Summary of the PhD-thesis of Jaap Kuper
"Sustainable development of Scots pine forests"

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 1985 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 have been planted and are therefore even-aged. 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, to offer opportunities for the successional processes characteristic of natural forests. Scots pine stands, which are the dominant forests in the Netherlands, offer good opportunities for rehabilitation 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 in 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 and 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, or were bare. 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 biggest financial profit. The financial diameter is reached as soon as the current value increment equals the sum of the interest of the net stumpage value of a 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 the same 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. 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.