relative DFOV PAR in a simulated 60-year-old Scots pine stand with gap type 16, 19 trees felled, s.d.i. 0.50.

At a specific stand density index, it was assumed that gap diameter is the parameter explaining the variables of relative TOTAL and DFOV PAR exclusively. The hypothesis was that the model is described by the equation:

$$\text{TOTAL PAR\%} = c_1 * \text{gap diameter} + c_2 \quad (2)$$

in which gap diameter is expressed in th (tree height), the dominant height of the trees surrounding the gap, c_1 and c_2 being empirical constants. Linear regression was carried out with that equation. The same regression was carried out for DFOV PAR%. Results are given in tables 41 and 42. Regression lines are given in figures 32 a and b. They are expressed at 3 stand densities.

Table 41. Regression of relative TOTAL PAR versus gap diameter in th in simulated 60-year-old Scots pine stands of yield class II.

s.d.i.	c_1	c_2	R^2
0.50	14.97	49.77	0.99
0.70	19.10	37.92	0.99
1.0	23.46	23.42	0.99

Table 42. Regression of relative DFOV PAR versus gap diameter in th in simulated 60-year-old Scots pine stands of yield class II.

s.d.i.	c_1	c_2	R^2
0.50	10.47	43.77	0.97
0.70	13.37	33.28	0.99
1.0	17.07	20.42	0.99

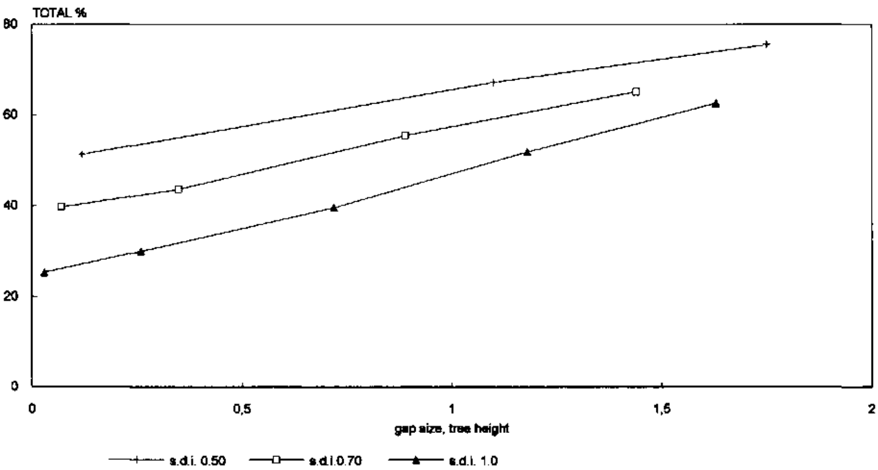

Fig. 32a. Relative TOTAL PAR on the forest floor in the middle of the gap versus gap sizes in simulated 60-year-old Scots pine stands with various stand density indices.

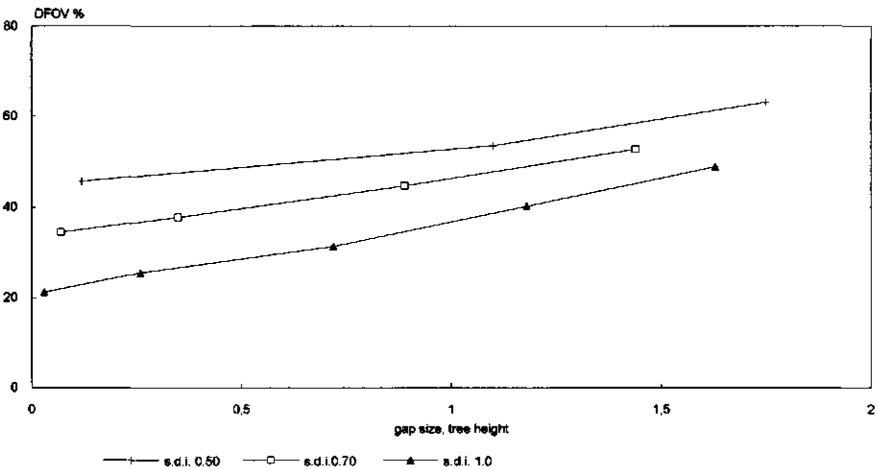

Fig. 32b. Relative DFOV PAR on the forest floor in the middle of the gap versus gap sizes in simulated 60-year-old Scots pine stands with various stand density indices.

Discussion and conclusions

Figures 30 a to c showed that a gap of 1 felled tree in a 60-year-old stand, with a stand density index of 1.0 does not change the relative TOTAL PAR on the forest floor noticeably. Gaps of 7 and 19 felled trees augment relative PAR considerably. The relative TOTAL PAR was highest at a spot north of the middle of the gap. This was due to the angle of the direct sunlight with the azimuth. Although it was not clear whether plants can make full use of momentary increases of direct PAR in sunny spots, the differences between TOTAL PAR and DFOV PAR pattern mean that at particular spots DFOV PAR is an inaccurate parameter of TOTAL PAR.

The differences between relative TOTAL PAR and DFOV PAR in gaps are greatest in stands with high densities, particularly so on the *edges* of the larger gaps (figures 33 a and b).

Light-demanding tree species only regenerate if gap sizes are large enough, or stand densities low enough for relative DFOV PAR to reach values for which the relationship between relative TOTAL PAR and DFOV PAR is near unity (section 7.4). Figures 33 a and b show how the relationship between relative TOTAL and DFOV PAR changes with gap size, stand density, and position in the gap. Relative DFOV PAR measurements therefore imperfectly predict the relative TOTAL PAR. However, Brechtel (1962) stated that relative DFOV PAR can be used as a parameter of ecological factors such as precipitation, soil moisture content, and air and soil temperature, all of which influence the regeneration of trees.

Brechtel might in general be right, but within the scale of individual gaps in the stand the relative DFOV PAR cannot be a proper measure for precipitation, because of the great differences between DFOV PAR at the edge and in the middle of gaps. This is illustrated in figure 31.

DFOV PAR is much easier to measure in the field than TOTAL PAR. Therefore, although fully aware of its drawbacks, in this study DFOV PAR was used as a parameter of TOTAL PAR reaching the forest floor.

Figures 32 a and b show the PAR percentages versus gap size at various stand densities. They show that the lower the stand density index is, the smaller the gaps can be to obtain the same relative amount of PAR on the forest floor, and hence to ensure successful regeneration. This was also confirmed by Hunziker (1956) and Koop (1981b). Koop (1981b) claimed that the amount of PAR reaching the ground has much to do with the density of tree crowns per ha, and with the inner cover of the tree crowns of the stand surrounding a canopy gap. Because inner crown cover of pioneer species is less than in climax species, the regeneration that occurs in small gaps in pioneer stands is similar to that in larger gaps in stands with climax species.

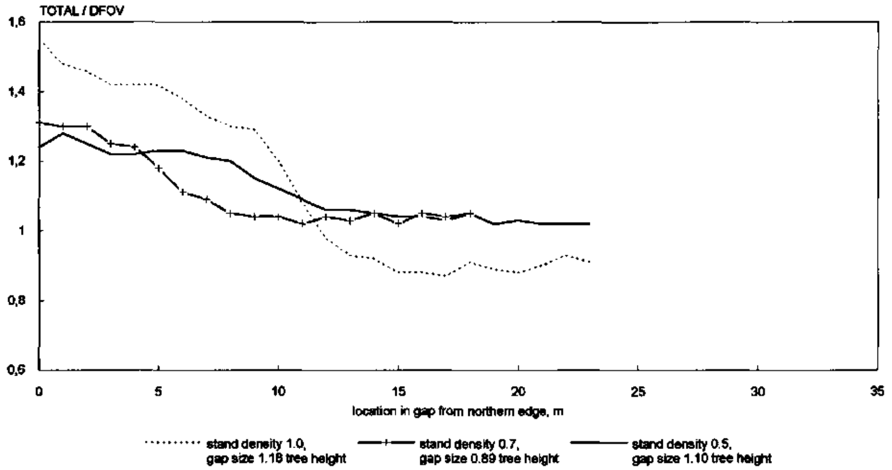

Fig. 33a. Relationship between relative TOTAL PAR and DFOV PAR on the forest floor over a north-south transect through the middle of gaps in a simulated 60-year-old Scots pine stand of yield class II, with various stand density indices.

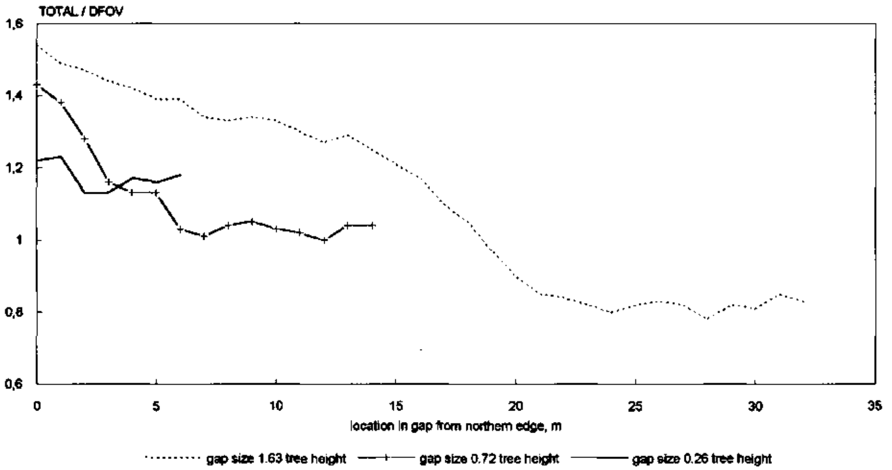

Fig. 33b. Relationship between relative TOTAL PAR and DFOV PAR on the forest floor over a north-south transect through the middle of gaps in a simulated 60-year-old Scots pine stand of yield class II with stand density index 1.0 and various gap sizes.

Figures 31 a to d show that the relative DFOV PAR in stands with decreasing stand indices increases considerably if a fixed number of trees (here 19), are felled as a group. The increase in relative DFOV PAR is due to the larger gap and to the increasing lateral PAR. The latter is due to the wider spacing of trees in stands with lower stand indices.

6.4.4 *Amounts of light and gap sizes in Scots pine stands; field experiments*

Relative DFOV PAR was measured in 7 gaps in Soeren 36, Gortel 50f and 134a. At the time of measurement Soeren 36 was a 40-year-old Scots pine stand on humus podzol, yield class III (Grandjean and Stoffels, 1955), Gortel 50f was a 62-year-old Scots pine stand on humus podzol, yield class III and Gortel 134a was a 67-year-old Scots pine stand on humus podzol yield class III.

In Soeren 36 measurements were performed in the middle of the gap. In Gortel 50f and 134a measurements were performed on a north-south transect.

Gap size was systematically increased by felling more trees. DFOV PAR was measured in each gap size. The gap size was expressed as a fraction of the height of the dominant trees in the surrounding stand.

The stand characteristics and relative DFOV PAR on the forest floor in the centre of the gaps are given in appendix 6.4.4. The relative DFOV PAR values, expressed as percentages, ranged from 18% to 84%, which is far from the natural limits 0 and 100%. Therefore transformation of data values or fitting of a nonlinear model was not considered necessary, and the relation between DFOV PAR% and gap size was modelled with a linear function. A linear regression model with terms for location, gap size and their interaction was fitted, to find if the slope and intercept of the linear relation did vary across locations. In order to investigate relations of slope and intercept with stand density index a mixed model was fitted by Residual Maximum Likelihood (REML; Patterson and Thompson, 1971). A mixed model contains both fixed (gap size, stand density index, interaction) and random (location) terms, and was necessary because stand density index and gap size are factors operating on different experimental units (location and gap, respectively).

Locations were numbered according to increasing stand density index values as given in table 43.

Table 43. Locations with increasing stand density, at which gaps were made for DFOV PAR measurements.

location	1	2	3	4	5	6	7
s.d.i.	0.78	0.83	0.96	0.97	1.05	1.24	1.27
stand no.	G50f#	G50f	G134a	S36	G50f	G134a	S36

G = Gortel, S = Soeren.

The results from the regression model are given in appendix 6.4.4. Gap size is the main contributing factor in explaining the variation in relative DFOV PAR. The effect of gap size already explains 75% of all DFOV PAR variation (see appendix 6.4.4). In addition there were also statistically significant differences in relative DFOV PAR between locations at comparable gap sizes (main effect location). However, there is no statistically significant evidence that these location differences depend on gap size (interaction between gap size and location). Consequently, a model without interaction was chosen to summarize the data. The hypothesis was that the model is described by the equation:

$$\text{DFOV\%} = c_1 * \text{gap diameter} + c_2 + c_i \tag{3}$$

in which gap diameter is expressed in th, c_1 and c_2 are empirical constants and c_i is a constant describing the difference between the response for location i ($i \geq 2$) and the response for location 1. This model explained 89% of variation in relative DFOV PAR. The estimated regression coefficients are listed in appendix 6.4.4. The estimated relations are plotted in figure 34.

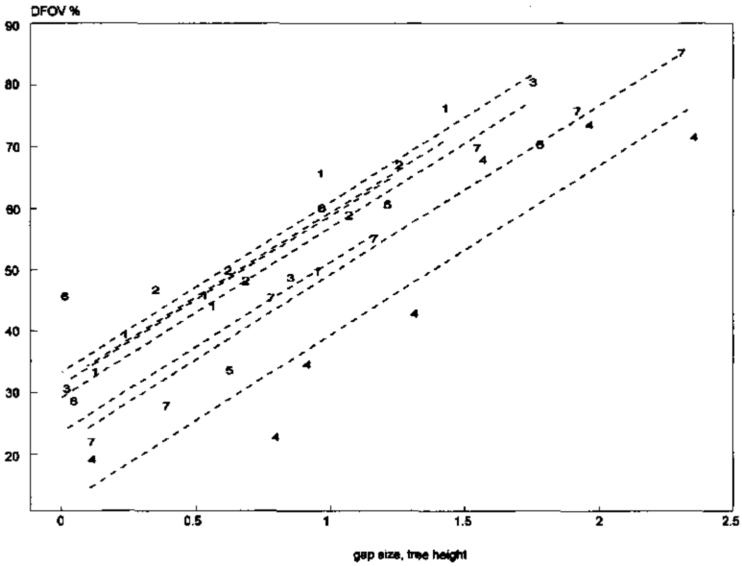

Fig. 34. Estimated relationship between gap size and relative DFOV PAR in the middle of gaps in Gortel 50f, 134a and Soeren 36. Data numbers are location numbers in table 43.

Figures 35 a to c give 3 selected examples of the relative DFOV PAR on the forest floor in Gortel 50f and 134a, over a north-south transect through the middle of various-sized gaps in stands with various density indices.

Discussion and conclusions

Location 4 had statistically significantly lower relative DFOV PAR values across all gap size values. Locations 7 and 5 also had lower DFOV PAR than other locations. These location differences may be caused either by unknown specific location circumstances or by inaccuracies in the stand density indices. Stand density indices were measured before felling the trees. DFOV PAR was measured after felling the trees. The stand density indices of the tree compartments around the felled gaps might have been different from those of the untouched compartment. In other words it was assumed that the tree compartments were homogeneous. In fact they might not have been. The effect of increasing DFOV PAR at lower stand density indices as shown in simulated stands (subsection 6.4.3) was not determined.

The mixed model analysis revealed no further pattern related to stand density index (appendix 6.4.4). From the ratios of effect to standard error, gap size was again identified as an important factor, but neither stand density index nor the interaction between gap size and stand density index were suggestive of any further relation.

Figures 35 a to c show relative DFOV PAR to be evenly spread over the gap width. The same proved true in the other 4 gaps in Soeren 36, Gortel 50f and 134a, not illustrated here.

6.4.5 Amounts of light and gaps in ground vegetation; field experiments

Not only old trees but also the ground vegetation affects relative PAR on the forest floor. This impact was assessed by PAR measurements in bilberry vegetation, in which gaps of various sizes were clipped. Relative DFOV PAR was measured in the centre of each gap, starting at bare soil level, and repeated every 10 centimetres higher. Gap sizes, height of the surrounding bilberry and relative DFOV PAR are given in appendix 6.4.5.

Figures 36 a to c show relative DFOV PAR at various heights above the forest floor in various gap sizes in ground vegetation of 30, 55 or 70 cm high respectively.

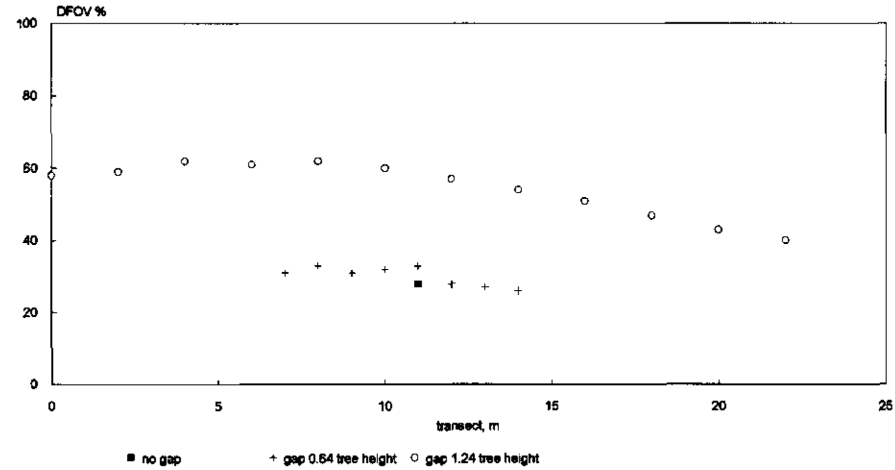

Fig. 35a. Relative DFOV PAR measured on the forest floor in Gortel 50f, over a north-south transect through the middle of the gap, various gap sizes, stand density index 0.83.

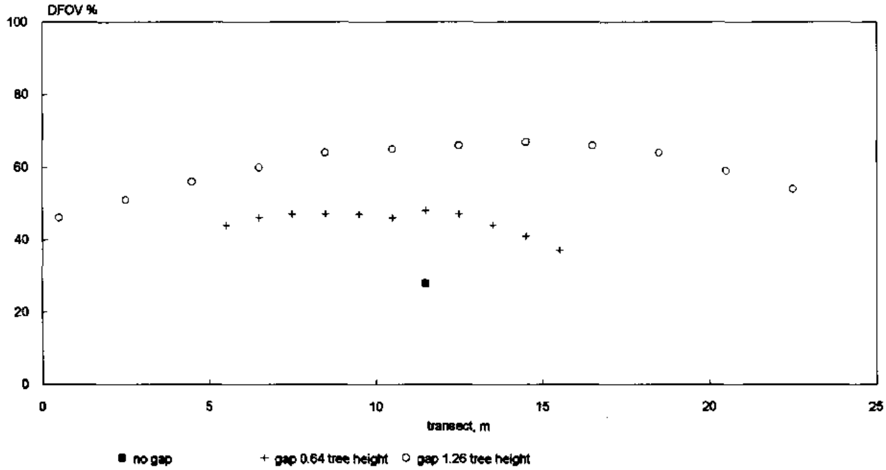

Fig. 35b. Relative DFOV PAR measured on the forest floor in Gortel 50f, over a north-south transect through the middle of the gap, various gap sizes, stand density index 1.05.

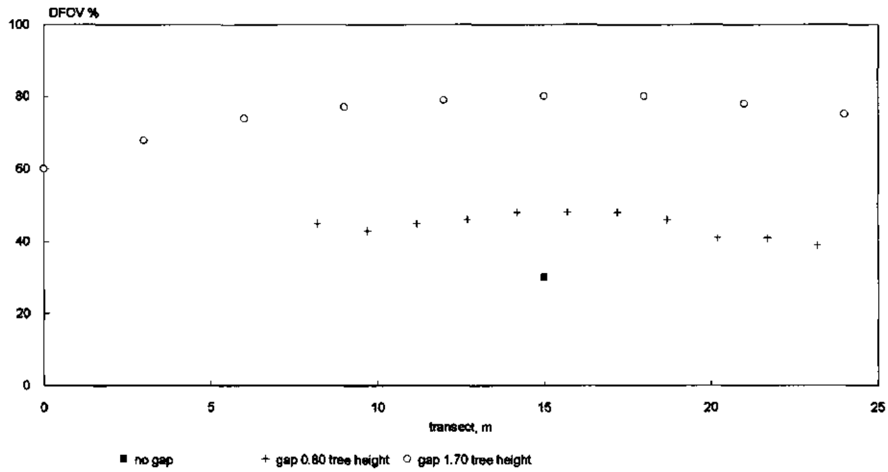

Fig. 35c. Relative DFOV PAR measured on the forest floor in Gortel 134a, over a north-south transect through the middle of the gap, various gap sizes, stand density index 1.24.

Table 44 summarizes the characteristics of the gaps in the ground vegetation, together with the positions below the top of the ground vegetation in that gap where DFOV PAR reaches 90% and 98% of its maximum value.

Discussion and conclusions

Table 44 shows that the wider the gap, the greater the depth at which high levels of DFOV are found. The distance from the top of the gap to the point

Table 44. Distance below the canopy of the ground vegetation, where DFOV PAR reaches 90% and 98% of its maximum value, at various gap sizes.

average height bilberry	average distance from centre of gap to edge	90% DFOV at distance under top	98% DFOV at distance under top
70 cm	15 cm	12 cm	5 cm
45	25	19	5
65	28	20	10
30	28	25	10
45	35	27	10
65	36	32	15
30	38	> 30	20
65	48	45	15
30	50	> 30	20
65	68	60	25
65	108	> 65	35

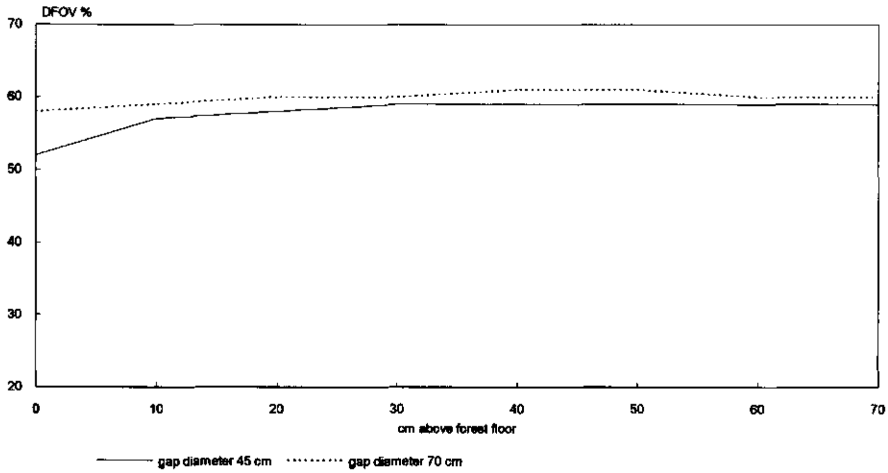

Fig. 36a. Relative DFOV PAR measured at various heights above the forest floor in various gap sizes in 30 cm high ground vegetation.

at which DFOV PAR is reduced to 90% of its possible maximum value, is approximately equal to the average distance from the centre of the gap to the edge of the gap. This means that in order to receive at least 90% of the possible DFOV PAR, gaps must be at least twice as wide as the height of the surrounding shrubs. In smaller gaps positions that still receive 98% of the maximum DFOV PAR lay not far below the top of the surrounding shrubs. Once gaps are substantial in size, 2 m^2 and more, up to 98% of the maximum DFOV PAR reaches 25 cm and more below the top of the surrounding shrubs. This means that seedbeds in bilberry vegetation should be at least 2 m^2, to encourage regeneration by Scots pine.

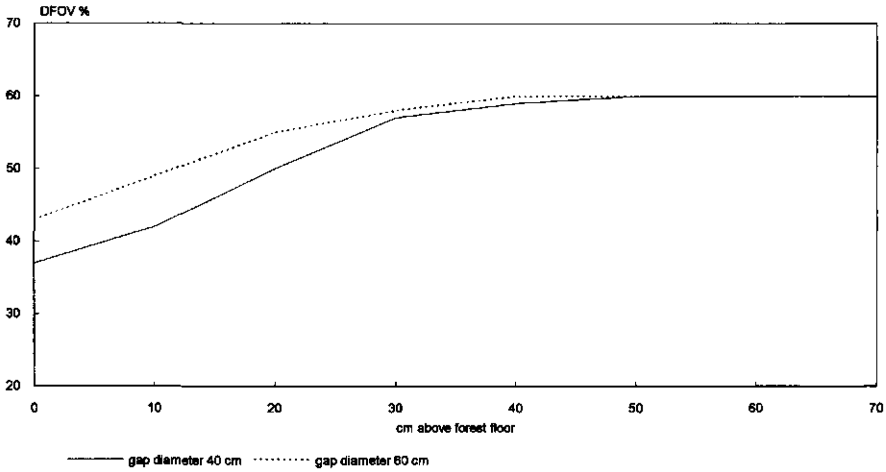

Fig. 36b. Relative DFOV PAR measured at various heights above the forest floor in various gap sizes in 55 cm high ground vegetation.

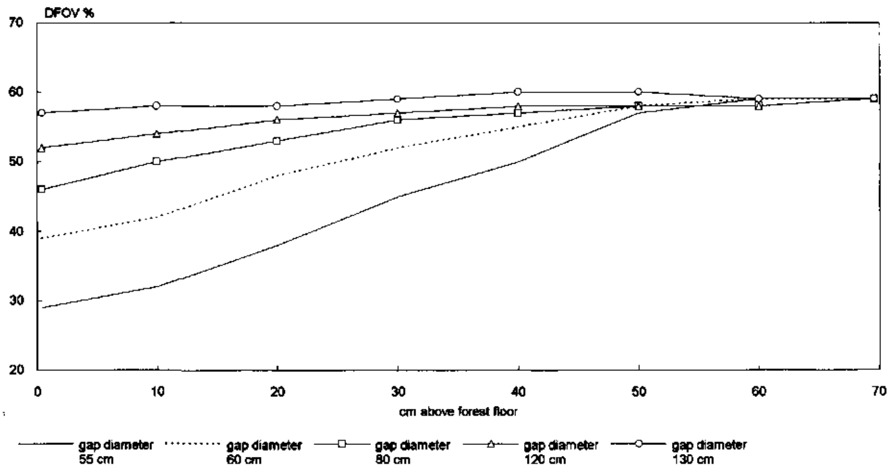

Fig. 36c. Relative DFOV PAR measured at various heights above the forest floor in various gap sizes in 70 cm high ground vegetation.

Jarvis (1964) measured DFOV PAR in heather from the top of the ground vegetation to the soil, but without making gaps. He too found a rapid reduction of DFOV PAR below the top of the ground vegetation.

6.5 Other potentialities for regeneration

6.5.1 Regeneration on organic topsoil with herbs and shrubs, with clipped herbs and shrubs, and without herbs and shrubs

Organic topsoil with herbs and shrubs

To investigate the hypothesis whether Scots pine saplings occurred more in places where the organic topsoil is thin, measurements were performed to compare the thickness of the organic topsoil where a Scots pine sapling was found with the thickness at randomly chosen spots 1 m away from the sapling (subsection 3.3.7). This was done for 25 saplings in each of 11 open Scots pine stands. These stands, which had a vegetation of herbs and shrubs on the forest floor, were found in 3 regions: Palace Park (13i and 19c), Uddel (52, 131 and 141), and Gortel (19b, 35c, 77g, 78d, 84a and 92). One stand (Gortel 84a) had a deviating soil type (brown podzolic soil).

The measured thickness varied between 0 and 15 cm. Per sapling the difference was calculated between the thickness at 1 m from the sapling and the thickness immediately under the sapling. Under the alternative hypothesis, this difference (d) is expected to be negative. Values of d ranged from –5 to 9, and had a fairly symmetrical distribution.

For the dataset from stands with undergrowth, differences between stands and between regions were investigated with analysis of variance and pairwise t-tests. The use of region as a classifying factor was suggested by the data. One-sided t-tests were performed for each stand, and also for each region, to find if d differed statistically significantly from 0.

Basic statistics of the thickness measurements, results from the comparison between stands and regions, and results from the t-tests for testing the difference between the two types of location are given in appendix 6.5.1. Ten of the 11 stands showed a positive mean difference between the thickness at the control spot and the thickness under the sapling. Moreover, the data suggested that regional differences accounted for most of the variation between stands. This was tested and confirmed by analysis of variance (appendix 6.5.1): after accounting for the highly statistically significant ($p < 0.001$) regional differences, no statistically significant variation was found between stands in the same region ($p = 0.64$). The mean difference in topsoil thickness was 1.6 cm for the Palace Park region, 1.1 cm for the Uddel region, and 0.3 cm for the Gortel region. The latter value was found to be statistically significantly lower than the former 2.

In the Palace Park and Uddel stands the mean thickness of the topsoil was statitically significantly higher at the control spots compared to the spots under the saplings (all p-values lower than 0.025). No conclusive evidence was obtained about the individual Gortel stands (p-values between 0.056 and 0.67). However, the combination of all data per region made the conclusion statistically significant ($p < 0.01$) for all 3 regions.

The results from the stand with a deviating soil type (Gortel 84a) did not differ noteworthy from those from the other stands.

Discussion and conclusions

Averaged over all stands the topsoil thickness under saplings was 3.8 cm, with individual values ranging from 0 to 12 cm. Scots pine regeneration in stands with undergrowth established with more success at spots where the organic topsoil was relatively thin. The mean difference in thickness in the Palace Park stands, the Uddel stands, and the Gortel stands, perhaps reflected less variability of the topsoil thickness. No statistically significant differences were found in these values between stands within regions.

After conducting experiments in Switzerland, Hunziker (1956) could not find any effect of the thickness of organic topsoil on the number of saplings over the thickness range up to 2.1 cm. Malcolm (1976) reported that Scots pine regeneration in Scotland failed because of organic topsoil. However, he mentioned layers of 30 cm or more. In Bavaria Seitz (1979) found higher numbers of saplings on thin organic topsoil than on thicker organic topsoil. When organic topsoil was less than 1 cm thick he recorded 1 to 31 saplings per m^2, whereas on organic topsoil of more than 10 cm thick he found 1 to 6 saplings per m^2.

Other examples of forest regeneration on layers of organic topsoil

In some parts of the Netherlands Scots pine stands were cleared after being damaged by the storms of 1972 and 1973, and Scots pine regenerated spontaneously. The following areas were examined: Amerongseberg 7b, Imbosch 3w, 13h, 23a, 24p, Petrea 12d, 12c and 12e. After the old Scots pine trees were removed in 1973 and 1974, no preparation was carried out for replanting at the Amerongseberg and at the Imbosch. At Petrea the branches of the removed trees were cleared from the area. In the latter area, the litter was removed during the years 1967-72, and little or no ground vegetation was present at the time of the storms (pers. com. Rondeboom, 1991). In the Imbosch area red deer were very abundant (80-100 individuals on 1400 ha), which prevented deciduous trees from regenerating; furthermore, there was a sparse ground vegetation cover, partly bilberry. This cover decreased after the timber had been removed, possibly because of moisture stress caused by sudden exposure (pers. com. Van den Born, 1991). At the Amerongseberg site there was already some regeneration by deciduous tree species as well as bilberry cover before the storm destroyed the stand in 1973 (pers. com. de Groot, 1991). In all those areas regenerating Scots pine appeared shortly after the timber had been removed.

Table 45. Numbers of saplings per ha and average organic topsoil thickness under Scots pine saplings, on areas where Scots pine stands had been removed.

stand no.	topsoil, cm	Scots pine	birch	oak	beech
Amerongseberg 7b	9.0	230	765	150	
Imbosch 13h	6.5	3430	430		1290
Imbosch 23a	6.6	3340	1240		40
Imbosch 24p	6.4	3290	1745		
Imbosch 3w	10.3	1700	470		
Petrea 12d	5.2	1725	2050		
Petrea 12c	5.8	500	3100		
Petrea 12e	6.0	1875	875		

In 1991 the thickness of the organic topsoil was measured under 25 randomly chosen Scots pine saplings in each stand, and numbers of regenerated saplings were counted in random sample circles of 500 m^2. The results are given in table 45.

Discussion and conclusions

The thickness of organic topsoil given in table 45 was measured in 1991, 10 to 17 years after regeneration took place. In that period the thickness of the organic topsoil might have changed, and therefore the regeneration may have occurred on thinner or thicker organic topsoil than measured in 1991. However, in places where organic topsoil had been removed in 3 open Scots pine stands at Het Loo (Soeren 98b and 101c, Gortel 133f) the thickness of the organic topsoil that developed in 8, 7 and 8 years was respectively 1.0, 0.9 and 1.2 cm. It is therefore unlikely that the organic topsoil noted in table 45, was formed after the storms of 1972 and 1973.

Other examples of regeneration of Scots pine on layers of organic topsoil are given under the heading: 'Organic topsoil without herbs and shrubs'.

From these data it can be concluded that Scots pine regenerates not only on mineral soil, but also on a layer of organic topsoil up to approximately 10 cm thick. This refutes the hypothesis that Scots pine regenerates only in spots where the organic topsoil has been removed, for instance caused by timber extraction. On the other hand, in section 6.1 it was shown that Scots pine does not regenerate in a dense ground vegetation of herbs and shrubs. That might explain the low numbers of regenerated Scots pine trees in Amerongseberg 7b compared to the other examples from table 45.

The cases of numerous Scots pine saplings per ha on areas with organic topsoil but without herbs and shrubs, warrant the conclusion that regeneration of Scots pine is strongly regulated by the ground vegetation.

Organic topsoil with clipped herbs and shrubs

In spring 1990 herbs and shrubs were clipped with a mulching machine in stands Gortel 6, 7 and 8. The herb and shrub vegetation consisted of a mosaic of bilberry, cowberry and wavy hair grass. The stands were opened up by the storm of January 25th 1990 to such an extent that on average less than 25% of the basal area of the old stand remained. Scots pine seedlings appeared in May and June 1990. At the end of the growing season the Scots pine seedlings that had survived the dry summer of 1990 were recorded. At the base of 100 seedlings the thickness of the organic topsoil was measured. On average this was 6.2 cm, measured from the top of the organic layer to the top of the mineral soil. At 5 localities in those stands, 485 seedlings were marked with wooden pegs. After 1 and 2 growing seasons the seedlings were re-recorded. Unfortunately most of the pegs were chewed up by wild boar, so only a limited number of seedlings could be relocated. After 1 year, 55% of 109 seedlings had survived, but 1 year later 32% of 63 saplings survived.

At the end of the first and second growing seasons the ground vegetation which dominated individual seedlings was recorded. For 322 seedlings at the end of the first season and 338 saplings at the end of the second season this resulted in the composition of ground vegetation cover in the clipped area as given in table 46.

The average height of 208 2-year-old saplings of Scots pine, which were recorded on these clipped plots was 6.1 cm. The average height above the ground of 102 measured bilberry shoots was 17.3 cm. The average height above the ground of 107 measured cowberry shoots was 8.9 cm.

Discussion and conclusions

The accurate recording of Scots pine seedlings among the ground vegetation was hampered by that ground vegetation. The hindrance was greater in cowberry than in bilberry, because cowberry does not shed its leaves in winter, which was the time the recording was done. The recording was obstructed at localities dominated by wavy hair grass that had flowered, because the inflorescences had

Table 46. Composition of ground vegetation cover around *surviving* Scots pine seedlings and saplings at Gortel 6, 7 and 8. In brackets, the average cover of bilberry, cowberry and wavy hair grass in the unclipped area is given.

	end 1990	end 1991	(untreated)
no ground vegetation	29%	44%	(–%)
bilberry only	41%	14%	(32%)
cowberry only	11%	22%	(28%)
bilberry and cowberry	18%	18%	
wavy hair grass	2%	1%	(40%)

bent over, concealing shorter plants. It is unlikely that Scots pine seedlings, as pioneer species, could have survived under such cover, just as they did not survive overtopping by mature bilberry and cowberry and wavy hair grass (section 6.1). Where wavy hair grass dominated after the second growing season, it covered everything underneath it. After 2 seasons inflorescences of wavy hair grass dominated the clipped areas much more than the untreated areas.

From the change in percentage of surviving Scots pine saplings among the various ground vegetation covers it may be concluded that Scots pine seedlings do not easily survive among bilberry, and that there is a better chance of survival when there is no ground vegetation or when the dominant ground vegetation includes cowberry. The stronger growth of the bilberry, which easily overgrows the Scots pine seedlings, might cause this effect. Cowberry does not overgrow Scots pine as fast as bilberry. The effect of shrub height on incoming PAR levels on the forest floor was elaborated in subsection 6.4.5.

The above conclusion is supported by the results obtained from the ground vegetation that was investigated around saplings, under the heading 'Organic topsoil with herbs and shrubs' (this subsection). Out of 250 Scots pine saplings investigated, which had established spontaneously in existing herb and shrub vegetation, 52 (21%) established in a gap in the ground vegetation, the diameter of which exceeded half the height of the surrounding shrubs, 120 (48%) established on a spot dominated by cowberry only and 56 (22%) on a spot which was dominated partly by cowberry and partly by bilberry. Only 22 (9%) Scots pine saplings grew on a spot dominated by bilberry only, in an area where on average 45% of the surface was dominated by bilberry, 52% by cowberry and 3% was dominated by grass. The Scots pine saplings investigated were 3 to 6 years old. Based on the data from subsection 6.2.4 it was assumed that the cover of bilberry and cowberry did not change significantly in those 3 to 6 years.

The number of Scots pine seedlings that survive on organic topsoil with clipped herbs and shrubs is low. In cases where the complete ground vegetation of the stands had been clipped with the mulching machine, there were, on the basis of results from 5 areas investigated in Gortel stands 6, 7 and 8, respectively 1492, 1104, 946, 259 and 215 2-year-old surviving saplings per ha. These numbers are too low to guarantee new generations of timber-producing trees.

From the results of the seedling establishment it can be concluded that regeneration on soils with clipped herbs and shrubs can, to a limited extent, be successful. Regeneration had succeeded better in spots that remained open in the clipped ground vegetation than in places where the ground vegetation recovered. Chances of success were better among cowberry than among bilberry. Chances among grasses were low.

Organic topsoil without herbs and shrubs

In many stands of shade-tolerant tree species, herbs and shrubs are absent. After felling a group of shade-tolerant trees the forest floor acts as seedbed without ground vegetation, but with the organic topsoil still in situ.

In Palace Park 14, beech trees were felled at 6 locations to create gaps in open Scots pine stands in spring 1988. This resulted in gaps in the stand without any ground vegetation. One year after the beeches had been removed, Scots pine regenerated in the larger gaps. The thickness of the organic topsoil under those Scots pine saplings was measured when the saplings were 3 years old. In these gaps the thickness of the organic topsoil was also measured at random where no Scots pine had established.

A similar investigation was carried out in Palace Park 13, in places where Douglas-fir had been felled, without any vegetation on the forest floor, and where Scots pine had established shortly after the Douglas-fir had been removed. Full data on the thickness of the organic topsoil are given in appendix 6.5.1.

Average organic topsoil thickness under Scots pine saplings from 9 samples in Palace Park 13 was 5.9 cm at locations where Douglas-fir was felled, and from 32 samples in Palace Park 14 it was 4.6 cm where beech was felled.

Discussion and conclusions

As was done earlier (see 'Organic topsoil with herbs and shrubs') a test was carried out, to find out whether the thickness of organic topsoil affects regeneration of Scots pine. Basic statistics on the thickness measurements and the results from the t-tests for testing the difference between the two types of location (under Scots pine saplings and random spots) are given in appendix 6.5.1. The thickness at control spots was not statistically significantly higher than under Scots pine saplings ($p > 0.3$). However, the few data pairs available for stand Palace Park 13 (in gaps after felling Douglas-fir) indicate the opposite. Topsoil thickness ranged from 0 to 10 cm.

The abundance of 2-year-old and 3-year-old Scots pine saplings in the beech gaps was 59 saplings on 121 m^2, which can be extrapolated to 4876 saplings per ha. In Uddel 156h, a mixed stand of beech and red oak on humus podzol, gaps were created by felling the dominant red oak trees. In these gaps, whose diameters were less than one tree height of the surrounding trees (cf. subsection 6.4.3), Scots pine saplings of 2 to 4 years old were present after 4 years. The average thickness of organic topsoil under Scots pine saplings was 2.5 cm after 4 years ($n = 25$). This organic topsoil was more compact than organic topsoil under bilberry or cowberry, and lacked the coarse roots of bilberry and cowberry.

From Switzerland, Hunziker (1956) reported on successful regeneration by

Scots pine on soils where the ground vegetation cover had been removed, but where the organic topsoil remained.

From Southern Germany and northern Switzerland, Koch (1968) mentioned Scots pine regeneration on organic topsoil of 1 to 3 cm, and even up to 6 cm in places with a good water supply in patches with mosses.

Other examples of regeneration on organic topsoil layers without herbs and shrubs

Six stands (Palace Park 14a, 14b, 14c, 14d and 19d and Soeren 46g) at Het Loo consisting of exotic shade-tolerant trees were clearfelled for nature conservation. There was no ground vegetation in these stands. In all areas, except Soeren 46g, the branches of the felled trees were removed. The number of regenerated saplings per ha, and the average thickness of organic topsoil measured from 25 samples in each area under the Scots pine saplings, are given in table 47.

Table 47. Numbers of regenerated Scots pine saplings per ha and average thickness of organic topsoil under the saplings, on areas where stands of shade-tolerant tree species had been removed.

stand no.	topsoil, cm	Scots pine number per ha
Pal.Park 14a	5.2	21,450
Pal.Park 14b	5.0	14,170
Pal.Park 14c	3.1	13,360
Pal.Park 14d	2.9	14,050
Pal.Park 19d	2.9	27,600
Soeren 46g	1.9	13,080

Discussion and conclusions

From Fulda, Germany, Faust (1992) mentioned that ten times as many seedlings appeared on mineral soil as on soil with its organic matter intact. He gave no more details. However, the same author also stated that Scots pine successfully regenerated in places where beech had been selectively felled in mixed Scots pine/beech stands; there, beech had prevented bilberry from growing and coarse organic matter from accumulating.

The data of table 47 warrant the conclusion that Scots pine regeneration is possible on soils where the organic topsoil is still present.

6.5.2 Establishment success of Scots pine saplings planted in old Scots pine stands

In 1984 3-year-old Scots pine saplings were planted in Scots pine stands immediately after the basal area had been reduced as described in subsection 3.2.4. The planted saplings suffered attacks of shoot blight (*Sphaeropsis sapinea*) and the large pine weevil (*Curculio abietes*).

Table 48. Survival percentage of planted Scots pine saplings after 3 and 7 years.

stand no.	stand density index	number planted	survival after 3 years	survival after 7 years
Pal.Park 20f	0.55	174	74%	51%
	0.61	175	55%	30%
	0.70	172	73%	37%
	0.83	166	65%	27%
Gortel 77gW	0.71	146	50%	4%[#]
	0.95	147	55%	4%[#]
Gortel 77gE	0.79	126	53%	5%[#]
	0.89	142	42%	5%

[#] These figures are the averages of Gortel 77gW and 77gE. In these stands the Scots pine saplings were also overgrown by birch.

After several growing seasons, a limited number of saplings remained. Table 48 gives the survival percentage of saplings after 3 and 7 growing seasons, for each Scots pine stand. Data on growth are given in section 7.4.

Two-year-old Scots pine saplings were planted in the fenced experimental subplots of Scots pine stand Uddel 2a. The saplings were planted in 1988, 1 year after the basal area had been reduced. Stand density indices and survival percentage of saplings after 3 growing seasons are given in table 49.

Discussion and conclusions

The planting of 3-year-old Scots pine in 1984 was not successful. According to De Kam and Van Dam (1987), 1984 and 1985 were years with serious attacks of shoot blight. On top of that, the saplings were planted immediately after the basal area had been reduced. That considerably increased the chances of attack by the large pine weevil (Doom and Frenken, 1980). This did indeed occur in the experiment.

It is unusual to plant Scots pine saplings under old Scots pine stands. Indeed, no results from such exercises are available in the literature. Nevertheless Olberg

Table 49. Survival of 2-year-old planted Scots pine saplings under old Scots pine after 3 seasons.

	s.d.i. at start	s.d.i. Feb.1990	no. planted	survival after 3 years
Uddel 2a	0.36	0.22	25	88%
	0.51	0.44	25	68%
	0.70	0.48	25	80%
	0.76	0.67	25	84%

(1957) stated that Scots pine saplings, planted additionally to existing regeneration under shelter, were susceptible to needle cast, because of their disrupted water supply. Olberg pointed at the less disrupted root systems in saplings which were planted with a good root ball. In that respect the 'container-grown' saplings now available might improve the chances of successfully planting Scots pines under shelter.

From data in table 49 it can be concluded that the planting of Scots pine saplings under old Scots pine stands can be successful. However, high losses of saplings can occur. The chances of increased mortality were higher if planting occurred immediately after felling. This is similar to what happens when planting is carried out immediately after clearfelling (cf. Doom, 1969).

It should be noted that if massive regeneration of deciduous trees occurred at the same time or earlier, Scots pine saplings easily become overgrown. This was observed in Gortel 77g and in the experimental stands of 1987 (subsection 6.2.3).

7 Height growth of young trees under Scots pine

7.1 Height growth of young oak

7.1.1 Height growth of spontaneously established young oaks at different basal areas of old Scots pine

Along the transects in Gortel 77g the height of 165 pedunculate oak saplings was measured in 4 consecutive years. These oak saplings had established after the stand was fenced. The basal area of the mature Scots pine trees present was measured with a Bitterlich Wedge Prism. The data on height growth over 3 years versus basal area are given in figure 37.

Discussion and conclusions

Figure 37 shows no relation between basal area of the Scots pine stand and the height growth over 3 years in pedunculate oak saplings in Gortel 77g. It is interesting to compare this finding with the results of similar research done in Great Britain. For example, near lake Windermere, Ovington and MacRae (1960) carried out experiments with sessile oak, not pedunculate oak, at various levels of shading, from the moment of sprouting until the saplings were 3 years old. They recorded maximum height growth in the shade class of 15% of the light of the full-light reference. In sessile oak woods in the Pennines, Jarvis (1964)

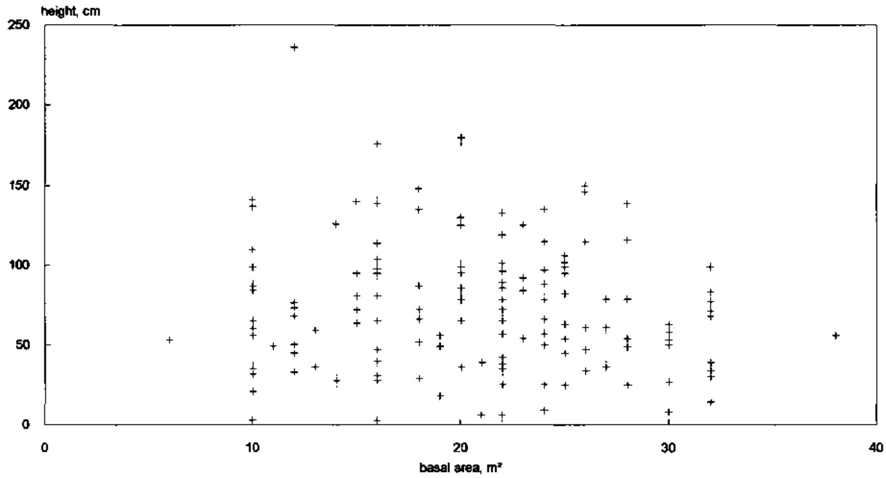

Fig. 37. Scatter diagram of height growth of pedunculate oak saplings over 3 years, measured in Scots pine stand Gortel 77g, versus basal area of the Scots pine.

found maximum height growth of sessile oak seedlings at 56% of the full daylight. Jarvis measured the relative light intensity in semi-natural oakwood, where tree spacing was 5 m, but did not give any further details on the stand. In that oakwood, relative light intensity on the forest floor at about noon on overcast days in June was 12% to 28%. In small clearings of 8 × 10 m from canopy edge to canopy edge, the relative light intensity was 40% to 65%. Jarvis stated that these light levels were sufficient for oak regeneration. Savill (1991), however, stated that in order to prevent defoliation by winter moth (*Operophtera brumata*) and oak leaf roller moth (*Tortrix viridana*), oak saplings must produce appreciable amounts of tannin, and old oak trees that overtop regeneration should be removed in order to prevent caterpillars falling on the young trees. Savill therefore suggested opening the canopy very rapidly once seedlings were established. He considered selection or group felling* systems for oak to be doomed to failure. This is, at least partially, refuted by the fact that oak saplings do well under heavy shelter in Scots pine in Gortel 77, and by the survival of oak saplings in the mixed oak/birch/Scots pine stand Duddel in Palace Park 13.

7.1.2 Height growth of older oaks under shelter of Scots pine

In Palace Park 14 and Gortel 80, Scots pine stands with undergrowth of beech, oak, birch and Scots pine (table 6), the height growth of 31 oaks was determined over the years. The average height for each age was calculated. In figure 38 these averages are joined by a line. The standard deviation and yield class curves of Im_{max} 3, 4 and 5 m^3 per ha per year (Oosterbaan, 1988) are also given.

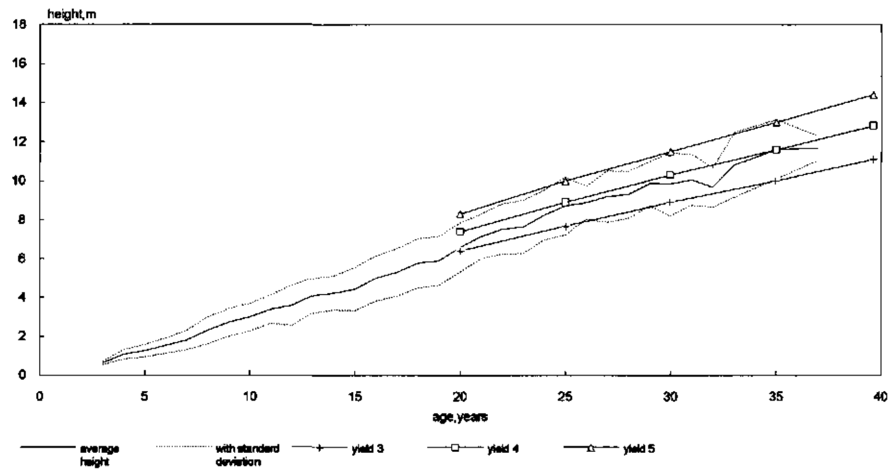

Fig. 38. Average height growth with standard deviation of oaks, measured in Scots pine stands Palace Park 14 and Gortel 80, with 3 yield class curves.

Discussion and conclusions

In spite of the shelter of the Scots pine, figure 38 shows an on-going average growth of the young oak trees over the years. It lies between the yield class curves of Im_{max} 3 and 4 m^3 per ha per year. The 31 selected oaks were dominant trees surrounded by oak or birch trees, and had survived the competition from birch.

Schaper (1978) showed that oak saplings in low densities grow slower than those in high densities. The birches surrounding the oaks in our experiment might well have forced the oaks to grow straighter, i.e. faster, (cf. subsection 5.2.2) than when the birches were not present.

7.1.3 Height growth of planted oak saplings

One-year-old oak saplings

In 1987 1-year-old oak saplings (pedunculate and sessile oak) were planted in the fenced sub-plots in the 1987 experimental stands. The height of the surviving saplings was measured at the end of the fifth year of investigation, i.e. after 5 growing seasons, and 2 years after the extra reduction of basal area that resulted from storm. Average results are given in table 50. Full data are given in appendix 7.1.3.

Table 50. Five years of growth of oak saplings, planted when 1 year old in Scots pine stands which had undergone an increment felling in 1987 and a reduction of basal area through storm in January 1990.

Stand no.	stand density index		average height growth of	
	at start	after storm	pedunculate oak, cm/year	sessile oak, cm/year
Pal.Park 19d	0.38	0.20	16.9 (n = 9)	7.5 (2)
	0.44	0.32	18.5 (9)	11.0 (4)
	0.69	0.62	21.0 (9)	12.8 (6)
	0.81	0.61	19.1 (10)	2.2 (1)
Uddel 2a	0.36	0.23	16.3 (9)	11.1 (7)
	0.51	0.46	17.6 (9)	8.9 (3)
	0.70	0.49	19.6 (8)	10.4 (3)
	0.76	0.67	15.3 (8)	13.3 (2)
Soeren 107b	0.38	0.23	13.9 (4)	16.7 (3)
	0.49	0.40	9.1 (5)	2.2 (1)
	0.67	0.59	10.7 (5)	4.6 (1)
	0.81	0.76	9.0 (8)	6.0 (4)
Gortel 84a	0.38	0.33	31.6 (9)	37.6 (6)
	0.57	0.48	38.0 (5)	32.8 (4)
	0.73	0.69	28.8 (8)	22.3 (4)

Four stand densities were created by felling of trees. In each sub-plot the density was characterized by the stand density index (s.d.i.), or by basal area. However, due to the storm of January 1990 a further reduction of density occurred in all experimental stands. Although new s.d.i. measurements were made, it was difficult to decide how old and new s.d.i. values should be combined when analysing the influence of stand density on height growth. Only the qualitative grouping in 4 densities (high, medium high, medium low, low) was used in the statistical analyses.

The design of the experiment was such that experimental units of different size are important. Growth was measured in individual trees, whereas density was a treatment applied to 40 x 20 m sub-plots. The data from the experiments were therefore analysed with multi-level analysis of variance. In most cases the numbers of observations were unevenly distributed over the experimental units and treatment combinations, and therefore special techniques had to be used to overcome this. These techniques were Residual Maximum Likelihood (REML; Patterson and Thompson, 1971), as implemented in Genstat (Anon., 1990) and the Genstat procedure VWALD (Thissen and Goedhart, 1992).

Models fitted with REML are called mixed models, because they contain both fixed and random terms. Fixed terms describe the effects of pre-selected treatments and classifications (density, species), random terms describe the variation of the experimental units which is assumed to be stochastic (e.g. stand, plot, and tree differences). REML fits a variance component for each random term, and calculates means and standard errors of differences (s.e.d.) for fixed, and optionally also random terms. VWALD can be used to calculate approximate chi-square tests for each of the fixed terms. However, these tests are only sensible if there are no higher-order interactions in the model, and therefore a repetition of model fits is sometimes needed, one for each maximum order of interaction.

After some trials it was decided to analyse height growth as such and not the logarithm of height growth, because residuals from the model fits appeared to be more symmetrically distributed without transformation.

The test results and summaries from REML are given in appendix 7.1.3.

Discussion and conclusions

There were statistically significant species differences ($p < 0.001$) among the fixed model terms. Surviving pedunculate oak had an average growth of 20 cm per year against only 15 cm per year for surviving sessile oak. In general, there were no important density effects ($p = 0.37$), although the limited data for sessile oak from stand Gortel 84a suggest that this may not be the case more locally. There were also large differences between the stands, with the mean growth in Gortel 84a (31 cm per year) being approximately twice that in Palace Park 19d (16 cm per year) and Uddel 2a (14 cm per year), and more than thrice that of Soeren 107b (9 cm per year). These differences can be compared against a standard error of differences of 2 cm per year.

Houtzagers (1954) already mentioned difference in juvenile growth of the 2 oak species.

Two-year-old saplings

Two-year-old pedunculate oak saplings were planted in Scots pine stands Gortel 77g East and West, and Uddel 140b in 1986. The stands were fenced against browsers, and had undergone reductions of basal area. Average height growth of the surviving oaks, after 6 years, is given in table 51. Full data are given in appendix 7.1.3.

Discussion and conclusions

As in the case of the 1-year-old oak saplings, REML as implemented in Genstat, and the Genstat procedure VWALD were used to test the qualitative grouping in 4 stand densities. In general, no clear density effects were established ($p = 0.10$). Examing the results more closely, it can be seen that the medium low density group had a relatively low growth rate (20 cm per year), and the medium high density group had a relatively high growth rate (24 cm per year), with the low and high density groups having intermediate values. However, the s.d.i. values within a group may be very different, with relatively low values at Uddel 140b. A REML analysis with s.d.i. (quantitative) instead of density (qualitative) did not show a relation of growth with s.d.i. either.

Table 51. Six years of height growth of oak saplings, planted when 2 years old in Scots pine stands which had undergone an increment felling.

stand no.	s.d.i.# at start	average height growth pedunculate oak, cm/year		s.d.i. after six years	basal area after six years, m^2/ha
Uddel 140b	0.58	22.7	(n = 44)	0.58	14.7
	0.63	20.5	(44)	0.69	17.4
	0.77	25.6	(44)	0.73	18.3
	0.88	25.5	(47)	0.91	22.9
Gortel 77gE	0.79	28.8	(36)	0.65	16.2
	0.85	21.9	(39)	0.80	20.0
	0.89	25.7	(36)	0.99	24.9
	1.08	19.2	(46)	1.00	25.0
Gortel 77gW	0.71	20.1	(32)	0.66	16.4
	0.86	15.8	(34)	0.75	18.5
	0.95	21.6	(40)	1.03	25.6
	1.06	19.0	(45)	1.29	31.9

s.d.i. = stand density index.

There were also stand differences. The average growth rate in Gortel 77gW (20 cm per year) was lower than in the other two stands (23-24 cm per year, s.e.d. 1.3 cm per year).

7.1.4 Effects of fencing on height growth of oak and birch

Five years after the regeneration experiment of 1987 was started, the saplings of deciduous trees which appeared on the permanent quadrats in the experimental stands were measured. Only the tallest sapling per permanent quadrat was measured. In order to compare the effects of browsing, the data from the fenced and unfenced areas were split. See table 52.

Table 52. Average height of the tallest, spontaneously established deciduous tree on the seedbeds, after 5 growing seasons. In brackets: total number of individuals.

	fenced	unfenced
Pal.Park 19d	55 cm, birch (n = 11)	17 cm, birch (8)
	107 cm, oak (4)	27 cm, oak (1)
Uddel 2a	100 cm, birch (6)	22 cm, birch (5)
Soeren 107b	96 cm, birch (5)	31 cm, birch (3)
Gortel 84a	137 cm, birch (34)	69 cm, birch (32)
	35 cm, oak (1)	26 cm, oak (2)

Discussion and conclusions

Although the number of saplings observed is small, it is obvious from table 52 that in the unfenced areas browsers reduce the height growth of deciduous tree saplings. Identical conclusions were drawn by Van de Veen (1979), Van Vuure (1985) and Tjebbes (1989), among many others.

In contrast to height growth, at the current abundance of game the numbers of spontaneously established deciduous tree saplings were not affected by the absence of a fence, as was noted from table 33 (subsection 6.2.3).

7.2 Height growth of young birch

7.2.1 Height growth of young birch in Scots pine stands with various basal areas

In the transects in Gortel 77g, the height of 371 birch saplings was measured in 4 consecutive years. The birch saplings had established after the stand was fenced. At the locations where the saplings grew, the basal area of the nearby mature Scots pine was determined with a Bitterlich Wedge Prism. The data on height growth over 3 years versus basal area are given in figure 39.

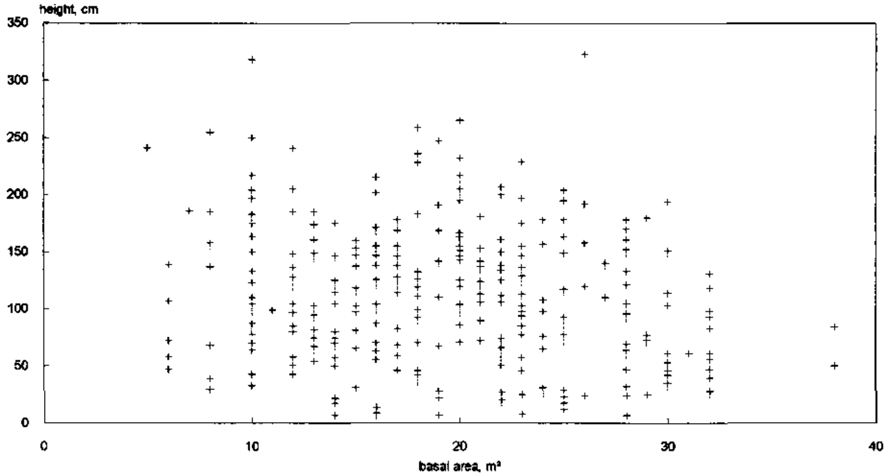

Fig. 39. Scatter diagram of height growth of birch saplings in 3 years, measured in Scots pine stand Gortel 77g, versus basal area of the Scots pine.

Discussion and conclusions

Figure 39 shows no relation between the basal area of the Scots pine and the height growth of birch saplings over 3 years. This is surprising for a tree species which has been described as light-demanding (e.g. Houtzagers, 1954).

7.2.2 Height growth of older birch trees under shelter of Scots pine

In Gortel 80a 33 birches which were dominant among the regenerated trees were selected. Their height growth over the years was measured, and the average height was calculated for each age. In figure 40 these averages are joined by a line. The standard deviation and yield class curves of Im_{max} 4, 6 and 8 m^3 per ha per year (Hamilton and Christie, 1971) are also given.

Discussion and conclusions

In spite of the shelter of the Scots pine, figure 40 shows an on-going average growth of the young birch trees over the years. Growth remains under the yield class curve of Im_{max} 4 m^3 per ha per year.

7.3 Height growth of young beech

The height growth of 10 dominant beeches in Palace Park 14 was measured. The average height was calculated for each age. In figure 41 these averages are joined by a line. The standard deviation and yield class curves of Im_{max} 4, 6 and 8 m^3 per ha per year (Hamilton and Christie, 1971) are also given.

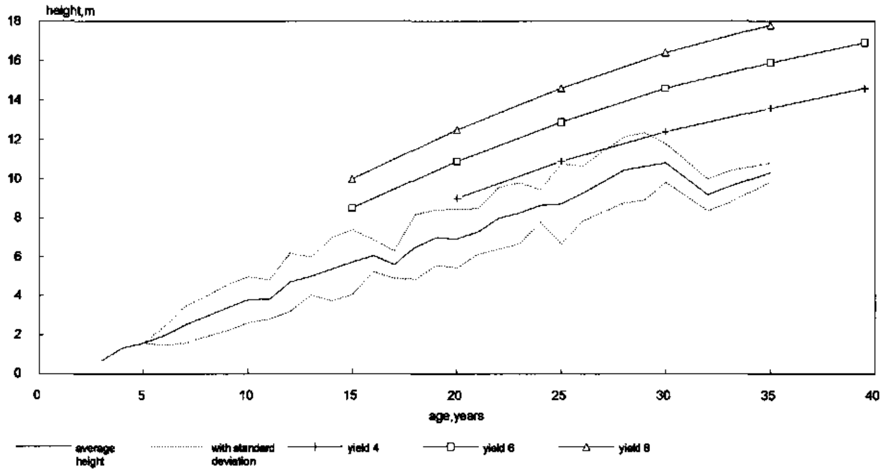

Fig. 40. Average height growth with standard deviation of birch trees, measured in Scots pine stand Gortel 80, compared with 3 yield class curves.

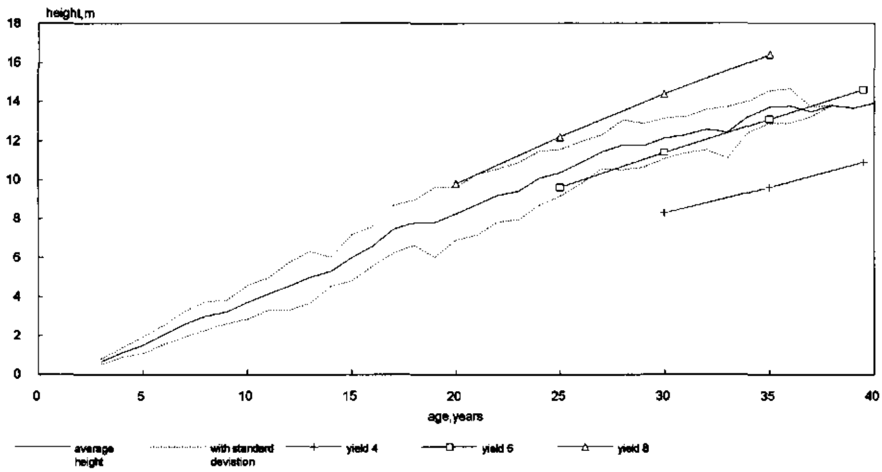

Fig. 41. Average height growth and standard deviation of beech trees, measured in Scots pine stand Palace Park 14, compared with 3 yield class curves.

Discussion and conclusions

In spite of the shelter of Scots pine, there was a considerable on-going average annual height growth in the beech trees. Because beech is a shade-tolerant tree, this is not surprising. The growth fits the yield class curve of Im_{max} 6 m^3 per ha per year (Hamilton and Christie, 1971).

7.4 Height growth of young Scots pines under old Scots pine

7.4.1 Height growth of young Scots pine saplings under shelter of Scots pine

7.4.1.1 Spontaneously regenerated Scots pine in Gortel 77g

The height of 325 Scots pine saplings was measured in the transects of Gortel 77g in 4 consecutive years. The Scots pine saplings had established after the stand was fenced. The basal area of the nearby mature Scots pine was determined with a Bitterlich Wedge Prism. The data on height growth over 3 years versus basal area are given in figure 42.

A relation was assumed between height growth of the Scots pine saplings and the basal area of the mature Scots pine in Gortel 77g. The hypothesis was that the model is described by the equation:

$$\text{height growth} = c_1 * g + c_2 \qquad (1)$$

in which g is the basal area of the Scots pine trees expressed in m^2, and c_1 and c_2 are constants. Regression was carried out with that equation. This resulted in the following answers: c_1 is –2.0, c_2 is 84.0, and R^2 is 0.14.

Discussion and conclusions

The relation between basal area of Scots pine stand Gortel 77g and the height growth over 3 years in Scots pine saplings was weak. This may be caused by the great variety of results at the low densities. This is in line with the results from the experimental stands, which are given in subsection 7.4.1.2. Figure 42 suggests that if the tallest saplings for each stand density were considered only,

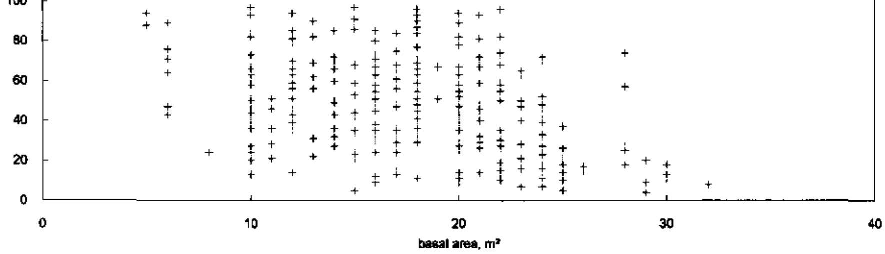

Fig. 42. Scatter diagram of 3 years of height growth of Scots pine saplings measured in Scots pine stand Gortel 77g versus the basal area of the Scots pine.

the relation between basal area and height growth becomes slightly stronger. Regression of the tallest saplings at each measured stand density confirmed this: c_1 is –3.2, c_2 is 137.4, and R^2 is 0.31. If regeneration consists of high numbers, only the tallest saplings are important, because these constitute the future trees.

7.4.1.2 Scots pine regeneration in the experimental stands

The effects of additional sowing, stand density, fencing and differences in soil tillage were tested on the height growth of Scots pine saplings. The tests were carried out with the data from the regeneration experiment in the 4 old Scots pine experimental stands of 1987. The experiment provided data over a period of 5 years.

Four stand densities were obtained by felling trees. In each sub-plot the stand density was characterized by the stand density index (s.d.i.), or by basal area. However, due to the storm of January 1990 a further reduction of density occurred in all experimental stands. Only the qualitative grouping in 4 densities (high, medium high, medium low, low) was used in the statistical analyses.

The design of the experiment was such that experimental units of different size are important. Growth is measured on individual trees, whereas density is a treatment applied to 40 x 20 m sub-plots. There were also 3 other treatment factors: fencing, applied to half sub-plots; soil treatment applied to rows within each sub-plot; and sowing, applied to permanent quadrats within each half row. The data from the experiments were therefore analysed with multi-level analysis of variance. In most cases the numbers of observations were unevenly distributed over the experimental units and treatment combinations, necessitating the use of special techniques for unbalanced data. Therefore, as in subsection 7.1.3, Residual maximum likelihood (REML) was used (Patterson and Thompson, 1971), as implemented in Genstat (Anon., 1990) and the Genstat procedure VWALD (Thissen and Goedhart, 1992).

The fixed terms in the models were density, fencing, soil treatment and sowing, the random terms included stand, plot, and tree differences.

The number of regenerated trees and average height growth per treatment combination per stand are given in table 53. The main test results and summaries from REML are given in appendix 7.4.1.2. The data of Palace Park 19d are plotted in figures 43a to d.

No statistically significant interactions were found between the 4 treatment factors. This facilitated the interpretation, which can then be in terms of main effects only. There were clearly significant effects ($p < 0.01$) of fencing and sowing, and also possible effects ($0.05 < p < 0.10$) of density and soil treatment. More specifically, fencing increased the average growth rate from 8.3 to 11.7 cm per year, and sowing increased the average growth rate from 9.2 to 10.8 cm per

Table 53. Average height growth of Scots pine saplings in the experimental stands of 1987, in cm per year.

			density:	low		med-low		med-high		high	
				mean	n	mean	n	mean	n	mean	n
stand	soiltr.	sowing	fence								
Pal.Park	kuloo	yes	yes	13.2	3	15.0	3	9.9	3	11.9	3
			no	13.3	3	13.2	3	10.8	2	7.6	3
		no	yes	11.4	3	*	0	7.4	1	2.2	1
			no	*	0	14.5	2	7.5	2	5.5	2
	rotov	yes	yes	8.8	3	18.1	2	9.8	3	7.8	1
			no	9.3	3	13.5	2	4.4	1	5.6	2
		no	yes	*	0	11.8	1	5.6	1	8.0	2
			no	11.4	1	10.8	2	6.6	1	6.9	2
Uddel	kuloo	yes	yes	16.7	3	18.9	3	17.2	3	9.0	3
			no	11.3	3	18.5	2	14.2	3	7.4	2
		no	yes	8.7	2	8.2	1	17.9	2	8.8	1
			no	14.0	2	15.5	2	8.7	2	10.0	1
	rotov	yes	yes	9.2	2	17.2	3	12.6	3	6.4	1
			no	11.4	3	12.5	3	7.9	3	6.0	1
		no	yes	14.8	1	10.6	1	8.8	1	*	0
			no	11.0	1	*	0	10.0	2	*	0
Soeren	kuloo	yes	yes	15.6	3	5.5	2	9.8	2	7.4	2
			no	7.8	3	5.1	2	4.2	1	8.2	3
		no	yes	7.2	1	*	0	6.6	1	2.4	1
			no	7.0	1	3.6	2	*	0	*	0
	rotov	yes	yes	19.1	3	9.2	1	6.8	1	7.8	1
			no	*	0	*	0	*	0	4.1	2
		no	yes	7.4	1	*	0	2.4	1	10.5	2
			no	5.2	1	*	0	*	0	*	0
Gortel	kuloo	yes	yes	15.2	3	15.0	3	13.3	3	12.3	3
			no	9.3	3	10.3	2	12.6	2	2.0	1
		no	yes	18.1	2	11.2	2	8.4	2	13.8	2
			no	13.7	2	8.8	1	6.6	1	6.7	3
	rotov	yes	yes	18.0	1	14.7	3	12.2	3	15.8	3
			no	1.4	1	8.8	3	6.0	1	8.0	2
		no	yes	15.0	2	11.7	3	13.7	3	9.4	2
			no	4.3	2	5.7	3	3.9	2	7.2	3

year. The highest average growth rates were found at medium low and low densities (11.4 to 11.5 cm per year) against 8.0 cm per year at high and 9.1 cm per year at medium high densities. There was a slight indication ($p = 0.09$) that soil treatment with the kuloo might be connected with a higher average growth rate than treatment with the rotovator (10.6 and 9.4 cm per year). No significant interactions were found between the investigated treatment factors. But in several cases there were large and significant differences in average height growth between stands.

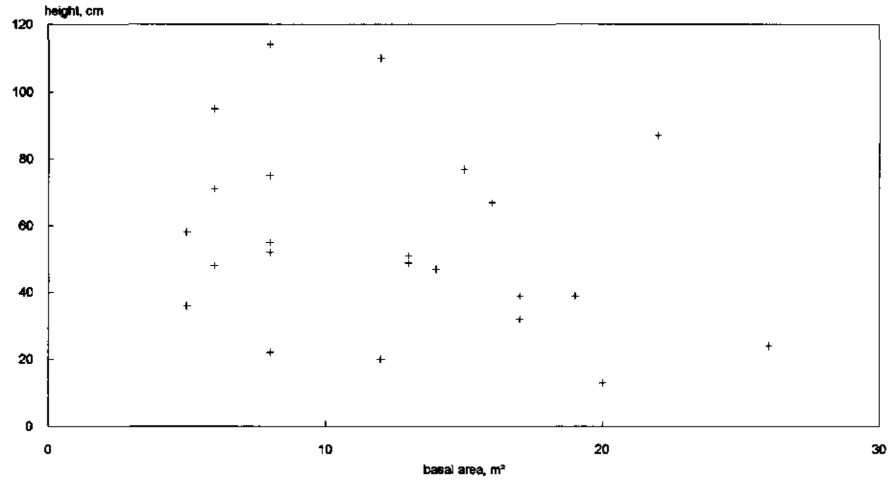

Fig. 43a. Scatter diagram of total height growth of Scots pine saplings over 5 years in a Scots pine stand, against basal area, fenced, with additional sowing, Palace Park 19d.

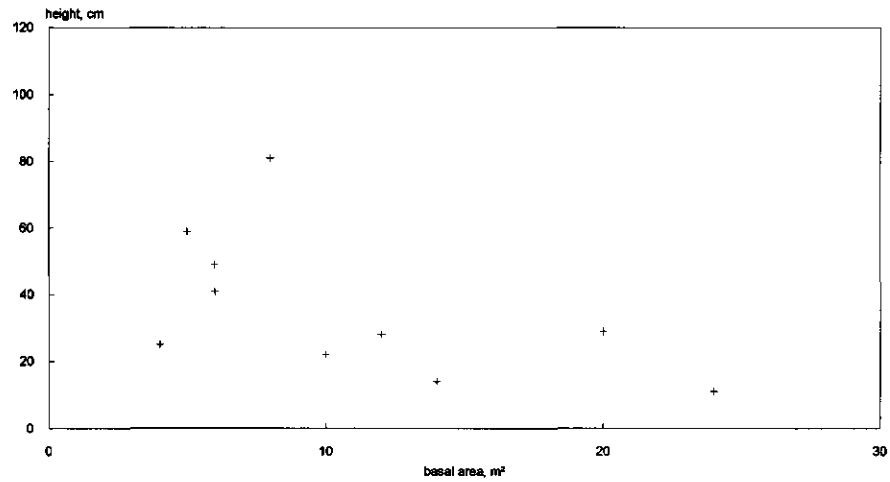

Fig. 43b. Scatter diagram of total height growth of Scots pine saplings over 5 years in a Scots pine stand, against basal area, fenced, no additional sowing, Palace Park 19d.

Discussion and conclusions

As in subsection 7.4.1.1 less height growth was found at higher stand densities, but the effect was small, and only statistically significant for the highest density. Again, the variety in data at low densities is great. This disguises probable stronger effects for the best growing individuals at various densities. Similar to deciduous species (subsection 7.1.4) fencing increased the average height

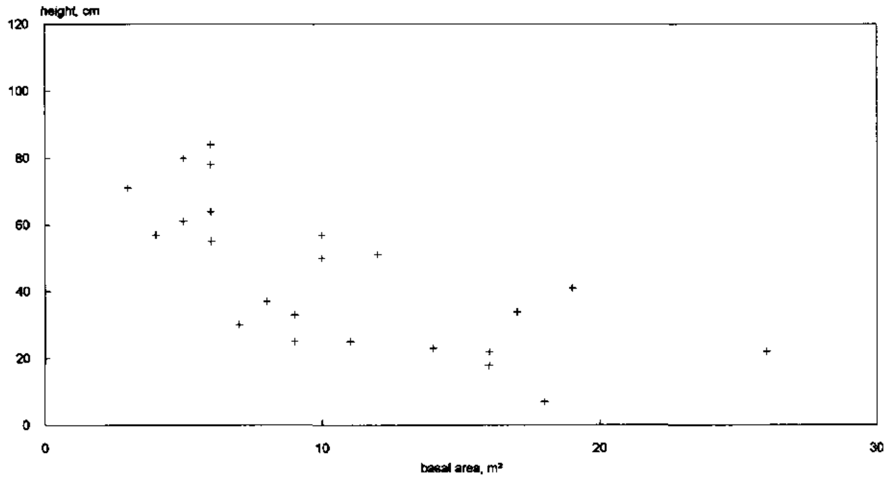

Fig. 43c. Scatter diagram of total height growth of Scots pine saplings over 5 years in a Scots pine stand, against basal area, unfenced, with additional sowing, Palace Park 19d.

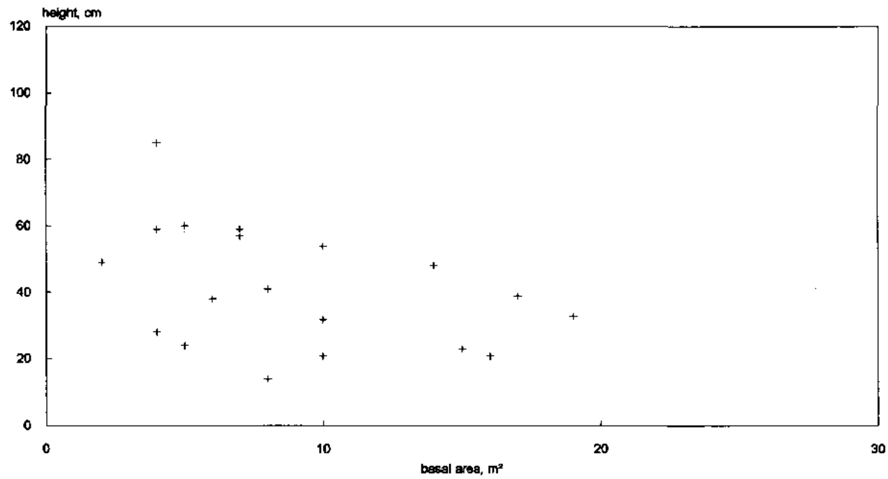

Fig. 43d. Scatter diagram of total height growth of Scots pine saplings over 5 years in a Scots pine stand, against basal area, unfenced, no additional sowing, Palace Park 19d.

growth of Scots pine saplings, although the effect on Scots pine was much less than on oak and birch. In the permanent quadrats with additional sowing the average height growth was higher than in the permanent quadrats without sowing. This might have been caused by the genetic qualities of the provenance selected for sowing.

Similarly to the effect of density described above, in Bavaria Seitz (1979) found diminishing height growth with increasing basal area. However, he mentioned various exceptions as well as differences in shoot growth from one year to another. In general, he found a considerable dispersal of height growth.

7.4.2 Height growth of older Scots pine saplings under shelter of Scots pine

From Palace Park 14 and 19, Uddel 26 and 52 and Gortel 8, 19, 92 and 133, the height growth of 258 Scots pine saplings taller than 1.3 m was analysed. The saplings were all growing under the canopy of old Scots pine. The average height was calculated for each age. In figure 44 these averages are joined by a line. The standard deviation and 3 site index curves are also given.

Discussion and conclusions

Average height growth of suppressed Scots pine showed an increase over the years. This may have been caused by the fact that the taller the sapling is, the nearer its crown is to the stand canopy, and the more light it receives. This is illustrated in figures 30 and 31. Figure 44 shows that after release the reduced height growth of the suppressed Scots pine saplings recovered to such an extent, that the Scots pines climb several site index levels. This is in line with the results from Weck (1947) and Backman's theory (1942 and 1943). Similarly, Voegeli (1954) and Seitz (1979) mentioned the recovery of growth in Scots pine after they had been released from suppressing larger trees in Switzerland and Bavaria. The recovering effect was not noted for suppressed oak, birch or beech (figures 38, 40 and 41). This suggests that Scots pine is much more a pioneer species than oak, birch and beech.

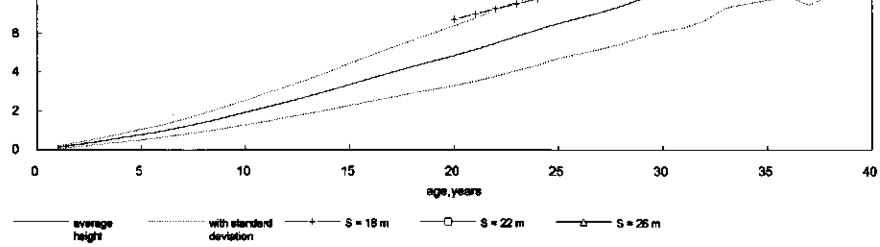

Fig. 44. Average height growth and standard deviation of Scots pine saplings under shelter of old Scots pine stands on humus podzols, compared with 3 site index curves.

7.4.3 Growth of Scots pine saplings and light availability

Growth and light in gaps

One gap was created in Palace Park 13 by felling trees and 6 were made in Palace Park 14 (subsection 6.5.1). Both are mixed stands of Scots pine, oak, birch and beech. Tree heights range from 4 to 24 m. In these gaps, which were fenced to exclude game, regeneration of various tree species appeared. In the larger gaps (approximately 0.9 to 1.1 th) this regeneration included Scots pine. The DFOV PAR percentage on the forest floor was measured along a line through the centre of the gaps. All seedling heights were measured. Data on DFOV PAR percentage and regenerated trees within 1 metre of the location of measurement are given in appendix 7.4.3. Height growth of Scots pine saplings in the gaps was plotted versus the percentage DFOV PAR (figure 45a).

Growth and light under shelter

Similar measurements were carried out in Scots pine stands with a reduced basal area. This was done in Gortel 133f, a 104-year-old Scots pine stand on humus podzol and Gortel 133h, a 99-year-old Scots pine stand on humus podzol. The reduction of basal area took place in 1984. The Scots pine regeneration established itself after soil scarification. Protection was given by a game fence. Heights of the tallest saplings within one metre of the location of PAR measurement were measured. The PAR measurements are given in appendix 7.4.3. The percentage of DFOV PAR was plotted versus average height growth per year for Scots pine in figure 45b.

Discussion and conclusions

Figures 45a and b warrant the conclusion that at relative DFOV PAR levels above 50%, average Scots pine sapling growth of 15 cm per year in the first 5 years is possible. According to figures 31 and 32 in subsection 6.4.3 (data from FOREYE), these radiation levels are reached on the forest floor in gaps of approximately 1.2 to 1.6 th (tree height) at stand densities 0.7 and 1.0 respectively. In field measurements 50% DFOV PAR levels were reached at gaps of 0.6 to 1.4 th in Scots pine stands with stand densities ranging from 0.8 to 1.3 (figure 34, subsection 6.4.4). These gaps are smaller than described above, which was concluded earlier in subsection 6.4.2. In Scots pine stands without gaps, 50% DFOV PAR was reached at basal area 12 m^2 (data from FOREYE; figure 27, subsection 6.4.1). Field measurements however, showed higher basal areas at 50% DFOV PAR, ranging from 15 to 25 m^2 (figures 28 and 29, subsection 6.4.2). The basal area of the old Scots pine in Gortel 133 in 1991 was 16.0 m^2. At that basal area relative DFOV PAR levels were higher than 50%. Hence, also higher than the data from FOREYE. However, Gortel 133 is much older than the simulated stands in FOREYE.

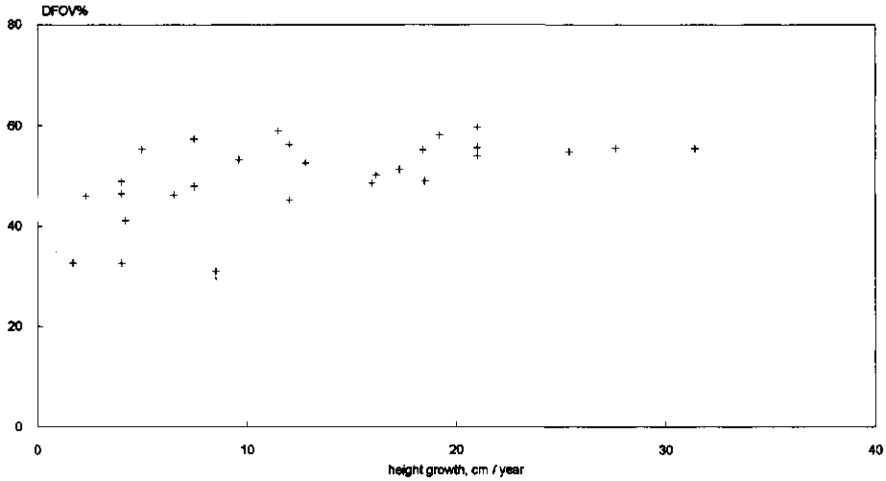

Fig. 45a. Scatter diagram of height growth of Scots pine sapling versus relative DFOV PAR, measured in gaps in Palace Park 13 and 14.

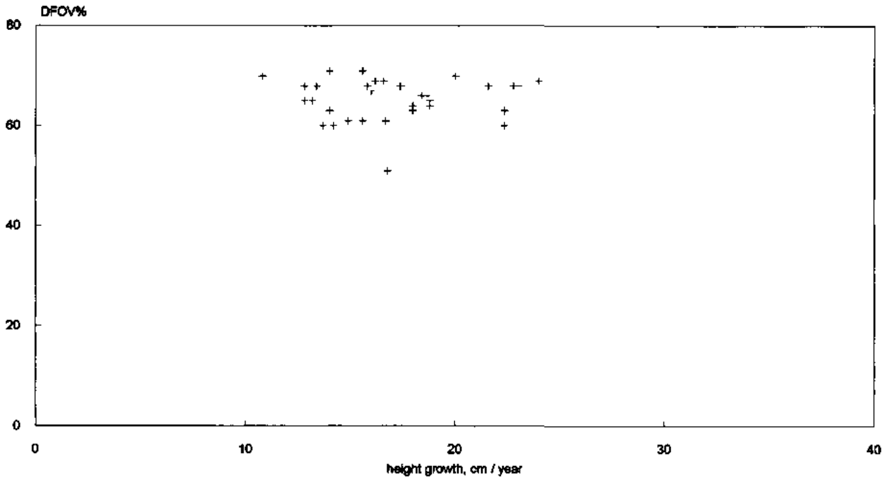

Fig. 45b. Scatter diagram of height growth of Scots pine saplings versus relative DFOV PAR, measured under shelter of Scots pine in Gortel 133f and h.

7.4.4 Height growth of Scots pine saplings, planted in old Scots pine stands

Average height growth of 2-year-old Scots pine saplings planted in the fenced experimental sub-plots of Scots pine stand Uddel 2a after 4 growing seasons are given in table 54.

Table 54. Average height growth over 4 years of Scots pine saplings planted under old Scots pine, Uddel 2a.

s.d.i. at start	s.d.i. Feb.1990	g, m^2 Feb.1990	no. alive	growth/y
0.36	0.22	6.1	21	27.9 cm
0.51	0.44	12.0	15	25.8 cm
0.70	0.48	12.8	18	26.3 cm
0.76	0.67	17.6	21	18.9 cm

Statistical analysis of the average growth over 4 years was carried out as in subsection 7.4.1.2. No difference could be ascertained between the fixed treatment factor 'density' and the random block factor 'plot'. This was, because only one stand with 4 plots was used, and each plot had its own density. If this fundamental confounding of effects is accepted, the statistical significance of differences between the 4 plots (=densities) could still be examined. An ordinary ANOVA can then be performed, because 'plot' is treated as a fixed factor.

Statistical test results and summaries from ANOVA are given in appendix 7.4.4.

There are statistically significant differences between plots, and therefore potentially between densities ($p=0.001$). Specifically, the average growth rate in the plot with the highest density was 21 cm per year, which is much lower than the rates in the 3 plots with lower densities (32, 28, and 30 cm per year respectively). The s.e.d. for comparing these values is 3 cm per year, so that differences between the latter 3 plots are statistically not significant.

Discussion and conclusions

Similar to the results of spontaneously regenerated Scots pine (subsection 7.4.1.1) and the Scots pine regeneration in the 1987 regeneration experiment (subsection 7.4.1.2) less height growth is found at higher stand densities. However, there is no strong relation between density and height growth. Scots pine can successfully be planted under shelter of mature Scots pine.

8 Rehabilitation measures to enhance ecological value

As stated in chapter 1, cultivated forests endure extraction of biomass, limitation of tree sizes, imposition of anthropogenic dynamics, manipulation of tree species composition, and manipulation of the distribution and abundance of game. If, apart from the sustainable provision of timber (section 1.1), the policy is to rehabilitate cultivated forests to become modified natural forests (section 1.1), then additional measures must be carried out to restore the effects of cultivation.

An ecological reference (cf. Baerselman and Vera, 1989) is needed to determine what natural processes are supposed to take place in forests on the Veluwe and what the forests should ultimately look like. For the reconstructed ecological reference for the Veluwe Baerselman and Vera (1989) stated (p33): 'Locally, large clearings occur, caused by storm or fire. On a smaller scale, openings in the forest are created by natural mortality of trees and by activities of large browsers. Locally, clearings are kept open by grazing over long periods.' and: 'forests with as most important tree species pedunculate and sessile oak, lime tree (*Tilia sp.*), elm (*Ulmus sp.*), beech and hornbeam (*Carpinus betulus*)'. Hence, trees will develop to big sizes, natural mortality provides dead wood, fragmentation provides a mosaic of age classes of indigenous tree species, and large browsers affect the occurrence of regeneration.

8.1 Big trees

Natural forests comprise trees of all sizes. The harvesting of trees, however, prevents trees from growing to sizes larger than the financial diameter. If species conservation is one of the objectives of sustainable forest development, big trees must be present to fulfil their specific niche development.

Big trees will develop in the forest if harvest is postponed. But the disadvantage of postponement is the loss of revenue from the interest from the trees that were not harvested earlier. Further research needs to be done to find the optimum postponement that will allow full species conservation.

8.2 Dead wood

Dead wood, whether standing or lying, is important to many species of organisms (Barkman et al., 1983; Barkman, 1983; Van der Werf, 1983; Mabelis, 1983;

Komdeur and Vestjens, 1983). Siepel (1992) reported that in the Netherlands 40 to 50% of all fauna species that are confined to forests are dependent on standing or lying dead wood.

Little dead wood is present in forest plantations. In contrast, considerable amounts are present in natural forests. Falinski (1976) reported from degrading lime-hornbeam forest (Tilio-Carpinetum) in Bialowieza, Poland, the decay of 29 m^3 and the addition of 40.3 m^3 dead wood per ha over a period of 10 years. Altogether, 71.3 m^3 dead wood (excluding branches) was still present per ha after the 10 years. From mature Douglas-fir forests with slow decay in western Montana, USA, Harvey et al. (1981) mentioned 154 to 430 m^3 dead wood per ha, equivalent to 37% to 59% of the total biomass. Koop (1981a) reported 10 to 15% of the total wood volume as dead wood from various forest types with, among others, oak, beech, ash and lime in Neuenburg and Hasbruch, Germany. He also pointed out the differences in amounts of dead wood, caused by the various developmental phases of the forest. The same author (1983) reported quantities of 50 to 100 m^3 dead wood per ha from various forest reserves in Germany, France and Poland.

In beech-silver fir forest in Badin, Slovakia, 29% of the total wood volume was reported to be dead wood (Anon., 1992b). Also in Slovakia, in beech forests, Korpel (1992) reported 30 to 210 m^3 dead wood per ha, depending on the developmental phase of the forest compartment. Standing live wood volume ranged from 250 to 800 m^3 per ha. Huber (1993) and Bönecke (1993) reported 32% and 28% of the living wood volume as dead wood in respectively spruce-beech forest and oak-ash-elm-sycamore forest in the Czech Republic.

Clearly, all natural or semi-natural forests contain substantial amounts of dead wood although there are differences in the amounts and percentages of dead wood in the various forest types. Therefore, if forests must be rehabilitated from the cultivated stage to a modified natural stage, dead wood must be produced. Because big dead trees contribute most ecological value (Cosijn, 1981; Barkman, 1983; Koop et al., 1990; Koop 1992), special emphasis must be paid to the larger trees.

Different tree species not only provide different substrates (Barkman et al.,1983), but also show different rates of decay (Koop et al., 1990; Korpel, 1992). Therefore it is important to provide big dead trees of different species. Preliminary measures such as felling, ringing and pulling trees over, can be applied. Natural dynamics will ensure a (dis)continuous supply of dead wood.

If dead trees of all sizes are wanted, it is not sufficient to postpone the harvest. Some of the trees must die, e.g. of old age. Dead wood will accumulate if part of the harvest is abandoned. This can be realized by creating zones (section 1.3) where no harvesting takes place. The disadvantages of no-harvest zones are: 1. the loss of revenue from interest from the not harvested trees; 2. the loss of revenue from valuable future trees*. Therefore, zones must be established before future trees are selected. More research needs to be done to ascertain the optimal size of no-harvest zones and the pattern of zoning.

By extracting timber from forests, the chances of ecological niches developing in dead wood are reduced. These chances cannot be *fully* restored by zoning or any other measure. More research needs to be done on the relation between absence of niches and loss of species, with the aim of identifying an economically acceptable and ecologically accountable level of reduction of chances.

8.3 Fragmentation

Natural forests are characterized by change (Bormann and Likens, 1985; Koop, 1981a; Oldeman, 1990; Otto, 1993). Trees die through competition, from old age or disease, or through uprooting by wind. This causes a shifting mosaic of young developmental phases among older ones. Species diversity is closely linked to the occurrence and spatial arrangement of these developmental phases (Koop and Hilgen, 1992). To ensure viable populations of various forest species, suitable habitats must be continuously present at short distance in a fine-grained mosaic. This is especially important for species confined to the old developmental phase which have low dispersal capacity. The chances of suitable habitats becoming colonized during their limited lifetime, depend on their distance from already colonized habitats (Koop, 1993).

In spite of its dynamic character, in the *mature* forest mosaic the proportions of different successional stages and developmental phases are stable and their typical temporal distribution is according to size of the eco-unit (Koop, 1981a), providing the forest covers a sufficiently large area. This area is defined by Koop as the 'minimum structure area' and for broadleaved forests of Europe this minimum area is approximately 40 ha (Koop, 1981a; Korpel, 1982).

Cultivated forests are also characterized by change. However, this change has been applied uniformly over large areas, especially in the case of clearfelling. Forests in advanced developmental phases have been replaced by early successional stages in their early developmental phase. A similar homogeneous effect is caused if the forests are thinned uniformly (Koop and Hilgen, 1992). If these cultivated forests are left untouched, it may take centuries for a natural pattern of the forest mosaic to re-emerge (Koop, 1986 and 1989). On the other hand, Koop (1981) found that 'open areas', which included the treeless and establishment phases with saplings smaller than 2 m, covered 10 to 15% in near-natural broadleaved forests on sandy soils in north-western Germany. He attributed the high percentage of 'open areas' in 1977 to the severe storms in 1972 and 1973 (pers. com., 1993).

In his research in semi-natural broadleaved forests on sandy soils in north-western Germany, Koop (1986) found that eco-units with diameter sizes larger than 2 times the height of surrounding trees were rare. Moreover, the eco-units were smaller in the species-richer forest types. Eco-units with diameters of ½ to 1 times the height of surrounding trees were the common feature, eco-units of 1 to 2 times the height of surrounding trees were much less common (Koop, 1981a). Koop's findings are corroborated by research done in Switzerland and the Black Forest in Germany by Schmidtke (1993). He also found, that with increasing size of the wind-blown area the number of such eco-units decreases exponentially.

If forests are to be rehabilitated from the cultivated stage to a modified natural stage, fragmentation of the stands speeds up the process. Initially the eco-units must have diameters ½ to 2 times the height of surrounding trees, with most eco-units of the smaller sizes. Koop and Hilgen (1992) suggested cutting 10 to 15% of the stands, as a preliminary measure.

Fragmentation by transitional management measures is done to speed up the natural process of fragmentation towards a more natural forest mosaic. In Scots pine forests this process is affected by regeneration by oak in the closed stand before the stand is 50 years old (chapter 5), provided browsers are not too abundant. Beech can regenerate even sooner in Scots pine. Therefore, Scots pine stands must be fragmented before these stands are approximately 50 years old. The first reason for starting fragmentation before the stand is this age is the need to prevent the period of years between the older trees and the regeneration being too long. Postponement of fragmentation reduces the period between anthropogenic fragmentation and spontaneous fragmentation. The second reason for starting fragmentation is to prevent regenerating deciduous trees giving rise to another homogeneous even-aged stand.

After preliminary fragmentation, natural dynamics will ensure that the forest mosaic develops.

8.4 Tree species

Baerselman and Vera (1989) based the occurrence of oak, lime tree, elm, beech and hornbeam on palynological data from Polak (1959). From excavations of grave mounds, Waterbolk (*in*: Maes and Van Vuure, 1993) found that lime trees had been common in the period 3500 to 2700 B.P.. However, according to Polak (1959) lime and elm pollen were rare throughout the Subboreal (5000 to 2900 B.P.). Although Polak found lime and elm pollen in the Uddelermeer, a small lake at Het Loo, it was not determined at what habitat near (or possibly far away from) the Uddelermeer these tree species occurred. Hornbeam was still rare during the Subboreal. Beech, as invading species, was already increasing. Birch pollen has been found throughout the samples from the Subboreal.

However, neither Westhoff and Den Held (1975) nor Van der Werf (1991) mentioned lime tree or elm in the Betulo-Quercetum and the Fago-Quercetum, although these are the potential plant communities that should dominate the Veluwe. Koop (1993) regarded leaching of the forest soils, and Tubbs (*in*: Koop, 1993) the increased abundance of game, as main causes for the disappearance of species such as lime and elm.

Yew tree (*Taxus baccata*) was not mentioned by Polak (1959). Van Zeist (*in*: Van Vuure, 1990) found yew pollen over the period 4500 to 1000 B.P. in Drenthe, the Netherlands. Van Vuure (1990) considered yew as a species of, among others, the Fago-Quercetum. Yew may have disappeared because of over-exploitation and browsing by game. He classified the management systems used on the Veluwe during recent centuries (either oak coppice or beech high forest) as unfit for yew; the former because of the cutting regime, the latter because of its heavy shade.

If forests must be rehabilitated from the cultivated stage to a modified natural stage, the tree species that comprise the natural forest must be available for regeneration. Whether they will successfully regenerate and survive is a different matter.

Pedunculate and sessile oaks are present all over the Veluwe. Acorns will be spread by jays (Bossema, 1979). Birch seeds are spread by wind. Beech is also a common species on the Veluwe. Although beech does not spread easily it spreads persistently, thanks to its shade-tolerance. Hornbeam is rarely found on the Veluwe, but at least, it occurs. None of these tree species are greatly hampered in their regeneration by the Scots pine. Lime tree, elm and yew are absent from most of the forest on the Veluwe.

In the light of the evidence presented above, the local introduction of the disappeared tree species could be considered as a transitional management measure in the Veluwe. All the tree species that currently occur in this area can survive competition with Scots pine. Therefore it is not necessary to favour any of them. However, favouring locally available species of the Querco-Betuletum and Fago-Quercetum will speed up the rehabilitation of the stands.

8.5 Game

The impact of game is a natural environmental factor affecting the vegetation (Londo, 1991). Because of the mobility of game, Cosijn (1981) stated that processes such as rooting, grazing, browsing, trampling and enrichment by droppings occur at various intensities in specific spatial patterns. At present roe deer, red deer and wild boar are the only large ungulates occurring in most parts of the Veluwe. It is not clear which ungulate species would be living in forests in north-western Europe if man had not hunted them. Van de Veen (1985), Van der Lans and Poortinga (1986), and Baerselman and Vera (1989) mentioned species such as moose (*Alces alces*), European bison (*Bison bonasus*), aurochs (*Bos taurus*) and wild horse (*Equus caballus*). Bottema (1987) has doubts about the occurrence of the wild horse from the Boreal onwards and of the European bison altogether. No data are available on the natural abundance of the animals that are found in the region today.

The above authors also disagreed about whether the ungulates were able to keep the forest more or less open, although there was little doubt that the animals were at least able to extend the period chablis remained open. In the present study area, both hampering of regeneration and selective regeneration could be observed in gaps in Soeren 46m and g, which are divided into fenced and unfenced areas. After 5 years the fenced area of Soeren 46m showed abundant regeneration of birch, beech, oak and Scots pine over 3 m tall. The unfenced part showed sparse regeneration of birch, beech and Scots pine less than 50 cm tall. A fenced area in Soeren 46g showed abundant regeneration of birch and Scots pine. Outside this area only Scots pine regenerated.

Selective regeneration, favouring Scots pine at the cost of deciduous species was also demonstrated in the experimental Scots pine stands of 1987 (subsections 6.2.3 and 7.1.4).

The regeneration in Soeren 46 established at an estimated animal abundance of ca. 4 red deer, ca. 4 roe deer and ca. 3 wild boar per 100 ha. Jongman et al. (1977) showed that the natural food available makes abundances of over 6 red deer per 100 ha possible on the Veluwe. At such abundances, gaps in the forest will certainly be kept open for longer than currently, and if some of the hunted-out ungulates were reintroduced, this effect would be intensified. Reduced numbers in regeneration and selective regeneration were also reported from the New Forest, England, by Putman (*in*: De Bie et al., 1987).

Although it is possible to determine what abundance of animals can survive, given the natural food available on the Veluwe, it will be impossible to determine what the natural abundance and distribution of the ungulates will be, because their predators are no longer present. At the moment, the large ungulates on the Veluwe are forced to live in fenced areas. This prevents them from migrating to richer habitats than the Veluwe. Such migrations might have caused fluctuations in abundance and distribution of game.

Whereas fluctuation in abundance results in regeneration opportunities or eco-units of young trees in the preliminary anthropogenic fragmentation (section 8.3), it also results in chablis where regeneration is hampered by browsing. The possible game management measures that imitate such fluctuations are the drastic reduction of numbers of game through fencing or culling, or relinquishing culling, which will result in increased numbers.

8.6 Conclusions on rehabilitation measures

Clearly, a range of possible measures is available to enhance the ecological value of cultivated forest stands. The implications of implementing these measures will be discussed in the next chapter, in relation to the economics of forest management. Further research needs to be done to ascertain the feasibility of full species conservation.

9 Implications for management

In this chapter, various economic and management parameters are considered in the light of the objective of sustainable forest development, using the data obtained from the fieldwork in Het Loo.

9.1 Financial diameters of individual crop trees*, based on 'profit only'

The objective of 'profit only' was applied on timber harvest in the zoning-harvesting model (section 1.3) where harvest is restricted to areas around forests that have been designated for strict species conservation. The objective of 'profit only' from timber implies exploitation to maximize the sum of revenue from timber harvest plus revenue from the interest that will be drawn from the harvest earnings. In this way the highest present net value is achieved. Trees will be harvested as soon as their current increment in value falls below the sum of the interest from their stumpage value and the soil rent (Johansson and Löfgren, 1985; Howe, 1979; Kuper, 1992a). For the calculations in this study, an interest rate of 3% was used (Kuper, 1992a). Alternative investment opportunities, after taxes, were assumed to be available at this level of interest.

In the Netherlands a distinction must be made between the rate of interest chosen for the forest owner's own money and the rate of interest for borrowed money. Own money can be used for various investments, but then tax must be paid on the returns from these investments. This produces the alternatives to investment in timber production. Timber revenues are not taxable in the Netherlands. Consequently costs of borrowed money are not tax-deductible. The full costs of borrowing must be deducted from the timber revenue, which is in fact revenue after tax. In this study, calculations were done on the assumption that own money is used for investments.

Speidel (1984) stated that interest should be calculated on all capital components, but he considered the interest on bare land and standing timber volume to be part of the enterprise's revenue. However, since the extent of the standing volume can be chosen, and this affects the amount of revenue, interest must be calculated on net stumpage values of trees. This does not apply to the land.

In the Netherlands, by law land that is designated forest land can be used for forest only. As long as soil fertility is not affected, the monetary value of the land does not change. Therefore, there is no need to calculate interest on land. The final net revenue, after management costs have been deducted, is the revenue from the land. If the interest earned from money obtained by selling the land is higher than the earnings from forestry from that land, then the land should be sold (Kuper, 1992a).

Financial diameter and percentage value increment

In section 4.3 the percentage value increment of individual trees in even-aged Scots pine stands was calculated. If no regeneration costs are incurred after the trees are harvested, and soil rent is zero, then the financial diameter of individual crop trees with a specific management history can be read from figures 20 a and b. *The net market interest percentage determines the financial diameter, measured over the bark, at the various site indices.*

The diameter at which the percentage value increment at price level 2 dropped to 3% was calculated for each of the 213 randomly sampled Scots pine trees. This was done by determining a regression line from the tree ring data of each tree. The trees were allocated to one of the 3 occurring site classes. The same procedure was applied to the solitary Scots pine trees mentioned in subsection 3.3.1. Nearly all these trees were in one site class. The statistics of the resulting financial diameters are given in table 55.

At site class 22 m the difference in average financial diameter of the randomly sampled Scots pine trees and the solitary Scots pine trees was tested statistically with the one-sided 2-sample t-test. The average financial diameter of the solitary trees was found to be statistically significantly lower than the average financial diameter of the randomly sampled trees ($p < 0.01$).

The difference in average financial diameter between the various site classes was tested in the same way. Although the trend was for average financial diameters to increase with the increasing site classes, this was only statistically signifi-

Table 55. Average financial diameters and standard deviation for Scots pine trees of various site classes at price level 2 and soil rent zero.

Randomly sampled Scots pine trees			
site class :	18 m	22 m	26 m
number of trees :	9	70	90
average financial diameter:	28.1	30.2	34.8
standard deviation :	7.2	9.4	12.1
standard error of the mean:	2.4	1.1	1.3
Solitary Scots pine trees			
site class :		22 m	
number of trees :		66	
average financial diameter:		33.6	
standard deviation :		6.5	
standard error of the mean:		0.8	

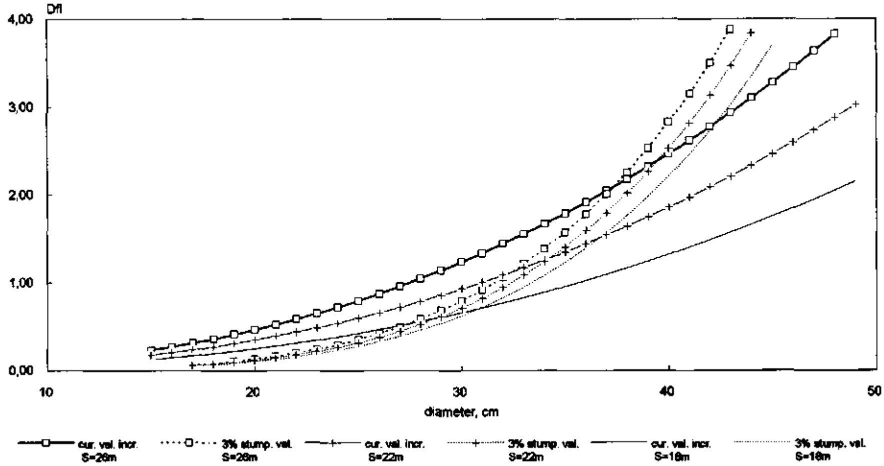

Fig. 46a. Fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at zero soil rent, at timber price level 2, for 3 chosen site indices.
cur.val.incr. = current increment in value,
stump.val. = stumpage value,
S = site index.

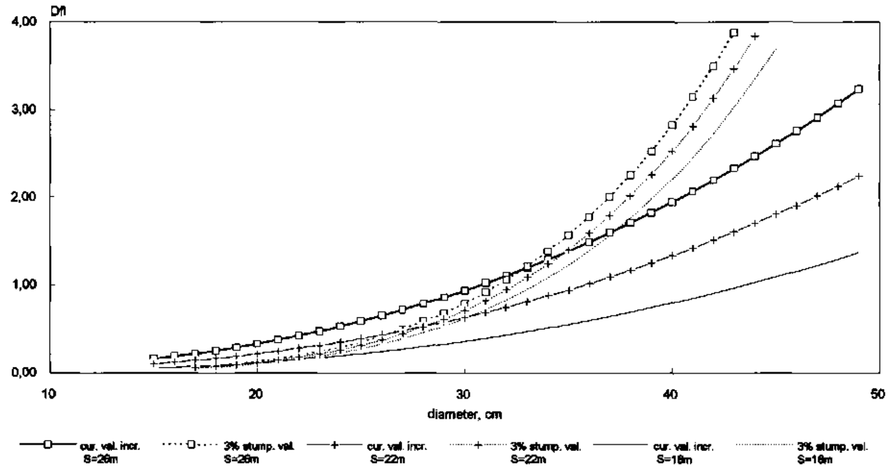

Fig.46b. Fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at soil rent Dfl 100 per ha, at timber price level 2, for 3 chosen site indices.

cant between site class 26 m and both smaller site classes ($p < 0.01$). The difference between site classes 18 m and 22 m was not statistically significant ($p = 0.26$).

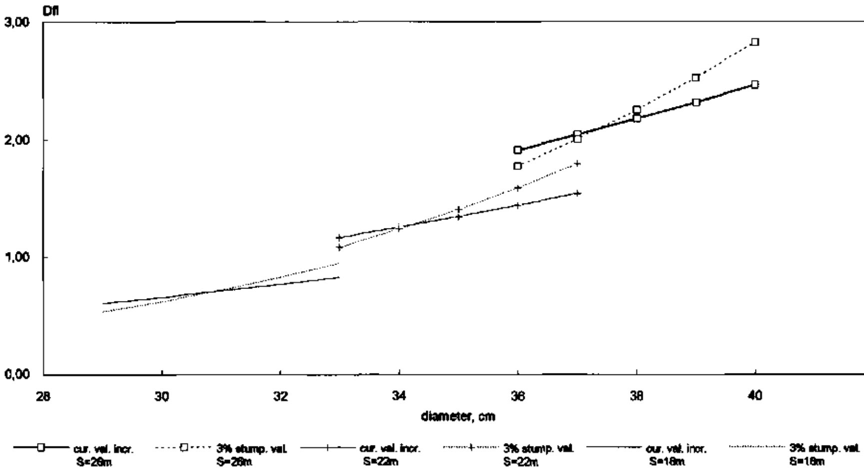

Fig. 47a. Enlarged detail of figure 46a.

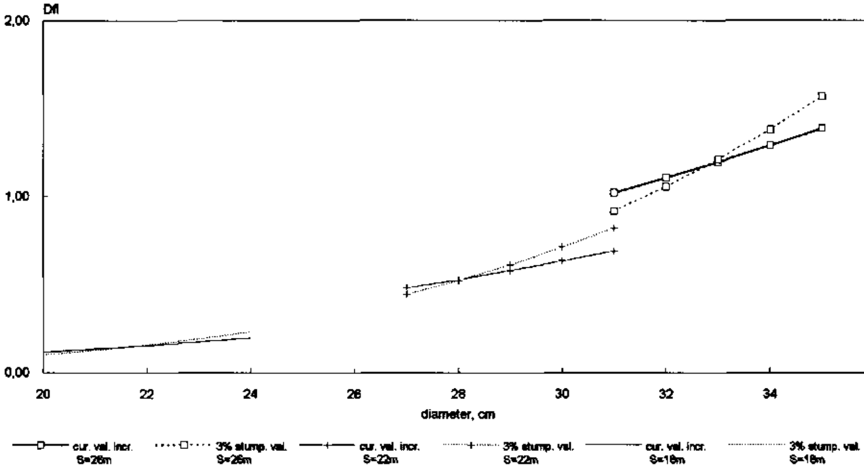

Fig. 47b. Enlarged detail of figure 46b.

Financial diameter and soil rent

At a fixed percentage interest, the financial diameter is determined by the *current increment in value*, the *stumpage value* and the *soil rent*. It is reached when the current (yearly) increment in value of a tree falls below the sum of the interest from its stumpage value plus the soil rent. In figure 46a the fitted current increment in value of individual trees in even-aged Scots pine stands (section 4.3) is plotted against the interest from the stumpage value of that tree at zero soil rent, at 3 chosen site indices and timber price level 2. In figure 46b the equal current increment in value is plotted against the sum of the interest from the stumpage value of the tree and a hypothetical soil rent of Dfl 100 per ha. A basal area of 24 m^2 is assumed. An interest rate of 3% is used. This procedure yields financial diameters, measured over the bark, for the specific management history.

Figures 47 a and b give enlarged details of figures 46 a and b respectively.

Financial diameter and regeneration cost

In calculations with the objective 'profit only', the financial diameter is determined by the *stumpage value*, *current increment in value*, the *soil rent* and the *interest rate*. Harvest is independent of the costs incurred for stand regeneration. Regeneration involves a new financial item, which influences the soil rent, but must not otherwise be used to determine the time of harvesting. In the Netherlands, however, forest owners are legally required (Anon., 1984) to reafforest land from which trees have been harvested, unless regeneration appears spontaneously within 3 years. Therefore, calculations were carried out to determine the financial diameter, measured over the bark, at various regeneration costs for 3 site indices and 2 timber price levels. The basal area of the stand was assumed to be 24 m^2. In figures 48 a and b, 49 a and b and 50 a and b the fitted current increment in value in Dfl per tree per year is plotted against the 3% interest yield of the stumpage value of the tree, after deducting various regeneration costs. This procedure was followed for 3 site indices and 2 timber price levels, all at zero soil rent.

Discussion and conclusions

The financial diameters which appear in this section are only valid at the specific management history of the stand, which at Het Loo is decades of low thinning. The financial diameters were calculated from data from living trees. No risks of storm, fire or other mortality were included in the calculation. Values other than those of revenue from timber, such as ecological and aesthetical value were not included in the calculations.

As illustrated in figures 48 to 50, the financial diameter increases with increasing site index. The standard deviations of these financial diameters are large. At price level 2, the difference between average financial diameters of groups of trees of site classes 22 m and 26 m was statistically significant. This was not the case between the average financial diameters of site classes 18 m and 22 m. This was probably caused by the low number of sampled trees. Solitary trees have a statistically significantly larger financial diameter than the randomly sampled trees. At increasing soil rents the financial diameters are smaller (see figures 46 and 47). Altogether, the financial diameters at Het Loo ranged from 30 to 50 cm under the chosen conditions, with zero soil rent. *As a result, no generally applicable financial diameter can be given. Financial diameters must, therefore,*

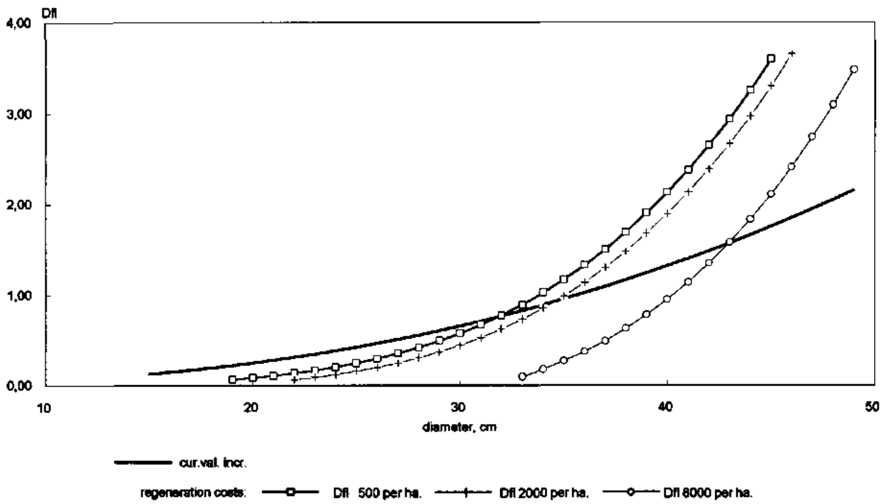

Fig. 48a. The fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at various regeneration costs, at timber price level 2, site index 18 m and zero soil rent.

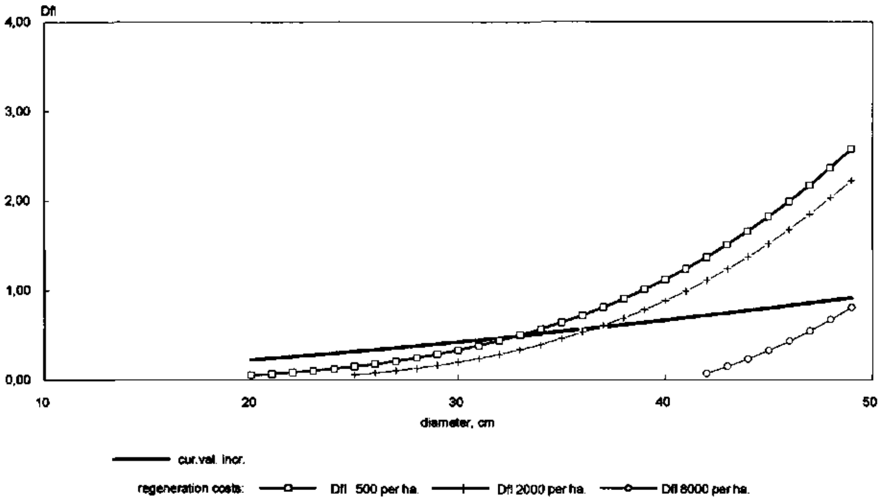

Fig. 48b. The fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at various regeneration costs, at timber price level 3, site index 18 m and zero soil rent.

be calculated from growth data obtained locally under the locally applicable management conditions.

All diameters cannot be equal in size at the same time, therefore, harvesting

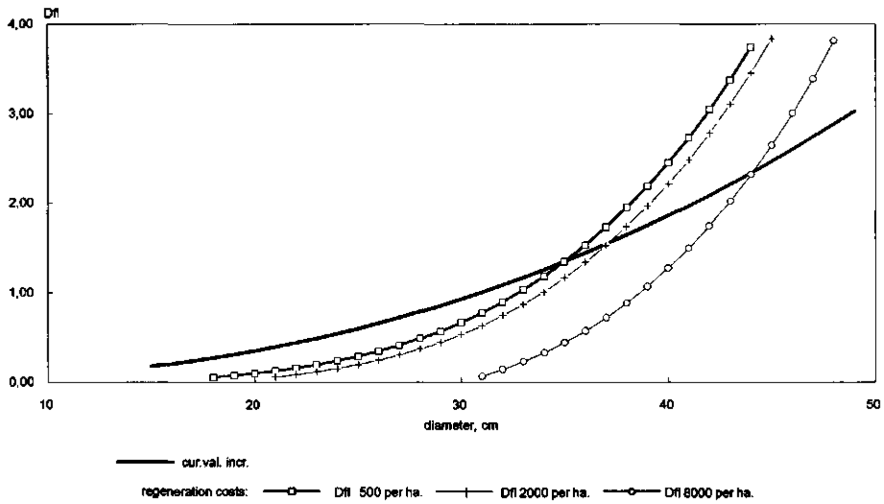

Fig. 49a. The fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at various regeneration costs, at timber price level 2, site index 22 m and zero soil rent.

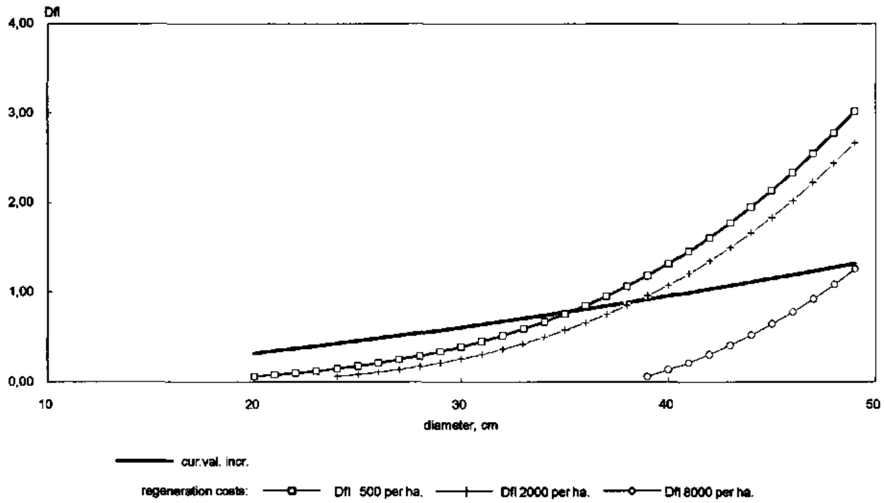

Fig. 49b. The fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at various regeneration costs, at timber price level 3, site index 22 m and zero soil rent.

trees at their financial diameter automatically implies selection felling. Group felling implies that most trees are not harvested at their financial, and therefore optimal, diameter. However, group felling might cause a rise in stumpage value, and also in soil rent. The latter will occur if regeneration is only successful if

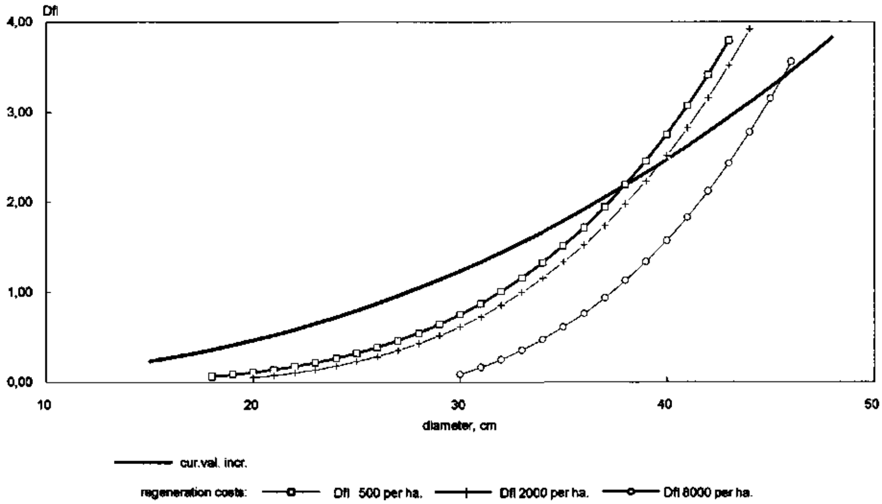

Fig. 50a. The fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at various regeneration costs, at timber price level 2, site index 26 m and zero soil rent.

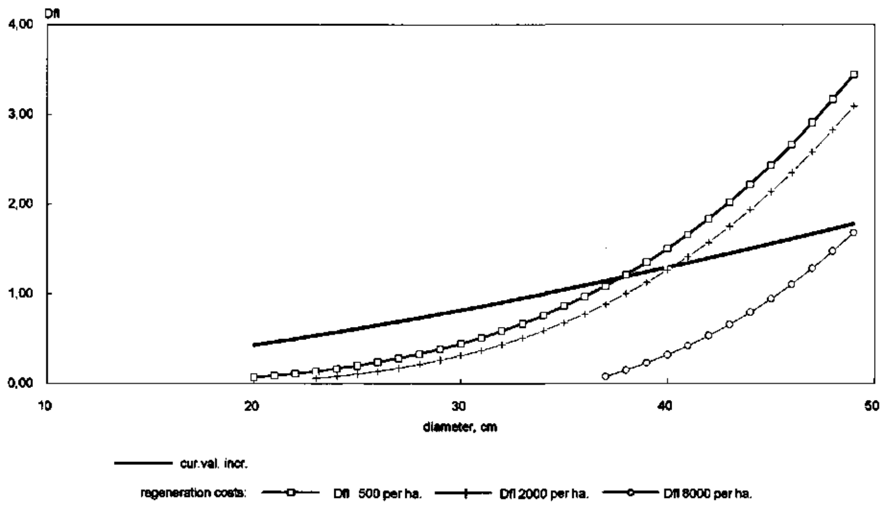

Fig. 50b. The fitted current increment in value per tree per year plotted against 3% interest yield of the stumpage value of the tree, at various regeneration costs, at timber price level 3, site index 26 m and zero soil rent.

gaps are created in the stand. Group felling is financially acceptable if the revenue from the rise in stumpage value and soil rent is greater than the loss of revenue from harvesting trees not at their financial diameter. However, such cases were not worked out.

Howe (1979), Johansson and Löfgren (1985) and Löfgren (1990) demonstrated that if soil rent is zero and maximum net return is wanted, even-aged stands should be cut as soon as their relative value increment equals the interest rate of alternative investment opportunities. These authors showed that the Faustmann-Pressler-Ohlin theorem holds (Johansson and Löfgren, 1985, p. 80): 'A forest stand shall be cut down, when the time rate of change of its value is equal to interest on the value of the stand plus interest on the value of the forest land'. The value of the forest land is derived from the maximum yearly earnings from the forest. However, this theorem is valid only if a stand is homogeneous. In practice, none is. There are not even 2 equal crop trees. The Faustmann-Pressler-Ohlin theorem can be applied to single crop trees, which are the smallest homogeneous management units (Kuper, 1992a). This theorem was used for the calculations given above.

From the Faustmann-Pressler-Ohlin theorem, applied to single crop trees, it can be concluded that the time needed for crop trees to reach their financial diameter depends solely on: 1. the interest rate, 2. the soil rent 3. the growth rate and 4. the stumpage value. The interest rate is not set by forestry. In the case of one single crop tree, the soil rent is set by the net present value of the growing area (land surface) occupied by that crop tree. The net present value of that growing area is maximal if the crop tree is harvested at the financial diameter. The growth rate depends directly on the site quality and the intensity of thinning*.

Thus, crop trees reach their financial diameter independent of the characteristics of surrounding trees, i.e. independent of the volume of the growing stock or the diameter distribution of the stand. This means that to maximize financial returns, there is no need to work towards a specific diameter distribution, nor towards a specific standing stock. This is the case even though high stand densities are required to boost the soil rent and to facilitate the rapid dy-back of low branches, which improves timber quality. The above seems to contrast with calculations made by Duerr and Bond (1952) and Davis and Johnson (1987). Their calculations, however, were intended to ascertain the optimum growing stock of an assumed homogeneous selection forest stand which has the optimum diameter distribution wanted in a selection forest. They calculated the maximum net return per unit of time. Their net return is maximized at the point where any small additional outlays for labour or supplies or other agents of production are just paid for by resulting increases in product. The maximum net return, or maximum soil rent, is reached at the point where cost of marginal growth and revenue from marginal growth are equal. They call this the 'marginal growth method'. This method should yield the same results as the Faustmann-Pressler-Ohlin theorem. The difference is that the marginal growth method assumes that the best diameter distribution at the start occurs and will be maintained, and that the largest diameter that occurs is known, whereas the Faustmann-Pressler-Ohlin theorem assumes that the soil rent is known.

In practice, 'the best diameter distribution' is unlikely to occur, or to be maintained. Nautiyal and Pearse (1967) and Adams and Ek (1974) showed that conversion from forest with irregular yield to sustained yield forest, with 'the best diameter distribution', causes costs, and they produced methods to calculate these. To avoid these costs the Faustmann-Pressler-Ohlin theorem must be applied to individual trees.

For thinning, choices must be made between trees of different diameter; this is elaborated in section 9.5. For crop trees the Faustmann-Pressler-Ohlin theorem must be applied. Crop trees should thus be harvested when they reach their financial diameter, irrespective of the growing stock or the diameter distribution of the stand. For selection forest as a whole, with guaranteed sustainable regeneration, the marginal growth method can only be considered as a model.

Chang (1981) demonstrated that the maximization of Forest Value, being the combined value of land and trees, in uneven-aged forests leads to the same formula as the maximization of Land Expectation Value* in even-aged forests. Thus he presents a unified approach to even-aged and uneven-aged management which produces the optimal choice of rotations. As with Duerr and Bond (1952), he did this on the basis of the marginal growth method and assumed homogeneous stands with constant regeneration costs. However, in practice, homogeneity can only be reached at the level of single trees, and regeneration costs are variable.

Chang (1981) showed that the stumpage price level has no impact on the length of the rotation or the optimal growing stock. This is correct because, with the marginal growth method, the financial diameter is reached as soon as the marginal revenue is equal to the marginal costs. The marginal revenue is given by the extra current increment in value divided by the value increment of the standing stock. In this equation, values are calculated with the same stumpage prices, independent of diameters. Then stumpage prices have no influence on the size of the financial diameter.

Figures 48 to 50 show that the financial diameters at the various timber prices and fixed regeneration costs are not identical. This is because prices for thin trees differ from those for big trees; in other words, stumpage prices are not equal for trees with different diameters. This means that the extra current increment in value in the marginal revenue is composed of the sum of the extra volume increment multiplied by the stumpage price for the occurring diameter plus the extra value increment of the existing volume caused by the higher stumpage price of the greater diameter.

Various researchers have investigated factors influencing financial diameters. Moog and Karberg (1992) found a decrease of the financial diameter with the increasing risk of quality loss of the timber. Earlier, Holm (1974, 1975) had revealed the relation between increasing size of the financial diameter at increasing regeneration costs, and of reducing financial diameters at a decreasing value increment and increasing interest. Haniel and Kleinschmit (1992) applied these findings to Scots pine, and found financial diameters of 42 cm and 50 cm at 3% interest if trees showed a current diameter growth of 4 and 6 mm per year. These financial diameters did not involve soil rent. Duerr and Bond (1952) and Chang (1981) pointed out that with rising interest levels, the optimal standing volume decreases and hence the financial diameter decreases. Filius and Dul (1992) also advocate advancing the harvest, to compensate for rising interest rates.

As stated in section 8.1, harvesting of trees at their financial diameter does not produce big trees. Therefore, for sustainable development the forest must be zoned into harvest and non-harvest areas.

9.2 Financial diameters of individual crop trees, based on 'maximum income generation'

The financial diameters as calculated in section 9.1 do not allow the occurrence of large diameters nor the development up to stand degradation phases. This fits in with the harvest in the zoning-harvesting model, but not with that in the low-level harvesting model (section 1.3) in which the whole forest area is harvested at an intensity low enough to guarantee the conservation of all plant and animal species. The objective of 'maximum income generation' allows harvest to be postponed, and may be used as a path towards the low-level harvesting model.

The objective of 'maximum income generation' from the stand means that timber harvest is such that trees are harvested at the moment the highest revenue is obtained from the stand itself, i.e. ignoring possible revenue from interest. Crop trees are harvested when their current increment in value falls below the average net value increment of the growing area (land surface) they occupy (Kuper, 1992a). To determine the financial diameters over bark with this objective in mind, the yield in Dfl per ha of a Scots pine stand with ideal diameter distribution was calculated for all diameter classes. It was assumed that the basal area of 24 m^2 was evenly spread over all diameter classes. This was done for 3 site indices and 2 timber price levels. The results are given in figures 51a and b.

Discussion and conclusion

Figures 51 a and b show that at Het Loo the maximum income generation is not yet reached at diameter 50 cm over bark at breast height. This is so for all local site indices and for all timber price levels. It should be noted that few data were available for trees over 50 cm diameter, and that the standard devia-

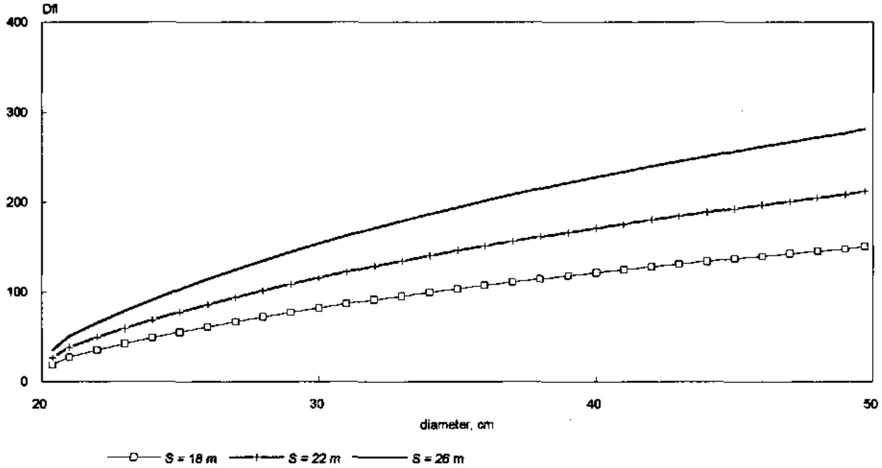

Fig. 51a. Calculated yield per ha per year versus largest harvest diameter, based on equal distribution of the basal area over all diameters, at timber price level 2.

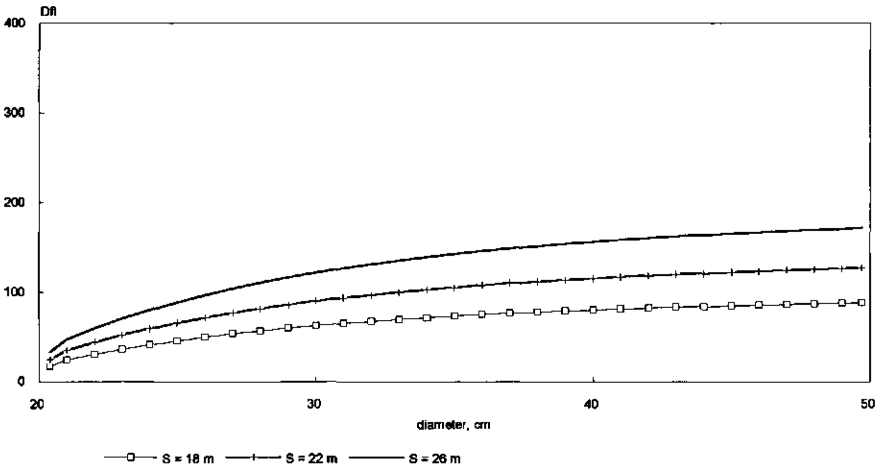

Fig. 51b. Calculated yield per ha per year versus largest harvest diameter, based on equal distribution of the basal area over all diameters, at timber price level 3.

tions for the values of the empirical constants in the current increment in value model are large. If there was no risk of death by storm, fire or other agent, the financial diameter in all cases exceeds 50 cm, even when regeneration costs are zero. If regeneration costs increase, the financial diameter increases. Schreyer (1986) and Ripken (1989) also concluded that maximum income generation increases with increasing diameters for stands in Bavaria and Lower Saxony.

Many authors (Bachmann, 1968; Leibundgut, 1976; Bernauer, 1981; Schoepffer, 1983; Schreyer, 1986; Reininger, 1987; Ebert, 1991) have presented arguments for using the maximum income generation as a base for the financial diameter. The most important arguments are the wish to allow the forest to produce the highest possible financial value in timber, next to optimal shelter and ecological and aesthetical value. In that case, it is common to forego potential revenue from interest.

As in 'profit only', however, 'maximum income generation' does not meet the objective of conserving the species that are associated with the degradation phases in forest development. Because trees are allowed to grow older and bigger in the 'maximum income generation' approach, there is a greater chance that *big* trees will die than in the 'profit only' approach. However, with 'maximum income generation' the trees are harvested anyway. If degradation phases in forest development are deemed necessary, the volume of old, big, trees harvested must be restricted. In this study the extent to which the harvest of big trees should be restricted was not investigated.

Big trees are the most interesting for nature conservation. They are also the trees in which the largest amount of money is invested. It is not good economics to leave these trees to decay.

Clearly, the 'maximum income generation' approach is a compromise that allows neither the highest financial revenue nor full nature conservation objectives. The low-level harvesting model, is therefore not an appropriate approach.

Increasing the nature conservation value by postponing the harvest brings certain costs: the foregoing of revenue from interest plus the loss of dead trees. These costs could also be spent on alternative and more promising solutions to enhance ecological value; for instance, by establishing strict reserves within the forest, which include degradation phases. In that case we arrive at the zoning-harvesting model.

Wyatt-Smith (1987) and Poore et al. (1989) mentioned the need for minimum harvest diameters, below which no logging is allowed, as a guarantee for sustainable production. That is an opposite approach to the one used in this study for the calculation of financial diameters. Their approach prevents revenue being obtained from thinning, even though this thinning does not threaten sustainability and conservation if carried out in single species tree compartments. If the minimum harvest diameter is larger than the financial diameter on the basis of 'profit only', revenue from interest is postponed. However, the determination of a minimum harvest diameter not only provides a very practical management instruction, which can be adjusted according to the silvicultural objectives, it also contributes to the sustainability in timber production. The use of financial diameters is only based on financial arguments, it does not consider any sustainability in timber production.

9.3 Harvesting costs of selection felling

To determine the cost of harvest by thinning in stands where regeneration already occurs, a study was carried out in Gortel 80a in 1986. The stand consisted of 75-year-old Scots pine with approximately 220 stems per ha. Throughout the stand, birch and oak had regenerated spontaneously, birch in high numbers, approximately 600 per ha, and oak approximately 100 per ha. Some regeneration of red oak (17 per ha) and beech (17 per ha) was also present. Only trees with diameters larger than 6 cm were counted. The oaks were on average 8.9 m tall, the birches 10.0 m. Some of the young oaks had straight stems. These were marked as future trees. Scots pines overtopping future oaks were marked to be thinned. The former State Institute for Research in Forestry and Landscape 'De Dorschkamp' was requested to perform a time-study for the following activities:

1. felling and trimming the marked Scots pine trees, and
2. hauling these trees to a road from which further transport by lorry can take place.

The felling of the Scots pine, which was supposed not to damage any of the future oaks, was carried out by forest labourers of Het Loo Royal Forest. Although these labourers were experienced, they had never felled trees with that specific assignment. Nevertheless, none of the oak future trees was damaged. The actual time-study was performed by N.A. Leek and A.H. Schaafsma. They reported their findings in an unpublished 'De Dorschkamp' report (Anon., 1986). The following data are drawn from that report.

Over the 9 ha stand, 84 Scots pine trees were felled. On average, 0.84 minute per tree was spent on walking from one tree to the next. Per tree, 4.95 minutes were spent on felling. Both these figures are net working time. Usually, 40 % General Time is added for work preparation (Anon. 1986).

Thirty-eight of the felled trees were hauled to the road by a 2-horse team. The cost of the 2-horse team plus driver was Dfl 45 per hour (Anon., 1986). Because of the abundance of the regeneration, at that time it was considered best to use a 2-horse team instead of a tractor. A small and powerful tractor, such as a Fendt 270 PA, however, would also have been able to do the job. Data on felling and trimming costs are given in table 56, data on hauling costs are given in table 57.

Discussion and conclusions

Comparison with the SBB (State Forestry Service) table of working time standards (Anon., 1990a) showed that the felling time per m^3 for trees of 0.54 m^3 in stands with undergrowth of young trees is less than the felling time given for trees of 0.59 m^3 in stands without undergrowth of young trees. Trees of the latter size have a felling time of 17.4 min/m^3. These data did not correspond. Part of this disparity may be caused by the fact that in the SBB working time

Table 56. Cost of felling and trimming Scots pine trees in stands with and without undergrowth of young trees, 1990 prices.

tree size, m^3	top cut at diam., cm	felling time, min. per m^3 incl. G.T.#	felling cost, Dfl. per m^3 incl. G.T.# (excl. overheads)	under-growth	source
0.54	13-14	15.0	10.21	yes	Anon.1986
0.59	7	17.4		no	Anon.1990a

G.T. = General Time 40%.

standards table, the top of the tree is cut at 7 cm diameter, but in the time-study in stand Gortel 80a the tops were cut at 13-14 cm diameter. According to Bol (1965) the shift from top diameter 7 cm to 11 cm will save 29% felling time. So a shift from 7 cm to 13-14 cm will save even more time. Bol (1965) also gave data on felling time per tree under conditions with and without undergrowth of young trees. He measured the working time per tree with up to 4325 individual trees in the undergrowth. He found working times up to 14% longer than for trees without undergrowth.

Schaafsma (1992) gave data on felling shelter trees above young regeneration. He stated that on average the harvest costs of such trees was more than 30% higher than the harvest of similar trees without undergrowth of young trees. In Schaafsma's study much time was lost by lack of working space and by lack of visibility in the undergrowth of coniferous regeneration, especially Douglas-fir. In the present study, the regeneration consisted either of deciduous trees or of light-demanding Scots pine. Visibility among the regeneration was therefore much better than in the cases Schaafsma investigated.

Compared to the figures given by Anon. (1990a), the felling costs in Gortel 80a, with regeneration of young trees, were not higher. On the other hand, felling costs are assumed to rise under more difficult circumstances.

Table 57. Cost of hauling felled Scots pine trees out of stands with and without undergrowth of young trees, 1990 prices.

tree size, m^3	hauling distance, m	hauling equipment	hauling time, min. per m^3 incl. G.T.#	hauling cost, Dfl per m^3 incl. G.T.# (excluding overheads)	under-growth	source
0.56	48	2-horse team	6.3	6.59	yes	Anon.1986
0.43	50	tractor + tongs	4.8	5.00	no	Anon.1990a
0.90	50	tractor + tongs	4.2	4.17	no	Anon.1990a

G.T. = General Time 40%.

The data collected by Leek and Schaafsma (Anon., 1986) could not be compared with other data from comparable situations without young trees in the undergrowth. The only possible conclusion is that felling costs may be safely assumed to be higher in stands with undergrowth of young trees, but that it is unknown how much higher they are.

The hauling costs, if performed with a 2-horse team, were considerably higher in the Gortel 80a stand than given by Anon. (1990a). It should be investigated whether the use of a small powerful tractor can reduce the hauling costs.

To adjust the stumpage prices for conditions with undergrowth of young trees, in subsection 3.4.2 the timber prices from the Meerjarenplan Bosbouw (1986) were reduced by an arbitrary 25% of the felling and hauling costs given by Anon. (1990a). This reduction rate is a rough assessment based on the incomplete facts available, as described above.

9.4 The number of future trees

In the previous sections (9.1 and 9.2) it was shown that financial diameters vary from 30 to over 50 cm. If it is assumed to be useful to select only those future trees that reach the financial diameter, the number of future trees can be calculated, assuming that all future trees reach the financial diameter at the same time, and that they are spread evenly over the stand.

The number of future trees was obtained by dividing the basal area of a stand by the basal area of one single future tree of financial diameter. In table 58 various numbers of future trees are given at different financial diameters and different assumed basal areas for stands, e.g. on different sites.

Discussion and conclusions

Smaller financial diameters allow a higher number of future trees. Larger basal areas do the same.

Future trees are trees with the highest current increment in value per area unit. They are selected for financial reasons, and are favoured throughout their lifespan. It is not good economics to allow some of these trees to die and decay in order to enhance species conservation. Hence, no big trees will be produced for degradation phases. Therefore, to achieve sustainable forest development, the forest must be zoned into harvest and non-harvest areas in an early phase, before any costs are spent on selecting and tending future trees.

9.5 Choosing the diameter when thinning

When low thinning* a stand, poor quality stems are cut first. Apart from

Table 58. The number of future trees at different financial diameters and different basal areas.

financial diameter, cm	basal area per tree, m^2	number of future trees per ha, at assumed basal area: $20\ m^2$	$25\ m^2$	$30\ m^2$
30	0.0706	283	354	424
31	0.0754	265	331	397
32	0.0804	249	311	373
33	0.0855	234	292	351
34	0.0907	220	275	330
35	0.0962	208	260	312
36	0.1017	196	246	295
37	0.1075	186	233	279
38	0.1134	176	220	265
39	0.1194	167	209	251
40	0.1256	159	199	239
41	0.1320	151	189	227
42	0.1385	144	180	217
43	0.1452	138	172	207
44	0.1520	132	164	197
45	0.1590	126	157	189
46	0.1661	120	150	181
47	0.1734	115	144	173
48	0.1809	111	138	166
49	0.1885	106	133	159
50	0.1963	102	127	153
51	0.2042	98	122	147
52	0.2123	94	118	141
53	0.2206	91	113	136
54	0.2290	87	109	131
55	0.2375	84	105	126
56	0.2463	81	102	122
57	0.2551	78	98	118
58	0.2642	76	95	114
59	0.2733	73	91	110
60	0.2827	71	88	106

that, thin trees are usually cut in favour of bigger trees. This is less the case in crown thinning*. On the other hand, as the financial diameter is reached, the bigger trees are cut, and thinner trees are left to grow bigger.

To increase the financial results, rules should be drawn up for deciding which trees should be selected for thinning for financial reasons in stands with trees of various diameter sizes. If a total of one square metre of basal area is to be felled as thinning, and one has to decide between trees of 2 different diameters, the diameter for felling should be chosen to maximize the sum of 1. the interest from the net stumpage value from the harvested trees per square metre basal area and 2. the net value increment per square metre basal area from the remaining trees. This calculation is done using the net current increment of trees per

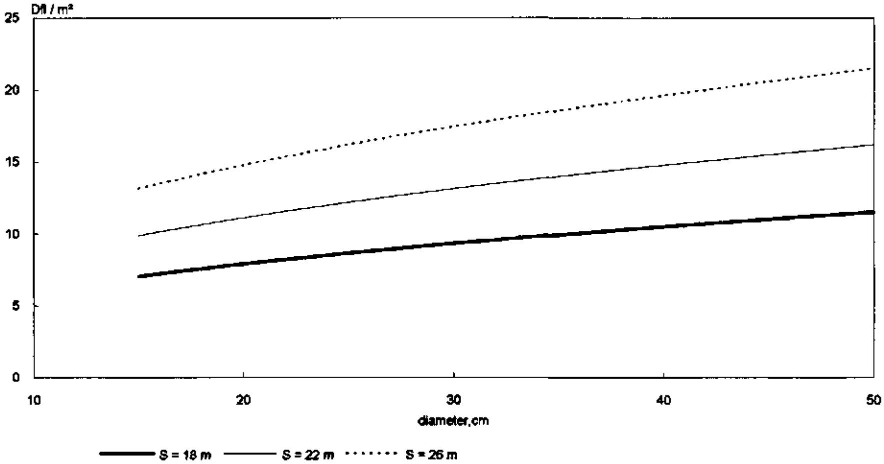

Fig. 52. Calculated current increment in value per square metre basal area versus diameter of the trees that compose the square metre, for 3 site indices, timber price level 2.

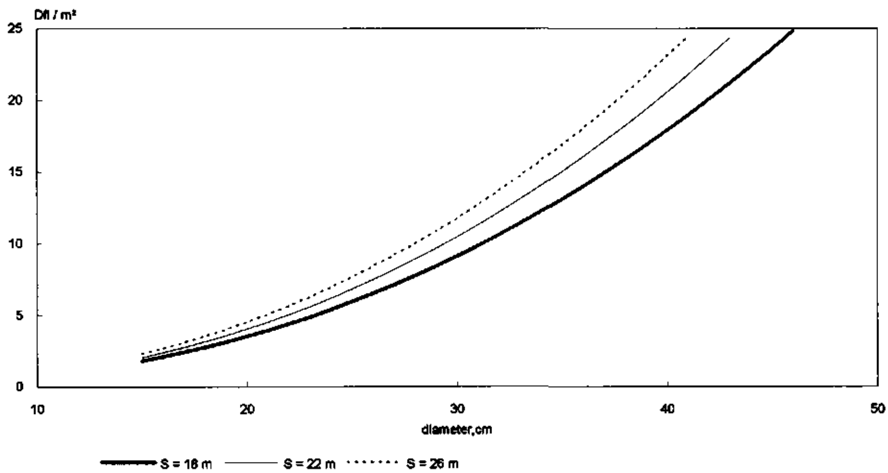

Fig. 53. Calculated interest earnings from stumpage value per square metre basal area versus diameter of the trees that compose the square metre, for 3 site indices, timber price level 2.

diameter for a basal area of one square metre, as illustrated in figure 52. Another calculation was done using the current interest from stumpage value per diameter for a basal area of one square metre, as illustrated in figure 53.

If there are trees A and trees B to chose from, then trees A are left standing if increment A_a (A alive) plus interest B_f (B felled) is greater than increment B_a (B alive) plus interest A_f (A felled):

$$iA_a + rB_f > iB_a + rA_f \qquad (1)$$

this is equal to:

$$iA_a - rA_f > iB_a - rB_f \qquad (2)$$

In words: the trees with the greatest difference between current increment in value and interest revenue from net stumpage value are to be left growing. The calculations were done at 3% interest, for timber price levels 2 and 3 of subsection 3.4.2, for site indices 18, 22 and 26 m. The results are given in figures 54 a and b.

Discussion and conclusions

From figures 54a and b it is concluded that trees with the smaller diameters have the greater differences between current increment in value and interest revenue from stumpage value. Therefore, the bigger trees must be chosen to be felled when thinning.

The above procedure for deciding whether or not to fell a tree with a specific diameter is only correct if all trees are of equal financial quality. If future trees are selected, and especially if they are pruned, there will be differences in value increment per unit of volume increment, and the above calculation will not be applicable. In the latter case, bigger trees to be thinned can be selected from those trees growing among future trees.

The above calculation also assumes that the remaining trees make equal use of the growing area. If a big tree with a specific basal area is thinned in favour of thin trees with equal basal area, one large canopy gap is made instead of several small ones by removing several smaller crowns. This causes differences in the availability and nature of growing area for the remaining trees.

The calculation also assumes that current increase in value of thin trees at their specific diameter is equal to the increase in value of the bigger trees when they had the diameter of the thin tree. In other words, it is assumed that the tree with the smaller diameter has a crown which equals the performance of the crown of the bigger tree at the time the latter had the smaller tree's diameter. Reininger (1979) stated that suppressed trees which are released in even-aged stands need more time to make full use of the newly opened-up growing area than suppressed and released trees in uneven-aged stands.

Deciding that trees with the smallest diameter should be left in the stand and felling the bigger trees reduces the stability of the stand. Opting for bigger trees to be thinned can thus only be done in sufficiently stable stands.

The dilemma of whether to harvest a tree which has a commercial sapling growing under it is a special case. The sapling does not yet have a current increment in value. The decision depends on the estimated present net values of the

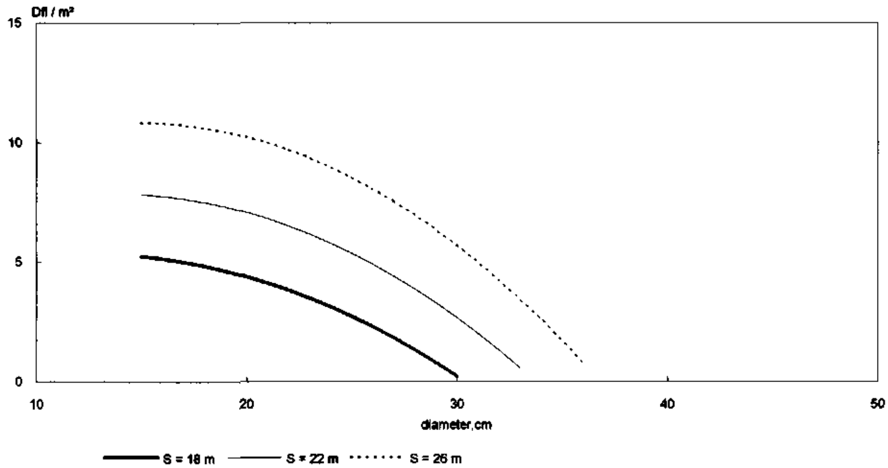

Fig. 54a. Calculated difference between interest revenue and current increment for trees with a basal area of one square metre versus diameter of the trees that compose the square metre, timber price level 2, for 3 site indices, at 3% interest, in Scots pine trees.

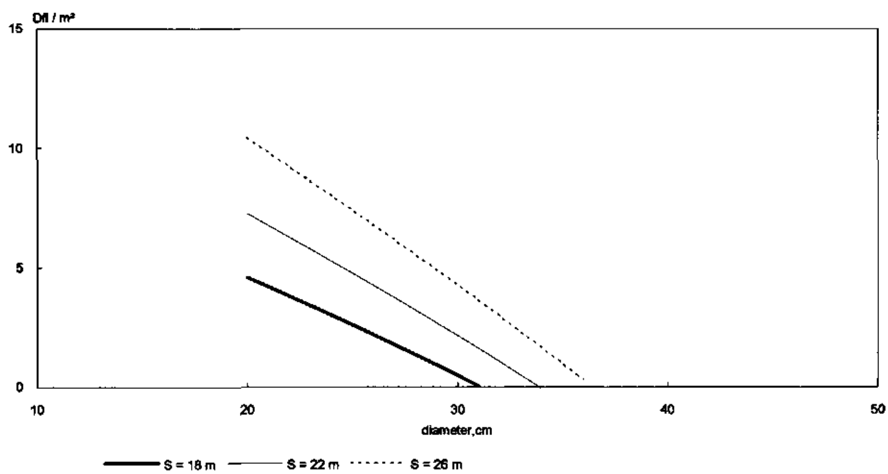

Fig. 54b. Calculated difference between interest revenue and current increment for trees with a basal area of one square metre versus diameter of the trees that compose the square metre, timber price level 3, for 3 site indices, at 3% interest, in Scots pine trees.

tree and the sapling. If the present stumpage value of the tree plus the estimated present net value of the released sapling is greater than the estimated present net value of the tree plus the estimated present net value of the suppressed sapling, then the tree should be harvested. This dilemma can only occur before the bigger tree reaches its financial diameter.

9.6 Regeneration techniques

Regeneration varies. It may be spontaneous, semi-spontaneous (merely preparing a seedbed), or artificial (planting).

Spontaneous regeneration establishes without specific investment. If game is present, spontaneous regeneration may fail to appear, especially in the case of deciduous tree species. To avert this, game can be reduced or eliminated from the area where regeneration is wanted. The reduction or elimination can be achieved by culling or by fencing. Culling is not dealt with in this study. Fencing is dealt with in subsection 9.7.1.

*Semi-spontaneous regeneration** by Scots pine and birch can be triggered by reduction of basal area, followed by treating the grass, herb and shrub vegetation by mulching machine, rotovator or kuloo (subsection 3.2.5). In the present study it was found that the mulching machine has the smallest impact on the ecosystem, but is least successful as far as regeneration of Scots pine and birch is concerned. The rotovator affects the ecosystem more severely. In Het Loo, the regeneration results after rotovation for Scots pine and birch were better than in patches treated by the mulching machine. The kuloo affected the vegetation in patches of limited size. There the ground vegetation and organic topsoil were severely disturbed. The mineral soil can remain untouched if the treatment is done properly. In the study area Scots pine and birch were the regenerating species. Regeneration by oak and beech is not stimulated by those techniques.

Planting of trees can be done as usual. Several thousands of saplings may be planted per ha, by hand or with a planting machine, on a clearfelled area. This method is not dealt with in this study. Enrichment planting of up to 200 saplings per ha, in a more or less open stand, is in line with the objective of sustainable use of the forest.

9.7 Costs of regeneration

The cost of investment in forestry as in other ventures, must be weighed against the net revenue to be expected as a result from that investment. In this study, an interest rate of 3% is used for reasons of comparability (Kuper, 1992a).

9.7.1 Costs of fencing

Spontaneous regeneration costs nothing if it works. If it does not work even though stand conditions are favourable, the failure should be explained. The presence of game is often the reason for the lack of success. This can be solved by fencing. There are various types of fences. Electric ones, fed by solar energy are cheapest. In 1990, 1991 and 1992, the costs of electric fences constructed at Het Loo were Dfl 6.42 to 16.92 per metre, depending on the length of the fence and the material used (see table 59). Electric fences 1.2 m high, consisting of 4 wires, effectively keep red deer out of the stand. Since roe deer jump between the wires of the fence, they cannot be kept out of the stand unless the electric fence is built of wire-mesh. In that case the cost of fencing is higher: see table 60. Only the costs required for building of the fences are given. The costs for maintenance and demolition, and revenue from remaining materials are not considered.

Discussion and conclusions

The sale of trees grown in the fenced area must cover the investment costs of the fence plus the soil rent without fencing. For 2 situations of fenced areas, one of 1 ha and one of 25 ha, the compound interest of the fence was calculated at 3% interest for when the stand reached the ages of 75 and 200 years (table 61). The amount calculated must be added to the amount expected from net timber sales from spontaneously regenerated trees without fencing.

Table 59. Cost of building electric fences in 1990, 1991 and 1992.

length of fence, m	kind of materials	materials, Dfl	labour, Dfl	cost in Dfl/m	cost incl. overheads, Dfl/m
2000	4 wires	7200	3490	5.35	6.42
1500	4 wires	7350	3220	7.05	8.46
1430	4 wires	6750	2513	6.48	7.78
1250	4 wires	6500	2932	7.55	9.06
920	4 wires	5002	2234	7.87	9.44
720	4 wires	4450	1265	7.94	9.53
630	5 wires	4250	960	8.27	9.92
600	4 wires	4166	1117	8.81	10.57
560	4 wires	5163	1138	11.25	13.50
420	4 wires	3697	1536	12.46	14.95
400	4 wires	4322	963	13.21	15.86
380	4 wires	4269	858	13.49	16.19
360	4 wires	3540	1536	14.10	16.92

Table 60. Costs of additional wire-mesh in 1992.

length	materials, Dfl	labour, Dfl	Dfl/m	Dfl/m incl.overh.
1500 m	1700	1120	1.88	2.26
560 m	706	315	1.81	2.18
400 m	500	210	1.78	2.14
380 m	475	175	1.72	2.06

If no regeneration would have taken place without the fence, the investment cost is the price that has to be paid to harvest timber from a forest which partially fulfils a nature conservation objective by providing a biotope for game. This can be explained in 2 ways: either the income from forests with such nature conservation objectives is lower than in the case that there was no such objective, or the desired level of abundance of browsers requires an extra investment cost per ha. The question remains whether the level of abundance desired is 'natural'. As mentioned, this calculation is valid for regeneration which can stand the pressure of browsing by roe deer. If roe deer has to be kept out of the regeneration area, then wire-mesh has to be added to the wires. That adds Dfl 2.26 per metre to the cost of fencing 25 ha. In that case semi-spontaneous regeneration of oak can take place too, if seed trees are available. The extra revenue needed to cover the investment was calculated over periods of 120 and 200 years (table 61).

In early 1993, 6 months after electric fences plus wire-mesh were erected, red deer were entering some of the fenced areas by jumping over the fence. At electric fences where the wire-mesh was attached 6 months after the wire fence had been erected, no instances of red deer jumping over the fences were recorded. Possibly, red deer recognize wire-mesh as an obstacle they can jump over. However, once they have touched the wires of a fence without wire-mesh, they avoid the fence from that moment, regardless of the presence or absence of wire-mesh. Time was too short to collect sufficient data to substantiate this. However, it may be assumed that once roe deer are kept out, red deer will return.

Compared with data from Meerjarenplan Bosbouw (1986) and Bosschap (1990), these data show that only at the lowest investment is there a chance that the investment can be recouped through extra net revenue.

From Germany, Klein and Backes (1993) quote the costs of building fences, for areas of 2.4 ha on average, at a rate of 12.84 German marks per metre in 1992, i.e. Dfl 14.38 at the 1993 exchange rate. These fences protected against roe deer and wild boar. No costs of overheads were included in their calculation. They concluded that individual protection of a small number of saplings is preferable to fencing, but that reducing the abundance of game is the best way to allow saplings to grow.

Table 61. Extra net revenue needed to cover fencing investments at 3% interest.

investment	area	period	extra revenue needed
4-wire fence	1 ha	75 years	Dfl 58,364 / ha
4-wire fence	25 ha	75 years	Dfl 4,725 / ha
wire-mesh	25 ha	200 years	Dfl 257,136 / ha
wire-mesh	25 ha	120 years	Dfl 24,095 / ha

9.7.2 *Costs of soil scarification*

Semi-spontaneous regeneration is stimulated by various treatments. In this study mulching machine, rotovator, and kuloo were investigated.

With a *mulching machine*, strips were made every 5 metres in a Scots pine stand at Het Loo. The total costs, in 1990, were Dfl 265 per ha (average over 40 ha). This was of the same order as the level of cost given by Anon. (1990a): Dfl 287 for 1 strip every 5 metres. By comparison, the cost of treatment by *rotovator* is Dfl 110 per ha when every 5 metres a strip on cultivated soil is treated (Anon., 1990a). In a forest stand this is considerably more expensive. The actual working time in a 3.7 ha Scots pine stand in Gortel 53d and 23fg, was 14.3 hours, which amounts to Dfl 232 per ha. The cost of the rotovator itself is Dfl 5.10 per hour, which adds an extra Dfl 15.30 per ha.

A *kuloo* treatment was carried out by personnel of Het Loo. Labour time of the tractor plus driver was 4 hours per ha when, on average, a row was treated every 4 metres (average out of 118 ha). This amounted to Dfl 240 per ha, price level 1990, including driver and tractor costs, but excluding the cost of the kuloo itself. Anon. (1990a) gave the standard cost for the use of a kulla, a machine that differs from the kuloo but has a similar effect on the vegetation. It treats smaller patches. The cost of a kulla itself is Dfl 7.70 per hour. If this cost level is also used for the kuloo, then a kuloo treatment amounts to Dfl 266 per ha. All data are given in table 62.

Discussion and conclusions

The compound interest of money invested in soil tillage was calculated, at a 3% interest rate over a period of 75 years (table 63). Removal of debris of

Table 62. Cost of soil tillage in 1990.

machine	approx. working time per ha in hours	total costs Dfl/ha (excl. overheads)	total costs incl. overheads	source
mulching machine (one row per 5 metres)	2½	265/ha	Dfl 318	own data
rotovator				own
– in forest	3	193/ha	Dfl 247	data
– on cultivated land (one row per 5 metres)		92/ha	Dfl 110	Anon. 1990a
kuloo – one row per 4 metres	4	266/ha	Dfl 319	own data

Table 63. Extra net revenue needed per ha, to cover soil tillage investments at 3% interest.

treatment	area	period	extra revenue needed
mulching mach.	1 ha	75 years	Dfl 2,926 / ha
rotovator	1 ha	75 years	Dfl 2,272 / ha
kuloo	1 ha	75 years	Dfl 2,935 / ha
remove debris	1 ha	75 years	Dfl 5,630 / ha

branches was included in the calculation. The amounts should be recouped by a higher net revenue from timber sales per ha, compared to timber sales without soil tillage. According to Bosschap (1990) such sales are possible for Scots pine of third yield class and higher. However, the sale must be compared to the potential sale from regeneration without investment.

Behrndt (1992) and Wolf (1992) mentioned a machine for soil tillage which has been available since 1990: the 'Bräcke-Hochleger'. This machine can be used to scarify the soil. It treats 2 rows at a time. The sod is removed patchwise, and a spade of mineral soil is deposited on top of the sod, which is dropped beside the treated row. The cost of this treatment, for 2500 to 5000 patches per ha, is 260 to 370 German marks, i.e. Dfl 290 to 415 (Behrndt, 1992; presumably without overheads). Under shelter-felled stands, Wolf (1992) calculated up to 430 German marks per ha (Dfl 480) for this machine.

These data show that if regeneration does not appear spontaneously, the above treatments are financially beneficial, if they lead to extra net revenue, which covers at least the stated amounts. Estimated present net values of stands resulting from semi-spontaneous regeneration are elaborated in section 9.9.

9.7.3 Costs of sowing on seedbeds

On the seedbeds prepared by kuloo in Gortel 7, additional sowing was carried out by hand and rake, over 2 ha. To cover this surface with, on average, 200 seedbeds per ha, 2 hours labour were needed plus Dfl 57 for seeds, i.e. approximately 2000 seeds, or 20 grams per ha. This amounts to Dfl 77 per ha, overheads included.

Discussion and conclusions

If it is assumed that 100 future trees will grow from the 200 seedbeds (section 6.3), and the period until financial diameter is 75 years, then net revenue per ha from those trees should, at 3% interest, be at least 9.2 x Dfl 77 = Dfl 708 higher than the net revenue from spontaneously or semi-spontaneously regenerated trees of local origin. Sowing cannot take place without soil scarification. In comparisons of final revenue, the latter investment must therefore be added to the investment in sowing (table 63, subsection 9.7.2).

9.7.4 *Costs of planting*

Planting is only considered useful if limited to a few saplings per ha. Some 200 saplings of proven quality might be sufficient to supplement the spontaneously or semi-spontaneously established trees. This holds for Scots pine, indigenous oak and beech. Scots pine saplings 2 years old were used, whereas the oak was 2 and 4 years old, and beech 2 years old. The 4-year-old oak saplings are so tall, that roe deer cannot browse their tops. The costs of these saplings in 1990 are given in table 64.

In 1992 container-grown Scots pine sapling ('P84') cost Dfl 0.41 per 1-year-old sapling (purchase, transport and taxes). The costs of planting are dependent on the distance walked in the stand and the time needed to select planting localities. This varies between Scots pine and oak. It is only useful to plant Scots pine if few other trees have invaded so far (section 6.2). In that case the stand is very open. Site selection for planting will thus be easy, as will be the handling of the small saplings.

Planting costs were calculated from the following numbers of saplings:

* 4-year-old oak: 8770 saplings over approximately 90 ha, covering 752 hours at Dfl 34.90 per hour (Anon., 1990a);
* 2-year-old beech saplings: 1000 saplings over an area of 5 ha;
* 2-year-old oak saplings: planting time was not investigated, but was assumed to be as much as the planting time of the beech saplings;
* 1-year-old container-grown Scots pine: 1000 saplings over an area of 5 ha.

Discussion and conclusions

Planting of saplings should generate extra revenue at the time of harvest. The extra revenue depends on the interest rate and the time needed to reach the financial diameter. At 3% interest the multiplication rates for 75, 120 and 200 years are respectively 9.2, 34.7 and 370.3. The extra revenue needed per ha at 3% interest are given in table 65.

Instead of planting the new generation of trees, it is also possible to plant

Table 64. Enrichment planting costs per oak and beech sapling in 1990, Scots pine in 1992.

material	planting time, minutes	planting cost, Dfl	purchase per sapling, Dfl	total planting costs incl. overheads
4-y-oak	5.1	2.99	2.28	Dfl 6.32
2-y-beech	1.60	0.93	0.64	Dfl 1.88
2-y-oak	1.60	0.93	0.62	Dfl 1.86
1-y-Sc.p.	0.67	0.39	0.41	Dfl 0.96

limited numbers of trees as seed sources for future regeneration. In sections 5.1 and 5.3 it was concluded that oak can be planted in Scots pine stands when the latter are 40 to 50 years old, and beech can be planted even earlier. Solitary oak and beech produce seeds as soon as they are 40 to 50 years old (Houtzagers, 1956; Krahl-Urban, 1959; Morris and Perring, 1974), although acorn production was observed on oaks aged 10 to 15 years (pers. obs.). If such 'seed-source' planting* is carried out by planting 10 saplings per ha at the highest cost mentioned in table 64, the cost of 'spontaneous' regeneration by oak or beech after a further 50 years is: Dfl 6.32 * 10 (number of saplings) * 4.4 (interest multiplier at 50 years) = Dfl 278. This case is added in table 65.

Also added to the data on enrichment planting or sowing is the estimated extra revenue needed for conventional reafforestation with Scots pine and oak. Estimated purchase plus planting cost per 2-year-old bare-root Scots pine sapling: (0.35 + 0.35) * 1.2 = Dfl 0.84. Per ha: 2500 * 0.84 = Dfl 2,100. Costs for treatment of debris by mulching machine, and preparation of planting patches, respectively Dfl 550 and Dfl 900, must be added. Total costs per ha are Dfl 3,550, all-in except fencing.

Estimated purchase plus planting cost per 2-year-old oak sapling: (0.35 + 0.62) * 1.2 = Dfl 1.16. Per ha: 5000 * 1.16 = Dfl 5,800. Adding Dfl 800 for treatment by mulching machine and Dfl 1,200 for preparation of planting patches makes a total of Dfl 7,800 per ha, all-in except fencing.

From the financial point of view, the investments calculated are only useful if they lead to extra net revenue, on top of the revenue generated by spontaneous regeneration only. In sections 9.8 to 9.11 examples of Present Net Values of

Table 65. Extra net revenue needed per ha to recover the costs of planting and sowing at 3% interest.

treatment	species	number#	period	extra revenue needed
planting	4-y-oak	200	200 y	Dfl 468,059 (unfenced)
planting	4-y-oak	200	120 y	Dfl 43,861 (unfenced)
planting	2-y-oak	200	120 y	Dfl 12,908 (unfenced)
planting	2-y-oak	200	120 y	Dfl 37,004 (25 ha fenced)
planting	2-y-beech	200	120 y	Dfl 13,047 (unfenced)
kuloo tr.	Sc.p. appr.	400	75 y	Dfl 2,935 (no sowing)
sowing	Sc.pine	200	75 y	Dfl 708 (no kuloo)
sowing	Sc.pine	200	75 y	Dfl 3,643 (with kuloo)
planting	1-y-Sc.p.	200	75 y	Dfl 1,766 (cont.spl.##)
s.-s.pl.###	oak/beech	10	50+120 y	Dfl 9,647 (unfenced)
planting	Sc.pine	2,500	75 y	Dfl 32,660
planting	2-y-oak	5,000	120 y	Dfl 270,660 (unfenced)

The number planted is not equal to the number harvested;
cont.spl. = container-grown sapling;
s.-s.pl. = seed-source planting.

realized regeneration are elaborated. In that case the calculation is done in the opposite direction.

From table 65 it can be concluded that the extra revenue needed to recover the costs of investment is low only if the investment period is short or the amount invested is small.

For oak and beech, seed-source planting requires the lowest extra revenue. Seed-source planting has the advantage that it speeds up the rehabilitation of the stand to the modified natural stage (section 8.4). Low extra revenue from Scots pine regeneration is required in the case of enrichment planting with container-grown saplings, and of patchwise soil scarification.

Klein and Backes (1993) estimated that 150 to 180 cm tall saplings of deciduous tree species could be purchased, planted and individually protected for 8.30 German marks per sapling. Their estimate was not based on empirical data. They considered the expenditure of 300 times 8.30, or in general 3,000 German marks per ha preferable to fencing.

9.8 Estimated present net value of a Scots pine plantation

As an example, the present net value of a Scots pine plantation was calculated for the 'profit only' approach, based on the assumption that all harvestable timber is indeed harvested. The present net value calculated is equal to Duerr's present net worth (Bentley and Teeguarden, 1965), with fixed management costs, and zero land value, for one rotation. The interest rate used was 3%.

The present net value of a Scots pine plantation with the following characteristics was calculated:

number of saplings planted	: 2,500 per ha
purchase and planting costs	: Dfl 2,100 per ha
mulching machine treatment	: Dfl 550 per ha
preparation planting sites	: Dfl 900 per ha
Site index	: 26.0 m, yield class II according to Grandjean and Stoffels (1955)
number of trees at 20 years	: 2,500
dominant height* at 20 years	: 9.7 m
basal area at 20 years	: 18.5 m^2
diameter at breast height	: 7.7 cm.

For calculation the following assumptions were made:
- no tending is carried out;
- first thinning is carried out as soon as net earnings are possible;
- thinning is done every 5 years;

– stumpage timber price level 2 from subsection 3.4.2 is used;
– for loss of bark and tree tops 25% deduction is calculated;
– the stumpage value at 75 years is considered as the final earning.

The '*pro*FORST' computer program of the Forstware HOLTLAND Company was used for calculation of volume growth, thinning volume, thinning diameters and earnings based on price level 2 of subsection 3.4.2. A brief description of the background of '*pro*FORST' is given in box 5.

Box 5. Brief description of the background of '*pro*FORST'.

The '*pro*FORST' program is based on data sets used for the OPTAB program (Faber, 1990). These data have been obtained from even-aged monocultures which have been managed in low thinning. The '*pro*FORST' program simulates growth in mixtures of various tree species, on the basis of mixtures of monocultures of these species. The mixtures are considered as sums of monocultures of the various tree species. The model does not consider the effects on growth of tree-by-tree mixtures, or interaction between species.

At low thinning, average diameters increase after every thinning. This is incorporated in the conventional yield tables. If no such low thinning is carried out, the average diameter in the growth model is affected. The real effect of not carrying out low thinning is not known. The yield table models no longer fit real growth. In contrast to the development of the average diameter, it is assumed that the development of the diameters of the dominant trees is hardly affected by not carrying out low thinning in the early phase of the tree compartment, when low thinning is still unprofitable.

Diameter development is a result of the natural development of the basal area and the drop-out of individual trees by anthropogenic or natural thinning. In '*pro*FORST' it is assumed that during the unprofitable thinnings the anthropogenic low thinning is replaced by natural thinning.

In this study, '*pro*FORST' was used to calculate the thinning rate with the highest earnings by trial and error.

An overview of the data in the *pro*FORST table in the successive years with harvest is given in appendix 9.8. The calculation of the present net value is given in table 66.

The calculated development of the basal area is given in figure 55.

Discussion and conclusions

The calculated present net value ignores loss of timber through hazards such as storm, fire or diseases. Ripken (1992) gave examples of the level of risks from various sources. On the basis of data from the Bavarian State Forestry Service he stated that 24% of the timber volume came from harvest that was necessary because of damage from unspecified causes. By comparison, Kleinschmit (*in*: Ripken, 1992) gave the percentage of the total harvested volume resulting from

Table 66. Calculation of present net value (PNV) of a hypothetical Scots pine plantation at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
planting preparations	0	–1,450	–1,450
planting	0	–2,100	–2,100
thinning harvest	45	284	75
thinning harvest	50	386	88
thinning harvest	55	496	98
thinning harvest	60	557	95
thinning harvest	65	588	86
thinning harvest	70	557	70
final stumpage value	75	9,851	1,073
total		9,169	**–1,965**

forced harvest because of damage as 5% for oak and beech, 10% for Scots pine, and 25% for Norway spruce.

In the Netherlands, loss of value through fire and storm can partly be insured against by the Onderlinge Bossenverzekering Maatschappij ('Mutual Forestry Insurance Company'; Anon. 1988b). This company calculates the following rates for full insurance against fire for Scots pine stands:
0 to 20 year-old stands: 3.5‰ * replacement value.

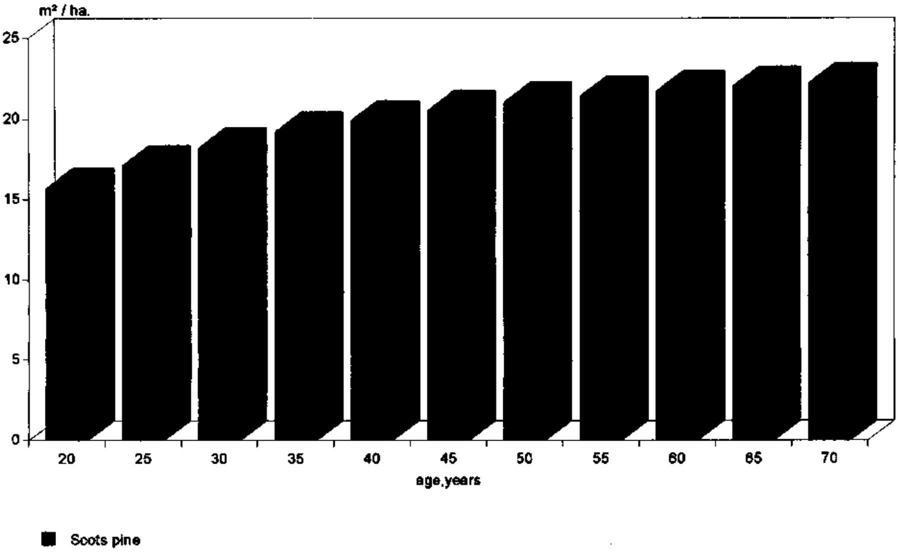

Fig. 55. Calculated development of basal area in a hypothetical Scots pine plantation, calculated with *pro*FORST.

20 to 30 year-old stands: 2.5‰ * replacement value,
stands older than 30 years: 1‰ * stumpage value.

The insurance for storm damage only covers 50% of the stumpage value, because it is assumed that windblown trees retain 50% of their net stumpage value. Storm damage insurance rates for Scots pine are:
0 to 20 year-old stands: 1‰ * 100% of the replacement value,
stands older than 20 years: 4‰ * 50% * stumpage value (Anon., 1990c).

For stands older than 30 years this means that the costs of both hazards combined are 3‰ of the stumpage value. When the financial diameters have been reached this covers approximately 10% of the current increment in value. With diameters above the financial diameter, the costs of both hazards cover a greater portion of the current increment in value.

The above insurance rates were not used in the calculation of the present net value. They are given to indicate the risk of fire and storm assumed by insurance companies.

No consideration was given to the need to leave a proportion of the timber in the forest as degradation phase in accordance with the objective of sustainable development as defined in this study, nor to the fact that in the absence of the plantation there would be revenue from timber anyhow (see section 9.9).

This calculation shows that at 3% interest, even without considering the natural hazards, the costs of land and the need for the degradation phase, Scots pine plantations have a negative present net value. Scots pine plantations are therefore not profitable.

9.9 Estimated present net values of spontaneous and semi-spontaneous regeneration on open areas

To obtain an indication of possible earnings from regeneration in group felled sites, 6 examples of spontaneous and semi-spontaneous regeneration which occurred on areas where the previous stands had been destroyed by storm, or had been clearfelled, were worked out. As in section 9.8, the present net value was calculated on the basis of 'profit only'.

The regeneration started immediately after removal of the old trees, or after the debris of the previous stand had been removed. The 6 examples had not yet reached the age of 20 years. The sapling numbers are given in table 45 in subsection 6.5.1. With one exception, oak and beech occurred much less frequently than birch. Therefore, to keep the calculation simple, all deciduous tree species were regarded as birch. The expected site index for Scots pine was 22 m, yield class III (Grandjean and Stoffels, 1955) and site index was 24 m for birch, yield class 6 (Hamilton and Christie, 1971). The normal basal area for

Table 67. Presumed regeneration characteristics at age 20 for 6 examples of spontaneous and semi-spontaneous regeneration on open areas, using *pro*FORST.

stand no.	tree sp.	N#	h_{dom}#,m	dbh#,cm	g#,m^2
Amerongseberg 7b	Sc.pine	229	8.2	9.3	1.6
	birch	914	10.2	9.3	6.2
Imbosch 13h	Sc.pine	3,087	8.2	6.9	11.6
	birch	1,458	10.2	6.9	5.5
Imbosch 24p	Sc.pine	2,961	8.2	6.9	11.1
	birch	1,570	10.2	6.9	5.9
Pal.Park 14c	Sc.pine	2,500	8.2	9.3	17.0
Petrea 12c	Sc.pine	450	8.2	8.2	2.4
	birch	2,790	10.2	8.2	14.7
Petrea 12e	Sc.pine	1,688	8.2	9.4	11.6
	birch	788	10.2	9.4	5.4

# Explanation of the symbols:
N = number of trees per ha,
h_{dom} = dominant height,
dbh = diameter at breast height,
g = basal area at breast height.

Scots pine of yield class III at 20 years is 17 m^2. This basal area was proportionally divided among the various tree species on the basis of the present tree numbers. This proportional division of basal area was assumed to be constant over the years.

In 3 of the 6 examples no site preparation was carried out, in the other 3 cases, Palace Park 14c, Petrea 12c and 12e, tree debris was removed at a cost of Dfl 612 per ha. The presumed regeneration characteristics at age 20 years are given in table 67.

The present net value was calculated for the moment the Scots pine regeneration started. The following assumptions were made:
- interest rate is 3%;
- no tending is carried out;
- first thinning is carried out as soon as net earnings are possible;
- thinning is done every 5 years;
- stumpage timber price level 2 from subsection 3.4.2 is used;
- for loss of bark and tree tops 25% deduction is calculated;
- the stumpage value at 75 years is considered as the final earning.

An overview of the data in the *pro*FORST-table in the successive harvesting years is given in appendix 9.9. The calculations of the present net values at the time of establishment are given in tables 68 to 73.

Table 68. Calculation of present net value at the time of establishment of a spontaneously regenerated stand at Amerongseberg 7b at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	35	64	23
thinning harvest	40	120	37
thinning harvest	45	112	30
thinning harvest	50	104	24
thinning harvest	55	117	23
thinning harvest	60	116	20
thinning harvest	65	113	17
thinning harvest	70	111	14
final stumpage value	75	2,417	263
total		3,274	**451**

The calculated development of the basal area is given in figure 56.

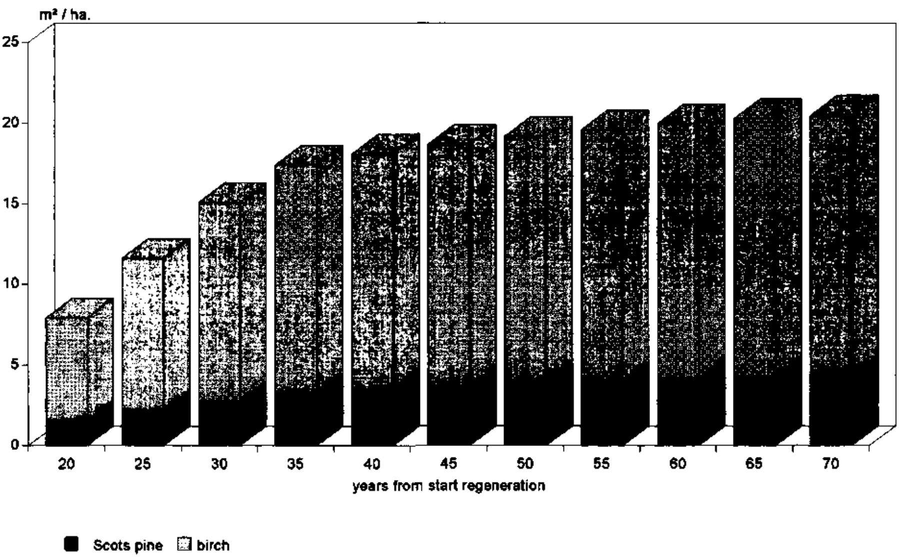

Fig. 56. Calculated development of basal area at Amerongseberg 7b, calculated with *pro*FORST.

Table 69. Calculation of present net value of a spontaneously regenerated stand at Imbosch 13h at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	45	48	13
thinning harvest	50	40	9
thinning harvest	55	40	8
thinning harvest	60	128	22
thinning harvest	65	155	23
thinning harvest	70	160	20
final stumpage value	75	4,261	464
total		4,832	**559**

The calculated development of the basal area is given in figure 57.

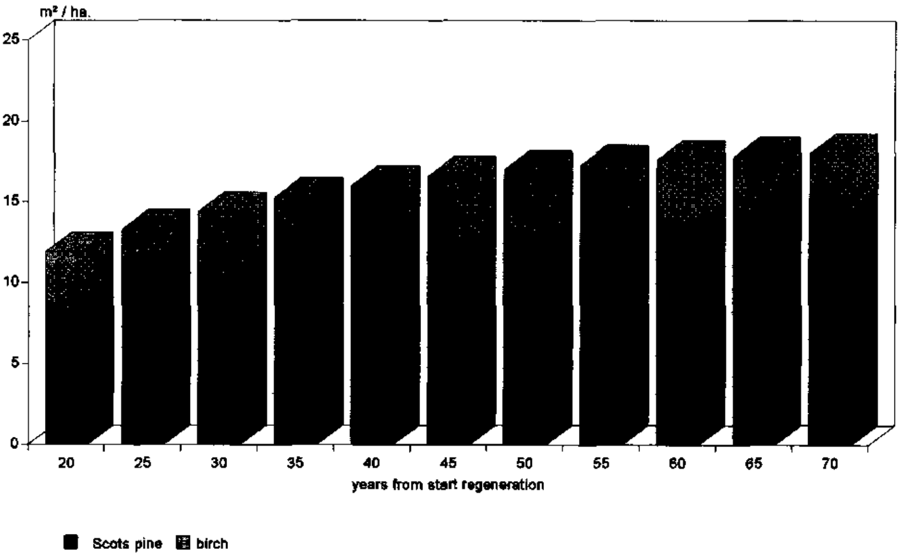

Fig. 57. Calculated development of basal area at Imbosch 13h, calculated with *pro*FORST.

Table 70. Calculation of present net value of a spontaneously regenerated stand at Imbosch 24p at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	45	48	13
thinning harvest	50	40	9
thinning harvest	55	143	28
thinning harvest	60	176	30
thinning harvest	65	180	26
thinning harvest	70	186	23
final stumpage value	75	3,906	426
total		4,679	**555**

The calculated development of the basal area is given in figure 58.

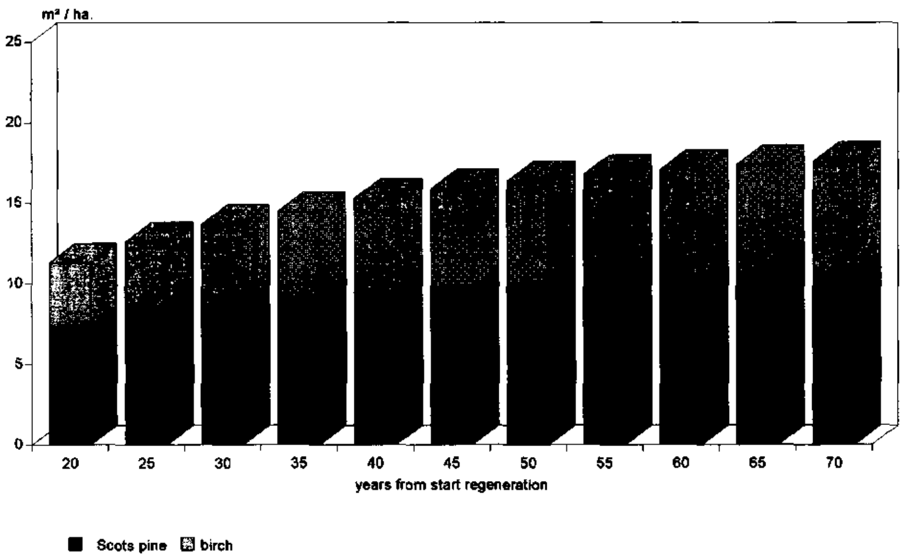

Fig. 58. Calculated development of basal area at Imbosch 24p, calculated with *pro*FORST.

Table 71. Calculation of present net value of a semi-spontaneously regenerated stand at Palace Park 14c at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
removal of debris	0	−612	−612
thinning harvest	50	168	38
thinning harvest	55	210	41
thinning harvest	60	243	41
thinning harvest	65	273	40
thinning harvest	70	318	40
final stumpage value	75	6,830	744
total		7,430	**333**

The calculated development of the basal area is given in figure 59.

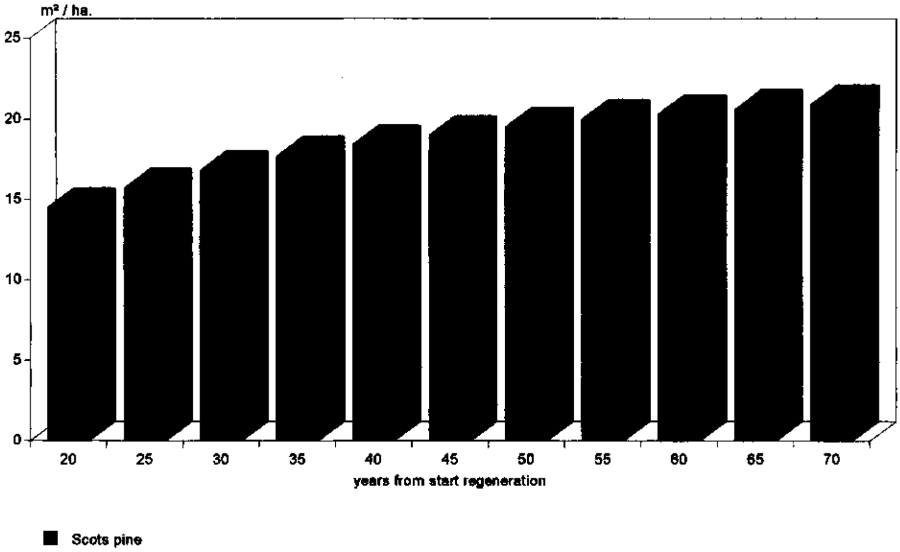

Fig. 59. Calculated development of basal area at Palace Park 14c, calculated with *pro*FORST.

Table 72. Calculation of present net value of a semi-spontaneously regenerated stand at Petrea 12c at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
removal of debris	0	– 612	– 612
thinning harvest	35	128	45
thinning harvest	40	120	37
thinning harvest	45	112	30
thinning harvest	50	131	30
thinning harvest	55	131	26
thinning harvest	60	130	22
thinning harvest	65	130	19
thinning harvest	70	105	13
final stumpage value	75	2,076	226
total		2,451	**– 164**

The calculated development of the basal area is given in figure 60.

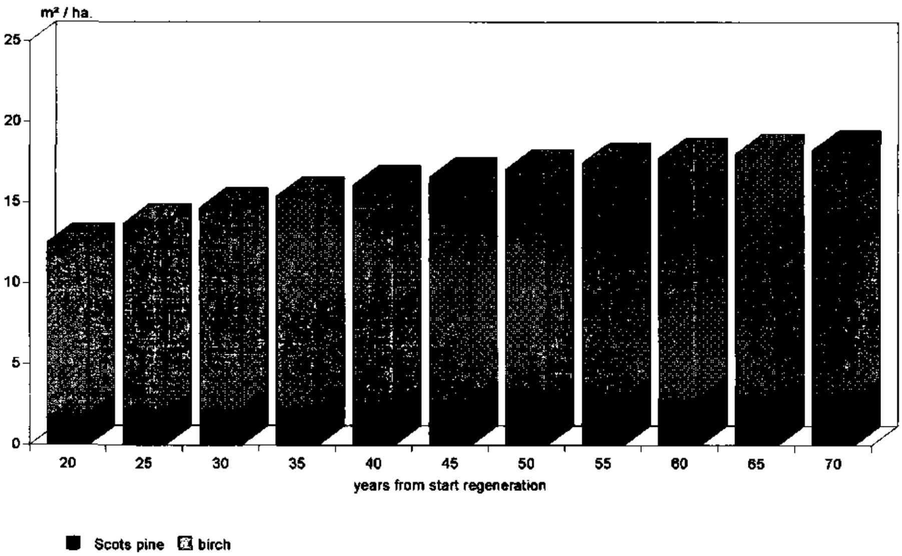

Fig. 60. Calculated development of basal area at Petrea 12c, calculated with *pro*FORST.

Table 73. Calculation of present net value of a semi-spontaneously regenerated stand at Petrea 12e at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
removal of debris	0	−612	−612
thinning harvest	35	48	17
thinning harvest	40	48	15
thinning harvest	45	139	37
thinning harvest	50	181	41
thinning harvest	55	203	40
thinning harvest	60	237	40
thinning harvest	65	245	36
thinning harvest	70	268	34
final stumpage value	75	5,561	606
total		6,318	**254**

The calculated development of the basal area is given in figure 61.

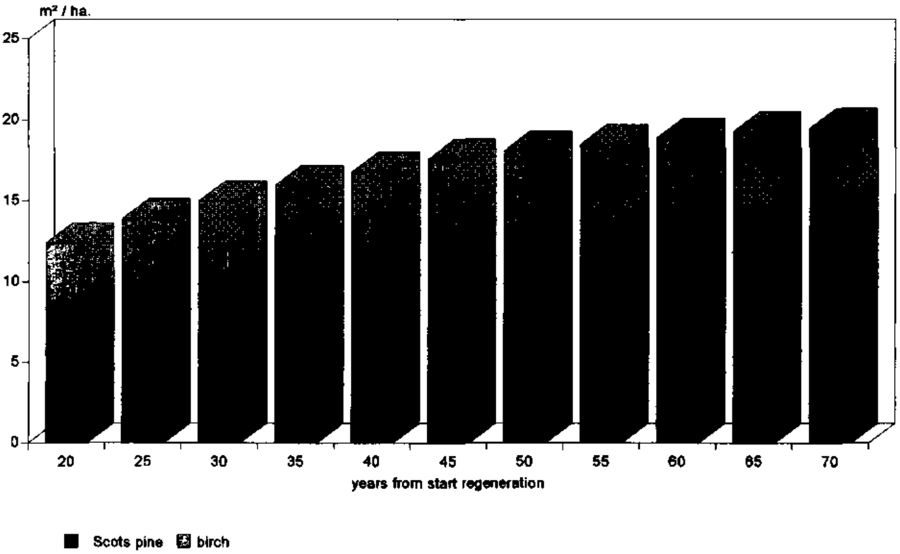

Fig. 61. Calculated development of basal area at Petrea 12e, calculated with *pro*FORST.

Discussion and conclusions

The risk of fire and storm in the above examples are similar to those in conventional plantations (section 9.8). These risks were not included in the calculations. Neither was timber reserved for degradation phases.

The examples without site preparation showed the highest present net values, even in the case of Amerongseberg 7b with its low tree numbers, most probably caused by the dense ground vegetation (section 6.1). Where site preparation was carried out, the present net value tended to be negative if regeneration was dominated by birch, even though the cost of site preparation was low. In the case of Palace Park 14c and Petrea 12e, present net value was positive. This was caused by the high number of saplings, which were all or mainly Scots pines. Birch saplings that could have competed with Scots pine had been eliminated or suppressed by deer (subsection 6.2.3).

If natural hazards were considered, and timber was reserved for degradation phases, then the stands without site preparation still showed positive present net values. If one-third of the timber was not harvested, the stands with site preparation showed negative present net values, with the exception of Palace Park 14c. In the latter case the present net value was still positive, but only just so.

The above data show that present net values are positive if regeneration appears without the need for site preparation. If site preparation was carried out at the cost of Dfl 612 per ha, and natural hazards and deliberate renouncement of part of the harvest were included to one-third of the production, the present net values tended to become negative.

The above calculations were carried out on the assumption that the proportions of basal area of the various species were kept constant. That does not necessarily lead to the highest present net value. For Petrea 12c the *highest* present net value was calculated on the assumption that the proportion of basal area for the various species was fully flexible. In that case the proportion of birch was reduced in favour of Scots pine. That resulted in the calculation given in table 74. Appendix 9.9 gives the calculation data in detail.

Table 74. Calculation of present net value of a semi-spontaneously regenerated stand at Petrea 12c at 3% interest, timber price level 2, favouring Scots pine, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
removal of debris	0	– 612	– 612
thinning harvest	35	416	148
thinning harvest	45	344	91
thinning harvest	55	512	101
final stumpage value	75	2,814	307
total		4,086	**35**

The calculated development of basal area is given in figure 62.

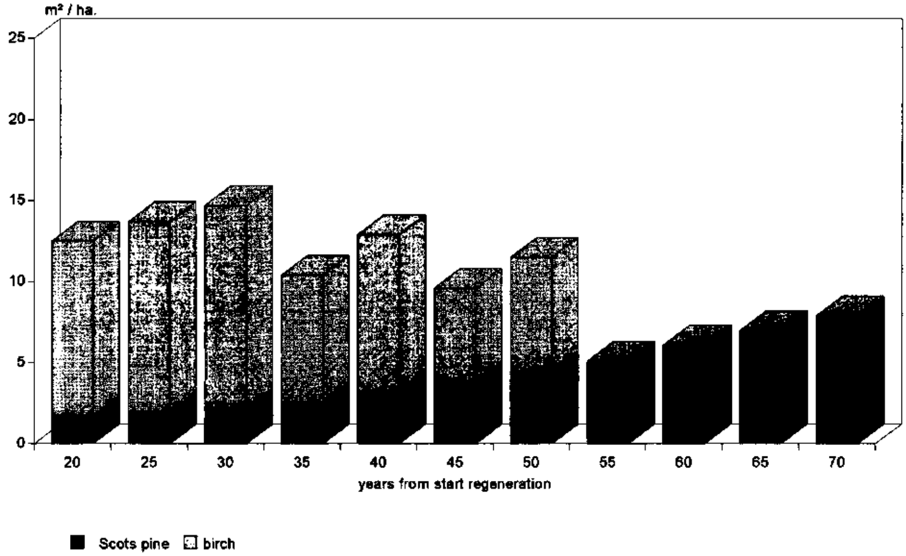

Fig. 62. Calculated development of basal area in Petrea 12c, if birch is harvested in favour of Scots pine, calculated with *pro*FORST.

If the thinning is carried out in such a way that Scots pine covers an increasing proportion of the basal area at the expense of birch, then the present net value increases. This increase is partly caused by the early harvest of birch, and partly by the increased harvest of Scots pine.

9.10 Estimated present net values of spontaneous regeneration in old stands

Five examples of spontaneous regeneration observed in old Scots pine stands were worked out. As in section 9.8 the present net value was calculated on the basis of 'profit only'. The present net value at the time of establishment of the regeneration was calculated at interest rate 3% and timber price level 2. The regeneration characteristics are given in table 75. The calculated site indices are also given. Site preparation was not carried out in any of the 5 examples. Other assumptions were as in section 9.8. The value of the old Scots pine stand was not included in the calculations, neither was future additional regeneration.

The earnings were calculated using *pro*FORST. The thinning was simulated in such a way that the proportion of basal area of different tree species remained constant over the years. After harvest of all Scots pine and birch at the age of 75 years, the proportions of oak and beech were kept constant. The intensity of thinning was found by trial and error, by running the *pro*FORST program as often as was needed to produce the highest earnings over the whole period.

Table 75. Regeneration characteristics of 5 examples of spontaneous regeneration in old Scots pine stands.

stand no.	tree sp.	N	h_{dom}, m	dbh, cm	g, m^2 young trees	site index, m	age, y young trees	g, m^2 old trees
Pal.Park 141	Sc.pine	171	11.9	16.0	3.5	19.3	40	13.9
	oak	229	14.2	15.3	4.2	33.3	40	
	birch	72	15.4	10.8	0.7	17.0	40	
	beech	286	15.9	19.4	8.4	29.7	40	
Uddel 26a	Sc.pine	722	7.4	11.0	6.9	13.4	31	5.5
Uddel 52n	Sc.pine	245	7.5	7.2	1.0	13.8	33	10.7
	oak	374	3.2	3.4	0.3	8.7	10	
	birch	800	11.1	7.6	3.6	19.3	33	
	beech	143	3.3	6.7	0.5	7.2	15	
Gortel 8d	Sc.pine	2,586	7.1	8.4	14.4	13.2	29	8.1
Gortel 80a	Sc.pine	333	6.5	5.6	0.8	11.1	34	14.9
	oak	303	5.7	6.4	1.0	15.1	25	
	birch	1,308	9.7	7.1	5.2	16.6	34	
	beech	92	6.6	8.6	0.5	14.1	25	

It was found that the height growth of young Scots pine under old Scots pine was reduced (subsections 7.4.1 and 7.4.2). When saplings approach the stand canopy this reduction is compensated (figure 44, subsection 7.4.2), or at least the height growth begins to resemble growth without suppression (Voegeli, 1954; Seitz, 1979). In order to estimate the most likely growth process, the age of the young Scots pine trees mentioned in table 75 was adjusted downwards to match their height (cf. Faber, 1990). The number of years difference was calculated by comparing the age of the saplings at a specific height with the age of the old Scots pine at that height. As a result, the Scots pine saplings in Uddel 26a, 52n and Gortel 8d and 80a were reduced in age by 9, 8, 9 and 9 years respectively. However, the young Scots pines in Palace Park 141 had already compensated in height growth.

An overview of the data in the *pro*FORST table in the successive harvesting years is given in appendix 9.10. The calculations of the present net values at the time of establishment of regeneration are given in tables 76 to 81. The assumptions were the same as those mentioned in section 9.9. For oak and beech the stumpage value at the age of 120 years was considered as final earnings. This 120 years was reached after compensation for belated regeneration.

Table 76. Calculation of present net value of a spontaneously regenerated stand at Palace Park 141 at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	40	40	12
thinning harvest	45	80	21
thinning harvest	50	123	28
thinning harvest	55	148	29
thinning harvest	60	168	29
thinning harvest	65	192	28
thinning harvest	70	220	28
thinning harvest	75	1,035	113
thinning harvest	105	119	5
thinning harvest	110	177	7
thinning harvest	115	185	6
final stumpage value	120	6,866	198
total		9,317	**504**

The calculated development of the basal area is given in figure 63.

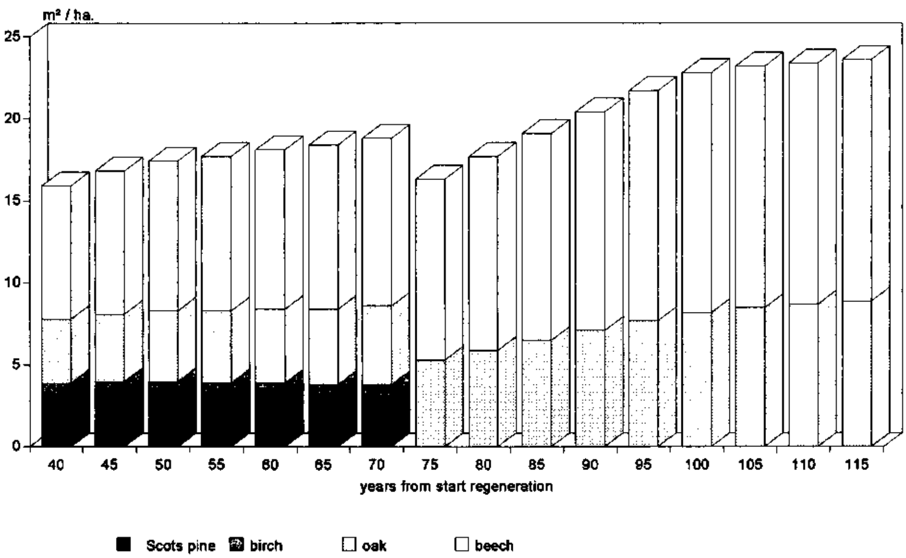

Fig. 63. Calculated development of basal area at Palace Park 141, calculated with *pro*FORST.

Table 77. Calculation of present net value of a spontaneously regenerated stand at Uddel 26a at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	64	114	17
thinning harvest	69	152	20
thinning harvest	74	168	19
thinning harvest	79	181	18
final stumpage value	84#	4,701	393
total		5,316	**466**

Because of growth suppression of Scots pine the final age is 9 years more than the assumed age of 75.

The calculated development of the basal area is given in figure 64.

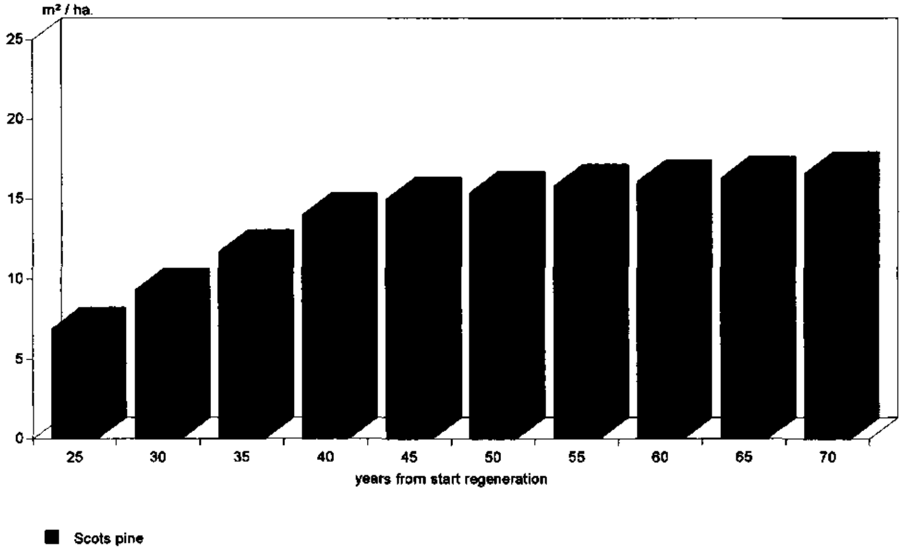

Fig. 64. Calculated development of basal area at Uddel 26a, calculated with *pro*FORST.

Table 78. Calculation of present net value of a spontaneously regenerated stand at Uddel 52n at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	50	32	7
thinning harvest	55	40	8
thinning harvest	60	40	7
thinning harvest	65	40	6
thinning harvest	70	48	6
thinning harvest	75	856	93
thinning harvest	83#	236	20
thinning harvest	120	352	10
final stumpage value	143##	1.010	15
total		2,654	**172**

\# Because of growth suppression of Scots pine the final age is increased by 8 years.
\## Because of belated regeneration of oak the final age is 23 years more than the assumed age of 120.

The calculated development of the basal area is given in figure 65.

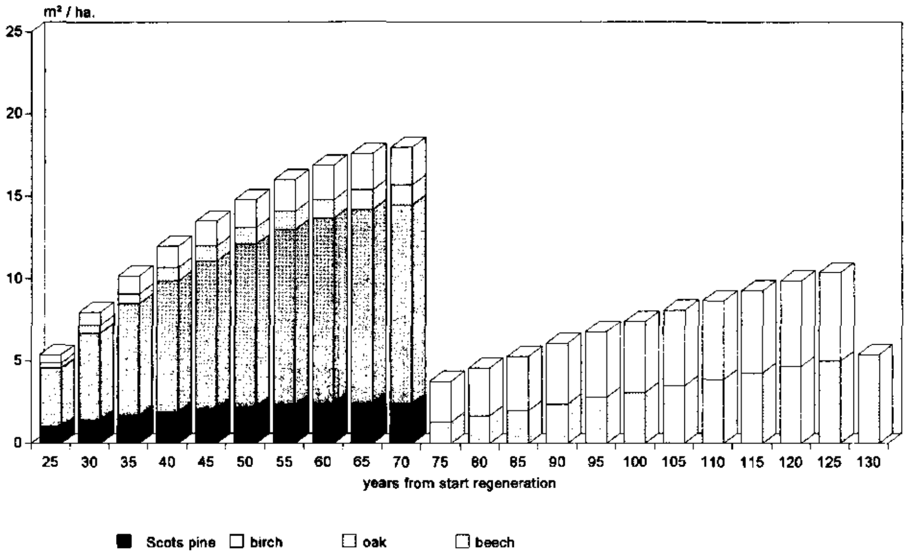

Fig. 65. Calculated development of basal area at Uddel 52n, calculated with *pro*FORST.

In table 78 calculations are based on the assumption that the proportion of basal area remained constant for the various species. If the thinning were carried out in such a way that Scots pine and oak are favoured at the cost of birch and beech, the calculation of the present net value will be as given in table 79. Detailed calculation data are given in appendix 9.10.

Table 79. Calculation of present net value of a spontaneously regenerated stand at Uddel 52n at 3% interest, timber price level 2, thinning favours Scots pine and oak, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	40#	200	61
thinning harvest	50	168	38
thinning harvest	65	272	40
thinning harvest	83	554	48
thinning harvest	120	400	12
final stumpage value	143	2.133	31
total		3.727	**230**

Early revenue was obtained from reducing the proportion of birch.

The calculated development of the basal area is given in figure 66.

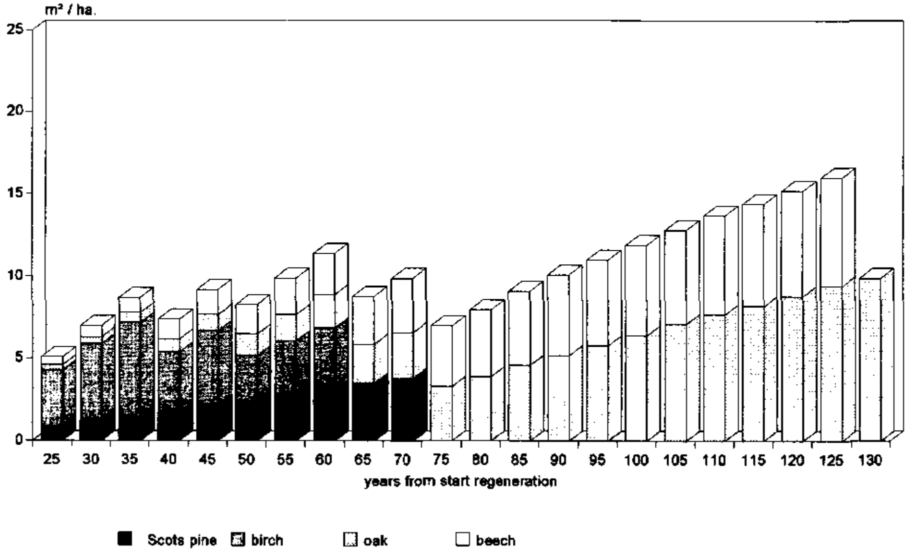

Fig. 66. Calculated development of basal area at Uddel 52n if thinning is done in favour of Scots pine and oak, calculated with *pro*FORST.

Table 80. Calculation of present net value of a spontaneously regenerated stand at Gortel 8d at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	64	126	19
thinning harvest	69	151	20
thinning harvest	74	166	19
thinning harvest	79	177	18
final stumpage value	84#	4,999	417
total		5,619	**493**

Because of growth suppression of Scots pine the final age is 9 years more than the assumed age of 75.

The calculated development of the basal area is given in figure 67.

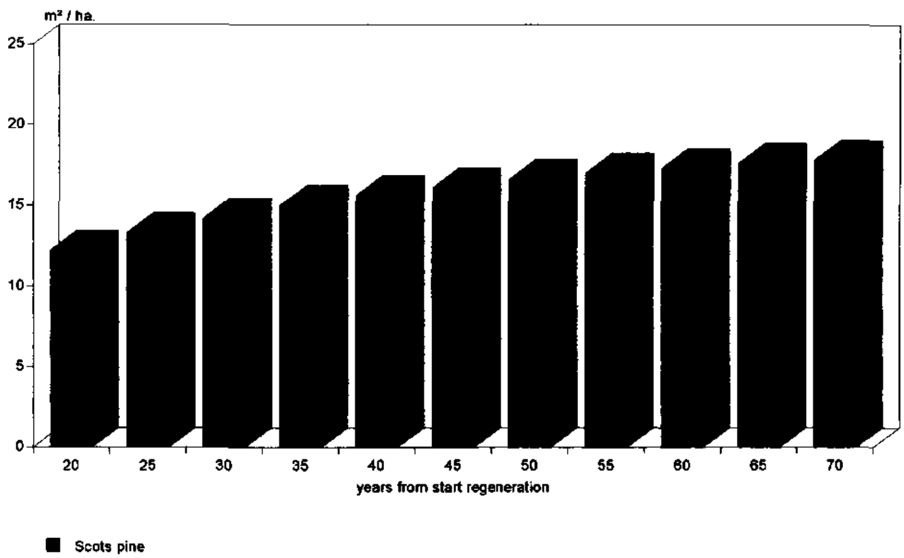

Fig. 67. Calculated development of basal area at Gortel 8d, calculated with *pro*FORST.

Table 81. Calculation of present net value of a spontaneously regenerated stand at Gortel 80a at 3% interest, timber price level 2, using *pro*FORST.

costs/earnings	year	amount, Dfl	PNV, Dfl
thinning harvest	60	56	10
thinning harvest	65	48	7
thinning harvest	70	40	5
thinning harvest	75	872	95
thinning harvest	79	8	1
thinning harvest	84#	110	9
thinning harvest	120	152	4
final stumpage value	129##	1,645	36
total		2,931	**167**

\# Because of suppression of Scots pine the final age is increased by 9 years.
\## Because of belated regeneration of oak the final age is 9 years more than the assumed age of 120.

The calculated development of the basal area is given in figure 68.

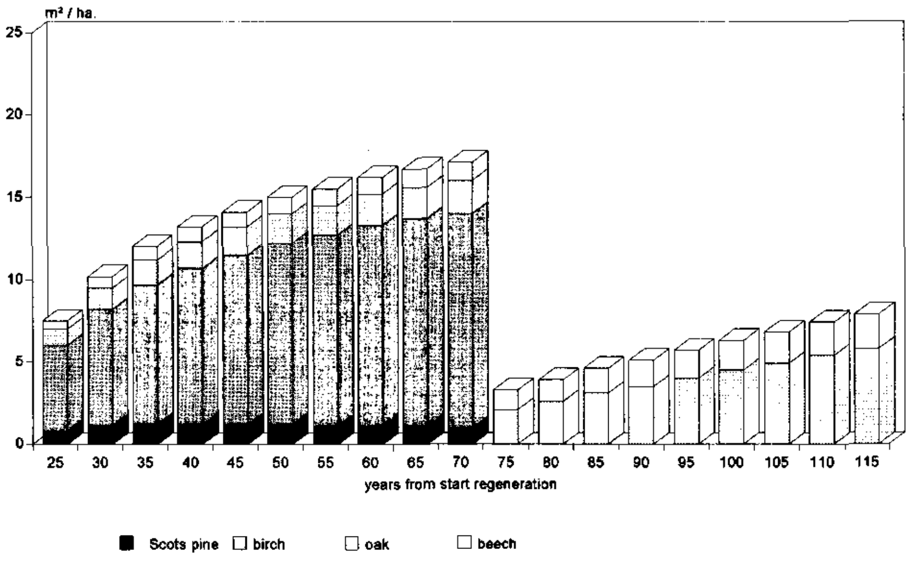

Fig. 68. Calculated development of basal area at Gortel 80a, calculated with *pro*FORST.

Discussion and conclusions

If returns are not deducted for natural hazards and for contribution to degradation phases in forest development, all examples show positive present net values. These values were particularly high for Uddel 26a and Gortel 8d which have many Scots pine saplings and few deciduous trees. Both stands are in areas where the red deer population was estimated at approximately 10 per 100 ha at the time the saplings established. Under those conditions deciduous saplings had little chance of surviving.

Stand Palace Park 141 also showed a high positive present net value. This was partly due to the high yield classes of the available oak and beech. Stands Uddel 52n and Gortel 80a showed positive, but low, present net values, because of the few young Scots pine trees plus the fact that the oak and beech trees are in low yield classes. The present net value could be increased by favouring Scots pine and oak at the cost of birch and beech. The increase is partly caused by the early harvest of birch and partly by increased production of Scots pine and oak.

The calculations assumed that no additional saplings will appear. That was a conservative assumption, certainly for the stands which still showed a substantial basal area of old Scots pine trees.

If deciduous trees are present, insurance companies assume lower risks of fire and storm. As the coniferous component drops below 25%, insurance rates fall below those mentioned in section 9.8 (Anon., 1988b). Fire insurance rates for mixed stands with less than 25% Scots pine are:
0 to 20 year-old stands: 2‰ * replacement value;
stands older than 20 years: 0.5‰ * stumpage value (Anon., 1988b).

The rates for storm insurance for mixed stands in which the canopy is composed of more than 25% deciduous trees, are:
0 to 20 years old stands: 1‰ * replacement value;
stands older than 20 years: 3‰ * 50% * stumpage value (Anon., 1990c).

The above rates were not used in the calculations of present net values. They are given to indicate the risks of fire and storm assumed by insurance companies.

Note that if one-third of the produced value of timber is not harvested because of natural risks or management objectives such as the contribution to degradation phases, all the stands mentioned above retain positive present net values.

9.11 Estimated present net values of enrichment planting

Some examples were worked out for present net values of trees grown from enrichment planting, again based on the 'profit only' approach. If little regeneration appears spontaneously, additional regeneration can be boosted by a kuloo treatment costing Dfl 319 per ha (subsection 9.7.2). Assuming that this treatment produced 400 patches of regeneration for Scots pine saplings which, at the age of 75 years, added 200 crop trees of site index 22m, yield class III

(Grandjean and Stoffels, 1955) to the stand, then the present net value at the time of soil tillage of these 200 trees, grown as in Palace Park 14c, was Dfl (352 – 319) = Dfl **33** per ha.

Sowing selected Scots pine seeds on 200 kuloo patches at the cost of Dfl 77 per ha was assumed to add 100 crop trees of site index 26.0 m, yield class II (Grandjean and Stoffels, 1955). These 100 trees of yield class II are instead of 100 trees of assumed yield class III that have regenerated spontaneously. The increase in present net value of the 100 crop trees, grown as in the hypothetical plantation of section 9.8, was Dfl {(299 – 176) – 77} = Dfl **46**.

If 200 selected container-grown Scots pine saplings ('P84') were planted, producing 100 crop trees of yield class II at 75 years, the present net value of the investment would be Dfl (299 – 192) = Dfl **107**.

If 100 4-year-old oak saplings were planted among regenerating birch, at the cost of Dfl 632 per ha, and at 120 years 50 of these saplings were expected to become crop trees of site index 33.3 m, yield class 5 (Oosterbaan, 1988), the present net value of these oaks, grown as in Palace Park 14l, would be Dfl (86 – 632) = Dfl **-546**.

If 100 2-year-old oak saplings were planted, and at 120 years 50 were expected to become crop trees of site index 33.3 m, yield class 5 (Oosterbaan, 1988), then the present net value of these oaks, grown as in Palace Park 14l, would be Dfl (86 – 186) = Dfl **-100**.

If 100 2-year-old beech saplings were planted, and at 120 years 50 were expected to become crop trees of site index 29.7 m, yield class 6 (Hamilton and Christie, 1971), the present net value of these beech trees, grown as in Palace Park 14l, would be Dfl (16 – 188) = Dfl **-172**.

Discussion and conclusions

If natural hazards are ignored, then kuloo treatment produced positive present net values, given the assumed yield classes. The present net value could be raised by sowing selected seeds on the kuloo patches. This means that on its own the extra investment of sowing also produced a net return higher than 3%.

Planting a limited number of container-grown Scots pine saplings also produces a positive present net value, and this is higher than the estimated present net value of the kuloo treatment plus sowing treatment. The assumption that only half of the number of planted container-grown saplings would become a crop tree was similar to the assumption for the planted bare-root saplings. However, insufficient data are available on container-grown saplings to test this assumption thoroughly (Grimbergen and Oosterbaan, 1992).

Enrichment planting of 4-year-old oak saplings did not produce positive present net values on the soils at Het Loo. Neither did enrichment planting of 2-year-old oak saplings, nor enrichment planting of 2-year-old beech saplings.

9.12 Sustainable production of timber volume

In addition to the objective that part of the timber production should not be harvested, to benefit nature conservation, there was the objective of sustainable harvest of timber (section 1.1). However, calculations of financial diameters do not assume that sustainable production of timber must be guaranteed. The financial diameters only pinpoint the maximum ongoing money flow from interest after the trees are harvested.

The 'profit only' approach, based on financial diameters, also conflicts with the use of minimum diameters that increases chances for sustainability of the timber flow, as has been noted by various authors (Wyatt-Smith, 1987; Poore et al., 1989; Jackson and Donnovan, 1992). See section 9.2.

If the aim is also a sustainable flow of timber volume, the average harvest over the years must never exceed the average yearly net increment, and regrowth must always be available. Net increment* is the total increment minus the volume that remains in the forest as a result of natural hazards or for species conservation purposes.

If regeneration fails to appear, timber increment decreases. This implies that harvest should decrease. In order to keep the harvest at a sustainable level, regeneration must then be stimulated through reduction of browsers, fencing, soil tillage, or planting. The level to which the average timber production is allowed to fall through loss of trees or forest cover, depends on the management objectives.

Average volume flow in plantations

The average volume production to be harvested in a plantation of Scots pine of site index 26 m, calculated over a period of 75 years with *pro*FORST, was 457 m^3. It excluded production loss before age 20 (section 9.8). It amounts to 6.1 m^3 per year and ha. This volume cannot wholly be sold at a profit. Only 4.7 m^3 per year and ha has diameters at breast height of over 16 cm (subsection 3.4.2).

Sustainable timber volume flow in examples of spontaneous and semi-spontaneous regeneration on open areas

The saleable volume produced in the examples of spontaneous and semi-spontaneous regeneration on open areas (section 9.9) calculated over a period of 75 years with *pro*FORST for Scots pine and birch is given in table 82.

Table 82. Volume of saleable timber produced per ha per year in the examples of spontaneous and semi-spontaneous regeneration on open areas, calculated with *pro*FORST.

stand no.	tree sp.	production, m^3	total, m^3
Amerongseberg 7b	Sc.pine	0.7	
	birch	3.2	
			3.9
Imbosch 13h	Sc.pine	3.1	
	birch	1.3	
			4.4
Imbosch 24p	Sc.pine	2.6	
	birch	1.7	
			4.3
Pal.Park 14c	Sc.pine	4.5	
			4.5
Petrea 12c	Sc.pine	0.6	
	birch	4.0	
			4.6
Petrea 12e	Sc.pine	3.1	
	birch	1.4	
			4.5

Sustainable timber volume flow in examples of spontaneous regeneration in old stands

The saleable volume produced in the examples of spontaneous regeneration in old stands (section 9.10) calculated with *pro*FORST over 75 years for Scots pine and birch, and over 120 years for oak and beech is given in table 83. The production of the old Scots pines is excluded.

Added timber flow in enrichment planting

If the stated numbers of trees become crop trees, the examples of enrichment planting mentioned in section 9.11, based on calculation with *pro*FORST, added the following volume of saleable timber production to the current production at every planting cycle:
200 Scots pines of site index 22.0 m: 1.2 m^3 per ha per year,
100 Scots pines of site index 26.0 m: 0.9 m^3 per ha per year,
50 pedunculate oaks of site index 33.3 m: 0.5 m^3 per ha per year,
50 beeches of site index 29.7 m: 0.6 m^3 per ha per year.

Discussion and conclusions

The Scots pine plantation as reafforestation and the examples of spontaneous and semi-spontaneous regeneration on open areas showed ongoing volume pro-

Table 83. Volume of saleable timber produced per ha per year in the examples of spontaneous regeneration in old stands, calculated with *pro*FORST.

stand no.	tree sp.	production, m^3	total, m^3
Pal.Park 14l	Sc.pine	0.6	
	birch	0.2	
	oak	1.1	
	beech	2.1	
			4.0
Uddel 26a	Sc.pine	2.6	
			2.6
Uddel 52n	Sc.pine	0.4	
	birch	1.9	
	oak	0.4	
	beech	0.4	
			3.1
Gortel 8d	Sc.pine	3.6	
			3.6
Gortel 80a	Sc.pine	0.2	
	birch	2.1	
	oak	0.5	
	beech	0.2	
			3.0

duction over the next 75 years. In the absence of sound local data the empirical assumption was made that soil fertility did not diminish after the previous stands had been destroyed. If this assumption is true the volume production would be sustainable. However, the stand development had reverted to pioneer conditions through clearfelling or storm, destroying the existing successional stage. Clearfelling enhances the intensity of dynamics, and thus reduces chances for niches; especially of late developmental phases. Therefore sustainable development is not possible under clearfelling (section 1.3). If the storm damage is part of the natural dynamics of the silvatic mosaic, the reversion to pioneer conditions is part of the succession, and hence part of sustainable development of the silvatic mosaic. The examples of spontaneous regeneration in old Scots pine stands, including the enrichment planting of oak, showed both sustainable volume production and sustainable development at stand level. The sustainable volumes produced were lower than in the Scots pine plantation. It should, however, be noted, that only the volume produced by the present regeneration was considered. The volume produced by the old Scots pines and the regeneration to come after harvest of the old Scots pines was not included in the calculations.

9.13 Successional stages

The theoretical natural succession sequences of tree species, as inspired by Fanta (1982) are given in figures 69a and 70a for the Betulo-Quercetum and the Fago-Quercetum respectively. Based on the results from this study (chapters 5, 6 and 7) the development opportunities for Scots pine stands to evolve to Betulo-Quercetum and Fago-Quercetum are given in figures 69b and 70b. Fanta's initial stage of the primary succession is replaced by Scots pine stands which were the initial stands used in this study.

Finally, in figures 69c and 70c succession opportunities to evolve to Betulo-Quercetum and Fago-Quercetum are given, if Scots pine seed sources and abundant browsing animals are present (chapter 6).

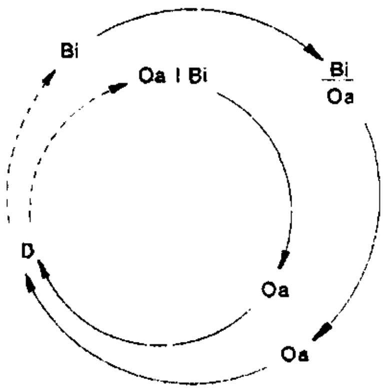

Fig. 69a. Theoretical model of the succession of Betulo-Quercetum. Inspired by Fanta (1982), his figure 15.
——▶ = steps in time with permanent forest cover, trees regenerate under old trees.
----▶ = steps in time with interrupted forest cover, trees regenerate in open areas.
D = degradation phase. Oa = oak, Bi = birch.

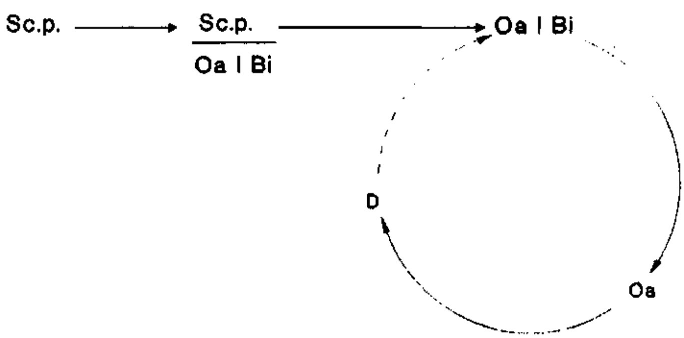

Fig. 69b. Succession opportunity for Scots pine stands to evolve to Betulo-Quercetum.
——▶ = steps in time with permanent forest cover, trees regenerate under old trees.
----▶ = steps in time with interrupted forest cover, trees regenerate in open areas.
D = degradation phase. Oa = oak, Bi = birch, Sc.p. = Scots pine.

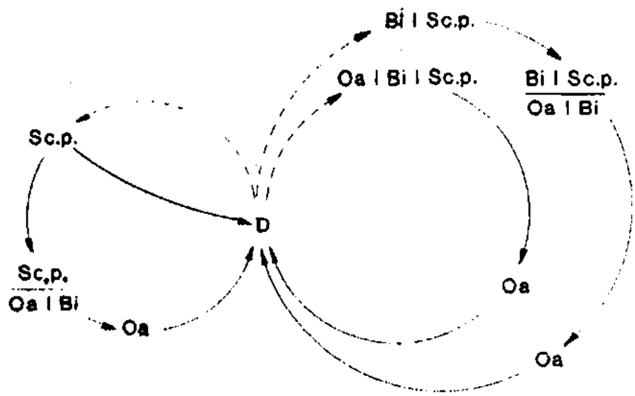

Fig. 69c. Succession opportunities to evolve to Betulo-Quercetum, with Scots pine seed sources and abundant browsers present.
——► = steps in time with permanent forest cover, trees regenerate under old trees.
- - - -► = steps in time with interrupted forest cover, trees regenerate in open areas.
D = degradation phase. Oa = oak, Bi = birch, Sc.p. = Scots pine.

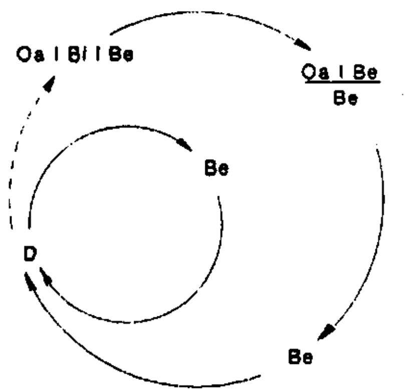

Fig. 70a. Theoretical model of the succession of Fago-Quercetum. Inspired by Fanta (1982), his figure 17.
——► = steps in time with permanent forest cover, trees regenerate under old trees.
- - - -► = steps in time with interrupted forest cover, trees regenerate in open areas.
D = degradation phase. Be = beech, Oa = oak, Bi = birch.

Discussion and conclusions

In developing Scots pine stands the establishment and occurrence of tree species of the Querco-Betuletum and Fago-Quercetum (Van der Werf, 1991) is not prevented by harvesting trees at their financial diameter. Birch and oak will establish under Scots pine before the latter reaches its financial diameter. The same happens with beech on substrate of Fago-Quercetum, if seed sources are

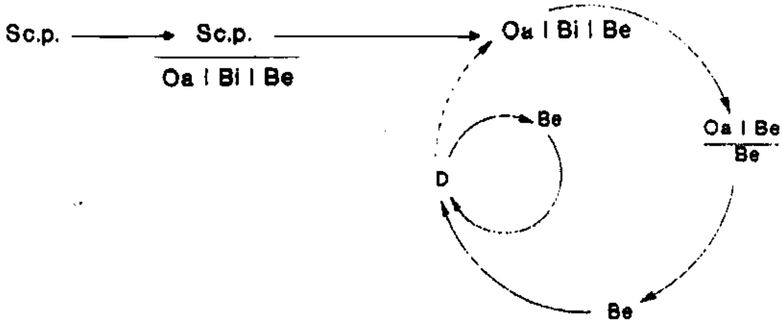

Fig. 70b. Succession opportunities for Scots pine stands to evolve to Fago-Quercetum.
——▶ = steps in time with permanent forest cover, trees regenerate under old trees.
- - - -▶ = steps in time with interrupted forest cover, trees regenerate in open areas.
D = degradation phase. Be = beech, Oa = oak, Bi = birch, Sc.p. = Scots pine.

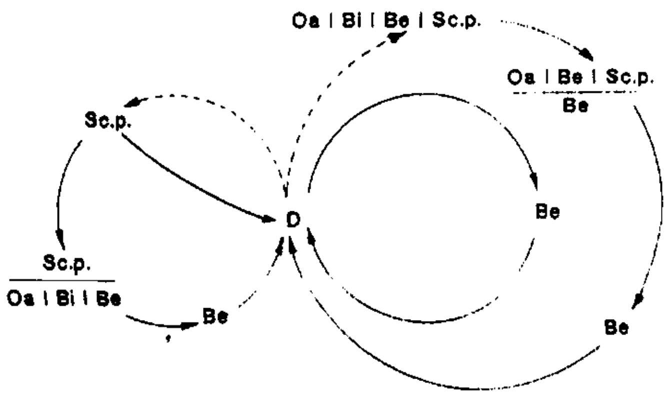

Fig. 70c. Succession opportunities to evolve to Fago-Quercetum, with Scots pine seed sources and abundant browsers present.
——▶ = steps in time with permanent forest cover, trees regenerate under old trees.
- - - -▶ = steps in time with interrupted forest cover, trees regenerate in open areas.
D = degradation phase. Be = beech, Oa = oak, Bi = birch, Sc.p. = Scots pine.

available. All indigenous tree species that play a role in the potential natural vegetation will be able to maintain themselves in the proposed silvicultural system by natural regeneration. Nevertheless, their relative proportion in the species composition of regenerating and mature stands is influenced by the degree and frequency of regression (size and frequency of canopy gaps; Oldeman 1990, p.388; Oliver and Larson, 1990, p.89).

The regeneration and survival of Scots pine depend on pioneer conditions.

In existing Betulo-Querceta and Fago-Querceta, pioneer conditions are created when browsing animals prevent deciduous tree species becoming established. Because deciduous tree species as well as grasses, herbs and shrubs compete with Scots pine seedlings and saplings (section 6.1), it is unlikely that Scots pine will be able to maintain itself in these forest types in the long run.

9.14 Developmental phases

Innovation and aggradation phases

The fragmentation of the homogeneous Scots pine stands was discussed in detail in chapter 8. If the occurrence of compartments of young trees is to imitate the pattern of the natural forest mosaic, group felling must be carried out as a preliminary measure, and browsing pressure of game must temporarily be reduced or eliminated. If near-permanent open areas are wanted, browsing pressure must be increased.

Degradation phases

The more trees are harvested, the slighter the chance that the developmental phases of old trees and old tree compartments will occur. This is certainly the case when trees are harvested at a relatively small financial diameter when 'profit only' is the objective. This affects the presence of living big trees, as well as the presence of degrading and dead big trees, including the niches for other organisms these create.

Decaying old trees with large diameters create specific niches, and contribute more to ecological value than small decaying trees (Koop, 1991; Van Tol, 1991) which are available anyway. Big trees also contribute most to the financial results. This is certainly the case for old trees of high stem quality (for instance, straight Scots pine and oak trees).

Trees that have died from natural cause, irrespective of their species, have negligible financial value. Oak is an exception to this rule. Birch and branched beech trees generally have less financial value than Scots pine and oak. Therefore it is cheaper to leave birches and poor quality beeches to decay, than straight oaks or Scots pines.

Since every tree species creates diverse and specific niches, opting for birch provides only a limited range of possible niches in decaying wood. An advantage of selecting birch as the species to be left to decay is the short life span of this species, which provides a quick flow of wood to decay. Disadvantages are the reduced occurrence of birch in late successional stages, and the rapid rate of decay in birch. That increases the causes of discontinuity in provision of dead wood.

Sparing specific tree species from harvest allows for easy and clear management instructions, but creates limited additional ecological value. Another source, or an extra source, of timber to be left in the forest can be wind-blown trees. However, this merely increases the volume of dead wood. It does not contribute to the occurrence of old trees or old tree compartments, nor to the slow degradation phase of the forest.

Another way of implementing the objective of degradation phases in forests is to establish strict reserves by zoning. The number and extent of strict reserves are a matter of further research and management objectives.

In order to allow continuous successional processes, resulting in all developmental phases of the various successional stages of the forest as parts of the forest mosaic, part of the timber production should not be harvested. Neither the intensity of harvest, nor the kind of zoning, nor the scale allowed to ensure conservation of all species, can be determined from the data from the present study.

In the case of 'maximum income generation', the financial diameter in Scots pine is high. This increases the chance that large dead trees will occur.

10 Conclusions

The sustainable development considered in this study deals with both nature conservation and timber production. It covers the sustainable use of timber together with the conservation of species.

As the preceding chapters have shown, the proposed *silvicultural design* starting from Scots pine stands generates a selection forest composed of indigenous tree species.

The way the silvicultural system is worked out at Het Loo cannot be extrapolated to other areas without risks. Differences in management objectives and ecological conditions will lead to different results in other areas.

There are two types of conclusions from this study: general conclusions, which apply to sustainable development of forests, and conclusions that are more specific. All the conclusions that were presented in earlier chapters are collected together in this chapter.

10.1 General conclusions

Deciduous tree species regenerate spontaneously in the Scots pine stands studied. At Het Loo, deciduous species can be used sustainably if browsing is kept within limits, i.e. at least less than in the experimental stands. Scots pine can only be used sustainably if pioneer conditions appear repeatedly in combination with an acceptable level of browsing, i.e. the level in the experimental stands (subsection 3.2.7).

The *silvicultural design* produced by this study rehabilitates Scots pine forests from the cultivated stage to the modified natural stage. In the study area successional processes which lead to actual Betulo-Quercetum and Fago-Quercetum could be observed in Scots pine stands which were used in a sustainable way. Regression by natural dynamics and lack of regeneration by non-pioneer species are also possible; these creating conditions which allow pioneer tree species to colonize.

If the various successional processes do occur and regeneration is not hampered, *sustainable use* is attainable in Scots pine forests. If, in addition, zones for nature conservation, including dead timber and hampered regeneration, are permitted to such an extent as to allow all successional stages to become an integrated part of the silvatic mosaic, then *sustainable development* is also attainable in Scots pine forests.

Where forests are managed with the aim of timber production, nature conservation must compromise. This involves allowing biomass to be extracted from the forest, the addition of anthropogenic dynamics through felling of trees, the manipulation of tree species composition, and the manipulation of the distribution and abundance of game. Similarly, where there is active nature conservation, timber production must compromise. This involves reduction of revenue by allowing browsers to reduce and damage tree regeneration, and by allowing trees not to be harvested until they decay in degradation phases of the forest. Because of these compromises it is impossible to fulfil full nature conservation and timber production simultaneously in the same place. *Conflicting demands on the forest can only be reconciled by zoning into harvest and non-harvest zones.* (Sections 8.1, 8.2, 9.2 and 9.4). The form of zoning, and the optimal proportion of harvest and non-harvest zones in order to conserve all forest species was not investigated in this study.

In order to minimize the loss of ecological value caused by harvesting, it was opted for selection felling as the harvest method (section 1.3). If full conservation of species is obtained in the non-harvest zone, selection felling for that specific purpose is not necessary in the harvest zone. In that case, selection felling will be applied for environmentally sound land use, and to maximize financial revenue and other forest values such as shelter and aesthetic values. As far as ecological value is concerned, application of selection felling in the harvest zone provides areas of the early developmental phases of indigenous forests and, hence extra chances for niches in those specific developmental phases.

If all trees were selectively harvested at their financial diameter, as they should be for financial gain, no trees would be spared to grow to the big sizes of trees known from natural forests, nor will degradation phases occur. In that case the only phases of the forest with ecological value are the treeless, sapling, pole and young tree phases.

10.2 Value increment in old Scots pine trees

Absolute volume and value increment increase with increasing diameters. Relative value increment decreases with increasing diameters. The values of R^2 from regression of volume increment, value increment and percentage value increment were low. (Chapter 4).

10.3 Oak regeneration

Indigenous oak could establish in 40- to 50-year-old Scots pine stands at Het Loo, even if the Scots pine stands had stand density indices of 0.7 and higher (section 5.1). However, oak only established if browsing by game was temporarily reduced or excluded.

Under the canopy of Scots pine stands there is a zone above the forest floor with little difference in photosynthetic active radiation (PAR) intensity. In simulated 60-year-old stands this height is approximately 10 m.

The rate of PAR increase in the first 10 m above the forest floor varies, depending on whether the stand does or does not have an undergrowth of young trees. In the stand with undergrowth of young trees the PAR gradient is steeper than in the stand without undergrowth. In addition to a vertical PAR gradient towards lighter conditions there are horizontal PAR gradients towards darker conditions in the stands with undergrowth of young trees (subsection 5.2.3). The young trees create ecological light shafts (figure 23) in which the PAR intensity deminishes towards the sides and increases towards the stand canopy. This forces saplings which grow in this shaft to grow straight.

Indigenous oak of various age, from 1 to 4 years, could be planted and more or less successfully established in Scots pine stands. Pedunculate oak saplings showed higher survival rates than sessile oak saplings (section 5.3). However, if red deer were present, the mortality of 4-year-old planted oak saplings rose to over 60% after 2 growing seasons. Roe deer do not browse the top shoot of 4-year-old oak saplings taller than 1.5 m. However, roe deer damage saplings by fraying. If oak saplings were planted in Scots pine stands without undergrowth of young trees, the damage by fraying was considerable. If oak saplings were planted among 1000 or more individuals of young trees per ha, the fray damage to the oak saplings was negligible. (Section 5.3).

Dominant axes in oak saplings bend towards the vertical over the years. If more than one top shoot develops, generally only one shoot becomes dominant and enhances its dominance over the years at the cost of the other shoots. (Subsection 5.2.2).

Oak saplings in half-shade at Het Loo survive competition with neighbouring birches (subsection 5.2.2). During the competition, the vertical dominant axes of the oaks are liable to strengthen themselves as mentioned above.

Therefore, enrichment planting of oak saplings in Scots pine stands with undergrowth of young birches is a useful silvicultural management option, if red deer are absent.

10.4 Scots pine regeneration

Seedlings

The number of Scots pine seedlings in the regeneration experiment was primarily determined by the factors sowing and soil tillage. On average, sowing increased the number of seedlings fivefold. Without soil tillage no regeneration of Scots pine occurred in the mixed herb and shrub vegetation consisting of bilberry, cowberry and wavy hair grass (section 6.1). Without sowing, no influence of stand density or fencing or of the 2 soil tillage treatments was found. With sowing there were differences between the two soil tillage treatments, with the kuloo giving most regeneration. Also a positive effect of fencing was found after sowing. No stand density effect was found. (Subsection 6.2.1).

Colonization by herbs, shrubs and mosses on the seedbeds occurred immediately after the soil tillage took place, and increased cover in the following years. Grass and bilberry cover increased faster on areas treated with rotovator than on areas treated with kuloo. Heather increased faster on the kuloo areas. Cowberry increased in cover, but slowly. Bramble was rare on the soils of the area. Sheep's sorrel, heath bedstraw and pill sedge never covered a substantial part of the seedbeds after 5 years, although sheep's sorrel and heath bedstraw covered up to 15% and 30% respectively in the early years of the experiment. (Subsection 6.2.4).

Mortality of Scots pine seedlings was highest in the first year. This was irrespective of the stand density, soil tillage, sowing or fencing treatment. Survival of Scots pine seedlings in the experiment was mainly dependent on soil tillage treatment and stand density. Soil tillage using the kuloo instead of the rotovator increased the average survival from 30% to 50%. At high and moderately high stand densities the average survival was slightly more than 30%, whereas more open stands had an average survival of almost 50%. The effect of fencing on survival was indicative (from 35% to 44%), though not statistically significant. No effect of sowing on survival was found. (Section 6.3).

Photosynthetic active radiation

In the Scots pine stands relative TOTAL photosynthetic active radiation (PAR) is only a fraction higher than relative DFOV PAR (DiFfuse PAR on OVercast moments). Therefore, relative DFOV PAR can serve as a practical index of relative TOTAL PAR. (Subsection 6.4.1). On the forest floor, both relative TOTAL and DFOV PAR decrease at increasing basal areas. (Subsection 6.4.2).

With increasing canopy gap sizes relative TOTAL PAR on the forest floor increases faster than relative DFOV PAR. However, at decreasing stand density indices the higher rate of increase for relative TOTAL PAR at increasing gap sizes lags behind the increase of relative DFOV PAR. This means that the differences between relative TOTAL PAR and relative DFOV PAR are greater in gaps in stands with high densities than in stands with low densities. (Subsection 6.4.3).

Regeneration of light-demanding tree species takes place if gap sizes are large enough, or stand densities low enough for relative DFOV PAR to reach values for which the ratio between relative TOTAL PAR and DFOV PAR is near unity. Therefore, for the prediction of the probability of regeneration of light-demanding tree species there are few restrictions for using relative DFOV PAR as a measure for relative TOTAL PAR. (Subsection 6.4.3).

Increase in gap size in a simulated stand increases the relative amount of PAR on the forest floor. The increase is strongest at low stand density indices. In field experiments the effect of increasing gaps was also measured. The effect of the stand density index could not be determined. (Subsections 6.4.3 and 6.4.4).

The distance below the top of a gap in herbs or shrubs where DFOV PAR was reduced to 90% of its maximum value, was approximately equal to the average radius of the gap. This means that in order to receive at least 90% of the maximum DFOV PAR, gaps must be at least twice as wide as the height of the surrounding shrubs. Once gaps were substantial in size (2 m^2 and more), up to 98% of the maximum DFOV PAR reached 25 cm and more under the top of the surrounding shrubs. This meant that for Scots pine regeneration in bilberry, seedbeds require a minimum size of 2 m^2. (Subsection 6.4.5).

Organic topsoil

Scots pine regenerates not only on mineral soil, but also on organic topsoil which consists of litter from Scots pine, herbs and shrubs. Such organic topsoil can be at least up to 15 cm thick, provided the herb and shrub vegetation is absent or open.

Although Scots pine seedlings established with more success on thinner than on thicker topsoils of the mentioned composition, the findings reported above refute the contention that Scots pine regenerates only where the organic topsoil has been removed. (Subsection 6.5.1).

Scots pine seedlings did not easily survive among clipped bilberry. There was a better chance of survival if the ground vegetation was solely, or at least partly, cowberry. The faster growth of the bilberry, which easily overtopped the Scots pine seedling, might be the cause. Cowberry did not overtop Scots pine as fast as bilberry. Scots pine saplings had better survival chances on open spots in the clipped vegetation than in places where the vegetation had recovered. Survival was worst among grasses. (Subsection 6.5.1).

Scots pine seedlings are able to establish on organic topsoil at least up to 10 cm thick which originated from litter from shade-tolerant tree species. It could not be assessed whether or not seedlings established more successfully on thin than on thicker organic topsoil of such composition. (Subsection 6.5.1).

Planted saplings

Scots pine saplings can successfully be planted in old Scots pine stands. However, high mortality of saplings can occur.

The use of container-grown saplings might improve the survival chances of planted Scots pines in old stands, especially if the planting is postponed to one year after harvest. If massive regeneration of deciduous trees occurs when Scots pine is germinating, the seedlings of the latter can easily be overgrown. (Subsections 6.5.2, 7.1.4 and 7.4.1.2).

10.5 Height growth of young oak, beech, birch and Scots pine

No clear relationship between height growth and stand density of the old trees could be established for planted oak saplings. The height growth of pedunculate oak was found to be greater than that of sessile oak. (Section 7.1).

For spontaneously regenerated Scots pine saplings in old stands, less height growth was found at higher stand densities, but the effect was small, and only statistically significant for the highest density. The same trend was seen for planted Scots pine. In the Scots pine regeneration experiment, fencing increased the average height growth. In the permanent quadrats with additional sowing the average height growth was greater than in the permanent quadrats without sowing. There was an indication that soil treatment with the kuloo enhanced height growth more than soil treatment with the rotovator. (Subsections 7.4.1.2 and 7.4.4).

Oak, birch and beech saplings that had regenerated under old Scots pines showed no increase in height growth once they reached the stand canopy. Saplings of Scots pine did. (Sections 7.1 to 7.4).

Gaps with diameters of 0.6 to 1.6 the height of the dominant surrounding trees allow over 50% PAR on the forest floor. This was sufficient for Scots pine saplings to grow over 15 cm per year. (Subsection 7.4.3).

10.6 Big trees, dead wood, fragmentation, tree species and game

To provide big trees, harvest must be postponed. If both alive and dead big trees are wanted, zones where harvesting of trees is banned must be designed.

Creating gaps $\frac{1}{2}$ up to 2 times the dominant surrounding tree height in diameter is a preliminary fragmentation measure in plantations, to speed up the process leading towards a more natural forest mosaic. For the same reason, tree species that have disappeared from the forest through anthropogenic activities could be reintroduced.

The natural abundance and distribution of game in the Veluwe are unknown. Even the natural species composition is uncertain. In order to improve the likelyhood of successful regeneration by the tree species of the Querco-Betuletum and the Fago-Quercetum, *browser abundance must temporarily be low*. In order to keep open areas in the forest open, *browsers must be locally abundant*. (Chapter 8).

10.7 Financial diameters

At specific stumpage prices the financial diameter of a tree depends on stumpage value, current increment in value, interest rate, costs of compulsory regeneration of the area occupied by that tree, soil rent of that area, and thinning regime (section 9.1). This diameter is independent of the characteristics of surrounding trees. So it is also independent of the diameter distribution of surrounding trees, and the stock of timber available in the stand. *This means that to maximize financial returns, there is no need to work towards a specific diameter distribution, nor towards a specific standing stock.*

At Het Loo, financial diameters for individual trees at various price levels, site classes, regeneration costs and soil rents, at interest rate 3%, calculated excluding mortality risks, ranged from 30 to 50 cm if the objective was 'profit only'. Solitary trees showed statistically significantly larger financial diameters than randomly sampled trees. The standard deviation of the financial diameter was considerable. The financial diameters calculated, including bark, were only valid at the thinning treatment used at Het Loo in recent decades. With different thinning regimes, financial diameters change. At Het Loo, low thinning was usual. However, in practice a thinning regime cannot be applied at a constant level for decades. On top of that, causes of natural thinning, such as storm, disturb the thinning regime applied. Crown thinning results in larger diameter growth, which results in larger financial diameters.

As interest rates and soil rent increase, financial diameters decrease. Better site classes and increasing regeneration costs cause financial diameters to increase. If stumpage prices are equal for all diameter sizes, financial diameters are independent of stumpage price levels. If stumpage prices vary with diameter size, financial diameters are no longer independent of price levels.

This means that no generally applicable financial diameter can be given. Local measurements of current increment in volume, interest rate, soil rent, regeneration cost and stumpage prices must provide the data for determination of local financial diameters. (Section 9.1).

Based on the data collected, the maximum income generation was not yet reached at a 50 cm diameter over bark at breast height. This was so for all site indices and for all price levels at a zero risk of mortality. Few data were obtained from trees over 50 cm diameter. (Section 9.2).

The increase of financial diameter from the 'profit only' level to the 'maximum income generation' level enhances the ecological value of the stand. This enhancement has associated costs. The money could also be spent on other ways of securing ecological value.

The use of financial diameters in a management strategy only contributes to the financial results. It does not contribute to the sustainable flow of timber. It prevents the occurrence of degradation phases in the forest, and it takes no account of ecological and aesthetical value. (Sections 9.1 and 9.2).

10.8 Harvesting costs of selection felling

In this study it was found that the felling time in a Scots pine stand with undergrowth of young trees was less than the felling time given in literature for similarly sized trees in a stand without undergrowth. This could be explained by the fact that in the cases from literature the tree tops were cut at 7 cm diameter. In the time study done at Het Loo the tops were cut at 13 to 14 cm diameter. Therefore no conclusions were drawn from this time study. (Section 9.3).

Costs of hauling, performed with a 2-horse team, were 32% higher in the case considered than those mentioned in literature for hauling similar trees by tractor in stands without undergrowth of young trees. (Section 9.3).

10.9 The number of future trees

The number of future trees was calculated assuming that all future trees reach the financial diameter at the same time, and that these trees are evenly spread over the stand. (Section 9.4).

10.10 Diameter choice when thinning

At thinning for profit-only, the biggest tree has to be harvested if there is a choice between trees of different diameter. However, this only applies if:
- the various trees show equal value increment per m^3;
- the smaller tree shows volume increment equal to that of the bigger one when it was the size of the smaller tree;

- the gaps after thinning are equally used by the remaining trees irrespective of the size of the gaps;
- choosing the bigger tree to be harvested does not reduce stand stability beyond acceptable risks. (Section 9.5).

A tree with a sapling growing under it should be harvested when the present stumpage value of the tree plus the estimated present net value of the released sapling is higher than the estimated present net value of the tree plus the estimated present net value of the suppressed sapling. (Section 9.5).

10.11 Regeneration techniques

Regeneration can occur spontaneously, without any human interference. A low level of interference is, for instance, the single use of a game fence, and/or seed-source planting. Patchwise soil tillage, a stronger interference, creates opportunities for regeneration favourable for pioneer species. Bare soils which occur under shade-tolerant tree species are ideal seedbeds for pioneer species once these shade-tolerant trees have been cut.

Planted trees can successfully establish in old Scots pine stands. However, the mortality of saplings, especially of Scots pine, can be considerable. (Section 9.6).

10.12 Costs of regeneration

The cheapest forms of non-spontaneous regeneration are: enrichment planting with container-grown Scots pine saplings, patchwise soil tillage with and without additional sowing, and seed-source planting of oak or beech.

The rates of return from regeneration investments were low, and often much less than 3%. The extra revenue needed to cover the investment at a 3% interest rate were calculated for fencing, soil scarification, sowing and planting. (Section 9.7).

10.13 Present net value of plantations

Scots pine plantations of yield class II, at 3% interest, showed a negative present net value at the time of planting. This was already the case without considering risks of fire, storm and disease. Thus, establishing Scots pine plantations is not financially worthwile. (Section 9.8).

10.14 Present net values of spontaneous and semi-spontaneous regeneration on open areas

Present net values of observed cases of spontaneous regeneration on open areas were positive, even if a considerable volume of the timber is excluded from harvest. In cases where site preparation was carried out, the present net value was positive in 2 out of 3 cases. In the cases with positive present net value, regeneration was mainly Scots pine. If harvesting was carried out to cover an increasing proportion of the basal area by Scots pine at the cost of birch, the present net value of the stand increased through the accelerated harvest of birch and the increased harvest of Scots pine. (Section 9.9).

10.15 Present net values of spontaneous regeneration in old stands

The cases of spontaneous regeneration observed in old stands showed positive present net values. They were particularly high if regeneration consisted entirely of Scots pine. The cases with deciduous trees showed a considerable proportion of the basal area still being occupied by the old stand. Replacement of that part of the basal area by new regeneration was not included in the calculations.

The present net values remained positive, when part of the timber was not harvested. If harvesting was carried out to cover an increasing proportion of the basal area by Scots pine and oak at the cost of birch and beech, present net value of the stand increased partly through the accelerated harvest of birch, to an increased production of Scots pine, and to a lesser extent by an increased production of oak. (Section 9.10).

10.16 Present net values of enrichment planting

Patchwise soil tillage produced a positive present net value. The present net value could be increased by additional sowing. Enrichment planting with container-grown Scots pine saplings also produced a positive present net value. This present net value was slightly higher than the present net value of kuloo treatment plus additional sowing.

Enrichment planting of 4-year-old oak saplings in the soils at Het Loo never produced positive present net values. Neither did enrichment planting with 2-year-old oak saplings, nor with 2-year-old beech saplings. The same was true when browsing pressure was low enough to allow these nursery-grown saplings to outgrow the browse height without protection from a fence. (Section 9.11).

10.17 Sustainable production of timber volume

Financial diameters and thinning diameters were calculated to maximize monetary returns. This maximization does not guarantee a sustainable flow of timber. To guarantee the latter, the average harvest must never be more than the net average production of timber, and regrowth must always be available. If net production has decreased through lack of regeneration, the latter must be stimulated by reduction of browsers, fencing, soil tillage or planting. The level to which timber production is allowed to decrease depends on the management objectives.

If soil fertility is guaranteed, sustained or improved, plantations can contribute to sustainable timber production. However, if the plantation is established by reafforestation as a consequence of clearfelling, it does not fit sustainable development in the sense of this study, because the existing successional stage has been deliberately destroyed, the intensity of dynamics enhanced, and thus chances for niches of late developmental phases reduced.

Spontaneous and semi-spontaneous forest regeneration was demonstrated to provide a basis for sustainable timber production. If the previous stands were deliberately destroyed there was no sustainable development in the sense of this study.

Spontaneous regeneration of oak, birch and beech in old Scots pine contributed to sustainable timber production. In places where beech shaded out the ground vegetation, the same was true for spontaneous regeneration of Scots pine, oak, birch and beech. Where spontaneous regeneration occurred in old stands, this fitted in with sustainable timber production as well as with sustainable development.

If investment in fencing or soil scarification is not profitable (subsections 9.7.1 and 9.7.2), then sustainable timber production is only possible if the abundance and distribution of game are manipulated so that spontaneous seedlings and saplings are not destroyed.

If game prevent deciduous tree species from regenerating, and Scots pine will not regenerate even if the basal area of the Scots pine stand has been reduced, then the herb and shrub vegetation prevents sufficient pioneer conditions for Scots pine regeneration. In such cases soil scarification makes Scots pine regeneration for sustainable timber production possible.

Enrichment planting of oak, beech and Scots pine saplings enhances sustainable timber production. (Section 9.12).

It should be noted that in all the above cases, where *forest regeneration* fits in with sustainable development, the *exploitation of the trees* so regenerated does not necessarily do so.

10.18 Successional stages

Timber harvest based on the silvicultural design tested does not eliminate any successional stage nor any indigenous tree species from the forest mosaic. As in nature, the chances of pioneer species establishing are connected with the occurrence of pioneer conditions. Natural dynamics can create pioneer conditions. Ongoing thinning in the presence of abundant browsers can also create pioneer conditions. (Subsection 7.1.4 and section 9.13).

10.19 Developmental phases

Harvest of timber eliminates living big trees. The sooner trees are harvested, the less chance of the occurrence of developmental phases containing old trees and old tree compartments. This will certainly be the case if trees are harvested at their financial diameter with the objective of 'profit only', and if the larger diameters are thinned preferentially. If the objective is 'maximum income generation', the financial diameter in Scots pine is higher than if the objective is 'profit only'. This increases the probability that dead trees of bigger sizes occur in forests managed with the former objective. However, if the objective is 'maximum income generation', big trees are harvested anyway.

If, conversely, occurrence of the degradation phase is one of the management objectives, it is necessary to leave part of the timber in the forest. Again, this can only be achieved by creating harvest and non-harvest zones.

Harvest that is restricted to thinning of trees with small diameters does not affect the occurrence of big dead trees.

The smallest zoning scale possible to fulfil the demand for both timber production and nature conservation is reached if the size of the non-harvest zones is reduced to the growing area of single big trees ('single-tree eco-units').

10.20 Final conclusions

Sustainable forest development in Scots pine forests can be implemented with the following silvicultural system:

- *The forest is divided into harvest and non-harvest zones;*
- *In the harvest zones trees are harvested through thinning and selection felling; the latter at the financial diameter;*

– Preliminary fragmentation is carried out;
– Reintroduction of absent indigenous tree species is considered;
– Regeneration appears spontaneously, semi-spontaneously through reduction of game, seed-source planting or patchwise soil tillage, or artificially through sowing or enrichment planting.

In this study, species conservation was dealt with only superficially, therefore no recommendations can be given for the extent, scale and pattern of non-harvest zones.

11 Prospects

Integration of production and nature function

Pressure of the various demands on the forests increases continualy (Anon., 1985; Hummel and Parren, 1992). Assigning several functions to the same forest, through integration of functions, is one suggestion for tackling this problem (Meerjarenplan Bosbouw, 1986; Anon., 1985). Integration is extremely feasible for some of the functions, however, for logging and nature conservation it is not. Although the above sources advocate the integration of logging and nature conservation, none of them has provided any answer to the question of whether or not this is possible.

The answers obtained to the questions posed at the start of this study show that stands in the 'cultivated forest' state can be sustainably used and rehabilitated to the 'modified natural forest' state through selection felling and zoning. The answers also make it clear when sustainable and maximum financial revenue will be obtained from Scots pine forests at Het Loo. Moreover, silvicultural methods have been worked out to ensure sustainability in timber volume production.

If a financial diameter which is reached at moderate tree sizes is adopted, this prevents opportunities for conservation of species connected with big trees, degrading tree compartments, and slowly decaying dead wood. It is difficult to combine timber production and nature conservation if the degradation phases of forests are part of the conservation goals, unless harvest is restricted to trees of small diameters at thinning. Hence, zoning should be applied for conservation of species. Zoning results in areas without logging juxtaposed with areas where logging is carried out by selection felling from compartments of indigenous trees. In the latter zone, nature conservation only covers the aggradation phases of the forest, i.e. treeless, pole tree, and young tree phases of the various successional stages of the indigenous forest.

If integration of logging and conservation only serves a limited conservation goal, and zoning must be applied to cover the full range of conservation, questions arise concerning the optimal allocation of functions in forestry. They include:
- How much timber, if any, can be harvested in a zone that should provide nature conservation over the full range of species of the forest mosaic?
- How much dead wood is sufficient for species conservation, how often should dead wood occur, and in what spatial pattern?

- What advantages, or disadvantages, has small-scale zoning of areas with and without logging, over large-scale zoning?
- What zoning system is optimal for the conservation of all forest species?
- What restrictions, if any, must be applied to the harvest zones?

Implications for forestry

Natural forests

The maximum level to which sustainable forest development can be applied in natural forests that should conserve their wealth of species was not determined in this study. It is an important question which urgently needs to be answered.

Cultivated forests

As already noted, cultivated forests comprising indigenous tree species can be rehabilitated towards modified natural forests through zoning, fragmentation and use of timber by selection felling.

New forests

New forests are often planned on former agricultural land or other degraded land. These forests are often intended to serve the following functions: 1. commercial timber production, 2. nature conservation, and 3. recreational use.

1. Commercial timber production.

The study has shown that the only way a positive net present value can be obtained is through spontaneous colonization by trees. Conventional planting of trees should not be done. Pioneer tree species will generally colonize spontaneously. If seed sources are not available, sowing or seed-source planting with pioneer tree species can be carried out locally. These practices are relatively cheap. If this does not produce the commercial species required, enrichment planting with a low number of saplings of these species can be done among the pioneers.

2. Nature conservation.

For nature conservation there is no need for afforestation. It is even counterproductive. If seed sources are absent, local and random sowing of pioneer species and local introduction of species from later stages of the forest succession might be considered.

3. Recreation.

Recreation needs space, silence, infrastructure and scenery. If the first three are available, the fourth does not necessarily have to be created by forest, and certainly not by a plantation. Wilderness or any other spontaneously developed vegetation will do. In this case the planting of trees is also a waste of money, because it has an artificial and therefore counterproductive result.

Forests under stress

Forests are suffering increasingly from stress* from anthropogenic causes. This makes future revenue and hence investment uncertain. It also threatens ecological value. The silvicultural system must be flexible if it is to cope with increased stress. The silvicultural design proposed as a result of this study is economically flexible because of the low investment level applied, and ecologically flexible because of the occurrence of all developmental phases of the forest.

Application elsewhere

The silvicultural design is used to harvest sustainably and to *rehabilitate* stands from the 'cultivated forest' state to the 'modified natural forest' state. The main parameters of the tested silvicultural design are:

- at a given location, forest must be the vegetation climax;
- indigenous tree species must occur;
- game must temporarily be at such abundance that regeneration is not prevented continuously;
- the maximum harvest level can be kept below the current timber production minus the need for dead wood;
- exotic trees that produce saplings that compete with the indigenous tree saplings are absent.

These parameters are not confined to Het Loo, nor to the sandy soils of northwestern Europe. Wherever stands to which these parameters apply occur in the cultivated forest state, they can be *rehabilitated* by using the silvicultural design proposed by this study. Of course, the tree species concerned will be different. Also, the silvicultural design should not be followed in detail. Management activities should concentrate on: zoning, thinning, selection felling, preliminary fragmentation, and temporary regulation of game and/or domestic browsers.

Unless logging is restricted to mere thinning activities, *sustainable use* of timber as such will not lead to the full conservation of species. Zoning of allocated functions can guarantee *sustainable forest development* in its full meaning.

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Appendix 1. List of maps of stand locations studied.

All the stands studied at Het Loo are indicated on the management maps of Het Loo Royal Forest (Koninklijke Houtvesterij Het Loo) and Het Loo Palace Park (Paleispark Het Loo), Koninklijk Park 1, 7315 JA Apeldoorn, the Netherlands. The following management maps exist at scale 1:10,000:
Paleis Park Het Loo, 1986,
Boswachterij Uddel Oost, 1976,
Boswachterij Uddel West, 1990,
Boswachterij Soeren Noord, 1975,
Boswachterij Soeren Zuid, 1975,
Boswachterij Gortel, 1984.

The Amerongseberg stand studied can be found on the Amerongse Berg management map, Staatsbosbeheer, 1978, scale 1:10,000. The Petrea stands can be found on the Petrea management map, Stichting Het Geldersch Landschap, 1989, scale 1:5,000. The Imbosch stands can be found on the De Imbosch management map, Vereniging tot Behoud van Natuurmonumenten in Nederland, 1978, scale 1:10,000.

Appendix 2. List of soil maps.

Soil maps of the fieldwork areas at scale 1:2,500 are available in the following publications:

Kleijer, H., H.Makken and P.Mekkink, 1988. De groeiverwachting voor boomsoorten en de te verwachten bosgemeenschappen in proefvelden in de Koninklijke Houtvesterij Het Loo. Stichting voor Bodemkartering, Wageningen. This publication covers: Palace Park 14, 20f, Uddel 140b, Gortel 77g, 80a, 84a, 92h, 94c, 133f and h.

Mekkink, P., 1989. De bodemgesteldheid en de vegetatiekundige gesteldheid van proefvelden in de Koninklijke Houtvesterij Het Loo. Staring Centrum rapport 27, Wageningen. This publication covers: Palace Park 19d, Uddel 2a and Soeren 107b.

Kleijer, H., 1991. Bodemgesteldheid in proefvelden in vak 13, 14, 52 en 64 in de Koninklijke Houtvesterij Het Loo. Staring Centrum rapport 178, Wageningen. This publication covers: Soeren 13 and 14 and Gortel 52 and 64.

Soil maps, scale 1:20,000, from the Het Loo management plans were used to determine the soil types of the remaining research locations.

Appendix 3. Data on tree ring sampling.

Scots pine numbers sampled for tree ring measurement.

stand no.	randomly sampled trees	solitary trees
Pal.Park 14	8	8
Pal.Park 19d		8
Uddel 2a	10	
Uddel 26a	10	6
Uddel 52n		11
Uddel 131f	10	
Uddel 140b	16	
Uddel 141a	4	
Soeren 107b	10	
Gortel 8d	26	12
Gortel 19b	10	14
Gortel 52b	8	
Gortel 77g	20	
Gortel 80a	45	
Gortel 84a	16	
Gortel 92h	8	7
Gortel 94c	4	
Gortel 133f	8	7

Appendix 4. Rainfall.

Rainfall at Deelen, Gelderland, in mm.

month	1987	1988	1989	1990	1991
January	46	128.8	23.2	64.9	82.7
February	39.2	87.4	60.8	136.2	21.9
March	101.5	109.6	89.8	46.6	14.3
April	28	9.5	49.9	66.7	29.4
May	82	49.7	6.1	54.2	52.8
June	85	9.8	97.3	120.6	140.7
July	168	138.8	55.3	44.7	27.2
August	82.2	72.9	73.8	67.6	16.8

Source: KNMI Maandoverzicht van het weer in Nederland, 1987 tot 1991.

Appendix 5. Data on oak regeneration.

Oak between birch.

Distances in cm between stems of oak and surrounding birch, at approximately 30 years of age in Gortel 80.

oak no.	distance to birch1	birch2	birch3	birch4	birch5
1	153	180	280	122	145
2	56	125	143	188	
3	175	185	246	163	
4	45	140	180	145	211
5	113	82	185		
6	188	210			
7	117	290	290		
8	231	315	132		
9	110	197			
10	210	257	291		

Appendix 6. Data and statistics on Scots pine regeneration.

Appendix 6.2.1

Scots pine regeneration: ANOVA on rank-transformed counts.

***** Analysis of variance *****

Variate: rank

source of variation	d.f.#	s.s.#	m.s.#	v.r.#	F pr.#
stand stratum	3	184965.	61655.	3.19	
stand.plot stratum					
density	3	37569.	12523.	0.65	0.604
Residual	9	174115.	19346.		
stand.plot.sub-plot stratum					
fence	1	31050.	31050.	3.89	0.072
density.fence	3	7253.	2418.	0.30	0.823
Residual	12	95741.	7978.	1.54	
stand.plot.setrows stratum					
	32	194477.	6077.		
stand.plot.sub-plot.setrows stratum					
	32	165720.	5179.	0.99	
stand.plot.setrows.row stratum					
soiltrea	1	78404.	78404.	10.80	0.002
density.soiltrea	3	21665.	7222.	0.99	0.404
Residual	44	319444.	7260.	1.38	
stand.plot.sub-plot.setrows.row stratum					
fence.soiltrea	1	3577.	3577.	0.68	0.414
density.fence.soiltrea	3	11523.	3841.	0.73	0.539
Residual	44	231311.	5257.	0.98	
stand.plot.sub-plot.setrows.row.pq stratum					
sowing	1	1984613.	1984613.	368.76	<.001
density.sowing	3	16815.	5605.	1.04	0.376
fence.sowing	1	15339.	15339.	2.85	0.093
soiltrea.sowing	1	128006.	128006.	23.78	<.001
density.fence.sowing	3	8437.	2812.	0.52	0.667
density.soiltrea.sowing	3	4366.	1455.	0.27	0.847
fence.soiltrea.sowing	1	43.	43.	0.01	0.929
Residual	179	963354.	5382.		
Total	383	4677786.			

# d.f. = degrees of freedom
s.s. = sum of squares
m.s. = mean squares
v.r. = variance ratio
F pr. = F probability.

Appendix 6.2.2

Established Scots pine seedlings in consecutive years.

Average numbers of newly established Scots pine seedlings from 6 equally treated permanent quadrats of 0.5 m^2, in 3 years, at 4 basal area (light) levels, for various soil/fencing treatments.

Palace Park 19b		*1987*	*1989*	*1990*
kuloo/fence	dark	2.3	0	0.2
		1.0	3	4.3
		0.3	0.2	2.8
	light	5.3	4.0	0.9
kuloo/no fence	dark	3.3	0.7	0.7
		2.3	2.3	4.5
		3.0	1.5	4.5
	light	1.3	0.7	3.2
rotovator/fence	dark	5.7	0.0	0.2
		3.3	0.2	0.9
		2.3	0.2	0.3
	light	4.7	0.0	0.2
rotovator/no fence	dark	5.0	0.8	1.2
		3.7	0.8	1.5
		1.0	1.3	0.8
	light	1.0	0.5	0.7
Uddel 2a				
		1987	*1989*	*1990*
kuloo/fence	dark	0.3	0.2	0.2
		5.3	1.9	0.6
		0.3	1.2	2.0
	light	2.3	0.5	0.3
kuloo/no fence	dark	1.7	1.2	0.2
		2.0	0.2	0.5
		2.0	1.0	1.2
	light	2.0	0.9	0.7
rotovator/ fence	dark	1.3	0.2	0.2
		2.0	0.0	0.0
		1.0	0.0	0.5
	light	0.7	0.0	0.0
rotovator/ no fence	dark	0.7	0.5	0.5
		1.0	0.5	0.5
		0.3	0.2	0.0
	light	0.7	0.2	1.0

Soeren 107b

		1987	*1989*	*1990*
kuloo/fence	dark	0.7	4.5	0.3
			2.7	1.5	0.5
			1.0	7.0	1.7
	light	0.3	1.0	0.5
kuloo/no fence	dark	0.7	8.8	5.4
			1.7	2.7	2.7
			2.3	9.5	2.7
	light	1.7	3.0	2.0
rotovator/ fence	dark	1.7	0.3	0.0
			1.0	0.0	0.0
			0.3	0.3	0.9
	light	0.3	0.0	0.5
rotovator no fence	dark	1.7	0.6	1.5
			2.3	1.2	0.2
			0.0	1.4	1.0
	light	1.7	1.2	0.6

Gortel 84a

		1987	*1989*	*1990*
kuloo/fence	dark	3.7	0.8	0.8
			3.0	2.5	0.8
			3.3	4.0	3.7
	light	2.0	1.0	2.7
kuloo/no fence	dark	3.7	4.3	2.0
			3.3	3.0	3.3
			1.0	1.2	3.3
	light	1.7	5.0	5.7
rotovator/ fence	dark	4.3	0.3	0.0
			6.7	0.5	0.3
			6.7	0.7	0.3
	light	1.3	0.0	0.3
rotovator/ no fence	dark	8.0	0.2	1.0
			3.0	0.8	1.9
			3.3	0.5	2.2
	light	3.0	1.0	2.3

Appendix 6.2.4.

Average herb and shrub cover percentage of 6 equally treated permanent quadrats in 5 consecutive years.

	1987	1988	1989	1990	1991
Grass cover Gortel 84a, top lines fenced, second lines not fenced, from A to D, first pairs rotovator treatment, second pairs kuloo treatment. A = b.a. 18.2 m^2, B = b.a. 13.2 m^2, C = b.a. 16.7 m^2, D = b.a. 9.8 m^2. R = rotovator, F = fenced, NF = unfenced, K = kuloo					
grassesA R F	3.3	5.8	8.7	18.3	15.8
grassesA R NF	6.2	11.2	25.8	25.9	35.9
grassesA K F	0.4	1.0	3.2	9.5	15.3
grassesA K NF	0	0.2	6.5	9.5	16.7
grassesB R	1.0	5.3	6.9	7.7	7.5
grassesB R	1.3	3.1	7.7	20.8	26.7
grassesB K	0.2	0.4	1.4	1.0	1.0
grassesB K	0.2	0	1.2	2.0	2.9
grassesC R	2.7	5.0	8.3	17.7	16.2
grassesC R	2.2	3.0	6.8	14.5	15.2
grassesC K	0	0	0.3	1.2	3.0
grassesC K	0.2	1.0	2.7	13.7	13.5
grassesD R	3.7	5.0	7.8	13.3	12.8
grassesD R	0.2	1.0	7.0	13.2	14.0
grassesD K	0	0	0.2	0.4	0.4
grassesD K	0.3	0.5	0.3	4.2	4.2
Heather cover Gortel 84a, top line fenced, second line not fenced, A to D, first pairs rotovator treatment, second pairs kuloo treatment. A = b.a. 18.2 m^2, B = b.a. 13.2 m^2, C = b.a. 16.7 m^2, D = b.a. 9.8 m^2.					
heatherA R F	0	1.5	7.5	19.2	21.8
heatherA R NF	0	0.7	3.0	12.8	21.0
heatherA K F	0.2	7.8	26.7	49.2	24.8
heatherA K NF	0.2	4.5	33.3	41.7	39.3
heatherB	0	2.7	27.7	38.3	38.3
heatherB	0	0.2	0.7	5.2	7.7
heatherB	0.3	2.7	24.2	44.2	46.8
heatherB	0	3.0	18.3	65.0	59.2
heatherC	0	0.5	4.3	11.0	6.7
heatherC	0	0.7	3.5	14.8	18.3
heatherC	0	1.7	20.8	46.7	47.5
heatherC	0	2.3	21.7	56.7	55.8
heatherD	0	1.2	8.7	28.3	30.0
heatherD	0	0.3	1.8	2.3	7.7
heatherD	0	3.8	15.8	46.7	55.2
heatherD	0.2	3.2	16.8	33.3	41.2

Bilberry cover Gortel 84a, top line fenced, second line not fenced, from A to D, first pairs rotovator treatment, second pairs kuloo treatment.
A = b.a. 18.2 m^2, B = b.a. 13.2 m^2, C = b.a. 16.7 m^2, D = b.a. 9.8 m^2.

bilberryA R F	1.7	6.3	10.3	15.2	17.7
bilberryA R NF	1.7	4.5	15.8	17.5	19.2
bilberryA K F	1.7	3.0	6.0	6.7	9.2
bilberryA K NF	1.7	2.3	4.5	6.8	6.7
bilberryB	1.7	3.5	11.2	15.0	18.3
bilberry	0.8	1.3	3.0	3.5	3.7
bilberry	1.2	1.3	1.3	2.7	2.8
bilberry	0.7	2.7	2.7	1.2	1.2
bilberryC	2.3	3.5	14.2	33.3	40.8
bilberry	3.2	5.5	9.2	20.0	21.7
bilberry	0.5	0.5	2.7	2.2	2.2
bilberry	0.5	0.7	3.5	6.8	6.8
bilberryD	5.5	7.8	20.8	36.0	42.7
bilberry	0.8	1.3	5.3	6.3	16.8
bilberry	0.6	1.2	3.7	3.8	5.3
bilberry	0.7	0.7	3.0	3.7	3.0

Grass cover Soeren 107b, top lines fenced, second lines not fenced, first pairs rotovator treatment, second pairs kuloo treatment, from A to D.
A = b.a. 9.6 m^2, B = b.a. 17.2 m^2, C = b.a. 20.8 m^2, D = b.a. 12.2 m^2.

grassesA R F	1.7	6.6	11.6	30.0	35.0
grassesA R NF	7.0	10.5	31.0	45.1	53.5
grassesA K F	0.5	0.5	2.2	0.9	2.3
grassesA K NF	1.4	5.5	12.0	14.6	15.0
grassesB R F	4.5	9.5	18.3	27.5	32.5
grassesB R NF	3.7	6.0	20.8	35.0	31.2
grassesB K F	0.2	3.0	9.2	23.5	42.5
grassesB K NF	0.2	2.2	11.8	40.3	22.2
grassesC R F	4.5	8.5	23.3	24.2	22.5
grassesC R NF	2.2	3.0	6.8	14.5	15.6
grassesC K F	0	0	0.3	1.2	3.0
grassesC K NF	0	1.5	4.5	17	16.8
grassesD R F	2.3	5.5	16.7	20.0	39.3
grassesD R NF	2.3	11.0	25.8	29.2	40.8
grassesD K F	0.3	2.0	5.7	7.7	15.8
grassesD K NF	0.3	1.8	5.3	6.2	7.0

Heather cover Soeren 107b
A = b.a. 9.6 m^2, B = b.a. 17.2 m^2, C = b.a. 20.8 m^2, D = b.a. 12.2 m^2.

heatherA R F	0	1.3	4.2	13.3	12.5
heatherA R NF	0.2	0	0.7	2.8	0.8
heatherA K F	0.2	3.7	34.2	54.2	57.5
heatherA K NF	0.2	3.0	16.0	39.2	35.8
heatherB R F	0	0.5	4.7	10.2	28.3
heatherB R NF	0	0.5	3.7	5.0	12.5
heatherB K F	0.2	2.8	18.7	32.0	29.3
heatherB K NF	0	1.7	14.3	23.5	20.2
heatherC R F	0	1.2	6.0	18.5	20.8
heatherC R NF	0	0.7	3.5	14.8	18.3
heatherC K F	0	1.7	20.8	46.7	47.5
heatherC K NF	1.2	1.0	6.7	20	20.0
heatherD R F	0.2	1.3	6.0	15.0	18.3
heatherD R NF	0	0.8	4.7	19.2	3.5
heatherD K F	0.2	8.7	30.0	45.0	50.8
heatherD K NF	0	1.5	8.3	32.5	46.7

Bilberry cover Soeren 107b
A = b.a. 9.6 m^2, B = b.a. 17.2 m^2, C = b.a. 20.8 m^2, D = b.a. 12.2 m^2.

bilberryA R F	1.5	1.3	4.2	7.7	10.2
bilberryA R NF	0.3	1.0	2.0	2.0	1.8
bilberryA K F	0.3	0.2	0.3	0.5	1.5
bilberryA K NF	0.3	0.3	1.2	1.2	1.2
bilberryB R F	2.5	5.3	15.0	18.7	22.7
bilberryB R NF	0.8	1.5	10.2	2.0	2.5
bilberryB K F	0	0.2	1.7	1.8	2.5
bilberryB K NF	0.3	0.5	1.3	2.0	3.5
bilberryC R F	1.0	7.0	11.5	14.7	19.3
bilberryC R NF	3.2	5.5	9.2	20.0	21.7
bilberryC K F	0.5	0.5	2.7	2.2	2.2
bilberryC K NF	0.3	1.0	1.2	1.2	0.5
bilberryD R F	1.5	3.2	8.2	10.5	19.2
bilberryD R NF	0.8	2.0	6.0	7.5	10.8
bilberryD K F	0.8	1.3	2.7	2.7	2.8
bilberryD K NF	0.2	0.2	0.8	0.8	0.8

Grass cover Uddel 2a, top lines fenced, second lines not fenced, first pairs rotovator treatment, second pairs kuloo treatment, from A to D.
A = b.a. 13.9 m^2, B = b.a. 18.8 m^2, C = b.a. 9.6 m^2, D = b.a. 20.0m^2.

grassesA R F	0	1.5	16.6	25.2	30.2
grassesA R NF	3.3	6.7	35.2	46.7	65.8
grassesA K F	0	0	1.0	3.8	24.2
grassesA K NF	0.8	6.5	9.5	13.7	21.8
grassesB	0.8	1.7	7.5	8.0	11.0
grassesB	0.2	2.2	8.5	17.5	27.5
grassesB	0	0.2	2.0	3.2	4.7
grassesB	0	0.7	5.2	23.3	34.2
grassesC	0.8	0.8	17.5	29.2	48.3
grassesC	0	0.2	5.0	12.5	16.7
grassesC	0	2.2	9.8	13.7	21.2
grassesC	0	0.2	1.8	7.8	12.7
grassesD	0	0	0	0.2	0.2
grassesD	0	0	0	0	0
grassesD	0	0	0	0	0
grassesD	0	0	0	0	0.2

Heather cover Uddel 2a
A = b.a. 13.9 m^2, B = b.a. 18.8 m^2, C = b.a. 9.6 m^2, D = b.a. 20.0m^2.

heatherA R F	0.2	8.8	10.0	12.7	14.0
heatherA R NF	0	2.3	19.3	3.7	3.7
heatherA K F	0.2	1.2	11.2	21.0	16.0
heatherA K NF	0	0.3	5.0	15.3	12.0
heatherB	0	0.2	0.3	9.0	5.2
heatherB	0	1.0	0.2	1.2	1.7
heatherB	0	0.2	0.2	1.0	1.8
heatherB	0	0.2	1.2	5.7	7.8
heatherC	0	0	0	0.8	0.8
heatherC	0	1.8	0	0	0
heatherC	0	0	5.0	10.2	13.3
heatherC	0	1.3	6.7	16.7	18.3
heatherD	0	0.5	4.7	26.8	38.0
heatherD	0	0.7	2.1	6.7	10.8
heatherD	0	0.7	12.2	26.7	37.5
heatherD	0	2.1	9.3	26.0	45.0

Bilberry cover Uddel 2a
A = b.a. 13.9 m^2, B = b.a. 18.8 m^2, C = b.a. 9.6 m^2, D = b.a. 20.0m^2.

bilberryA R F	1.0	3.8	12.8	21.7	20.2
bilberryA R NF	0.7	2.7	5.2	5.5	9.2
bilberryA K F	0.3	0.7	1.2	5.8	9.5
bilberryA K NF	2.2	2.7	6.0	6.0	9.5
bilberryB	1.2	4.8	13.3	18.7	23.5
bilberry	0.8	2.2	3.5	4.3	9.3
bilberry	0	0.5	0.8	3.8	7.5
bilberry	1.8	0.3	0.7	1.7	2.3
bilberryC	2.0	10.3	15.0	21.7	23.3
bilberry	0.8	2.8	4.3	5.8	7.5
bilberry	0.3	1.2	1.3	2.0	3.3
bilberry	1.8	0.2	1.3	2.3	2.8
bilberryD	0.5	1.5	2.1	3.7	3.1
bilberry	0.5	0.7	1.3	2.8	3.7
bilberry	0.2	1.0	1.3	2.2	2.3
bilberry	3.0	4.8	4.8	6.5	10.5

Grass cover Pal.Park 19d, top lines fenced, second lines unfenced, first pairs rotovator treatment, second pairs kuloo treatment, from A to D.
A = b.a. 9.6 m^2, B = b.a. 19.7 m^2, C = b.a. 16.9 m^2, D = b.a. 11.3 m^2.

grassesA R F	0	0	0	0	0
grassesA R NF	0	0.2	0.2	0.8	0.8
grassesA K F	0	0	0	0	0
grassesA K NF	0	0	0	0	0
grassesB R F	0	0	0	0	0
grassesB R NF	0	0	0	0	0
grassesB K F	0	0	0	0	0
grassesB K NF	0	0	0.2	0.2	1.7
grassesC R F	0.2	0.8	0.8	0.8	0.8
grassesC R NF	0	0	0	0	0
grassesC K F	0	0	0	0	1.0
grassesC K NF	0	0	0	0	0.2
grassesD R F	0.2	0.3	0.7	2.3	3.0
grassesD R NF	0	0	0	1.3	2.5
grassesD K F	0	0	0.5	1.3	3.3
grassesD K NF	0	0.2	0.2	1.7	2.2

Heather cover Pal.Park 19b
A = b.a. 9.6 m^2, B = b.a. 19.7 m^2, C = b.a. 16.9 m^2, D = b.a. 11.3 m^2.

heatherA R F	0	2.5	13.7	43.5	45
heatherA R NF	0	1.5	2.8	12.2	17.7
heatherA K F	0.5	10.0	40.0	68.3	73.3
heatherA K NF	0	5.2	11.8	44.2	50.8
heatherB R F	0	2.3	9.5	30.8	60.0
heatherB R NF	0	0.7	3.2	8.0	12.5
heatherB K F	0.2	7.2	32.5	70.0	76.7
heatherB K NF	0	1.0	4.7	20.0	30.8
heatherC R F	0	2.3	27.5	44.2	56.7
heatherC R NF	0	0.8	4.3	23.5	28.5
heatherC K F	0	3.0	13.3	31.8	45.0
heatherC K NF	0	5.3	25.3	50.0	58.3
heatherD R F	0	0.5	0.5	2.7	6.2
heatherD R NF	0	0.5	0.5	1.7	2.7
heatherD K F	0	1.3	6.7	15.3	22.7
heatherD K NF	0	1.0	2.7	10.8	20.8

Bilberry cover Pal.Park 19b
A = b.a. 9.6 m^2, B = b.a. 19.7 m^2, C = b.a. 16.9 m^2, D = b.a. 11.3 m^2.

bilberryA R F	0	0.2	0.3	0.3	0.2
bilberryA R NF	0.2	0.2	0.5	0.7	0.3
bilberryA K F	2.0	0.5	0.7	0.7	0.3
bilberryA K NF	0.3	0.2	1.0	1.2	1.0
bilberryB R F	1.0	1.7	5.2	5.3	4.3
bilberryB R NF	2.0	4.5	9.3	14.8	22.7
bilberryB K F	1.0	1.0	3.0	4.5	5.5
bilberryB K NF	6.2	7.5	17.0	27.8	34.3
bilberryC R F	3.0	6.5	9.2	16.5	21.0
bilberryC R NF	0.7	2.0	3.3	19.3	10.2
bilberryC K F	1.5	1.3	3.8	5.5	7.7
bilberryC K NF	0.8	1.0	1.7	3.2	4.7
bilberryD R F	4.8	6.8	12.7	26.8	38.5
bilberryD R NF	0.5	1.3	3.0	2.5	4.5
bilberryD K F	2.2	3.0	5.7	11.5	15.0
bilberryD K NF	0.8	1.3	2.5	5.5	9.2

Appendix 6.3.

Survival of Scots pine seedlings: ANOVA on empirical logits.

***** Analysis of variance *****

Variate: logity

source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
stand stratum	3	32.6345	10.8782	10.10	
stand.plot stratum					
density	3	16.6055	5.5352	5.14	0.024
Residual	9	9.6950	1.0772		
stand.plot.sub-plot stratum					
fence	1	5.1354	5.1354	2.68	0.127
density.fence	3	4.7501	1.5834	0.83	0.504
Residual	12	22.9751	1.9146	1.41	
stand.plot.row stratum					
soiltrea	1	23.4423	23.4423	16.77	0.001
density.soiltrea	3	1.1098	0.3699	0.26	0.850
Residual	12	16.7767	1.3981	1.03	
stand.plot.sub-plot.row stratum					
fence.soiltrea	1	0.0198	0.0198	0.01	0.906
density.fence.soiltrea	3	1.4927	0.4976	0.37	0.779
Residual	12	16.3031	1.3586	2.00	
stand.plot.sub-plot.row.pq stratum					
sowing	1	0.3648	0.3648	0.54	0.468
density.sowing	3	2.8403	0.9468	1.39	0.257
fence.sowing	1	0.0211	0.0211	0.03	0.861
soiltrea.sowing	1	0.6095	0.6095	0.90	0.349
density.fence.sowing	3	1.0914	0.3638	0.53	0.661
density.soiltrea.sowing	3	4.0944	1.3648	2.01	0.126
fence.soiltrea.sowing	1	0.7882	0.7882	1.16	0.287
density.fence.soiltrea.sowing	3	3.0348	1.0116	1.49	0.230
Residual	48	32.6656	0.6805		
Total	127	196.4503			

Appendix 6.4.2

Light measurements at various times of the day

DFOV PAR percentages at permanent quadrats (pq) in Gortel 84a at various times of the day.

Gortel 84a, basal area 11.9 m²

pq\time nr.	8.30/ 8.41	10.09/ 10.21	11.29/ 11.39	12.02/ 12.14	13.43/ 13.51	14.43/ 15.08	16.01/ 16.10
361f	0.62	0.65	0.60	0.67	0.67	0.66	0.60
362f	0.46	0.51	0.52	0.49	0.50	0.49	0.48
365k	0.48	0.49	0.51	0.56	0.52	0.55	0.50
366k	0.48	0.51	0.54	0.54	0.52	0.52	0.46
367f	0.50	0.52	0.49	0.54	0.52	0.49	0.50
368f	0.50	0.53	0.55	0.53	0.59	0.54	0.51
369k	0.59	0.53	0.55	0.58	0.59	0.54	0.59
370k	0.56	0.57	0.60	0.56	0.59	0.57	0.57
373f	0.57	0.54	0.59	0.58	0.59	0.58	0.55
374f	0.53	0.53	0.54	0.57	0.54	0.56	0.51
375k	0.53	0.52	0.48	0.53	0.50	0.47	0.50
376k	0.60	0.61	0.61	0.60	0.62	0.63	0.58
379k	0.54	0.60	0.61	0.56	0.54	0.51	0.55
380k	0.54	0.52	0.59	0.56	0.51	0.52	0.58
381f	0.48	0.44	0.46	0.51	0.43	0.43	0.45
382f	0.47	0.43	0.46	0.49	0.42	0.46	0.43
385f	0.44	0.38	0.46	0.48	0.43	0.43	0.38
386f	0.44	0.40	0.40	0.45	0.37	0.43	0.42
387k	0.43	0.41	0.45	0.42	0.43	0.39	0.37
388k	0.40	0.39	0.41	0.43	0.34	0.41	0.41
389k	0.35	0.29	0.41	0.37	0.31	0.36	0.31
390k	0.34	0.28	0.37	0.37	0.29	0.32	0.36
393f	0.28	0.31	0.35	0.32	0.25	0.26	0.25
394f	0.31	0.25	0.31	0.31	0.28	0.25	0.27

Gortel 84a, basal area 15.4 m^2

pq\time nr	8.47 9.03	10.29 10.44	11.46 11.56	12.18 12.30	13.57 14.13	15.12 15.22	16.15 16.29
325f	0.43	0.46	0.49	0.49	0.44	0.51	0.51
326f	0.45	0.45	0.43	0.48	0.41	0.43	0.47
327k	0.44	0.45	0.43	0.50	0.40	0.44	0.43
328k	0.42	0.40	0.41	0.46	0.37	0.40	0.41
333f	0.51	0.44	0.51	0.49	0.38	0.44	0.43
334f	0.46	0.38	0.42	0.45	0.39	0.41	0.46
335k	0.44	0.47	0.38	0.46	0.41	0.42	0.39
336k	0.37	0.38	0.37	0.41	0.33	0.38	0.37
337f	0.43	0.43	0.41	0.49	0.39	0.41	0.45
338f	0.45	0.43	0.40	0.51	0.39	0.42	0.46
339k	0.39	0.40	0.36	0.44	0.39	0.37	0.44
340k	0.47	0.45	0.40	0.47	0.42	0.43	0.43
345f	0.45	0.38	0.47	0.40	0.36	0.45	0.43
346f	0.44	0.38	0.47	0.42	0.38	0.45	0.45
347k	0.50	0.49	0.49	0.47	0.43	0.44	0.45
348k	0.49	0.49	0.45	0.47	0.46	0.43	0.47
349f	0.38	0.44	0.43	0.43	0.36	0.35	0.41
350f	0.34	0.33	0.36	0.42	0.39	0.31	0.39
353k	0.30	0.32	0.39	0.40	0.32	0.29	0.35
354k	0.32	0.37	0.39	0.40	0.28	0.27	0.33
355f	0.30	0.37	0.41	0.34	0.30	0.30	0.35
356f	0.31	0.30	0.34	0.31	0.33	0.28	0.32
357k	0.35	0.40	0.46	0.37	0.33	0.32	0.39
358k	0.26	0.31	0.36	0.26	0.27	0.25	0.31

Means of measurement periods (in decimal hours).

period	1	2	3	4	5	6	7
plot 1	8.59	10.25	11.57	12.13	13.78	14.92	16.09
plot 2	8.92	10.61	11.85	12.40	14.08	15.28	16.37
mean	8.76	10.43	11.71	12.26	13.93	15.10	16.23

Relation DFOV PAR with time of the day.

***** Analysis of variance *****

Variate: y

source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ppq stratum					
plot	1	0.4695047	0.4695047	10.87	0.002
Residual	46	1.9869381	0.0431943	55.44	
ppq.*Units* stratum					
period	6	0.0659310	0.0109885	14.10	<.001
plot.period	6	0.0200202	0.0033367	4.28	<.001
Residual	276	0.2150202	0.0007791		
Total	335	2.7574143			

*** Table of means ***

plot	period 1	2	3	4	5	6	7
1	0.4767	0.4671	0.4942	0.5008	0.4729	0.4737	0.4638
2	0.4042	0.4050	0.4179	0.4308	0.3721	0.3833	0.4125

*** Standard errors of differences of means ***
s.e.d. = 0.02387
Except when comparing means with the same level(s) of plot: s.e.d = 0.00806

*** Schematic representation of pairwise t-tests ***
Periods with a common underlining have no significantly different DFOV PAR

Plot 1:

period:	7	2	5	6	1	3	4
	16.09	10.25	13.78	14.92	8.59	11.57	12.13
	[----------	----------	----------	----------	----------]	[----------	----------]

Plot 2:

period:	5	6	1	2	7	3	4
	14.08	15.28	8.92	10.61	16.37	11.85	12.40
	[----------	----------]	[----------	----------	----------]	[----------	----------]

Appendix 6.4.3

PAR percentage on the forest floor in gaps in simulated 60-year-old Scots pine stands of yield class II.

PAR percentage on the forest floor in gaps in simulated 60-year-old Scots pine stands of yield class II.

gap no.	stand density index	gap size in tree height	three highest percentages of TOTAL PAR, %			value of three most central located measurements DFOV PAR, %		
1	1.0	0.03	25.4#			21.2#		
2	1.0	0.26	29.6	30.0	29.8	26.6	25.5	23.7
3	1.0	0.72	39.4	39.6	39.2	31.8	31.4	30.1
4	1.0	1.18	51.8	51.9	51.7	39.0	40.3	40.2
5	1.0	1.63	61.7	61.6	62.6	48.0	48.9	49.0
6	0.85	0.05	32.8#			28.3#		
7	0.85	0.29	36.5	35.4	35.3	31.2	31.7	31.3
8	0.85	0.79	47.0	47.6	46.5	37.6	37.3	37.1
9	0.85	1.29	58.1	57.6	57.5	46.0	45.1	45.2
10	0.70	0.07	39.7#			34.5#		
11	0.70	0.35	42.8	42.9	43.7	38.4	37.8	38.5
12	0.70	0.89	54.5	55.6	54.1	43.8	44.8	43.2
13	0.70	1.44	64.5	64.4	65.2	53.2	52.8	52.5
14	0.50	0.12	51.3#			45.7#		
15	0.50	1.10	66.1	65.6	67.3	54.5	53.6	54.5
16	0.50	1.75	73.3	75.5	74.0	63.5	63.1	63.2
17	0.30	0.21	65.0#			58.0#		

Gaps nos 1, 6, 10, 14 and 17 are in stands where no trees are removed. There is thus no gap. In those cases the PAR percentages are the average from fifty randomly chosen locations on the forest floor in those simulated stands.

Appendix 6.4.4

DFOV PAR percentage in Gortel 50f.

DFOV PAR on the forest floor in gaps in stand Gortel 50f

gap no.	h.dom, m	s.d.i.	N/ha	gap size in m	gap size in tree height	DFOV PAR, % in the centre of the gap
1	17.7	0.91	537	–	–	32.6
				9.7	0.52	45.1
				17.5	0.94	49.0
				26.7	1.43	75.8
2				5.5	0.33	45.9
				9.8	0.59	49.2
				17.5	1.05	58.1
3				4.0	0.21	38.6
				9.8	0.52	43.6
				17.5	0.94	65.2
4				–	–	27.5
				10.9	0.60	32.7
				21.4	1.18	60.3
5				–	–	27.7
				10.8	0.66	47.3
				20.0	1.23	66.0

DFOV PAR percentage in Gortel 134a.

DFOV PAR on the forest floor in gaps in stand Gortel 134a.

gap no.	h.dom, m	s.d.i.	N/ha	gap size in m	gap size in tree height	DFOV PAR, % in the centre of the gap
1	18.1	0.98	578	10.5	0.58	54%
				29.9	1.65	75
2				–	–	30
				14.8	0.80	48
				31.6	1.71	80
3				–	–	41
				17.0	0.96	59
				31.7	1.79	70

DFOV PAR percentage in Soeren 36.

DFOV PAR on the forest floor in gaps in stand Soeren 36.

gap no.	h.dom m	s.d.i.	N/ha	gap size, m	gap size, tree heigth	DFOV PAR, % in the centre of the gap
1	13.0	1.09	1358	–	–	18%
				9.6	0.75	22
				11.6	0.91	34
				16.6	1.30	42
				20	1.56	67
				25	1.95	73
				30	2.34	71
2				–	–	21
				5	0.38	27
				10	0.76	44
				15	1.15	54
				20	1.53	69
				25	1.91	75
				30	2.29	84

Relation DFOV% to gap size (gs) and location.

***** Regression Analysis *****
*** Accumulated analysis of variance ***

change	d.f.	s.s.	m.s.	v.r.	F pr.
+ gs	1	8938.71	8938.71	261.31	<.001
+ location	6	1905.77	317.63	9.29	<.001
+ gs.location	6	314.45	52.41	1.53	0.214
Residual	22	752.55	34.21		
Total	35	11911.48	340.33		

***** Regression Analysis *****
Response variate: dfov
Fitted terms: Constant + gs + location
Percentage variance accounted for 88.8

*** Estimates of regression coefficients ***

	estimate	s.e.	t	t pr.
Constant	31.53	2.59	12.16	<.001
gs	27.61	1.69	16.34	<.001
location 2	−0.35	3.43	−0.10	0.920
location 3	−2.42	4.27	−0.57	0.575
location 4	−19.96	3.45	−5.78	<.001
location 5	−7.93	4.26	−1.86	0.073
location 6	1.72	4.28	0.40	0.691
location 7	−10.13	3.40	−2.98	0.006

Relation DFOV with gap size and s.d.i.

*** Estimated Components of Variance with standard error ***

location	65.65	47.29
units	38.10	10.37

*** Table of effects and standard errors ***

sdi	–0.4297	20.29
gs	35.76	10.22
int	–7.969	9.497

Appendix 6.4.5

PAR percentage of DFOV in bilbery of 60-80 cm height.

height above ground, cm	% DFOV PAR in gap of 20 × 40 cm
0	13%
10	16%
20	17%
30	24%
40	23%
50	33%
60	58%
70	60%
80	60%
90	60%
100	60%

PAR percentage of DFOV in bilberry of 35-55 cm height.

height above ground, cm	% DFOV PAR in gap of 60 × 40 cm	% DFOV PAR in gap of 60 × 80 cm
0	37%	43%
10	42%	49%
20	50%	55%
30	57%	58%
40	59%	60%
50	61%	60%
60	60%	60%
70	60%	60%
80	60%	60%
90	60%	60%
100	60%	60%

PAR percentage of DFOV in bilberry of 30 cm height.

height above ground, cm	% DFOV PAR in gap of size indicated in cm		
	45 × 65	70 × 80	100 × 100
0	52%	58%	58%
10	57%	59%	59%
20	59%	60%	60%
30	59%	60%	60%
40	59%	61%	61%
50	59%	61%	60%
60	59%	60%	61%
70	59%	60%	61%
80	59%	60%	61%
90	60%	60%	61%
100	60%	60%	61%

PAR percentage of DFOV in bilberry of 60-70 cm height.

height above ground, cm	% DFOV PAR in gap of size indicated in cm				
	55 × 55	60 × 85	90 × 100	120 × 150	130 × 300
0	29%	39%	46%	52%	57%
10	32%	42%	50%	54%	58%
20	40%	48%	53%	56%	58%
30	45%	52%	56%	57%	59%
40	50%	55%	57%	58%	60%
50	57%	58%	58%	58%	60%
60	59%	59%	58%	58%	59%
70	59%	59%	59%	59%	59%
80	59%	59%	59%	59%	59%
90	59%	59%	59%	59%	60%
100	59%	59%	59%	59%	60%

Appendix 6.5.1
Sample number of organic topsoil with a specific thickness, under Scots pine saplings in open Scots pine stands.

stand no.	thickness organic topsoil in cm												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Pal.Park 13	8	4	1	3	3	1	4						1
Pal.Park 19			4	4	9	2	1		2				
Uddel 52			1	7	4	10	3						
Uddel 131	1	6	1	3	3	1	6	3	1				
Uddel 141		2	1	1	6	7	2	1	2	2		1	
Gortel 19b		2	7	8	2	3	2	1					
Gortel 35			1	7	7	6	4						
Gortel 84a		1	3	6	4	2	5						
Gortel 78			5	7	5	7	1						
Gortel 77g		1	10	5	6	3							
Gortel 92		3	5	3	6	5	1	2					

Sample number of organic topsoil with a specific thickness, taken at random in open Scots pine stands.

stand no.	thickness organic topsoil in cm													
	0	1	2	3	4	5	6	7	8	9	10	11	12	15
Pal.Park 13	4	5	1	1	3	1	1	1	4		2	1		1
Pal.Park 19			1	4	4	1	9	1	1	1				
Uddel 52			2	4	3	3	6	6		1				
Uddel 131		3	3	1	3	2	1	4	4	2	1	1		
Uddel 141		1	1	1	4	3	5	4	3	1	1		1	
Gortel 19b			7	6	7	1	2	2						
Gortel 35			3	7	6	5	2	2						
Gortel 84a		1	5	1	5	6	2		1					
Gortel 78			3	5	9	3	3	2						
Gortel 77g			7	8	6	1	3							
Gortel 92		1	2	6	5	7	3	1						

Sample number of organic topsoil with a specific thickness under Scots pine saplings on vegetationless organic topsoil.

stand no.	thickness organic topsoil in cm										
	0	1	2	3	4	5	6	7	8	9	10
Pal.Park 14	1	1	2	5	8	8	3	2	1	1	
Pal.Park 13				1	3		1	2	1		1

Sample number of organic topsoil with a specific thickness taken at random on vegetationless organic topsoil.

stand no.	thickness organic topsoil in cm										
	0	1	2	3	4	5	6	7	8	9	10
Pal.Park 14	1	3	1	3	3	6	7	4	3		
Pal.Park 13				2	2	4	1	2			

Basic statistics from top soil thickness measurements in stands with undergrowth.

	thickness under sapling, cm			thickness at 1 m, cm		
	mean	sd	nos	mean	sd	nos
stand						
PP13i	2.720	2.965	25	4.720	4.188	25
PP19c	4.000	1.662	22	5.136	1.781	22
U52	4.280	1.137	25	5.200	1.848	25
U131	3.960	2.458	25	5.560	3.029	25
U141	5.200	2.432	25	6.000	2.466	25
G19b	3.280	1.595	25	3.640	1.551	25
G35	4.200	1.155	25	4.080	1.441	25
G84a	3.667	1.606	24	4.042	1.628	24
G78	3.680	1.215	25	4.160	1.434	25
G77g	3.042	1.160	24	3.417	1.316	24
G92	3.640	1.753	25	4.120	1.453	25
mean	3.789			4.552		
range	0-12			0-15		

Differences in topsoil thickness between stands and regions in stands with undergrowth.
Analysis of variance and pairwise comparisons.

*** Accumulated analysis of variance ***

change	d.f.	s.s.	m.s.	v.r.	F pr.
+ region	2	69.931	34.966	8.65	<.001
+ stand	8	24.337	3.042	0.75	0.645
Residual	259	1046.561	4.041		
Total	269	1140.830	4.241		

***** Pairwise differences *****
Fitted terms: Constant + stand
(no significant differences (= 0.05) between stands with common underlining)

```
G35    G19b    G77g    G84a    G78    G92    U141    U52    PP19c    U131
PP13i
[----------------------------------------------------------------------]
        [-----------------------------------------------------------------------]
                                                   [-----------------------------------]
[---------------------------------------]
```

***** Pairwise differences *****
Fitted terms: Constant + region
(no significant differences (= 0.05) between regions with common underlining)

```
Gortel Uddel PPark
 [-----] [-------------]
```

Mean differences in topsoil thickness between control spots and spots under saplings. P-values from one-sided t-tests in stands with undergrowth.

stand no.	mean	sd	nos	t	pval
PP13i	2.0000	3.291	25	3.038	0.0013
PP19c	1.1364	1.612	22	3.306	0.0005
U52	0.9200	1.498	25	3.071	0.001
U131	1.6000	2.915	25	2.744	0.0032
U141	0.8000	2.021	25	1.979	0.0244
G19b	0.3600	1.350	25	1.333	0.0918
G35	-0.1200	1.333	25	-0.450	0.6735
G84a	0.3750	2.018	24	0.911	0.1817
G78	0.4800	1.503	25	1.596	0.0558
G77g	0.3750	1.583	24	1.161	0.1234
G92	0.4800	1.873	25	1.281	0.1007
region	**mean**	**sd**	**nos**	**t**	**pval**
Pal.Park	1.596	2.651	47	4.126	0.000025
Uddel	1.107	2.221	75	4.314	0.000011
Gortel	0.324	1.613	148	2.446	0.007543

Basic statistics from topsoil thickness measurements in stands without undergrowth.

	thickness under sapling, cm			thickness at 1 m, cm		
stand no.	mean	sd	nos	mean	sd	nos
stand no.						
PP14	4.581	2.110	31	4.839	2.208	31
PP13	5.889	2.315	9	4.889	1.537	9

Mean differences in topsoil thickness between control spots and spots under saplings in stands without undergrowth, p-values from one-sided t-tests.

stand no.	mean	sd	nos	t	pval
PP14	0.2581	2.804	31	0.512	0.3057
PP13	–1.0000	1.581	9	–1.897	0.9673

Appendix 7. Data and statistics on height growth.

Appendix 7.1.3

Planted 1-year-oak, average height growth over 5 years in cm.

Pal.Park 19d,

s.d.i.	0.20	0.32	0.61	0.62
Pedunculate oak	16.8	29.4	12.2	6.4
	6.6	16.4	22.8	12.0
	21.0	12.8	13.8	26.2
	25.4	15.8	26.6	24.8
	18.4	24.0	22.4	28.6
	20.0	20.0	26.2	20.0
	13.4	18.0	18.8	20.8
	8.2	8.8	15.2	33.6
	22.0	21.0	14.6	16.4
			18.8	
Sessile oak	10.0	29.4	2.2	12.8
	5.0	7.6		12.8
		5.6		7.6
		1.2		12.2
				18.2
				13.4

Uddel 2a

s.d.i.	0.23	0.46	0.49	0.67
Pedunculate oak				
	29.8	9.4	29.2	17.4
	10.6	25.8	21.8	15.4
	9.8	13.6	10.4	29.4
	10.4	14.8	13.0	16.6
	28.0	28.2	26.6	19.8
	16.0	15.4	21.0	2.2
	11.4	18.6	7.0	10.6
	11.2	20.4	28.0	11.2
	19.6	11.8		
Sessile oak				
	8.0	10.8	7.0	17.4
	13.4	7.2	14.6	9.2
	18.0	8.6	9.6	
	8.4			
	2.8			
	6.4			
	21.0			

Soeren 107b

s.d.i.	0.23	0.40	0.59	0.76
Pedunculate oak	15.0	10.4	5.6	3.4
	13.2	3.0	9.4	19.4
	14.0	4.0	5.0	7.2
	13.2	7.4	16.4	14.2
		20.6	17.0	4.8
				6.0
				12.8
				3.8
Sessile oak				
	14.2	2.2	4.6	4.6
	10.0			5.0
	25.8			10.2
				4.2

Gortel 84a

s.d.i	0.33	0.48	0.69
Pedunculate oak	21.0	54.8	20.2
	22.8	30.0	20.4
	31.0	36.4	19.4
	29.2	39.0	28.8
	33.0	29.8	33.0
	45.6		31.6
	38.2		44.8
	17.4		32.0
	46.6		
Sessile oak			
	36.0	28.4	23.0
	41.4	28.8	27.8
	37.0	24.8	16.4
	41.6	49.0	21.8
	40.6		
	29.0		

Results from statistical analyses of height growth of planted 1-year-old oak saplings.

Wald tests

CHIsq.	d.f.#	prob.#	
5.761	3	0.124	density . species
3.134	3	0.371	density
14.488	1	0.000	species

*** Tables of mean effects ***

density	low	med-low	med-high	high
	18.62	17.95	18.66	15.47
		standard error of differences:		2.0 – 2.3
species	ped.oak	ses.oak		
	20.05	15.29		
		Standard error of differences:		1.252
stand	PPark19d	Uddel2a	Soeren107b	Gortel84a
	15.51	14.32	9.44	31.42
		Standard error of differences:		1.7 – 2.1

# d.f. = degrees of freedom
prob. = probability.

Planting of 2-year-old pedunculate oak.

Planted 2-year-old pedunculate oak. Total height growth over 6 years in cm.

Uddel 140b

s.d.i.	0.58	0.63	0.77	0.88
	114	93	140	182
	213	120	90	235
	106	190	82	154
	156	238	88	93
	178	64	94	213
	173	57	85	88
	156	185	118	115
	90	156	178	178
	207	190	147	179
	214	221	280	258
	177	168	132	234
	149	169	93	171
	270	89	223	165
	146	99	164	158
	77	84	94	167
	47	133	163	125
	73	62	172	181
	194	167	139	131
	130	83	150	48
	44	88	165	162
	88	153	60	183
	180	184	211	224
	157	117	159	145
	255	124	46	30
	199	209	176	198
	131	40	175	68
	130	164	171	70
	17	202	219	91
	116	56	99	233
	51	118	98	130
	109	60	105	150
	35	102	232	154
	107	75	174	139
	199	47	152	98
	173	75	158	42
	258	165	149	168
	99	116	160	180
	170	125	193	174
	103	121	166	184
	221	104	272	183
	99	143	75	82
	31	132	236	100
	136	129	249	239
	2	107	131	201
				137
				180
				161

Gortel 77g E

s.d.i.	0.79	0.85	0.89	1.08
	22	79	107	141
	132	181	46	23
	210	153	280	257
	9	106	139	109
	175	165	117	77
	36	111	201	69
	14	143	83	51
	140	54	188	34
	219	162	209	72
	227	153	214	203
	137	26	230	154
	204	195	54	153
	252	104	112	165
	150	119	158	143
	203	99	127	13
	153	89	131	44
	81	128	218	48
	110	272	226	162
	192	89	183	112
	153	95	98	81
	310	176	212	54
	182	67	85	51
	117	154	352	91
	178	215	129	90
	120	217	125	93
	321	105	206	55
	248	132	207	0
	347	128	262	202
	229	209	91	108
	157	237	92	150
	275	57	199	153
	181	140	84	168
	140	106	146	132
	227	92	80	103
	132	112	132	73
	248	148	19	5
		131		234
		104		119
		80		196
				185
				96
				123
				169
				244
				172
				109

Gortel 77g W

s.d.i.	0.71	0.86	0.95	1.06
	124	136	143	275
	76	133	70	136
	131	74	201	144
	28	92	135	161
	142	207	79	88
	201	79	165	116
	125	133	201	142
	120	105	143	145
	143	103	146	66
	234	96	74	162
	93	48	40	105
	184	28	186	149
	9	10	96	100
	157	127	155	175
	155	58	86	113
	167	112	93	92
	47	154	113	179
	107	89	44	58
	151	63	130	116
	129	−3	86	97
	164	59	102	85
	74	72	207	108
	155	20	202	183
	110	133	97	143
	144	23	116	34
	172	42	107	14
	48	75	35	50
	68	83	10	176
	76	109	232	173
	113	232	152	78
	111	170	77	38
	109	114	187	188
		56	191	71
		184	166	64
			108	165
			151	79
			214	106
			206	53
			99	153
			133	66
				62
				113
				97
				50
				150

Results of statistical analyses of height growth of planted 2-year-old oak saplings.

W a l d t e s t s

CHIsq.	d.f.	prob.	
6.225	3	0.101	density

*** Tables of mean effects ***

density	low	med-low	med-high	high
	23.85	19.57	24.23	21.20
		standard error of differences:		2.14 – 2.17
stand	Uddel140b	Gortel77gE	Gortel77gW	
	23.33	23.56	19.74	
		Standard error of differences:		1.30 – 1.33

Appendix 7.4.1.2
Statistical test results from height growth of Scots pine regeneration in the experimental stands of 1987.

W a l d t e s t s

CHIsq.	d.f.	prob.	
0.771	3	0.856	((density · fence) · soiltrea) · sowing
0.373	3	0.946	(density · fence) · soiltrea
1.177	3	0.759	(density · fence) · sowing
1.380	3	0.710	(density · soiltrea) · sowing
0.000	1	0.999	(fence · soiltrea) · sowing
0.573	3	0.903	density · fence
0.232	1	0.630	soiltrea · sowing
2.378	3	0.498	density · soiltrea
1.926	3	0.588	density · sowing
7.094	3	0.069	density
17.780	1	0.000	fence
2.803	1	0.094	soiltrea
7.045	1	0.008	sowing

*** Tables of mean effects ***

density	low	med-low	med-high	high
	11.42	11.50	9.09	8.00
		standard error of differences:		1.58 – 1.63
fence	yes	no		
	11.69	8.32		
		Standard error of difference:		0.7970
soiltrea	kuloo	rotov		
	10.62	9.39		
		Standard error of difference:		0.7304
sowing	yes	no		
	10.82	9.19		
		Standard error of difference:		0.6124
stand	PalPark	Uddel	Soeren	Gortel
	10.01	11.80	7.70	10.51
		Standard error of differences:		0.74 – 0.88

Appendix 7.4.3

PAR percentage and tallest regenerated sapling per species in gaps in Pal.park 13 en 14.

stand no./ gap no.	DFOV PAR, %	Scots pine height, cm/ age, year	birch height, cm	oak height, cm	beech height, cm	rowan height, cm
13/1	48.5	80/5		20		
	50.2	81/5	55			
	53.2	48/5	83	22		
	55.2	92/5	145	90		
	55.6	105/5	130			
	55.5	138/5	260			
	59.7	105/5	220			
	58.2	96/5	300			
	55.4	157/5	220			
	54.8	127/5	260			
14/1	51.6					30
	51.8			7		
	48.0	30/4				
	46.5	8/2	60			
14/2	54.7		90			
	54.3					150
	48.3			6		
14/3	29.2			10		
	30.0	7/2				
	30.9	34/4	155	12		
	32.6	16/4				
	32.9			20		
	32.5				20	
	32.6	7/4				
	32.7			16		
	31.7		150			

stand no./ gap no.	DFOV PAR, %	Scots pine	birch	oak	beech	rowan
14/4	41.1	16/4	160			
	46.1	7/3		22		
	48.9	16/4				
	47.9			7		
	42.5			6		
14/5	45.2	48/4				
	46.2	26/4	300		30	
	49.0	74/4	200	26		
	51.3	69/4		50	55	
	52.6	49/4	200		90	
	54.0	84/4		15		
	55.3	10/2	200	34	49	
	56.3	48/4			50	
	57.4	30/4			20	
	59.0	46/4		50	31	

DFOV PAR percentage in Scots pine stands after increment felling with established regeneration of Scots pine.

stand no.	basal area, m^2 (stand density index)	DFOV PAR, %	Scots pine saplings height, cm/age, year
Gortel 133f	14.4 in March 1984	65%	64/5
	16.3 in Sept 1991	67	80/5
	(0,56 in 1984,	63	90/5
	0.63 in 1991)	63	70/5
		63	112/5
		60	112/5
		60	71/5
		60	68/5
		61	74/5
		61	83/5
		68	115/5
		68	108/5
		65	66/5
		68	79/5
		64	94/5
		65	89/5

stand no.	basal area, m^2 (s.d.i.)	DFOV PAR %	Scots pine saplings height, cm/age, year
Gortel 133h	14.4 in March 1984	64%	90/5
	16.0 in Sept. 1991	66	93/5
	(0.56 in 1984,	66	92/5
	0.62 in 1991)	68	87/5
		70	115/5
		68	115/5
		68	114/5
		69	83/5
		69	120/5
		71	78/5
		70	54/5
		71	70/5
		68	64/5
		69	81/5
		68	67/5
		61	78/5
		51	84/5

Appendix 7.4.4

Results of statistical analyses of height growth of planted Scots pine saplings.

***** Analysis of variance *****

Variate: y

source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
plot	3	1385.97	461.99	5.86	0.001
Residual	71	5598.28	78.85		
Total	74	6984.25			

***** Tables of means *****

Variate: y

Grand mean 27.5

plot	1	2	3	4
density	0.23	0.46	0.49	0.67
	31.7	27.5	30.2	21.0
N	21	15	18	21

*** Standard errors of differences of means ***
s.e.d. 3.24 min.N; 3.00 max-min; 2.74 max.N

Appendix 8. List of fauna and flora species mentioned.

English name	*Latin name*
alder buckthorn	*Frangula alnus* Mill.
American black cherry	*Prunus serotina* Ehrh.
aurochs	*Bos taurus* L.
bank vole	*Clethrionomys glareolus* (Schreber)
beech	*Fagus sylvatica* L.
bilberry	*Vaccinium myrtillus* L.
black pine	*Pinus nigra* Arnold
bracken	*Pteridium aquilinum* (L.) Kuhn
brambling	*Fringilla montifringilla* L.
chaffinch	*Fringilla coelebs* L.
common bent	*Agrostis capillaris* L.
cowberry	*Vaccinium vitis-idaea* L.
crowberry	*Empetrum nigrum* L.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
European birch	*Betula verrucosa* Ehrh.
European bison	*Bison bonasus* L.
fallow deer	*Dama dama* L.
grand fir	*Abies grandis* Ldl.
great tit	*Parus major* L.
green oak tortrix	*Tortrix viridana* L.
heath bedstraw	*Galium saxatile* L.
heather	*Calluna vulgaris* (L.) Hull
hornbeam	*Carpinus betulus* L.
jay	*Garrulus glandarius* L.
large pine weevil	*Curculio abietes* L.
moose	*Alces alces* L.
needle cast	*Lophodermium seditiosum* Minter, Staley & Millar
Norway spruce	*Picea abies* (L.) Karst.
oak leaf roller moth	*Tortrix viridana* L.
pedunculate oak	*Quercus robur* L.
pill sedge	*Carex pilulifera* L.
pubescent birch	*Betula pubescens* Ehrh.
purple moor-grass	*Molinia caerulea* (L.) Moench
red oak	*Quercus rubra* L.
red deer	*Cervus elephas* L.
roe deer	*Capreolus capreolus* L.
rowan	*Sorbus aucuparia* L.
Scots pine	*Pinus sylvestris* L.
sessile oak	*Quercus petraea* (Mattuschka) Lieblein
sheep's fescue	*Festuca ovina* L.
sheep's sorrel	*Rumex acetosella* L.
shoot blight	*Sphaeropsis sapinea* = *Diplodia pinea* (Desm.)
silver fir	*Abies alba* Mill.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
wavy hair grass	*Deschampsia flexuosa* (L.) Trin.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
wild boar	*Sus scrofa* L.
wild horse	*Equus caballus* L.

winter moth	*Operophtera brumata* L.
wood mouse	*Apodemus sylvaticus* L.
wood small-reed	*Calamagrostis epigejos* (L.) Roth
yew tree	*Taxus baccata* L.

Campylopus flexuosis (Hedw.) Brid.
Campylopus pyriformis (K.F.Schultz) Brid.
Dicranella heteromalla (Hedw.) Schimp.
Dicranum scoparium Hedw.
Dicranum undulatum Schrad. ex Brid.
Hypnum jutlandicum Holmen et Warncke
Pleurozium schreberi (Brid.) Mitt.
Polytrichum formosum Hedw.
Pseudoscleropodium purum (Hedw.) Fleisch. et Broth.

Appendix: 9.8
Scots pine plantation.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age	Stand --- Basal area
1 -Scots pine	20	18.5

Year	Species	Age	Dom. Ht.	before thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	Stumpage value	after thinning Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stumpage value	Current Value Incr.	Mean Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year	Dfl/year
0	Sc.P	20	9.7	18.5	2500	9.7	94	2.8	557	8.0	14	0	15.7	1943	10.1	80	0.0	4.7	0	0	0
	Total			18.5			94	2.8			14	0	15.7			80			0		
5	Sc.P	25	11.5	20.8	1943	11.7	123	3.7	506	9.6	22	0	17.1	1437	12.3	101	8.6	5.5	0	0	0
	Total			20.8			123	3.7			22	0	17.1			101			0		
10	Sc.P	30	13.2	21.6	1437	13.8	145	3.4	341	11.3	23	0	18.2	1096	14.6	122	8.8	6.0	0	0	0
	Total			21.6			145	3.4			23	0	18.2			122			0		
15	Sc.P	35	14.6	22.3	1096	16.1	164	3.2	232	13.1	23	0	19.2	864	16.8	141	8.4	6.4	1534	307	44
	Total			22.3			164	3.2			23	0	19.2			141			1534		

20	Sc.P 40	15.9	22.8	864	18.3	180	2.9	155	15.4	23	0	19.9	709	18.9	157	7.8	6.6	2567	207	64
	Total		22.8			180	2.9			23	0	19.9			157			2567		
25	Sc.P 45	17.1	23.1	709	20.4	194	2.6	108	17.6	22	284	20.5	601	20.8	172	7.4	6.6	3797	303	91
	Total		23.1			194	2.6			22	284	20.5			172			3797		
30	Sc.P 50	18.1	23.4	601	22.3	206	2.4	78	19.7	21	386	21.0	523	22.6	185	6.8	6.7	5196	357	117
	Total		23.4			206	2.4			21	386	21.0			185			5196		
35	Sc.P 55	19.0	23.6	523	23.9	215	2.1	58	21.6	20	496	21.4	465	24.2	195	6.0	6.6	6465	353	139
	Total		23.6			215	2.1			20	496	21.4			195			6465		
40	Sc.P 60	19.8	23.7	465	25.5	223	1.9	44	23.4	18	557	21.7	421	25.6	205	5.6	6.5	7284	275	150
	Total		23.7			223	1.9			18	557	21.7			205			7284		
45	Sc.P 65	20.5	23.8	421	26.8	230	1.7	35	25.1	17	588	22.0	386	27.0	213	5.0	6.4	8031	267	159
	Total		23.8			230	1.7			17	588	22.0			213			8031		
50	Sc.P 70	21.1	23.8	386	28.0	235	1.6	27	26.6	15	557	22.2	359	28.1	220	4.4	6.3	8711	247	165
	Total		23.8			235	1.6			15	557	22.2			220			8711		
55	Sc.P 75	21.7	23.8	359	29.1	239	23.8	359	29.1	239	9851	0.0	0	0.0	0	3.8	6.1	0	228	170
	Total		23.8			239	23.8			239	9851	0.0			0			0		

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Appendix: 9.9

Amerongse berg 7b.

*pro*FORST

Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Stand ---- Age	Basal area
1 -Scots pine	20	1.6
2 -Birch	20	6.3

year	Spe-cies	Age	Dom. Ht.	before thinning Basal Area	before thinning Number of trees	before thinning Mean Diam.	before thinning Timber Volume	thinning Basal Area	thinning Number of trees	thinning Mean Diam.	thinning Timber Volume	thinning Stum-page value	after thinning Basal Area	after thinning Number of trees	after thinning Mean Diam.	after thinning Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.	Mean Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year	Dfl/year
0	Sc.P	20	8.2	1.6	229	9.4	7	0.0	0	0.0	0	0	1.6	229	9.4	7	0.0	0.4	0	0	0
	Bi	20	10.2	6.3	914	9.4	31	0.0	0	0.0	0	0	6.3	914	9.4	31	0.0	1.6	0	0	0
	Total			7.9			38	0.0			0	0	7.9			38			0		
5	Sc.P	25	9.8	2.2	229	11.1	12	0.0	0	0.0	0	0	2.2	229	11.1	12	0.9	0.5	0	0	0
	Bi	25	11.8	9.4	914	11.4	52	0.0	0	0.0	0	0	9.4	914	11.4	52	4.3	2.1	0	0	0
	Total			11.6			64	0.0			0	0	11.6			64			0		
10	Sc.P	30	11.1	2.9	229	12.6	17	0.0	3	10.3	0	0	2.8	226	12.7	17	1.0	0.6	0	0	0
	Bi	30	13.1	12.5	914	13.2	77	0.2	17	11.8	1	0	12.3	897	13.2	76	4.9	2.6	610	122	20
	Total			15.3			94	0.2			1	0	15.1			93			610		

15	Sc.P	35	12.4	3.5	226	13.9	22	0.2	18	11.4	1	0	3.3	208	14.1	21	1.0	0.6	0	0	0
	Bi	35	14.3	15.2	897	14.7	101	1.1	84	13.1	8	64	14.1	813	14.8	93	5.0	2.9	744	40	23
	Total			18.7			123	1.3			9	64	17.3			114			744		
20	Sc.P	40	13.5	3.8	208	15.3	26	0.3	28	12.5	2	0	3.5	180	15.7	24	1.0	0.7	0	0	0
	Bi	40	15.3	16.6	813	16.1	118	2.1	127	14.4	15	120	14.6	686	16.4	103	5.0	3.2	823	40	25
	Total			20.5			144	2.4			17	120	18.1			127			823		
25	Sc.P	45	14.5	4.0	180	16.8	29	0.3	21	13.9	2	0	3.7	159	17.2	27	1.0	0.7	320	64	7
	Bi	45	16.3	16.8	686	17.7	125	1.9	95	15.8	14	112	15.0	591	18.0	111	4.5	3.3	889	36	26
	Total			20.9			154	2.2			16	112	18.7			138			1210		
30	Sc.P	50	15.3	4.2	159	18.3	31	0.3	15	15.3	2	0	3.9	144	18.5	29	0.9	0.7	450	26	9
	Bi	50	17.1	17.0	591	19.1	131	1.7	72	17.1	13	104	15.3	519	19.4	118	3.9	3.4	943	32	27
	Total			21.2			162	2.0			15	104	19.2			147			1393		
35	Sc.P	55	16.1	4.3	144	19.5	34	0.3	12	16.6	2	21	4.0	132	19.7	32	0.9	0.7	587	31	11
	Bi	55	17.8	17.1	519	20.5	137	1.5	57	18.4	12	96	15.6	462	20.7	125	3.7	3.4	996	30	27
	Total			21.4			170	1.8			14	117	19.6			156			1583		
40	Sc.P	60	16.7	4.4	132	20.7	36	0.2	9	17.9	2	28	4.2	123	20.8	34	0.8	0.7	742	37	13
	Bi	60	18.5	17.2	462	21.7	141	1.4	45	19.5	11	88	15.8	417	22.0	130	3.2	3.4	1037	26	27
	Total			21.6			176	1.6			13	116	20.0			163			1779		
45	Sc.P	65	17.3	4.5	123	21.7	38	0.2	7	19.0	2	33	4.3	116	21.8	36	0.8	0.7	898	38	15
	Bi	65	19.1	17.2	417	22.9	144	1.2	36	20.7	10	80	16.0	381	23.1	134	2.9	3.4	1072	23	27
	Total			21.7			182	1.4			12	113	20.3			170			1969		
50	Sc.P	70	17.9	4.6	116	22.6	39	0.2	6	20.0	2	39	4.4	110	22.6	37	0.7	0.7	1044	37	17
	Bi	70	19.6	17.2	381	24.0	147	1.1	29	21.7	9	72	16.1	352	24.1	138	2.5	3.3	1100	20	26
	Total			21.8			186	1.3			11	111	20.5			175			2144		
55	Sc.P	75	18.3	4.7	110	23.4	40	4.7	110	23.4	40	1225	0.0	0	0.0	0	0.7	0.7	0	36	18
	Bi	75	20.0	17.2	352	25.0	149	17.2	352	25.0	149	1192	0.0	0	0.0	0	2.3	3.2	0	18	26
	Total			21.9			190	21.9			189	2417	0.0			1			0		

Appendix: 9.9
Imbosch 13h.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Stand ---- Age	Basal area
1 -Scots pine	20	11.5
2 -Birch	20	5.5

year	Spe-cies	Age	Dom. Ht.	before thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	Stum-page value	after thinning Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	20	8.2	11.5	3087	6.9	50	3.1	1484	5.1	13	0	8.4	1603	8.2	37	0.0	2.5	0	0
	Bi	20	10.2	5.5	1458	6.9	28	2.0	686	6.1	10	0	3.5	772	7.6	18	0.0	1.4	0	0
	Total			17.0			78	5.1			23	0	11.9			55			0	
5	Sc.P	25	9.8	11.2	1603	9.4	57	1.7	359	7.7	9	0	9.5	1244	9.8	48	4.0	2.8	0	0
	Bi	25	11.8	4.8	772	8.9	27	1.1	190	8.4	6	0	3.8	582	9.1	21	1.9	1.5	0	0
	Total			16.0			84	2.7			15	0	13.3			69			0	
10	Sc.P	30	11.1	12.0	1244	11.1	69	1.6	242	9.1	9	0	10.4	1002	11.5	60	4.2	3.0	0	0
	Bi	30	13.1	5.0	582	10.4	31	1.0	135	9.6	6	0	4.0	447	10.6	25	1.9	1.6	0	0
	Total			17.0			100	2.6			15	0	14.4			85			0	

15	Sc.P	35	12.4	12.7	1002	12.7	81	1.5	175	10.4	9	0	11.2	827	13.1	72	4.0	3.2	0	0
	Bi	35	14.3	5.0	447	11.9	33	0.9	99	10.7	6	0	4.1	348	12.2	27	1.7	1.6	217	43
	Total			17.7			114	2.4			15	0	15.3			99			217	
20	Sc.P	40	13.5	13.3	827	14.3	91	1.4	132	11.7	10	0	11.9	695	14.8	81	3.8	3.3	0	0
	Bi	40	15.3	4.9	348	13.4	35	0.8	73	12.0	6	0	4.1	275	13.8	29	1.5	1.6	231	3
	Total			18.2			125	2.3			16	0	16.0			109			231	
25	Sc.P	45	14.5	13.8	695	15.9	99	1.3	99	13.0	10	0	12.5	596	16.3	89	3.8	3.3	861	172
	Bi	45	16.3	4.8	275	14.9	36	0.8	54	13.3	6	48	4.1	221	15.3	30	1.4	1.5	237	11
	Total			18.6			135	2.1			16	48	16.5			119			1098	
30	Sc.P	50	15.3	14.2	596	17.4	108	1.2	74	14.4	9	0	13.0	522	27.8	99	3.6	3.4	1325	93
	Bi	50	17.1	4.7	221	16.4	36	0.7	40	14.6	5	40	4.0	181	16.7	31	1.2	1.5	247	10
	Total			18.8			143	1.9			14	40	16.9			129			1572	
35	Sc.P	55	16.1	14.5	522	18.8	114	1.1	55	15.9	9	0	13.4	467	19.1	105	3.2	3.3	1780	91
	Bi	55	17.8	4.5	181	17.8	36	0.6	30	15.9	5	40	3.9	151	18.1	31	1.0	1.5	246	8
	Total			19.0			150	1.7			14	40	17.3			136			2026	
40	Sc.P	60	16.7	14.8	467	20.1	120	1.0	43	17.2	8	96	13.8	424	20.3	112	2.9	3.3	2271	117
	Bi	60	18.5	4.3	151	19.1	35	0.5	23	17.1	4	32	3.8	128	19.5	31	0.9	1.4	252	7
	Total			19.1			155	1.5			12	128	17.6			143			2523	
45	Sc.P	65	17.3	15.0	424	21.2	125	0.9	33	18.5	8	123	14.1	391	21.4	117	2.7	3.2	2812	133
	Bi	65	19.1	4.2	128	20.4	35	0.5	18	18.3	4	32	3.7	110	20.7	31	0.7	1.4	249	6
	Total			19.2			160	1.4			12	155	17.8			148			3061	
50	Sc.P	70	17.9	15.2	391	22.2	130	0.8	27	19.7	7	128	14.4	364	22.4	123	2.5	3.2	3361	135
	Bi	70	19.6	4.0	110	21.6	34	0.4	14	19.4	4	32	3.6	96	21.9	30	0.7	1.3	244	5
	Total			19.2			164	1.2			11	160	18.0			153			3604	
55	Sc.P	75	18.3	15.4	364	23.2	133	15.4	364	23.2	133	3989	0.0	0	0.0	0	2.1	3.1	0	126
	Bi	75	20.0	3.9	96	22.7	34	3.9	96	22.7	34	272	0.0	0	0.0	0	0.7	1.3	0	6
	Total			19.3			167	19.3			167	4261	0.0			0			0	

Appendix: 9.9
Imbosch 24p.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age	Stand Basal area
1 -Scots pine	20	11.1
2 -Birch	20	5.9

year	Species	Age (year)	Dom. Ht. (m)	before thinning: Basal Area (m2)	before thinning: Number of trees	before thinning: Mean Diam. (cm)	before thinning: Timber Volume (m3)	thinning: Basal Area (m2)	thinning: Number of trees	thinning: Mean Diam. (cm)	thinning: Timber Volume (m3)	thinning: Stumpage value (Dfl)	after thinning: Basal Area (m2)	after thinning: Number of trees	after thinning: Mean Diam. (cm)	after thinning: Wood Volume (m3)	Current Volume Incr. (m3/year)	Mean Volume Incr. (m3/year)	Stumpage value (Dfl)	Current Value Incr. (Dfl/year)
0	Sc.P	20	8.2	11.1	2961	6.9	48	3.7	1623	5.4	16	0	7.4	1338	8.4	32	0.0	2.4	0	0
	Bi	20	10.2	5.9	1570	6.9	30	2.0	688	6.1	10	0	3.9	882	7.5	20	0.0	1.5	0	0
	Total			17.0			78	5.7			26	0	11.2			52			0	
5	Sc.P	25	9.8	9.8	1338	9.7	51	1.7	353	7.9	9	0	8.1	985	10.2	42	3.7	2.7	0	0
	Bi	25	11.8	5.5	882	8.9	31	1.0	179	8.3	5	0	4.5	703	9.0	26	2.2	1.6	0	0
	Total			15.3			81	2.7			14	0	12.6			67			0	
10	Sc.P	30	11.1	10.3	985	11.5	60	1.6	228	9.5	9	0	8.7	757	12.1	51	3.6	2.8	0	0
	Bi	30	13.1	5.9	703	10.3	37	0.9	127	9.6	6	0	5.0	576	10.5	31	2.2	1.7	0	0
	Total			16.2			97	2.5			15	0	13.7			82			0	

15	Sc.P	35	12.4	10.7	757	13.4	68	1.5	161	10.9	10	0	9.1	596	14.0	58	3.4	2.9	0	0
	Bi	35	14.3	6.3	576	11.8	42	0.9	97	10.6	6	0	5.4	479	12.0	36	2.2	1.8	288	58
	Total			16.9			110	2.4			16	0	14.6			94			288	
20	Sc.P	40	13.5	10.9	596	15.3	75	1.4	114	12.5	10	0	9.5	482	15.8	65	3.4	3.0	0	0
	Bi	40	15.3	6.6	479	13.2	47	0.8	73	11.8	6	0	5.8	406	13.5	41	2.2	1.8	326	8
	Total			17.5			122	2.2			16	0	15.3			106			326	
25	Sc.P	45	14.5	11.0	482	17.1	80	1.3	81	14.1	9	0	9.8	401	17.6	71	3.1	3.0	927	185
	Bi	45	16.3	6.9	406	14.7	51	0.7	55	13.1	6	48	6.1	351	14.9	45	2.0	1.9	359	16
	Total			17.9			131	2.0			15	48	15.9			116			1286	
30	Sc.P	50	15.3	11.1	401	18.8	84	1.2	58	15.9	9	0	10.0	343	19.3	75	2.6	2.9	1303	75
	Bi	50	17.1	7.1	351	16.0	54	0.7	42	14.3	5	40	6.4	309	16.2	49	1.9	1.9	394	15
	Total			18.2			139	1.8			14	40	16.4			125			1698	
35	Sc.P	55	16.1	11.2	343	20.4	89	1.0	42	17.6	8	103	10.2	301	20.7	81	2.6	2.9	1747	109
	Bi	55	17.8	7.2	309	17.3	58	0.6	33	15.4	5	40	6.6	276	17.5	53	1.7	1.8	422	13
	Total			18.4			146	1.7			13	143	16.8			133			2169	
40	Sc.P	60	16.7	11.2	301	21.8	92	0.9	32	19.1	8	136	10.3	269	22.1	84	2.2	2.9	2187	115
	Bi	60	18.5	7.4	276	18.5	60	0.6	26	16.5	5	40	6.8	250	18.6	55	1.5	1.8	443	12
	Total			18.6			152	1.5			13	176	17.1			139			2631	
45	Sc.P	65	17.3	11.2	269	23.0	94	0.8	25	20.6	7	148	10.4	244	23.3	87	2.1	2.8	2628	118
	Bi	65	19.1	7.5	250	19.6	63	0.5	21	17.5	4	32	7.0	229	19.8	59	1.5	1.8	473	12
	Total			18.7			157	1.4			11	180	17.4			146			3101	
50	Sc.P	70	17.9	11.2	244	24.2	96	0.8	20	21.9	6	154	10.4	224	24.3	90	1.7	2.7	2988	103
	Bi	70	19.6	7.7	229	20.6	65	0.5	17	18.5	4	32	7.2	212	20.8	61	1.3	1.8	491	10
	Total			18.8			161	1.2			10	186	17.6			151			3480	
55	Sc.P	75	18.3	11.1	224	25.2	97	11.1	224	25.2	97	3370	0.0	0	0.0	0	1.5	2.6	0	76
	Bi	75	20.0	7.8	212	21.6	67	7.8	212	21.6	67	536	0.0	0	0.0	0	1.2	1.7	0	9
	Total			18.9			164	18.9			164	3906	0.0			0			0	

Appendix: 9.9
Paleispark 14c.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age (Stand)	Basal area (Stand)
1 -Scots pine	20	17.0

year	Spe-cies	Age year	Dom. Ht. m	before thinning Basal Area m2	Number of trees	Mean Diam. cm	Timber Volume m3	thinning Basal Area m2	Number of trees	Mean Diam. cm	Timber Volume m3	Stum-page value Dfl	after thinning Basal Area m2	Number of trees	Mean Diam. cm	Wood Volume m3	Current Volume Incr. m3/year	Mean Volume Incr. m3/year	Stum-page value Dfl	Current Value Incr. Dfl/year
0	Sc.P	20	8.2	17.0	2500	9.3	74	2.5	552	7.6	11	0	14.5	1948	9.7	63	0.0	3.7	0	0
	Total			17.0			74	2.5			11	0	14.5			63			0	
5	Sc.P	25	9.8	18.7	1948	11.1	95	3.0	457	9.1	15	0	15.7	1491	11.6	80	6.4	4.2	0	0
	Total			18.7			95	3.0			15	0	15.7			80			0	
10	Sc.P	30	11.1	19.6	1491	12.9	112	2.8	317	10.6	16	0	16.8	1174	13.5	96	6.4	4.6	0	0
	Total			19.6			112	2.8			16	0	16.8			96			0	
15	Sc.P	35	12.4	20.3	1174	14.8	127	2.6	223	12.1	16	0	17.7	951	15.4	111	6.2	4.8	0	0
	Total			20.3			127	2.6			16	0	17.7			111			0	
20	Sc.P	40	13.5	20.8	951	16.7	140	2.3	159	13.7	16	0	18.4	792	17.2	124	5.8	5.0	1481	296
	Total			20.8			140	2.3			16	0	18.4			124			1481	

25	Sc.P 45	14.5	21.2	792	18.4	152	2.1	112	15.5	15	0	19.0	680	18.9	137	5.6	5.0	2231	150
	Total		21.2			152	2.1			15	0	19.0			137			2231	
30	Sc.P 50	15.3	21.5	680	20.0	161	1.9	82	17.2	14	168	19.5	598	20.4	147	4.8	5.0	3023	192
	Total		21.5			161	1.9			14	168	19.5			147			3023	
35	Sc.P 55	16.1	21.7	598	21.5	169	1.7	62	18.8	13	210	20.0	536	21.8	156	4.4	4.9	3941	226
	Total		21.7			169	1.7			13	210	20.0			156			3941	
40	Sc.P 60	16.7	21.9	536	22.8	176	1.6	47	20.3	12	243	20.3	489	23.0	164	4.0	4.9	4827	226
	Total		21.9			176	1.6			12	243	20.3			164			4827	
45	Sc.P 65	17.3	22.0	489	23.9	182	1.4	37	21.6	11	273	20.6	452	24.1	171	3.6	4.8	5641	217
	Total		22.0			182	1.4			11	273	20.6			171			5641	
50	Sc.P 70	17.9	22.1	452	25.0	187	1.2	30	22.9	11	318	20.9	422	25.1	176	3.2	4.7	6097	155
	Total		22.1			187	1.2			11	318	20.9			176			6097	
55	Sc.P 75	18.3	22.2	422	25.9	190	22.2	422	25.9	190	6830	0.0	0	0.0	0	2.8	4.5	0	147
	Total		22.2			190	22.2			190	6830	0.0			0			0	

Appendix: 9.9
Petrea 12c.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age	Stand ---- Basal area
1 -Scots pine	20	2.4
2 -Birch	20	14.7

				before thinning				thinning					after thinning							
year	Species	Age	Dom. Ht.	Basal Area	Number of trees	Mean Diam.	Timber Volume	Basal Area	Number of trees	Mean Diam.	Timber Volume	Stumpage value	Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stumpage value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	20	8.2	2.4	450	8.2	10	0.5	155	6.7	2	0	1.8	295	8.9	8	0.0	0.5	0	0
	Bi	20	10.2	14.7	2790	8.2	74	4.0	967	7.3	20	0	10.7	1823	8.6	54	0.0	3.7	0	0
	Total			17.1			84	4.6			22	0	12.5			62			0	
5	Sc.P	25	9.8	2.4	295	10.2	13	0.4	74	8.4	2	0	2.0	221	10.8	11	0.8	0.6	0	0
	Bi	25	11.8	14.7	1823	10.1	83	3.0	434	9.4	17	0	11.7	1389	10.3	66	5.9	4.1	0	0
	Total			17.1			96	3.4			19	0	13.7			77			0	
10	Sc.P	30	11.1	2.5	221	12.1	15	0.4	48	9.9	2	0	2.2	173	12.7	13	0.8	0.6	0	0
	Bi	30	13.1	15.2	1389	11.8	94	2.7	302	10.6	17	0	12.5	1087	12.1	77	5.6	4.4	617	123
	Total			17.7			109	3.1			19	0	14.7			90			617	

15	Sc.P	35	12.4	2.7	173	14.0	17	0.3	33	11.4	2	0	2.3	140	14.5	15	0.8	0.7	0	0
	Bi	35	14.3	15.6	1087	13.5	103	2.4	211	12.0	16	128	13.1	876	13.8	87	5.2	4.5	699	42
	Total			18.2			120	2.7			18	128	15.5			102			699	
20	Sc.P	40	13.5	2.7	140	15.8	19	0.3	23	12.9	2	0	2.4	117	16.3	17	0.8	0.7	160	32
	Bi	40	15.3	15.8	876	15.2	113	2.2	151	13.5	15	120	13.7	725	15.5	98	5.0	4.6	780	40
	Total			18.6			131	2.5			17	120	16.1			114			940	
25	Sc.P	45	14.5	2.8	117	17.5	20	0.3	16	14.6	2	0	2.5	101	17.9	18	0.7	0.7	253	19
	Bi	45	16.3	16.1	725	16.8	119	1.9	110	15.0	14	112	14.1	615	17.1	105	4.3	4.5	841	34
	Total			18.9			139	2.2			16	112	16.7			123			1093	
30	Sc.P	50	15.3	2.9	101	19.1	22	0.3	12	16.2	2	19	2.6	89	19.4	20	0.7	0.7	354	24
	Bi	50	17.1	16.2	615	18.3	126	1.8	83	16.4	14	112	14.5	532	18.6	112	4.1	4.5	893	33
	Total			19.1			148	2.0			16	131	17.1			132			1247	
35	Sc.P	55	16.1	3.0	89	20.6	23	0.2	9	17.8	2	27	2.7	80	20.8	21	0.7	0.7	467	28
	Bi	55	17.8	16.4	532	19.8	130	1.6	64	17.7	13	104	14.8	468	20.1	117	3.8	4.4	940	30
	Total			19.3			154	1.8			15	131	17.5			139			1407	
40	Sc.P	60	16.7	3.0	80	21.9	24	0.2	7	19.2	2	34	2.8	73	22.1	22	0.6	0.7	588	31
	Bi	60	18.5	16.5	468	21.2	134	1.4	50	19.0	12	96	15.0	418	21.4	122	3.4	4.3	980	27
	Total			19.5			159	1.6			14	130	17.8			145			1568	
45	Sc.P	65	17.3	3.0	73	23.0	25	0.2	5	20.6	2	42	2.9	68	23.1	23	0.6	0.7	697	30
	Bi	65	19.1	16.5	418	22.4	138	1.3	39	20.2	11	88	15.2	379	22.6	127	3.2	4.3	1020	26
	Total			19.6			164	1.5			13	130	18.1			151			1717	
50	Sc.P	70	17.9	3.1	68	24.0	26	0.2	4	21.7	1	25	2.9	64	24.1	25	0.6	0.7	828	31
	Bi	70	19.6	16.6	379	23.6	142	1.2	32	21.3	10	80	15.4	347	23.8	132	2.8	4.2	1053	23
	Total			19.7			168	1.3			11	105	18.3			157			1881	
55	Sc.P	75	18.3	3.1	64	24.9	27	3.1	64	24.9	27	924	0.0	0	0.0	0	0.4	0.6	0	19
	Bi	75	20.0	16.6	347	24.7	144	16.6	347	24.7	144	1152	0.0	0	0.0	0	2.5	4.0	0	20
	Total			19.7			171	19.7			171	2076	0.0			0			0	

Appendix: 9.9
Petrea 12c (Opt. PNV).

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Stand ---- Age	Basal area
1 -Scots pine	20	2.4
2 -Birch	20	14.7

year	Spe-cies	Age	Dom. Ht.	before thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	Stum-page value	after thinning Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	20	8.2	2.4	450	8.2	10	0.6	155	6.7	2	0	1.8	295	8.9	8	0.0	0.5	0	0
	Bi	20	10.2	14.7	2790	8.2	74	4.0	966	7.3	20	0	10.7	1824	8.6	54	0.0	3.7	0	0
	Total			17.1			84	4.6			22	0	12.5			62			0	
5	Sc.P	25	9.8	2.4	295	10.2	12	0.4	72	8.4	2	0	2.0	223	10.8	10	0.8	0.6	0	0
	Bi	25	11.8	14.7	1824	10.1	83	3.0	432	9.4	17	0	11.7	1392	10.3	66	5.9	4.1	0	0
	Total			17.1			96	3.4			19	0	13.7			77			0	
10	Sc.P	30	11.1	2.6	223	12.1	15	0.4	51	9.9	2	0	2.2	172	12.7	13	0.8	0.6	0	0
	Bi	30	13.1	15.2	1392	11.8	94	2.7	304	10.6	17	0	12.5	1088	12.1	77	5.6	4.4	617	123
	Total			17.8			109	3.1			19	0	14.7			90			617	

15	Sc.P	35	12.4	2.6	172	14.0	17	0.0	0	0.0	0	0	2.6	172	14.0	17	0.8	0.6	0	0
	Bi	35	14.3	15.6	1088	13.5	103	7.8	544	13.5	52	416	7.8	544	13.5	51	5.3	4.5	412	42
	Total			18.2			120	7.8			52	416	10.4			68			412	
20	Sc.P	40	13.5	3.2	172	15.5	23	0.0	0	0.0	0	0	3.2	172	15.5	23	1.2	0.7	0	0
	Bi	40	15.3	9.7	544	15.1	69	0.0	0	0.0	0	0	9.7	544	15.1	69	3.5	4.4	552	28
	Total			13.0			92	0.0			0	0	13.0			92			552	
25	Sc.P	45	14.5	3.8	172	16.8	28	0.0	0	0.0	0	0	3.8	172	16.8	28	1.0	0.8	302	60
	Bi	45	16.3	11.7	544	16.5	87	5.9	273	16.5	43	344	5.8	271	16.5	44	3.5	4.3	350	28
	Total			15.5			115	5.9			43	344	9.6			72			652	
30	Sc.P	50	15.3	4.5	172	18.2	35	0.0	0	0.0	0	0	4.5	172	18.2	35	1.5	0.8	515	43
	Bi	50	17.1	7.0	271	18.1	54	0.0	0	0.0	0	0	7.0	271	18.1	54	2.0	4.1	429	16
	Total			11.5			89	0.0			0	0	11.5			89			944	
35	Sc.P	55	16.1	5.1	172	19.5	41	0.0	0	0.0	0	0	5.1	172	19.5	41	1.3	0.9	743	46
	Bi	55	17.8	8.1	271	19.5	64	8.1	271	19.5	64	512	0.0	0	0.0	0	2.1	3.9	0	17
	Total			13.3			106	8.1			64	512	5.1			42			743	
40	Sc.P	60	16.7	6.1	172	21.3	54	0.0	0	0.0	0	0	6.1	172	21.3	54	2.5	1.0	1270	105
	Total			6.1			54	0.0			0	0	6.1			54			1270	
45	Sc.P	65	17.3	7.0	172	22.8	63	0.0	0	0.0	0	0	7.0	172	22.8	63	1.8	1.1	1815	109
	Total			7.0			63	0.0			0	0	7.0			63			1815	
50	Sc.P	70	17.9	7.9	172	24.2	72	0.0	0	0.0	0	0	7.9	172	24.2	72	1.8	1.1	2386	114
	Total			7.9			72	0.0			0	0	7.9			72			2386	
55	Sc.P	75	18.3	8.7	172	25.4	80	8.7	172	25.4	80	2814	0.0	0	0.0	0	1.6	1.1	0	85
	Total			8.7			80	8.7			80	2814	0.0			0			0	

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Appendix: 9.9
Petrea 12e.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age	Stand ---- Basal area
1 -Scots pine	20	11.7
2 -Birch	20	5.5

year	Spe-cies	Age	Dom. Ht.	before thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	Stum-page value	after thinning Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	20	8.2	11.7	1688	9.4	51	3.0	645	7.7	13	0	8.7	1043	10.3	38	0.0	2.5	0	0
	Bi	20	10.2	5.5	788	9.4	28	1.8	297	8.8	9	0	3.7	491	9.8	19	0.0	1.4	0	0
	Total			17.2			79	4.8			22	0	12.4			57			0	
5	Sc.P	25	9.8	11.5	1043	11.8	59	1.7	226	9.7	9	0	9.8	817	12.3	50	4.2	2.9	0	0
	Bi	25	11.8	5.1	491	11.5	29	1.0	117	10.4	6	0	4.1	374	11.8	23	2.0	1.5	0	0
	Total			16.5			87	2.7			15	0	13.9			72			0	
10	Sc.P	30	11.1	12.3	817	13.9	71	1.6	160	11.3	9	0	10.7	657	14.4	62	4.3	3.1	0	0
	Bi	30	13.1	5.3	374	13.4	33	0.9	83	12.0	6	0	4.3	291	13.8	27	2.0	1.6	214	43
	Total			17.6			104	2.5			15	0	15.1			89			214	

15	Sc.P	35	12.4	13.0	657	15.9	83	1.5	113	13.0	10	0	11.5	544	16.4	73	4.1	3.3	722	144
	Bi	35	14.3	5.4	291	15.3	36	0.9	59	13.7	6	48	4.5	232	15.7	30	1.8	1.6	239	15
	Total			18.4			119	2.4			16	48	16.1			103			962	
20	Sc.P	40	13.5	13.6	544	17.9	93	1.4	80	14.9	10	0	12.2	464	18.3	83	4.0	3.4	1233	102
	Bi	40	15.3	5.4	232	17.2	38	0.8	42	15.4	6	48	4.6	190	17.6	32	1.7	1.6	259	13
	Total			19.0			131	2.2			16	48	16.9			115			1492	
25	Sc.P	45	14.5	14.1	464	19.7	102	1.3	57	16.8	9	99	12.9	407	20.1	93	3.8	3.4	1803	134
	Bi	45	16.3	5.4	190	19.0	40	0.7	31	17.0	5	40	4.7	159	19.4	35	1.5	1.6	280	12
	Total			19.5			142	2.0			14	139	17.5			128			2083	
30	Sc.P	50	15.3	14.6	407	21.3	110	1.2	43	18.6	9	141	13.4	364	21.6	101	3.3	3.4	2494	166
	Bi	50	17.1	5.3	159	20.7	41	0.6	23	18.6	5	40	4.7	136	21.0	36	1.3	1.6	291	10
	Total			19.9			151	1.8			14	181	18.1			137			2785	
35	Sc.P	55	16.1	14.9	364	22.8	117	1.1	32	20.4	8	163	13.8	332	23.0	109	3.2	3.4	3211	176
	Bi	55	17.8	5.3	136	22.2	42	0.6	18	20.0	5	40	4.7	118	22.5	37	1.1	1.5	297	9
	Total			20.2			159	1.6			13	203	18.6			146			3508	
40	Sc.P	60	16.7	15.2	332	24.2	123	1.0	25	21.9	8	205	14.2	307	24.3	115	2.8	3.3	3828	164
	Bi	60	18.5	5.2	118	23.7	43	0.5	14	21.4	4	32	4.7	104	24.0	39	1.1	1.5	309	9
	Total			20.4			166	1.5			12	237	18.9			154			4137	
45	Sc.P	65	17.3	15.5	307	25.3	128	0.9	20	23.3	7	213	14.6	287	25.4	121	2.7	3.3	4273	132
	Bi	65	19.1	5.1	104	25.1	43	0.5	11	22.8	4	32	4.7	93	25.3	39	0.8	1.5	311	7
	Total			20.6			171	1.3			11	245	19.3			160			4584	
50	Sc.P	70	17.9	15.7	287	26.4	133	0.8	17	24.6	7	236	14.9	270	26.5	126	2.3	3.2	4658	124
	Bi	70	19.6	5.1	93	26.3	43	0.4	9	23.9	4	32	4.6	84	26.5	39	0.9	1.4	313	7
	Total			20.7			176	1.2			11	268	19.5			165			4971	
55	Sc.P	75	18.3	15.9	270	27.3	136	15.9	270	27.3	136	5217	0.0	0	0.0	0	2.0	3.1	0	112
	Bi	75	20.0	5.0	84	27.4	43	5.0	84	27.4	43	344	0.0	0	0.0	0	0.8	1.4	0	6
	Total			20.8			179	20.8			179	5561	0.0			0			0	

Appendix: 9.10
Gortel 8d.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Stand --- Age	Basal area
1 -Scots pine	20	14.3

year	Spe- cies	Age	Dom. Ht.	before thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	Stum- page value	after thinning Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum- page value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	20	7.5	14.3	2586	8.4	58	2.1	571	6.9	9	0	12.2	2015	8.8	49	0.0	2.9	0	0
	Total			14.3			58	2.1			9	0	12.2			49			0	
5	Sc.P	25	9.0	15.9	2015	10.0	75	2.6	489	8.2	12	0	13.3	1526	10.5	63	5.2	3.4	0	0
	Total			15.9			75	2.6			12	0	13.3			63			0	
10	Sc.P	30	10.2	16.6	1526	11.8	89	2.4	328	9.7	13	0	14.2	1198	12.3	76	5.2	3.7	0	0
	Total			16.6			89	2.4			13	0	14.2			76			0	
15	Sc.P	35	11.4	17.2	1198	13.5	100	2.2	232	11.0	13	0	15.0	966	14.0	87	4.8	3.8	0	0
	Total			17.2			100	2.2			13	0	15.0			87			0	
20	Sc.P	40	12.4	17.6	966	15.2	111	2.0	165	12.4	13	0	15.6	801	15.7	98	4.8	4.0	0	0
	Total			17.6			111	2.0			13	0	15.6			98			0	

25	Sc.P 45	13.3	18.0	801	16.9	120	1.8	120	13.9	12	0	16.1	681	17.4	108	4.4	4.0	1334	267
	Total		18.0			120	1.8			12	0	16.1			108			1334	
30	Sc.P 50	14.1	18.2	681	18.5	127	1.6	87	15.5	11	0	16.6	594	18.9	116	3.8	4.0	1881	109
	Total		18.2			127	1.6			11	0	16.6			116			1881	
35	Sc.P 55	14.8	18.4	594	19.9	134	1.5	64	17.0	11	126	17.0	530	20.2	123	3.6	3.9	2438	137
	Total		18.4			134	1.5			11	126	17.0			123			2438	
40	Sc.P 60	15.4	18.6	530	21.1	139	1.3	49	18.4	10	151	17.3	481	21.4	129	3.2	3.9	3085	159
	Total		18.6			139	1.3			10	151	17.3			129			3085	
45	Sc.P 65	15.9	18.7	481	22.3	144	1.2	38	19.7	9	166	17.6	443	22.5	135	3.0	3.8	3721	160
	Total		18.7			144	1.2			9	166	17.6			135			3721	
50	Sc.P 70	16.4	18.8	443	23.3	148	1.1	31	20.8	8	177	17.8	412	23.4	140	2.6	3.7	4327	157
	Total		18.8			148	1.1			8	177	17.8			140			4327	
55	Sc.P 75	16.8	18.9	412	24.2	151	18.9	412	24.2	151	4999	0.0	0	0.0	0	2.2	3.6	0	135
	Total		18.9			151	18.9			151	4999	0.0			0			0	

Appendix: 9.10
Gortel 80a.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age (Stand)	Basal area (Stand)
1 -Scots pine	25	0.8
2 -Birch	25	5.2
3 -Oak	25	1.0
4 -Beech	25	0.5

year	Species	Age	Dom. Ht.	before thinning: Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning: Basal Area	Number of trees	Mean Diam.	Timber Volume	Stumpage value	after thinning: Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stumpage value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	25	8.9	0.8	333	5.5	4	0.0	0	0.0	0	0	0.8	333	5.5	4	0.0	0.2	0	0
	Bi	25	10.5	5.2	1308	7.1	26	0.0	0	0.0	0	0	5.2	1308	7.1	26	0.0	1.1	0	0
	Oak	25	7.4	1.0	303	6.5	4	0.0	0	0.0	0	0	1.0	303	6.5	4	0.0	0.1	0	0
	Be	25	7.5	0.5	92	8.3	1	0.0	0	0.0	0	0	0.5	92	8.3	1	0.0	0.0	0	0
	Total			7.5			35	0.0			0	0	7.5			35			0	
5	Sc.P	30	10.2	1.1	333	6.4	6	0.0	4	4.9	0	0	1.1	329	6.4	6	0.4	0.2	0	0
	Bi	30	11.7	7.2	1308	8.4	40	0.0	8	7.5	0	0	7.1	1300	8.4	40	2.7	1.3	0	0
	Oak	30	8.6	1.3	303	7.5	6	0.0	3	5.9	0	0	1.3	300	7.5	6	0.4	0.2	0	0
	Be	30	8.9	0.7	92	9.7	2	0.0	0	0.0	0	0	0.7	92	9.7	2	0.1	0.1	0	0
	Total			10.3			53	0.1			0	0	10.2			53			0	
10	Sc.P	35	11.3	1.3	329	7.1	8	0.1	64	5.4	1	0	1.2	265	7.5	7	0.4	0.2	0	0
	Bi	35	12.7	9.1	1300	9.5	55	0.7	105	8.9	4	0	8.5	1195	9.5	51	3.0	1.6	0	0
	Oak	35	9.6	1.7	300	8.5	8	0.2	47	6.6	1	0	1.5	253	8.8	7	0.5	0.2	0	0
	Be	35	10.1	0.9	92	10.9	3	0.1	10	8.8	0	0	0.8	82	11.1	3	0.2	0.1	0	0
	Total			13.0			73	1.0			6	0	12.0			67			0	

15	Sc.P	40	12.3	1.4	265	8.2	9	0.2	65	6.2	1	0	1.2	200	8.7	8	0.4	0.2	0	0
	Bi	40	13.7	10.4	1195	10.5	66	0.9	121	9.7	6	0	9.5	1074	10.6	60	3.1	1.8	0	0
	Oak	40	10.7	1.9	253	9.7	9	0.2	47	7.7	1	0	1.6	206	10.0	8	0.5	0.3	0	0
	Be	40	11.3	1.0	82	12.2	4	0.1	11	10.0	0	0	0.9	71	12.4	4	0.2	0.1	29	6
	Total			14.6			88	1.4			8	0	13.2			80			29	
20	Sc.P	45	13.2	1.4	200	9.4	9	0.2	49	7.2	1	0	1.2	151	10.0	8	0.3	0.3	0	0
	Bi	45	14.5	11.2	1074	11.5	75	0.9	107	10.4	6	0	10.3	967	11.6	69	3.0	1.9	0	0
	Oak	45	11.6	1.9	206	10.9	11	0.2	36	8.9	1	0	1.7	170	11.3	10	0.4	0.3	0	0
	Be	45	12.3	1.0	71	13.5	4	0.1	9	11.3	0	0	0.9	62	13.8	4	0.1	0.1	34	1
	Total			15.6			99	1.4			8	0	14.1			91			34	
25	Sc.P	50	14.0	1.4	151	10.7	10	0.2	35	8.1	1	0	1.2	116	11.4	9	0.2	0.3	0	0
	Bi	50	15.2	11.9	967	12.5	82	0.9	90	11.2	6	0	11.0	877	12.6	76	2.7	2.0	612	122
	Oak	50	12.5	2.0	170	12.2	11	0.2	26	10.0	1	0	1.8	144	12.5	10	0.4	0.3	84	17
	Be	50	13.3	1.1	62	14.7	5	0.1	7	12.5	0	0	1.0	55	15.0	5	0.1	0.1	39	1
	Total			16.3			108	1.4			8	0	14.9			100			735	
30	Sc.P	55	14.7	1.3	116	12.0	10	0.2	26	9.1	1	0	1.1	90	12.7	9	0.2	0.2	0	0
	Bi	55	15.9	12.4	877	13.4	89	0.8	73	12.0	6	0	11.6	804	13.6	83	2.6	2.0	666	11
	Oak	55	13.3	2.0	144	13.4	12	0.2	20	11.2	1	0	1.8	124	13.7	11	0.4	0.3	91	1
	Be	55	14.1	1.1	55	15.9	6	0.1	5	13.6	0	0	1.0	50	16.0	6	0.1	0.1	44	1
	Total			16.9			117	1.3			8	0	15.6			109			801	
35	Sc.P	60	15.3	1.3	90	13.4	9	0.2	19	10.1	1	0	1.1	71	14.1	8	0.2	0.2	0	0
	Bi	60	16.5	12.9	804	14.3	95	0.8	60	12.7	6	48	12.2	744	14.4	89	2.4	2.1	715	19
	Oak	60	14.1	2.1	124	14.5	13	0.2	15	12.3	1	8	1.9	109	14.8	12	0.4	0.3	97	3
	Be	60	14.9	1.1	50	16.8	6	0.1	4	14.6	0	0	1.0	46	17.0	6	0.1	0.1	49	1
	Total			17.4			124	1.2			8	56	16.2			116			860	
40	Sc.P	65	15.8	1.2	71	14.7	9	0.1	14	11.1	1	0	1.1	57	15.4	8	0.2	0.2	0	0
	Bi	65	17.0	13.3	744	15.1	101	0.7	49	13.4	5	40	12.6	695	15.2	96	2.3	2.1	765	18
	Oak	65	14.8	2.1	109	15.6	14	0.2	11	13.4	1	8	1.9	98	15.8	13	0.3	0.3	103	3
	Be	65	15.6	1.1	46	17.7	7	0.1	3	15.5	0	0	1.1	43	17.8	7	0.1	0.1	53	1
	Total			17.8			130	1.1			7	48	16.7			123			921	
45	Sc.P	70	16.3	1.1	57	16.0	9	0.1	11	12.1	1	0	1.0	46	16.8	8	0.2	0.2	87	17
	Bi	70	17.5	13.7	695	15.8	105	0.7	43	14.1	5	40	13.0	652	15.9	100	1.9	2.1	801	15
	Oak	70	15.4	2.1	98	16.6	15	0.2	9	14.4	1	8	2.0	89	16.7	14	0.3	0.3	108	3
	Be	70	16.2	1.2	43	18.5	7	0.1	3	16.3	0	0	1.1	40	18.6	7	0.1	0.1	56	1
	Total			18.1			136	1.0			7	48	17.1			129			1052	
50	Sc.P	75	16.8	1.1	46	17.3	9	1.1	46	17.3	9	110	0.0	0	0.0	0	0.2	0.2	0	5
	Bi	75	17.9	14.0	652	16.5	109	14.0	652	16.5	109	872	0.0	0	0.0	0	1.8	2.0	0	14
	Oak	75	16.1	2.1	89	17.5	15	0.0	0	0.0	0	0	2.1	89	17.5	15	0.3	0.3	121	3
	Be	75	16.7	1.2	40	19.2	7	0.0	0	0.0	0	0	1.2	40	19.2	7	0.1	0.1	60	1
	Total			18.4			140	15.1			118	982	3.3			23			181	

55	Oak	80	16.6	2.6	89	19.3	19	0.0	0	0.0	0	0	2.6	89	19.3	19	0.7	0.3	172	10
	Be	80	17.2	1.3	40	20.5	10	0.0	0	0.0	0	0	1.3	40	20.5	10	0.6	0.1	84	5
	Total			3.9			29	0.0			0	0	3.9			29			255	
60	Oak	85	17.2	3.1	89	20.9	22	0.0	0	0.0	0	0	3.1	89	20.9	22	0.7	0.4	243	14
	Be	85	17.7	1.5	40	21.6	12	0.0	0	0.0	0	0	1.5	40	21.6	12	0.3	0.1	96	2
	Total			4.5			34	0.0			0	0	4.5			34			339	
65	Oak	90	17.7	3.5	89	22.4	27	0.0	0	0.0	0	0	3.5	89	22.4	27	0.9	0.4	349	21
	Be	90	18.0	1.6	40	22.6	13	0.0	0	0.0	0	0	1.6	40	22.6	13	0.3	0.1	108	2
	Total			5.1			40	0.0			0	0	5.1			40			457	
70	Oak	95	18.2	4.0	89	23.9	31	0.0	0	0.0	0	0	4.0	89	23.9	31	0.8	0.4	507	32
	Be	95	18.4	1.7	40	23.5	15	0.0	0	0.0	0	0	1.7	40	23.5	15	0.2	0.2	116	2
	Total			5.7			45	0.0			0	0	5.7			45			623	
75	Oak	100	18.6	4.5	89	25.2	35	0.0	0	0.0	0	0	4.5	89	25.2	35	0.8	0.4	686	36
	Be	100	18.7	1.8	40	24.2	16	0.0	0	0.0	0	0	1.8	40	24.2	16	0.3	0.2	126	2
	Total			6.3			50	0.0			0	0	6.3			50			813	
80	Oak	105	19.0	4.9	89	26.5	39	0.0	0	0.0	0	0	4.9	89	26.5	39	0.8	0.4	892	41
	Be	105	19.0	1.9	40	24.9	17	0.0	0	0.0	0	0	1.9	40	24.9	17	0.2	0.2	134	1
	Total			6.9			55	0.0			0	0	6.9			55			1025	
85	Oak	110	19.4	5.4	89	27.7	43	0.0	0	0.0	0	0	5.4	89	27.7	43	0.8	0.5	1126	47
	Be	110	19.2	2.0	40	25.4	18	0.0	0	0.0	0	0	2.0	40	25.4	18	0.2	0.2	143	2
	Total			7.4			61	0.0			0	0	7.4			61			1269	
90	Oak	115	19.8	5.8	89	28.8	47	0.0	0	0.0	0	0	5.8	89	28.8	47	0.8	0.5	1380	51
	Be	115	19.4	2.1	40	25.9	19	0.0	0	0.0	0	0	2.1	40	25.9	19	0.2	0.2	149	1
	Total			7.9			66	0.0			0	0	7.9			66			1529	
95	Oak	120	20.1	6.2	89	29.9	51	6.2	89	29.9	51	1645	0.0	0	0.0	0	0.8	0.5	0	53
	Be	120	19.6	2.2	40	26.3	19	2.2	40	26.3	19	152	0.0	0	0.0	0	0.2	0.2	0	1
	Total			8.4			71	8.4			70	1797	0.0			1			0	

Appendix: 9.10
Uddel 26a.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age	Stand Basal area
1 -Scots pine	25	6.9

year	Species	Age	Dom. Ht.	before thinning Basal Area	before thinning Number of trees	before thinning Mean Diam.	before thinning Timber Volume	thinning Basal Area	thinning Number of trees	thinning Mean Diam.	thinning Timber Volume	thinning Stumpage value	after thinning Basal Area	after thinning Number of trees	after thinning Mean Diam.	after thinning Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stumpage value	Current Value Incr.	Mean Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year	Dfl/year
0	Sc.P	25	8.9	6.9	722	11.0	35	0.0	0	0.0	0	0	6.9	722	11.0	35	0.0	1.4	0	0	0
	Total			6.9			35	0.0			0	0	6.9			35			0		
5	Sc.P	30	10.2	9.3	722	12.8	51	0.0	0	0.0	0	0	9.3	722	12.8	51	3.2	1.7	0	0	0
	Total			9.3			51	0.0			0	0	9.3			51			0		
10	Sc.P	35	11.3	11.7	722	14.4	70	0.0	0	0.0	0	0	11.7	722	14.4	70	3.8	2.0	0	0	0
	Total			11.7			70	0.0			0	0	11.7			70			0		
15	Sc.P	40	12.3	14.0	722	15.7	89	0.0	0	0.0	0	0	14.0	722	15.7	89	3.8	2.2	0	0	0
	Total			14.0			89	0.0			0	0	14.0			89			0		
20	Sc.P	45	13.2	16.2	722	16.9	109	1.2	80	13.9	8	0	15.0	642	17.3	101	4.0	2.4	1220	244	27
	Total			16.2			109	1.2			8	0	15.0			101			1220		

25	Sc.P 50	14.0	17.0	642	18.4	119	1.6	85	15.4	11	0	15.4	557	18.8	108	3.6	2.5	1733	103	35
	Total		17.0			119	1.6			11	0	15.4			108			1733		
30	Sc.P 55	14.7	17.2	557	19.8	125	1.4	63	17.0	10	114	15.8	494	20.2	115	3.4	2.6	2276	131	43
	Total		17.2			125	1.4			10	114	15.8			115			2276		
35	Sc.P 60	15.3	17.4	494	21.2	130	1.3	48	18.4	10	152	16.1	446	21.4	120	3.0	2.7	2888	153	53
	Total		17.4			130	1.3			10	152	16.1			120			2888		
40	Sc.P 65	15.8	17.5	446	22.3	134	1.1	37	19.8	9	168	16.3	409	22.6	125	2.8	2.7	3487	153	60
	Total		17.5			134	1.1			9	168	16.3			125			3487		
45	Sc.P 70	16.3	17.6	409	23.4	138	1.0	29	21.0	8	181	16.6	380	23.6	130	2.6	2.7	4068	152	67
	Total		17.6			138	1.0			8	181	16.6			130			4068		
50	Sc.P 75	16.8	17.7	380	24.3	141	17.7	380	24.3	141	4701	0.0	0	0.0	0	2.2	2.6	0	127	71
	Total		17.7			141	17.7			141	4701	0.0			0			0		

Appendix: 9.10
Uddel 52n.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age (Stand)	Basal area (Stand)
1 -Scots pine	25	1.0
2 -Birch	25	3.6
3 -Oak	10	0.3
4 -Beech	15	0.5

				before thinning				thinning					after thinning							
year	Spe-cies	Age	Dom. Ht.	Basal Area	Number of trees	Mean Diam.	Timber Volume	Basal Area	Number of trees	Mean Diam.	Timber Volume	Stum-page value	Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year
0	Sc.P	25	8.9	1.0	245	7.2	5	0.0	4	5.7	0	0	1.0	241	7.2	5	0.0	0.2	0	0
	Bi	25	11.1	3.6	800	7.6	19	0.0	10	6.7	0	0	3.6	790	7.6	19	0.0	0.8	0	0
	Oak	10	3.4	0.3	374	3.2	1	0.0	28	1.6	0	0	0.3	346	3.3	1	0.0	0.1	0	0
	Be	15	4.2	0.5	143	6.7	0	0.0	2	5.1	0	0	0.5	141	6.7	0	0.0	0.0	0	0
	Total			5.4			26	0.1			0	0	5.4			26			0	
5	Sc.P	30	10.2	1.4	241	8.5	8	0.0	1	7.0	0	0	1.4	240	8.5	8	0.5	0.3	0	0
	Bi	30	12.4	5.3	790	9.2	31	0.0	3	8.7	0	0	5.3	787	9.2	31	2.4	1.0	0	0
	Oak	15	4.9	0.5	346	4.2	1	0.0	6	2.7	0	0	0.5	340	4.2	1	0.1	0.1	0	0
	Be	20	5.7	0.8	141	8.4	1	0.0	0	0.0	0	0	0.8	141	8.4	1	0.1	0.1	0	0
	Total			7.9			41	0.0			0	0	7.9			41			0	

10	Sc.P	35	11.3	1.8	240	9.7	11	0.1	14	7.9	0	0	1.7	226	9.7	11	0.6	0.3	0	0
	Bi	35	13.5	7.0	787	10.6	45	0.2	32	9.8	2	0	6.8	755	10.7	43	2.6	1.3	0	0
	Oak	20	6.3	0.7	340	5.1	2	0.0	33	3.8	0	0	0.6	307	5.2	2	0.2	0.1	0	0
	Be	25	7.1	1.1	141	9.9	2	0.0	6	7.9	0	0	1.1	135	10.0	2	0.2	0.1	0	0
	Total			10.5			60	0.4			2	0	10.1			58			0	
15	Sc.P	40	12.3	2.0	226	10.7	13	0.1	21	8.9	1	0	1.9	205	10.9	12	0.5	0.3	0	0
	Bi	40	14.5	8.4	755	11.9	56	0.5	50	10.7	3	0	8.0	705	12.0	53	2.8	1.5	428	86
	Oak	25	7.5	0.9	307	5.9	3	0.1	44	4.6	0	0	0.8	263	6.1	3	0.2	0.1	0	0
	Be	30	8.4	1.4	135	11.4	3	0.1	9	9.3	0	0	1.3	126	11.5	3	0.2	0.1	0	0
	Total			12.7			76	0.7			4	0	12.0			72			428	
20	Sc.P	45	13.2	2.2	205	11.8	15	0.2	20	9.7	1	0	2.1	185	12.0	14	0.6	0.4	0	0
	Bi	45	15.4	9.6	705	13.2	68	0.5	50	11.7	4	0	9.0	655	13.3	64	2.9	1.6	510	17
	Oak	30	8.7	1.0	263	6.9	4	0.1	38	5.3	0	0	0.9	225	7.1	4	0.2	0.1	0	0
	Be	35	9.6	1.6	126	12.8	5	0.1	8	10.6	0	0	1.5	118	12.9	5	0.3	0.1	39	8
	Total			14.4			92	0.9			5	0	13.6			87			549	
25	Sc.P	50	14.0	2.4	185	12.8	17	0.2	18	10.5	1	0	2.2	167	13.0	16	0.5	0.4	0	0
	Bi	50	16.2	10.5	655	14.3	77	0.6	45	12.7	4	32	9.9	610	14.4	73	2.7	1.7	585	21
	Oak	35	9.8	1.1	225	7.8	5	0.1	31	6.1	0	0	1.0	194	8.0	5	0.2	0.1	0	0
	Be	40	10.7	1.8	118	14.1	6	0.1	7	11.9	0	0	1.7	111	14.2	6	0.3	0.2	50	2
	Total			15.8			105	0.9			5	32	14.9			100			635	
30	Sc.P	55	14.7	2.5	167	13.8	18	0.2	16	11.2	1	0	2.3	151	14.0	17	0.5	0.4	0	0
	Bi	55	16.9	11.3	610	15.4	85	0.6	40	13.7	5	40	10.7	570	15.5	80	2.4	1.8	642	19
	Oak	40	10.8	1.2	194	8.7	6	0.1	25	6.9	0	0	1.1	169	9.0	6	0.2	0.1	0	0
	Be	45	11.6	2.0	111	15.2	8	0.1	6	13.0	0	0	1.9	105	15.3	8	0.3	0.2	62	2
	Total			17.0			117	0.9			6	40	16.0			111			704	
35	Sc.P	60	15.3	2.6	151	14.7	19	0.2	15	12.0	1	0	2.4	136	14.9	18	0.4	0.4	0	0
	Bi	60	17.5	11.9	570	16.3	93	0.6	38	14.5	5	40	11.3	532	16.4	88	2.5	1.8	701	20
	Oak	45	11.8	1.2	169	9.6	7	0.1	22	7.7	1	0	1.1	147	9.9	6	0.2	0.2	0	0
	Be	50	12.5	2.2	105	16.3	9	0.1	6	14.1	0	0	2.1	99	16.4	9	0.3	0.2	74	2
	Total			17.9			128	1.0			7	40	16.9			121			776	
40	Sc.P	65	15.8	2.6	136	15.5	20	0.2	13	12.7	1	0	2.4	123	15.8	19	0.3	0.4	0	0
	Bi	65	18.0	12.4	532	17.2	99	0.6	34	15.4	5	40	11.8	498	17.4	94	2.2	1.9	750	18
	Oak	50	12.7	1.3	147	10.5	7	0.1	18	8.5	1	0	1.2	129	10.8	6	0.3	0.2	0	0
	Be	55	13.3	2.3	99	17.3	11	0.1	5	15.1	0	0	2.2	94	17.4	11	0.3	0.2	86	2
	Total			18.6			137	1.0			7	40	17.6			130			836	

45	Sc.P	70	16.3	2.6	123	16.4	20	0.2	12	13.4	1	0	2.4	111	16.6	19	0.3	0.4	200	40
	Bi	70	18.5	12.8	498	18.1	104	0.7	32	16.1	5	40	12.1	466	18.2	99	1.9	1.9	788	16
	Oak	55	13.5	1.3	129	11.4	8	0.1	15	9.3	1	0	1.2	114	11.6	7	0.3	0.2	0	0
	Be	60	14.1	2.4	94	18.2	12	0.1	5	16.0	1	8	2.3	89	18.3	11	0.3	0.2	89	2
	Total			19.1			144	1.0			8	48	18.1			136			1078	
50	Sc.P	75	16.8	2.6	111	17.2	20	2.6	111	17.2	20	236	0.0	0	0.0	0	0.2	0.4	0	7
	Bi	75	19.0	13.0	466	18.9	107	13.0	466	18.9	107	856	0.0	0	0.0	0	1.7	1.9	0	14
	Oak	60	14.3	1.3	114	12.3	9	0.0	0	0.0	0	0	1.3	114	12.3	9	0.3	0.2	70	14
	Be	65	14.7	2.5	89	19.1	13	0.0	0	0.0	0	0	2.5	89	19.1	13	0.5	0.2	108	4
	Total			19.5			149	15.6			127	1092	3.9			22			177	
55	Oak	65	15.0	1.7	114	13.7	11	0.0	0	0.0	0	0	1.7	114	13.7	11	0.5	0.2	90	4
	Be	70	15.3	2.9	89	20.5	20	0.0	0	0.0	0	0	2.9	89	20.5	20	1.3	0.3	158	10
	Total			4.6			31	0.0			0	0	4.6			31			248	
60	Oak	70	15.7	2.0	114	15.1	14	0.0	0	0.0	0	0	2.0	114	15.1	14	0.6	0.2	112	4
	Be	75	15.8	3.3	89	21.8	23	0.0	0	0.0	0	0	3.3	89	21.8	23	0.6	0.3	184	5
	Total			5.4			37	0.0			0	0	5.4			37			296	
65	Oak	75	16.3	2.4	114	16.4	17	0.0	0	0.0	0	0	2.4	114	16.4	17	0.6	0.3	136	5
	Be	80	16.2	3.7	89	22.9	26	0.0	0	0.0	0	0	3.7	89	22.9	26	0.6	0.3	208	5
	Total			6.1			43	0.0			0	0	6.1			43			344	
70	Oak	80	16.9	2.8	114	17.6	20	0.0	0	0.0	0	0	2.8	114	17.6	20	0.7	0.3	164	6
	Be	85	16.7	4.0	89	23.9	29	0.0	0	0.0	0	0	4.0	89	23.9	29	0.6	0.4	232	5
	Total			6.8			49	0.0			0	0	6.8			49			395	
75	Oak	85	17.5	3.1	114	18.8	24	0.0	0	0.0	0	0	3.1	114	18.8	24	0.6	0.3	207	9
	Be	90	17.0	4.3	89	24.8	31	0.0	0	0.0	0	0	4.3	89	24.8	31	0.4	0.4	249	4
	Total			7.4			55	0.0			0	0	7.4			55			457	
80	Oak	90	18.0	3.5	114	19.9	27	0.0	0	0.0	0	0	3.5	114	19.9	27	0.7	0.3	267	12
	Be	95	17.3	4.6	89	25.5	34	0.0	0	0.0	0	0	4.6	89	25.5	34	0.5	0.4	270	4
	Total			8.1			61	0.0			0	0	8.1			61			537	
85	Oak	95	18.5	3.9	114	20.9	31	0.0	0	0.0	0	0	3.9	114	20.9	31	0.7	0.4	333	13
	Be	100	17.6	4.8	89	26.2	36	0.0	0	0.0	0	0	4.8	89	26.2	36	0.5	0.4	291	4
	Total			8.7			67	0.0			0	0	8.7			67			623	

90	Oak	100	18.9	4.3	114	21.9	34	0.0	0	0.0	0	0	4.3	114	21.9	34	0.7	0.4	405	14
	Be	105	17.9	5.0	89	26.8	38	0.0	0	0.0	0	0	5.0	89	26.8	38	0.4	0.4	306	3
	Total			9.3			72	0.0			0	0	9.3			72			711	
95	Oak	105	19.3	4.7	114	22.8	37	0.0	0	0.0	0	0	4.7	114	22.8	37	0.6	0.4	519	23
	Be	110	18.1	5.2	89	27.3	40	0.0	0	0.0	0	0	5.2	89	27.3	40	0.4	0.4	321	3
	Total			9.8			77	0.0			0	0	9.8			77			840	
100	Oak	110	19.7	5.0	114	23.7	41	0.0	0	0.0	0	0	5.0	114	23.7	41	0.7	0.4	657	28
	Be	115	18.3	5.4	89	27.7	42	0.0	0	0.0	0	0	5.4	89	27.7	42	0.4	0.4	335	3
	Total			10.4			83	0.0			0	0	10.4			83			992	
105	Oak	115	20.1	5.4	114	24.5	44	0.0	0	0.0	0	0	5.4	114	24.5	44	0.7	0.4	798	28
	Be	120	18.5	5.5	89	28.1	44	5.5	89	28.1	44	352	0.0	0	0.0	0	0.4	0.4	0	3
	Total			10.9			88	5.5			44	352	5.4			44			798	
110	Oak	120	20.4	5.9	114	25.6	49	5.9	114	25.6	49	1010	0.0	0	0.0	0	0.9	0.4	0	42
	Total			5.9			49	5.9			49	1010	0.0			0			0	

Appendix: 9.10
Uddel 52n (Opt. PNV).

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Stand --- Age	Basal area
1 -Scots pine	25	1.0
2 -Birch	25	3.6
3 -Oak	10	0.3
4 -Beech	15	0.5

year	Spe-cies	Age	Dom. Ht.	before thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	thinning Basal Area	Number of trees	Mean Diam.	Timber Volume	Stum-page value	after thinning Basal Area	Number of trees	Mean Diam.	Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.	Mean Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year	Dfl/year
0	Sc.P	25	8.9	1.0	245	7.2	5	0.1	29	5.5	0	0	0.9	216	7.4	5	0.0	0.2	0	0	0
	Bi	25	11.1	3.6	800	7.6	19	0.2	57	6.7	1	0	3.4	743	7.7	18	0.0	0.8	0	0	0
	Oak	10	3.4	0.3	374	3.2	1	0.0	105	1.6	0	0	0.3	269	3.6	1	0.0	0.1	0	0	0
	Be	15	4.2	0.5	143	6.7	0	0.0	14	5.1	0	0	0.5	129	6.8	0	0.0	0.0	0	0	0
	Total			5.4			26	0.3			1	0	5.1			25			0		
5	Sc.P	30	10.2	1.3	216	8.8	7	0.1	29	6.6	1	0	1.2	187	9.1	6	0.4	0.2	0	0	0
	Bi	30	12.4	5.1	743	9.3	30	0.4	66	8.8	2	0	4.7	677	9.4	28	2.3	1.0	0	0	0
	Oak	15	4.9	0.5	269	4.7	1	0.0	46	3.3	0	0	0.4	223	4.9	1	0.1	0.1	0	0	0
	Be	20	5.7	0.7	129	8.6	1	0.1	16	6.7	0	0	0.7	113	8.8	1	0.1	0.1	0	0	0
	Total			7.6			40	0.6			3	0	7.0			37			0		

10	Sc.P	35	11.3	1.6	187	10.3	10	0.1	25	7.8	1	0	1.4	162	10.7	9	0.6	0.3	0	0	0
	Bi	35	13.5	6.3	677	10.9	40	0.5	63	10.0	3	0	5.8	614	11.0	37	2.4	1.2	0	0	0
	Oak	20	6.3	0.6	223	5.9	2	0.0	24	4.5	0	0	0.6	199	6.1	2	0.2	0.1	0	0	0
	Be	25	7.1	1.0	113	10.5	2	0.1	14	8.4	0	0	0.9	99	10.7	2	0.2	0.1	0	0	0
	Total			9.5			54	0.7			4	0	8.7			50			0		
15	Sc.P	40	12.3	1.8	162	11.8	11	0.1	9	8.9	0	0	1.7	153	12.0	11	0.6	0.3	0	0	0
	Bi	40	14.5	7.4	614	12.4	50	3.7	306	12.4	25	200	3.7	308	12.4	25	2.6	1.4	198	80	10
	Oak	25	7.5	0.8	199	7.1	3	0.0	8	5.5	0	0	0.8	191	7.1	3	0.2	0.1	0	0	0
	Be	30	8.4	1.2	99	12.3	3	0.0	3	10.2	0	0	1.2	96	12.4	3	0.2	0.1	24	5	1
	Total			11.1			67	3.8			25	200	7.3			42			222		
20	Sc.P	45	13.2	2.1	153	13.2	15	0.0	0	0.0	0	0	2.1	153	13.2	15	0.6	0.4	0	0	0
	Bi	45	15.4	4.6	308	13.9	33	0.0	0	0.0	0	0	4.6	308	13.9	33	1.6	1.4	260	12	10
	Oak	30	8.7	1.0	191	8.3	4	0.0	0	0.0	0	0	1.0	191	8.3	4	0.3	0.1	0	0	0
	Be	35	9.6	1.5	96	14.1	5	0.0	0	0.0	0	0	1.5	96	14.1	5	0.3	0.1	38	3	1
	Total			9.3			56	0.0			0	0	9.3			56			298		
25	Sc.P	50	14.0	2.5	153	14.3	18	0.1	5	10.8	0	0	2.4	148	14.4	18	0.6	0.4	0	0	0
	Bi	50	16.2	5.6	308	15.2	41	2.8	154	15.2	21	168	2.8	154	15.1	20	1.6	1.4	158	13	11
	Oak	35	9.8	1.3	191	9.4	6	0.0	6	7.4	0	0	1.3	185	9.4	6	0.4	0.2	0	0	0
	Be	40	10.7	1.8	96	15.6	7	0.1	3	13.4	0	0	1.8	93	15.7	7	0.4	0.2	53	3	1
	Total			11.2			71	2.9			21	168	8.2			50			211		
30	Sc.P	55	14.7	2.8	148	15.5	21	0.0	0	0.0	0	0	2.8	148	15.5	21	0.7	0.4	0	0	0
	Bi	55	16.9	3.3	154	16.4	25	0.0	0	0.0	0	0	3.3	154	16.4	25	0.9	1.4	196	8	10
	Oak	40	10.8	1.6	185	10.6	8	0.0	0	0.0	0	0	1.6	185	10.6	8	0.4	0.2	0	0	0
	Be	45	11.6	2.2	93	17.2	9	0.0	0	0.0	0	0	2.2	93	17.2	9	0.4	0.2	71	4	2
	Total			9.9			63	0.0			0	0	9.9			63			267		
35	Sc.P	60	15.3	3.1	148	16.4	24	0.0	0	0.0	0	0	3.1	148	16.4	24	0.6	0.4	239	48	4
	Bi	60	17.5	3.8	154	17.6	29	0.0	0	0.0	0	0	3.8	154	17.6	29	0.9	1.4	234	8	10
	Oak	45	11.8	2.0	185	11.7	11	0.0	0	0.0	0	0	2.0	185	11.7	11	0.5	0.2	0	0	0
	Be	50	12.5	2.5	93	18.6	11	0.0	0	0.0	0	0	2.5	93	18.6	11	0.5	0.2	91	4	2
	Total			11.4			76	0.0			0	0	11.4			76			563		
40	Sc.P	65	15.8	3.5	148	17.2	27	0.0	0	0.0	0	0	3.5	148	17.2	27	0.6	0.5	328	18	5
	Bi	65	18.0	4.2	154	18.7	34	4.2	154	18.7	34	272	0.0	0	0.0	0	1.0	1.3	0	8	10
	Oak	50	12.7	2.4	185	12.8	14	0.0	0	0.0	0	0	2.4	185	12.8	14	0.6	0.3	112	22	2
	Be	55	13.3	2.9	93	19.9	14	0.0	0	0.0	0	0	2.9	93	19.9	14	0.5	0.3	111	4	2
	Total			12.9			89	4.2			34	272	8.7			55			551		

45	Sc.P	70	16.3	3.8	148	18.1	31	0.0	0	0.0	0	0	3.8	148	18.1	31	0.8	0.5	445	23	6
	Oak	55	13.5	2.8	185	14.0	17	0.0	0	0.0	0	0	2.8	185	14.0	17	0.7	0.3	139	6	3
	Be	60	14.1	3.3	93	21.2	18	0.0	0	0.0	0	0	3.3	93	21.2	18	0.7	0.3	140	6	2
	Total			9.9			66	0.0			0	0	9.9			66			725		
50	Sc.P	75	16.8	4.1	148	18.9	34	4.1	148	18.9	34	554	0.0	0	0.0	0	0.6	0.5	0	22	7
	Oak	60	14.3	3.3	185	15.1	21	0.0	0	0.0	0	0	3.3	185	15.1	21	0.8	0.4	172	6	3
	Be	65	14.7	3.7	93	22.4	21	0.0	0	0.0	0	0	3.7	93	22.4	21	0.6	0.3	166	5	3
	Total			11.1			76	4.1			34	554	7.0			42			338		
55	Oak	65	15.0	3.9	185	16.5	26	0.0	0	0.0	0	0	3.9	185	16.5	26	1.0	0.4	212	8	3
	Be	70	15.3	4.1	93	23.7	25	0.0	0	0.0	0	0	4.1	93	23.7	25	1.0	0.4	204	8	3
	Total			8.0			52	0.0			0	0	8.0			52			416		
60	Oak	70	15.7	4.6	185	17.7	32	0.0	0	0.0	0	0	4.6	185	17.7	32	1.1	0.5	254	8	4
	Be	75	15.8	4.5	93	24.8	29	0.0	0	0.0	0	0	4.5	93	24.8	29	0.7	0.4	230	5	3
	Total			9.0			61	0.0			0	0	9.0			61			484		
65	Oak	75	16.3	5.2	185	18.9	37	0.0	0	0.0	0	0	5.2	185	18.9	37	1.1	0.5	331	15	4
	Be	80	16.2	4.9	93	25.8	32	0.0	0	0.0	0	0	4.9	93	25.8	32	0.6	0.4	255	5	3
	Total			10.0			69	0.0			0	0	10.0			69			586		
70	Oak	80	16.9	5.8	185	20.0	43	0.0	0	0.0	0	0	5.8	185	20.0	43	1.1	0.5	428	20	5
	Be	85	16.7	5.2	93	26.6	35	0.0	0	0.0	0	0	5.2	93	26.6	35	0.7	0.4	283	6	3
	Total			11.0			78	0.0			0	0	11.0			78			711		
75	Oak	85	17.5	6.4	185	21.0	49	0.0	0	0.0	0	0	6.4	185	21.0	49	1.2	0.6	537	22	6
	Be	90	17.0	5.5	93	27.4	38	0.0	0	0.0	0	0	5.5	93	27.4	38	0.6	0.4	305	5	3
	Total			11.9			87	0.0			0	0	11.9			87			842		
80	Oak	90	18.0	7.1	185	22.0	54	0.0	0	0.0	0	0	7.1	185	22.0	54	1.1	0.6	652	23	7
	Be	95	17.3	5.7	93	28.0	40	0.0	0	0.0	0	0	5.7	93	28.0	40	0.4	0.4	323	4	3
	Total			12.8			94	0.0			0	0	12.8			94			975		
85	Oak	95	18.5	7.7	185	22.9	60	0.0	0	0.0	0	0	7.7	185	22.9	60	1.2	0.6	857	41	9
	Be	100	17.6	6.0	93	28.6	43	0.0	0	0.0	0	0	6.0	93	28.6	43	0.5	0.4	344	4	3
	Total			13.6			103	0.0			0	0	13.6			103			1201		

90	Oak	100	18.9	8.2	185	23.8	66	0.0	0	0.0	0	0	8.2	185	23.8	66	1.1	0.7	1073	43	11
	Be	105	17.9	6.2	93	29.1	45	0.0	0	0.0	0	0	6.2	93	29.1	45	0.4	0.4	361	3	3
	Total			14.4			111	0.0			0	0	14.4			111			1434		
95	Oak	105	19.3	8.8	185	24.6	71	0.0	0	0.0	0	0	8.8	185	24.6	71	1.1	0.7	1305	46	12
	Be	110	18.1	6.4	93	29.6	47	0.0	0	0.0	0	0	6.4	93	29.6	47	0.4	0.4	376	3	3
	Total			15.2			118	0.0			0	0	15.2			118			1682		
100	Oak	110	19.7	9.4	185	25.4	76	0.0	0	0.0	0	0	9.4	185	25.4	76	1.0	0.7	1540	47	14
	Be	115	18.3	6.6	93	29.9	49	0.0	0	0.0	0	0	6.6	93	29.9	49	0.4	0.4	392	3	3
	Total			15.9			125	0.0			0	0	15.9			125			1931		
105	Oak	115	20.1	9.9	185	26.1	82	0.0	0	0.0	0	0	9.9	185	26.1	82	1.0	0.7	1787	50	16
	Be	120	18.5	6.7	93	30.3	50	6.7	93	30.3	50	400	0.0	0	0.0	0	0.3	0.4	0	2	3
	Total			16.6			132	6.7			50	400	9.9			82			1787		
110	Oak	120	20.4	10.6	185	27.0	88	10.6	185	27.0	88	2133	0.0	0	0.0	0	1.3	0.7	0	69	18
	Total			10.6			88	10.6			88	2133	0.0			0			0		

 Date: 23-02-93 22:05 Time elapsed: 27:49

Appendix: 9.10
Paleispark 141.

*pro*FORST
Growth and yield prognosis for mixed stands

The prognosis is done for the following list of species over a period of 55 years with a thinning period of 5 years

Species	Age	Stand ---- Basal area
1 -Scots pine	40	3.4
2 -Birch	40	0.7
3 -Oak	40	4.2
4 -Beech	40	8.5

year	Spe-cies	Age	Dom. Ht.	before thinning Basal Area	before thinning Number of trees	before thinning Mean Diam.	before thinning Timber Volume	thinning Basal Area	thinning Number of trees	thinning Mean Diam.	thinning Timber Volume	thinning Stum-page value	after thinning Basal Area	after thinning Number of trees	after thinning Mean Diam.	after thinning Wood Volume	Current Volume Incr.	Mean Volume Incr.	Stum-page value	Current Value Incr.	Mean Value Incr.
		year	m	m2		cm	m3	m2		cm	m3	Dfl	m2		cm	m3	m3/year	m3/year	Dfl	Dfl/year	Dfl/year
0	Sc.P	40	13.5	3.4	171	15.9	23	0.2	15	13.0	1	0	3.2	156	16.1	22	0.0	0.6	203	0	5
	Bi	40	15.4	0.7	72	11.1	5	0.0	5	10.1	0	0	0.7	67	11.2	5	0.0	0.1	0	0	0
	Oak	40	14.2	4.2	229	15.3	28	0.3	20	13.0	2	16	3.9	209	15.5	26	0.0	0.7	206	0	6
	Be	40	15.9	8.5	286	19.5	52	0.4	18	17.4	3	24	8.1	268	19.6	49	0.0	1.3	389	0	10
	Total			16.8			108	0.9			6	40	15.8			102			798		
5	Sc.P	45	14.5	3.7	156	17.4	27	0.4	26	14.4	3	0	3.3	130	17.9	24	0.9	0.6	324	24	7
	Bi	45	16.3	0.8	67	12.1	6	0.1	9	10.9	1	0	0.7	58	12.3	5	0.2	0.1	38	8	1
	Oak	45	15.4	4.7	209	17.0	33	0.6	34	14.7	4	32	4.1	175	17.4	29	1.5	0.8	235	12	6
	Be	45	17.4	9.6	268	21.4	65	0.9	31	19.5	6	48	8.7	237	21.6	59	3.3	1.5	475	27	12
	Total			18.8			131	2.1			14	80	16.8			117			1072		

10	Sc.P	50	15.3	3.7	130	19.0	28	0.4	21	16.1	3	27	3.3	109	19.5	25	0.9	0.6	447	30	9
	Bi	50	17.2	0.8	58	13.2	6	0.1	8	11.8	1	0	0.7	50	13.3	5	0.3	0.1	41	1	1
	Oak	50	16.6	4.9	175	18.8	37	0.6	27	16.7	5	40	4.3	148	19.2	32	1.4	0.9	290	19	8
	Be	50	18.7	10.1	237	23.3	76	1.0	26	21.7	7	56	9.1	211	23.4	69	3.2	1.7	549	26	14
	Total			19.4			146	2.1			16	123	17.3			130			1328		
15	Sc.P	55	16.1	3.6	109	20.6	29	0.4	16	17.8	3	41	3.2	93	21.0	26	0.7	0.6	579	35	12
	Bi	55	17.9	0.8	50	14.2	6	0.1	6	12.6	1	8	0.7	44	14.3	5	0.2	0.2	42	2	1
	Oak	55	17.7	5.0	148	20.7	39	0.6	20	18.7	4	35	4.4	128	20.9	35	1.5	0.9	385	26	9
	Be	55	19.9	10.4	211	25.0	85	0.9	21	23.5	8	64	9.4	190	25.2	77	3.3	1.8	616	26	15
	Total			19.8			159	2.0			16	148	17.8			143			1622		
20	Sc.P	60	16.7	3.6	93	22.1	29	0.4	12	19.5	3	53	3.2	81	22.4	26	0.7	0.6	706	36	14
	Bi	60	18.6	0.8	44	15.0	6	0.1	5	13.4	1	8	0.7	39	15.2	5	0.2	0.2	43	2	1
	Oak	60	18.7	5.1	128	22.4	42	0.5	15	20.7	4	43	4.5	113	22.6	38	1.3	0.9	510	34	11
	Be	60	21.0	10.6	190	26.6	94	0.9	17	25.2	8	64	9.7	173	26.8	86	3.4	2.0	687	27	16
	Total			20.0			171	1.8			16	168	18.2			155			1945		
25	Sc.P	65	17.3	3.5	81	23.4	29	0.3	9	20.9	3	67	3.1	72	23.5	26	0.6	0.6	807	34	15
	Bi	65	19.1	0.8	39	15.9	6	0.1	4	14.2	1	8	0.7	35	16.0	5	0.2	0.2	44	2	1
	Oak	65	19.7	5.1	113	24.1	44	0.5	12	22.5	4	53	4.6	101	24.2	40	1.3	1.0	698	48	14
	Be	65	21.9	10.8	173	28.2	102	0.8	14	26.8	8	64	10.0	159	28.3	94	3.1	2.1	749	25	16
	Total			20.2			181	1.7			16	192	18.4			165			2297		
30	Sc.P	70	17.9	3.4	72	24.4	29	0.3	8	22.2	3	80	3.1	64	24.6	26	0.5	0.6	867	28	16
	Bi	70	19.7	0.8	35	16.7	7	0.1	3	14.8	1	8	0.7	32	16.6	6	0.2	0.2	44	2	1
	Oak	70	20.6	5.2	101	25.7	47	0.5	10	24.1	4	69	4.8	91	25.8	43	1.3	1.0	903	55	17
	Be	70	22.8	10.9	159	29.6	109	0.8	12	28.3	8	64	10.2	147	29.7	101	3.0	2.1	806	24	17
	Total			20.3			191	1.6			16	220	18.7			175			2620		
35	Sc.P	75	18.3	3.3	64	25.5	28	3.3	64	25.5	28	987	0.0	0	0.0	0	0.5	0.6	0	24	17
	Bi	75	20.1	0.7	32	17.3	6	0.7	32	17.3	6	48	0.0	0	0.0	0	0.2	0.2	0	1	1
	Oak	75	21.4	5.3	91	27.3	49	0.0	0	0.0	0	0	5.3	91	27.3	49	1.2	1.0	1224	64	20
	Be	75	23.6	11.0	147	30.8	115	0.0	0	0.0	0	0	11.0	147	30.8	115	2.8	2.2	918	22	17
	Total			20.3			198	4.0			34	1035	16.3			164			2141		
40	Oak	80	22.2	5.9	91	28.8	56	0.0	0	0.0	0	0	5.9	91	28.8	56	1.4	1.0	1628	81	24
	Be	80	24.2	11.8	147	32.0	131	0.0	0	0.0	0	0	11.8	147	32.0	131	3.3	2.2	1050	27	18
	Total			17.8			187	0.0			0	0	17.8			187			2678		

45	Oak	85	22.9	6.5	91	30.2	63	0.0	0	0.0	0	0	6.5	91	30.2	63	1.5	1.1	2094	93	28
	Be	85	24.9	12.6	147	33.1	144	0.0	0	0.0	0	0	12.6	147	33.1	144	2.5	2.3	1149	20	18
	Total			19.2			207	0.0			0	0	19.2			207			3243		
50	Oak	90	23.6	7.1	91	31.6	70	0.0	0	0.0	0	0	7.1	91	31.6	70	1.5	1.1	2593	100	32
	Be	90	25.4	13.3	147	34.0	155	0.0	0	0.0	0	0	13.3	147	34.0	155	2.3	2.3	1241	18	18
	Total			20.5			225	0.0			0	0	20.5			225			3833		
55	Oak	95	24.2	7.7	91	32.8	77	0.0	0	0.0	0	0	7.7	91	32.8	77	1.3	1.1	3098	101	36
	Be	95	25.9	14.0	147	34.8	166	0.0	0	0.0	0	0	14.0	147	34.8	166	2.3	2.3	1331	18	18
	Total			21.7			243	0.0			0	0	21.7			243			4429		
60	Oak	100	24.8	8.2	91	33.9	84	0.0	0	0.0	0	0	8.2	91	33.9	84	1.4	1.1	3629	106	39
	Be	100	26.3	14.6	147	35.5	176	0.0	0	0.0	0	0	14.6	147	35.5	176	2.0	2.2	1410	16	18
	Total			22.8			260	0.0			0	0	22.8			260			5039		
65	Oak	105	25.3	8.7	91	35.0	90	0.2	2	34.0	2	87	8.5	89	34.9	88	1.3	1.1	4051	102	42
	Be	105	26.7	15.1	147	36.1	185	0.4	3	35.9	4	32	14.7	144	36.1	181	1.8	2.2	1451	15	18
	Total			23.8			276	0.6			6	119	23.2			270			5502		
70	Oak	110	25.9	9.0	89	35.9	94	0.3	3	34.9	3	137	8.7	86	35.9	91	1.2	1.1	4428	103	45
	Be	110	27.0	15.2	144	36.6	190	0.4	4	36.5	5	40	14.7	140	36.6	185	1.6	2.2	1477	13	18
	Total			24.2			284	0.7			8	177	23.4			276			5905		
75	Oak	115	26.3	9.2	86	36.8	97	0.3	2	35.8	3	145	8.9	84	36.6	94	1.1	1.1	4757	95	47
	Be	115	27.3	15.1	140	37.1	193	0.4	3	37.1	5	40	14.7	137	37.0	188	1.6	2.2	1501	13	17
	Total			24.3			289	0.7			8	185	23.6			281			6258		
80	Oak	120	26.8	9.3	84	37.5	100	9.3	84	37.5	100	5314	0.0	0	0.0	0	1.2	1.1	0	111	50
	Be	120	27.6	15.1	137	37.4	194	15.1	137	37.4	194	1552	0.0	0	0.0	0	1.3	2.1	0	10	17
	Total			24.4			294	24.4			294	6866	0.0			0			0		

Glossary

Aggradation phase: a phase in eco-unit development that follows the innovation phase or a release from suppression.

Architecture: the visible, morphological, expression of the genetic blueprint of organic growth and development. (Hallé et al, 1978).

Artificial regeneration: regeneration resulting from sowing or planting.

Autecology: ecology of one population in a central role, and the rest of the ecosystem as its environment. (Oldeman, 1990).

Basal area: the sum of all horizontal cross sections of the trees per ha, at 1.30 m above the ground.

Biostatic phase: the phase in eco-unit development that follows an aggradation phase.

Canopy: more or less closed upper layer of tree crowns. (Koop, 1989).

Chablis: a gap in the forest produced by the fall of a tree; the fall of the tree itself and the resulting forest damage (translated from French, Hallé et al., 1978).

Climax: a plant association which has reached its full development and is likely to remain stable unless disturbed by climatic or other environmental changes. (Gray, 1967).

Compartment: a set of abiotic and/or biotic subsystems or components in a living system, that is delimited as a recognizable, functional ensemble. (Oldeman, 1990).

Competition: the hardships which result to organisms from the proximity of neighbours. (Miles, 1979).

Component: an organism, or an abiotic system of the same order, considered as an individual subsystem in a forest ecosystem. (Oldeman, 1990).

Conservation: the maintenance of conditions through which specific objects can survive in perpetuity.

Container-grown: of a sapling, cultivated in a small cell, box or container. The sapling is planted together with the substrate it was grown on.

Crown thinning: mainly involves trees in the upper crown classes: codominant and dominant trees that are competing strongly with the most promising individuals of these classes are removed.

Crop tree: tree that has reached the financial diameter.

Degradation phase: a phase in eco-unit development that follows the biostatic phase; tallest trees are senescent.

DFOV: Diffuse radiation at overcast moments.

Disturbance: the disruption of the pattern of the ecosystem by physical forces; fire, wind, and the force of falling trees. (Bormann and Likens, 1985).

Dominant height: the dominant height or top height is the average height of the hundred tallest trees per ha. (Schütz and van Tol, 1982).

Dominant tree: a tree whose crown extends above the general level of the crown cover and receives full light from above and partly from the sides; larger than the average trees in the stand, and with its crown well-developed, but possibly somewhat crowded on the sides. (Munns, 1950).

Ecosystem: a system of plants, animals and other organisms together with the non-living components of their environment. (IUCN/UNEP/WWF, 1991).

Ecological value: the sum of the valuation given to individual natural components. (Kuper, 1992b).

Eco-unit: a unit of vegetation which started its development at the same time and on the same surface. (Oldeman, 1990).

Enrichment planting: this embraces all planting, whether along regular lines and spacing, or as groups, or as irregularly spaced individuals (patch planting), within an overall matrix of the original vegetation, however this is treated, where the planted trees constitute less than 50 per cent of the estimated future crop. It excludes planting and sowing whether with indigenous or exotic species in areas clear-felled and burnt. (Wyatt-Smith, 1987).

Established: (of a seedling) a seedling that has survived the first year.

Even-aged stand: a stand in which all trees are of the same age.

Financial diameter: the diameter at which the best economic performance is achieved.

Forest expectation value: the total net income to be expected from the forest system in years to come, without consuming the forest system itself.

Forest rent: the net yearly earnings from the forest system.

Future tree: tree which is expected to reach the financial diameter.

Fragmentation: the splitting up of a system into several smaller systems with a similar organization type. (Oldeman, 1990).

Genotype: the genotype of an individual describes the complete set of inherited genes. (Suzuki et al., 1989).

Ground vegetation: the vegetation excluding trees.

Group felling: felling a group of neighbouring trees at the same time.

Growing area: the area available to a tree, i.e. the area in which a tree is more competitive than its neighbours. (cf. Leersnijder, 1992).

Growth: 1. the process of growing or developing; a) gradual development towards maturity; b) formation and development. 2. a) degree of increase in size, weight, power, etc.; b) the full extent of such increase. (Neufeldt and Guralnik, 1988).

Heliotropism: lopsided growth because only one side is exposed to light.

Herbs: non-woody higher plants.

Increment felling: a reduction of the basal area through felling, which leads to an increase in growth per tree, and at the same time to a reduction of growth per ha.

Indigenous: occurring in a specific locality, without human interference.

Innovation phase: the phase in eco-unit development that starts after the zero event and ends as soon as the canopy closes. (Oldeman, 1990).

Intensity of thinning: a measure of the combined frequency and weight of thinnings, in terms of the volume removed during any succession of thinnings. (Ford-Robertson, 1971).

Interaction: mutual influence. There are different kinds of interaction, e.g. competition, parasitism, commensalism, synergism. (Leersnijder, 1992).

Irradiance: the amount of light calculated per unit area of surface receiving light in W/m^2. (Fliervoet, 1984).

Kuloo: soil treating machine as shown in figure 14.

Land expectation value: the total net income to be expected from a tract of land in years to come. (cf. Chang, 1981).

Low thinning: thinning of the smallest trees. Anticipates natural thinning of a stand through competition.

Natural: developed without human interference.

Naturalness: degree of non-interference by humans.

Natural regeneration: regeneration which occurs as a result of natural processes, without any human interference.

Nature: whatever one sees around oneself, and which is considered not yet altered by man. (translated from Dutch, Geerts et al., 1984).

Net increment: the total increment minus the volume left in the forest deliberately or as a result of natural risks.

Organic topsoil: the layer from the top of the dead organic matter to the top of the mineral soil, equivalent to A_0 (Anon., 1954).

PAR: Photosynthetic Active Radiation.

Permanent quadrat: plot that is permanently marked in the field and is reassessed in time.

Phase: state in a cyclic successional series that is characterized by the age of the stage of which it is part.

Phenotype: an organism as observed, i.e. as judged by its visually perceptible characters resulting from the interaction of its genotype with the environment. (Ford-Robertson, 1971).

Pioneer species: a species capable of invading bare areas, often in large numbers and over a considerable area, and persisting until displaced as forest succession proceeds. (Munns 1950, cf. Ford-Robertson 1971).

Potential tree: a tree in a developmental phase in which height growth is more important than stem-diameter growth and crown-extension growth. (cf. Peters, 1992).

Regeneration: 1. the process of establishment of young trees,
2. the young trees.

Released growth: for potential trees, growth under high light levels. (Peters, 1992).

Rotovator: soil treating machine as shown in figure 16.

Sapling: young tree, older than one year.

Seedling: young tree less than one year old.

Seed-source planting: planting of trees which will have to produce the seeds for spontaneous regeneration.

Semi-spontaneous regeneration: regeneration which occurs after a specific human activity has taken place, not being artificial regeneration (e.g. soil tillage, fencing).

Shelter tree: tree that remains after an increment felling has been carried out.

Shrubs: woody plants, excluding trees.

Silvatic mosaic: every forest area that is situated in one continuous volume and subjected to the same regime of climate and soil, which shows the same complex of silvigenetic dynamics, resulting in an eco-unit composition that oscillates around a specific state and determining the architecture and ecological functioning as long as the resource regime remains unchanged. (Oldeman, 1990).

Site index: the dominant height a stand can reach at infinite age. (Schütz and van Tol, 1982).

Soil rent: the net average sum of money becoming available from forest exploitation per unit of time and area.

Species composition: the occurrence and distribution of all species over a tract of land.

Spontaneous regeneration: regeneration which occurs after a human activity which was not directed to regeneration (e.g. timber extraction).

Stage (of succession): state in a successional series determined by its own characteristic species composition.

Stand: an independent management unit in a forest.

Stand density: the extent of the basal area in a stand.

Stand density index: the ratio between the basal area in a particular stand and the basal area in a chosen yield table.

Stress: any factor that diminishes or disturbs vital processes in a living system. (Levitt, *in* Oldeman, 1990)

Structure: includes all data in time and space which are derived from models, not directly from living systems. (Oldeman, 1990).

Suppressed growth: for potential trees, growth under low light levels. (Peters, 1992).

Suppressed trees: trees which are relatively short because of strong competition from taller neighbours.

Sustainability: a characteristic of a process or state that can be maintained indefinitely. (IUCN/UNEP/WWF, 1991).

Sustainable forest development: consistent, deliberate, and sustained, yet flexible, action to maintain in a balanced manner the goods and services of the forest and to use these to increase the contribution of the forest to social well-being. (Poore, 1993).

System: arrangement of units or activities which function together.

Target forest/stand: a forest/stand with a species composition, production, rotation, architecture, fauna and management, defined as a result of political decisions.

Thinning: harvesting a tree so that neighbouring trees have more room to grow.

TOTAL: The total of direct and diffuse radiation.

Transect: a stretch through part of a forest represented on a map or as a profile diagram of stems and crowns of trees. It may also contain much more data, for example on shrubs, herbs, dead wood etc. (Leersnijder, 1992).

Tree height (th): the dominant height of the trees surrounding a chablis.

Uneven-aged stand: a stand in which trees of different age occur.

Undergrowth: the vegetation growing under the canopy of an old stand. It may include young trees.

Value increment: the increase in net commercial value of an object between 2 consecutive years.

Yield table: a table showing for one or more species the growth pattern of a managed even-aged stand, derived from measurements at regular intervals covering its useful life; it includes mean diameter (generally dbh) and height, number of stems, and standing volume per unit area, and may further include e.g. volume of thinnings, main crop or total volume, current annual increment and mean annual increment, main crop basal area, and other data. (Ford-Robertson, 1971).

Zero event: the factor which causes forest development locally to start anew (such as fire, wind, water, pests, and harvests which cause gaps or clearings). (Leersnijder, 1992).

Curriculum vitae

Jacob Hendrik Kuper was born on November 6th 1946 in Amsterdam.
He attended secondary school in Haarlem at the HBSb of the Lourens Costerlyceum. He graduated from Wageningen Agricultural University in Forestry and Food Technology. The forestry subjects he studied were silviculture, nature management, industrial management, and marketing.

After two years in wildlife research for the government of Zambia, and two years in wildlife management at the FAO Regional Office in Bangkok, he started work at the management of Het Loo Royal Forest in 1978.

As well as being a member of the Voorlopige Commissie Nationale Parken, he is in the Commission on National Parks and Protected Areas of the International Union for the Conservation of Nature and Natural Resources, and on the board of Pro Silva Europe.

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